NPFC

North Pacific Fisheries Commission

NPFC-2022-TWG CMSA05-WP08

Fitting VPA and SAM to pseudo data generated from POPSIM: A first analysis for chub mackerel in Northwestern Pacific

Shota Nishijima, Momoko Ichinokawa, and Kazuhiro Oshima

Fisheries Resources Institute,

Japan Fisheries Research and Education Agency (FRA)

(Corresponding author: Shota Nishijima, nishijimash@affrc.go.jp)

Background

The Technical Working Group on Chub Mackerel Stock Assessment (TWG CMSA) in NPFC determined that (1) the candidates of stock assessment models (VPA, ASAP, KAFKA, and SAM) would be compared by an operating model, and (2) the operating model would be based on POPSIM-A (NPFC 2019). POPSIM-A uses a stock assessment model as an operating model and, therefore, input data are needed for the development of operating models by fitting stock assessment model candidates (Deroba et al. 2014). At the TWG CMSA04, the TWG members have determined six scenarios or input data to fit each stock assessment model to (NPFC 2021). As intersessional works, the members have then submitted estimated results for the use of input data for the operating model POPSIM-A to the invited expert Dr. Joel Rice. The members have also determined performance measures for comparing stock assessment models, which include state variables, depletion statistics, biological reference points (BRPs), and relative fishing impacts (NPFC-2022-TWG CMSA05-WP01). We fitted VPA and SAM to pseudo datasets (PS_data_ver2.zip, available from here) and calculated performance measures. In this document, we report the results of performance measures obtained by fitting VPA and SAM to the pseudo datasets.

Calculating performance measures

We developed the R package ‘OMutility’ that easily computes the performance measures (NPFC-2022-TWG CMSA05-WP01) from output results of stock assessment models. In the process of calculating the performance measures, however, we found the following bugs in OMutility.

1. Installation error of the package downloaded from the Collaboration site
2. No identifier of pseudo dataset (A_3, A_15, …and F20) available
3. Not output the depletion statistics in the 2010s
4. Wrongly output the same values of depletion statistics of total biomass as those of spawning stock biomass
5. Not able to find the biological reference point of F0.1
6. Wrongly Output parameters of stock-recruitment relationship that are not included in the performance measures

We personally fixed these bugs except for No. 6 and show results with the bugs fixed. We will re-distribute a bug-fixed version of OMutility to the members of SWG OM after we hear and discuss issues regarding this package among the members at the meeting of NPFC TWG CMSA05.

Fitting VPA to pseudo data

There are zero data of catch number at age in some pseudo datasets. Since VPA cannot directly treat zero catch data, we added a small constant value to zero catch samples as an ad-hoc approach. We used the half of the minimum value of positive catch-at-age in a single iteration to zero catch samples, so that the added value corresponded to the middle of the range from zero to the minimum positive value. We could fit VPA to the pseudo data in the same way as in fitting VPA to the actual data (Nishijima et al. 2022).

We found that a single pseudo dataset per scenario generated much different trajectories of state variables from the other datasets (see A_3, B_13, C_2, D_19, E_4, and F_5 in Fig. 1). This suggests that an operating model may generate much different values in pseudo datasets from the other operating models. Furthermore, the estimates with these pseudo datasets little differed among iterations, indicating that variations in pseudo data from the operating model were low. By contrast, we found that two pseudo datasets per scenario (e.g., A_15, A_18 for scenario A) have large variations in state variables.

Regarding BRPs related to fishing mortality (F), some iterations in some pseudo datasets generated F_{ref} = 10 for F0.1, Fmax, Fmsy_0.9_BH, and Fmsy_HS (Fig. 2). This suggests that the optimization reached the upper boundary of F value. Some treatments or improvements may be necessary for this issue. Regarding BRPs related to total biomass and spawning stock biomass, some extraordinarily high estimates in BRP have been found in some pseudo datasets (Fig. 3). The results of relative fishing impacts (ratios of current F to F reference points) are shown in Fig. 4. As for depletion statistics, we found large variations in the pseudo datasets having large uncertainties in state variables (e.g., A_15, A_18 for scenario A) (Fig. 5).

Fitting SAM to pseudo data

SAM also cannot treat zero catch data. We therefore employed the same ad-hoc approach to adding a small value as in VPA. In addition, SAM often caused estimation errors (not finish optimization), failures to converge (detected by nlminb function), and unrealistic estimates ($F \approx 0$) when we fitted SAM to pseudo datasets in the same model configurations in fitting VPA to the actual data (Nishijima et al. 2022). Therefore, when we found these signs of errors and failures in estimation, we gradually simplified model configurations from No. 1 to 7 as follows:

1. The same model configurations in fitting VPA to the actual data were used.
2. The same configurations as No. 1 except that the same standard deviation in observation errors for all the six abundance indices were assumed.
3. The same configurations as No. 2 except that the same standard deviation in process errors of F random walk among age classes were assumed.
4. The same configurations as No. 3 except that the same standard deviation in observation errors of catch at age among age classes were assumed.
5. The same configurations as No. 4 except that the nonlinear coefficients of abundance indices from Chinese and Russian fisheries were assumed to be 1.
6. The same configurations as No. 5 except that we estimated F random walk from 2010 to 2011 (removed in the original analysis).
7. The same configurations as No. 6 except that correlation coefficients of multivariate normal distribution of F random walk were assumed to be 1 (selectivity became constant over years).

We did not calculate performance measures for pseudo datasets with which even model No. 7 caused an estimation or convergence error. Which model was used depended strongly on pseudo datasets (Fig. 6). The original model was used for most iterations with two pseudo datasets per scenario (e.g., A_15, A_18 for scenario A), whereas more simplified models were frequently used with the other pseudo datasets (e.g., A_24, A_3 for scenario A).

As in the case with VPA, SAM estimated much different trajectories of total biomass for a single pseudo dataset under each scenario (see A_3, B_13, C_2, D_19, E_4, and F_5 in Fig. 7). SAM estimated declining trends of weighted-average F for a single pseudo dataset under each scenario (A_18, B_21, C_8, D_6, E_22, and F_7), although large variations in the estimates were found. SAM led to relatively robust estimates of state variables for the other pseudo datasets except for C_14.

Compared with VPA, we found that differences of BRPs among four pseudo datasets within each scenario were relatively large in the SAM analysis (Fig. 8-9). The pseudo datasets showing the declining trends of weighted average F led to lower relative fishing impacts than other pseudo datasets (Fig. 10). SAM estimated more robust depletion statistics than VPA (Fig. 11).

References

Deroba, J. J., D. S. Butterworth, R. D. Methot, J. A. A. DeOliveira, C. Fernandez, A. Nielsen, S. X. Cadrin, M. Dickey-Collas, C. M. Legault, J. Ianelli, J. L. Valero, C. L. Needle, J. M. O'Malley, Y. J. Chang, G. G. Thompson, C. Canales, D. P. Swain, D. C. M. Miller, N. T. Hintzen, M. Bertignac, L. Ibaibarriaga, A. Silva, A. Murta, L. T. Kell, C. L. DeMoor, A. M. Parma, C. M. Dichmont, V. R. Restrepo, Y. Ye, E. Jardim, P. D. Spencer, D. H. Hanselman, J. Blaylock, M. Mood, and P. J. F. Hulson. 2014. Simulation testing the robustness of stock assessment models to error: Some results from the ICES strategic initiative on stock assessment methods. ICES Journal of Marine Science 72:19–30.

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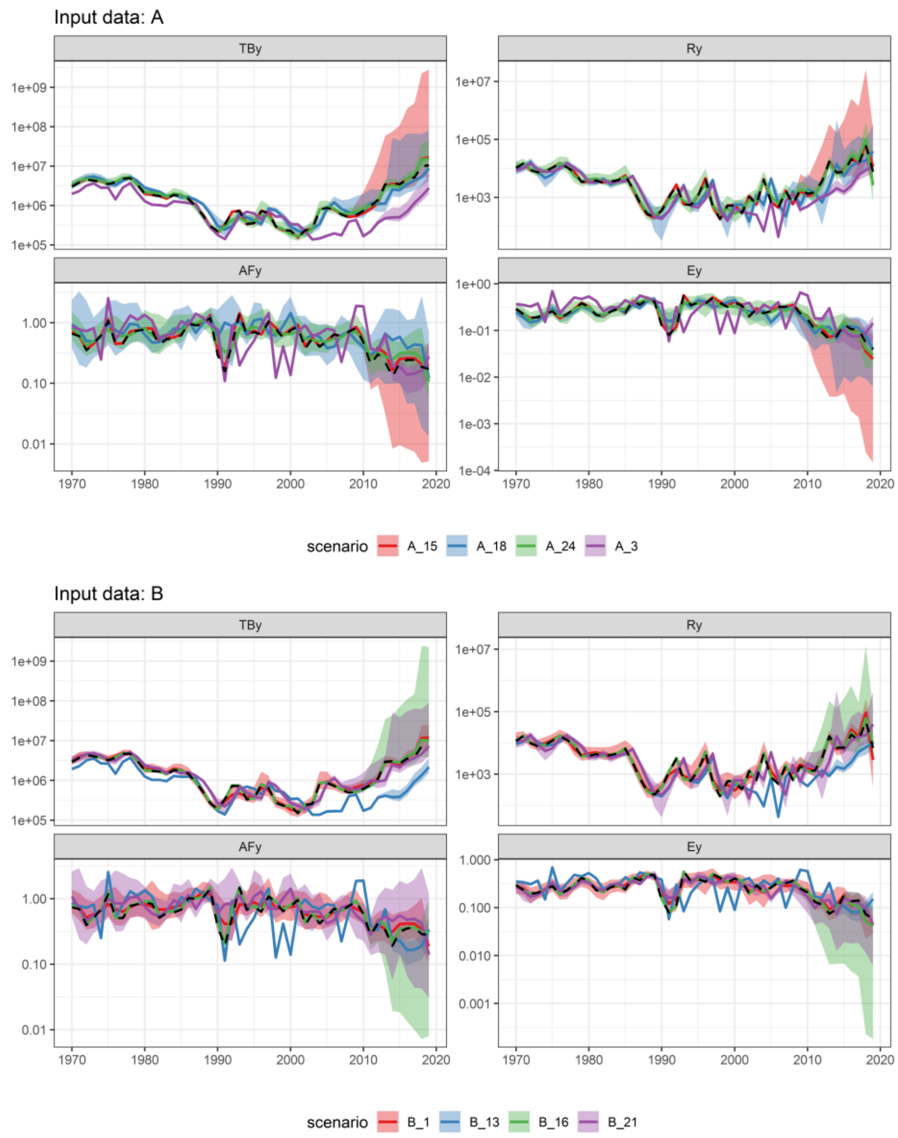
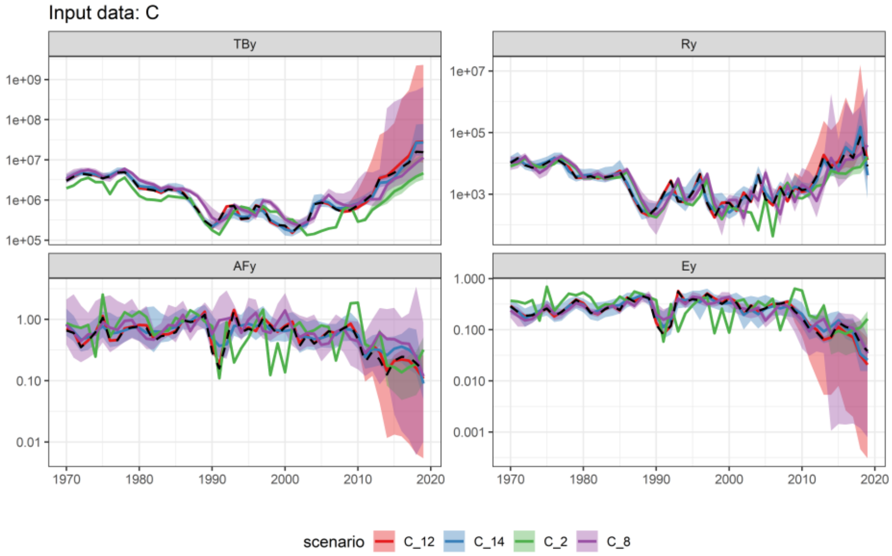
NPFC 2019. 2nd Meeting of the Technical Working Group on Chub Mackerel Stock Assessment. 2019. 2nd Meeting Report. NPFC-2019-TWG CMSA02-Final Report.

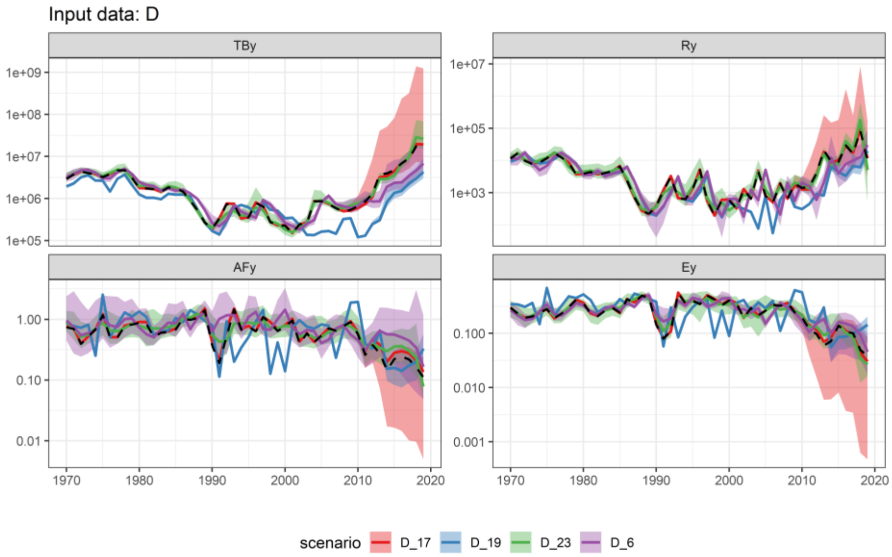
(available at www.npfc.int)
NPFC 2021. 4th Meeting of the Technical Working Group on Chub Mackerel Stock Assessment. NPFC-2020-TWG CMSA03-Final Report. (available at www.npfc.int)
NPFC-2022-TWG CMSA05-WP01. Summary of 2nd Meeting of the Small Working Group on Operating Model for Chub Mackerel Stock Assessment.

Fig. 1: Time series of state variables (TBy: total biomass, Ry: the number of recruits, AFy: F at age weighted by catch weight at age, and Ey: exploitation rate) with VPA from scnario (input data) A to F. The coloured lines indicates the median values among iterations per dataset while the shadowed areas indicate 95% intervals. The dashed lines indicate estimates when we fitted VPA to the real data under scenarios A to F. Note that the *y*-axes are log-transformed for visualization of large intervals.

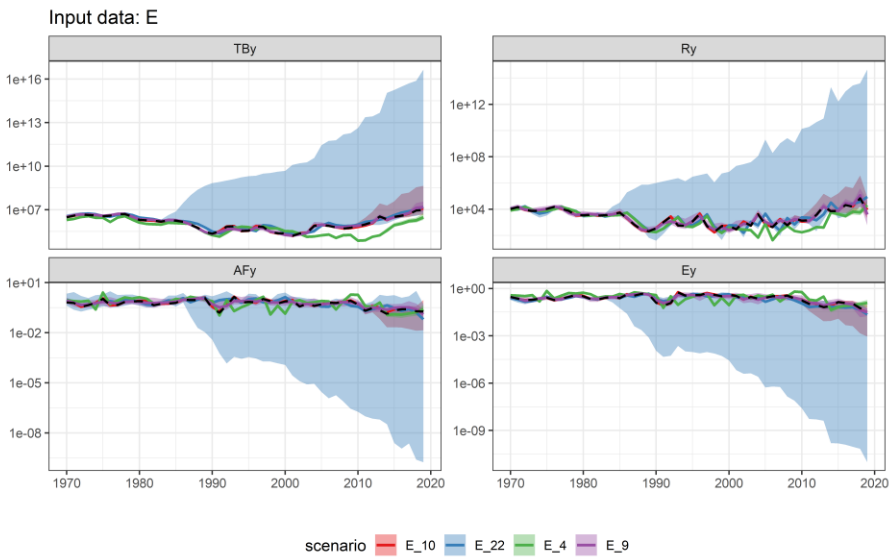




Input data: C
TBy
Ry
AFy
Ey
1e+09
1e+08
1e+07
1e+06
1e+05
1e+07
1e+05
1e+03
1.00
0.10
0.01
1.000
0.100
0.010
0.001
1970
1980
1990
2000
2010
2020
scenario
C_12
C_14
C_2
C_8



Input data: D
TBy
Ry
AFy
Ey
1e+09
1e+08
1e+07
1e+06
1e+05
1e+07
1e+05
1e+03
1.00
0.10
0.01
0.100
0.010
0.001
1970
1980
1990
2000
2010
2020
scenario
D_17
D_19
D_23
D_6



Input data: E
TBy
Ry
AFy
Ey
1e+16
1e+13
1e+10
1e+07
1e+12
1e+08
1e+04
1e+01
1e-02
1e-05
1e-08
1e+00
1e-03
1e-06
1e-09
1970
1980
1990
2000
2010
2020
scenario
E_10
E_22
E_4
E_9

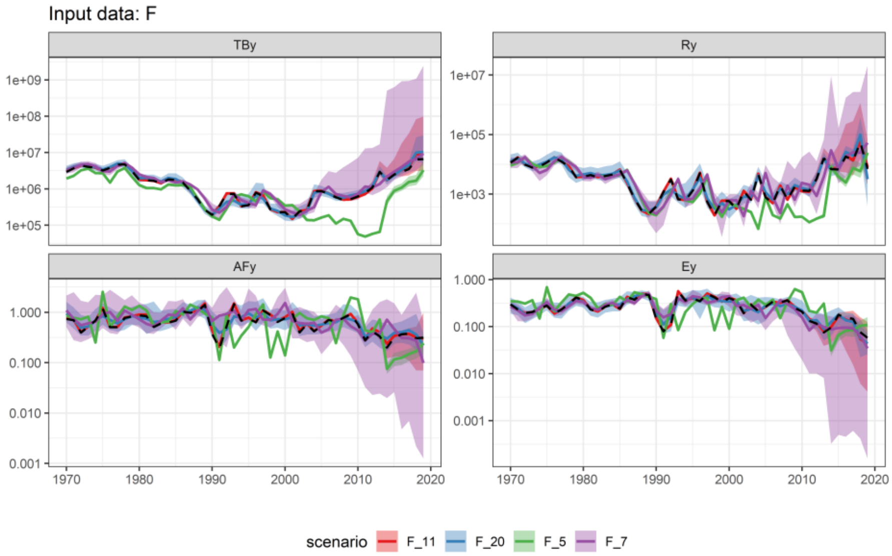
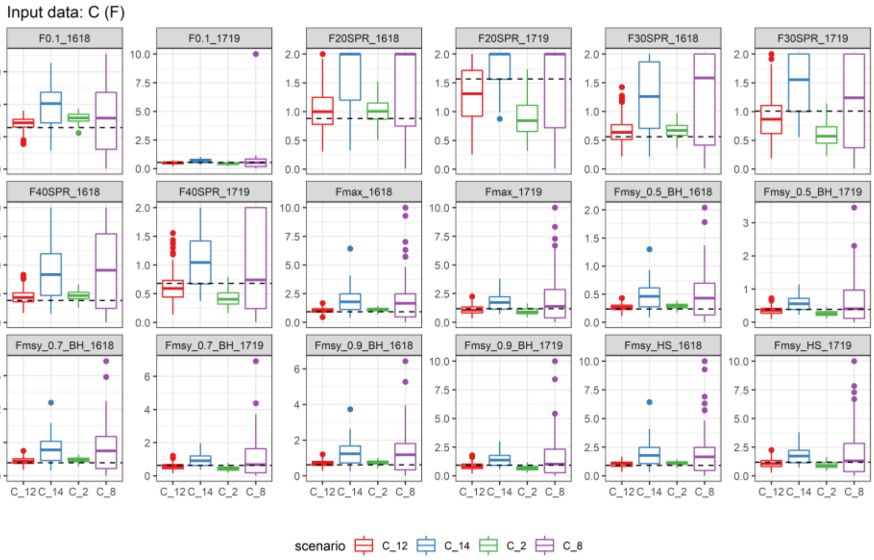

Input data: F
TBy
Ry
AFy
Ey
1e+09
1e+08
1e+07
1e+06
1e+05
1e+07
1e+05
1e+03
1.000
0.100
0.010
0.001
1970
1980
1990
2000
2010
2020
scenario
F_11
F_20
F_5
F_7

Fig 2: BRPs related to fishing mortality with VPA from scnario (input data) A to F. The dashed lines indicate the values in fitting VPA to the real data under scenarios A to F.


Input data: C (F)
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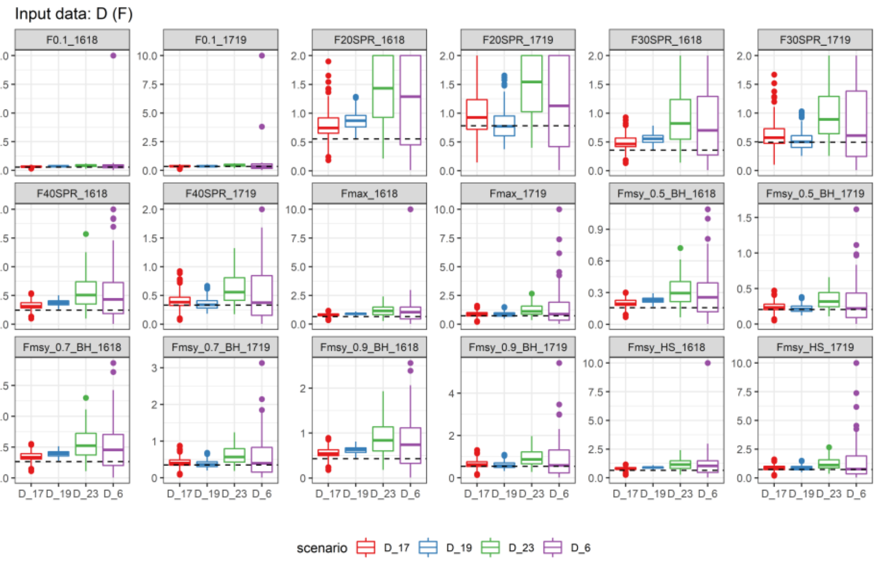
F0.1_1719
F20SPR_1618
F20SPR_1719
F30SPR_1618
F30SPR_1719
F40SPR_1618
F40SPR_1719
Fmax_1618
Fmax_1719
Fmsy_0.5_BH_1618
Fmsy_0.5_BH_1719
Fmsy_0.7_BH_1618
Fmsy_0.7_BH_1719
Fmsy_0.9_BH_1618
Fmsy_0.9_BH_1719
Fmsy_HS_1618
Fmsy_HS_1719
scenario C_12 C_14 C_2 C_8


Input data: D (F)
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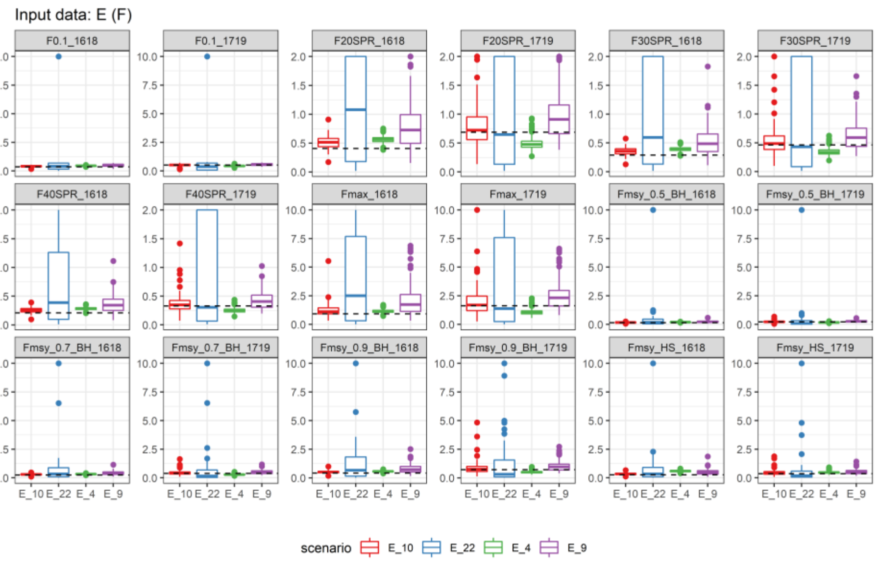
F0.1_1719
F20SPR_1618
F20SPR_1719
F30SPR_1618
F30SPR_1719
F40SPR_1618
F40SPR_1719
Fmax_1618
Fmax_1719
Fmsy_0.5_BH_1618
Fmsy_0.5_BH_1719
Fmsy_0.7_BH_1618
Fmsy_0.7_BH_1719
Fmsy_0.9_BH_1618
Fmsy_0.9_BH_1719
Fmsy_HS_1618
Fmsy_HS_1719
scenario D_17 D_19 D_23 D_6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F0.1_1618
F0.1_1719
F20SPR_1618
F20SPR_1719
F30SPR_1618
F30SPR_1719
F40SPR_1618
F40SPR_1719
Fmax_1618
Fmax_1719
Fmsy_0.5_BH_1618
Fmsy_0.5_BH_1719
Fmsy_0.7_BH_1618
Fmsy_0.7_BH_1719
Fmsy_0.9_BH_1618
Fmsy_0.9_BH_1719
Fmsy_HS_1618
Fmsy_HS_1719
scenario E_10 E_22 E_4 E_9

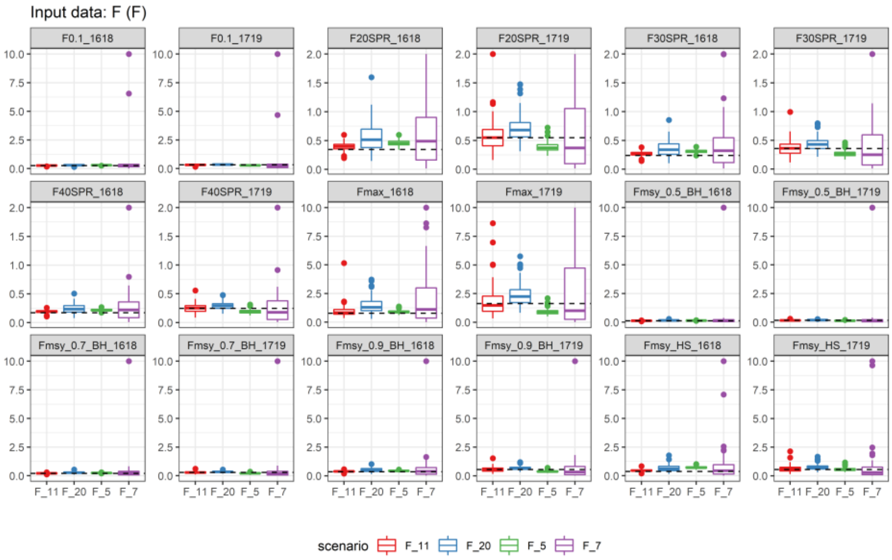
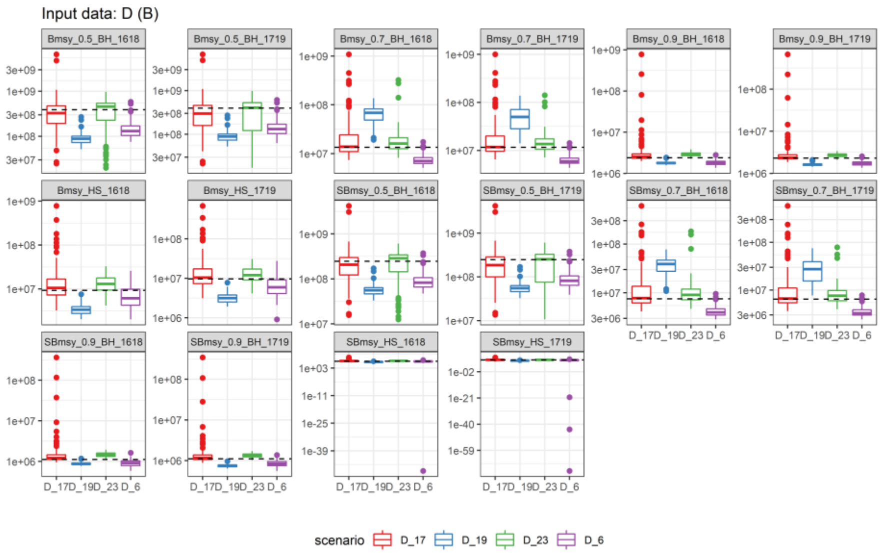

Input data: F (F)
F0.1_1618
F0.1_1719
F20SPR_1618
F20SPR_1719
F30SPR_1618
F30SPR_1719
F40SPR_1618
F40SPR_1719
Fmax_1618
Fmax_1719
Fmsy_0.5_BH_1618
Fmsy_0.5_BH_1719
Fmsy_0.7_BH_1618
Fmsy_0.7_BH_1719
Fmsy_0.9_BH_1618
Fmsy_0.9_BH_1719
Fmsy_HS_1618
Fmsy_HS_1719
F_11 F_20 F_5 F_7
scenario F_11 F_20 F_5 F_7

Fig 3: BRPs related to total biomass and spawning stock biomass with VPA from scnario (input data) A to F. The dashed lines indicate the values in fitting VPA to the real data under scenarios A to F.


Input data: C (B)
Bmsy_0.5_BH_1618
Bmsy_0.5_BH_1719
Bmsy_0.7_BH_1618
Bmsy_0.7_BH_1719
Bmsy_0.9_BH_1618
Bmsy_0.9_BH_1719
Bmsy_HS_1618
Bmsy_HS_1719
SBmsy_0.5_BH_1618
SBmsy_0.5_BH_1719
SBmsy_0.7_BH_1618
SBmsy_0.7_BH_1719
SBmsy_0.9_BH_1618
SBmsy_0.9_BH_1719
SBmsy_HS_1618
SBmsy_HS_1719
scenario C_12 C_14 C_2 C_8


Input data: D (B)
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Bmsy_0.5_BH_1719
Bmsy_0.7_BH_1618
Bmsy_0.7_BH_1719
Bmsy_0.9_BH_1618
Bmsy_0.9_BH_1719
Bmsy_HS_1618
Bmsy_HS_1719
SBmsy_0.5_BH_1618
SBmsy_0.5_BH_1719
SBmsy_0.7_BH_1618
SBmsy_0.7_BH_1719
SBmsy_0.9_BH_1618
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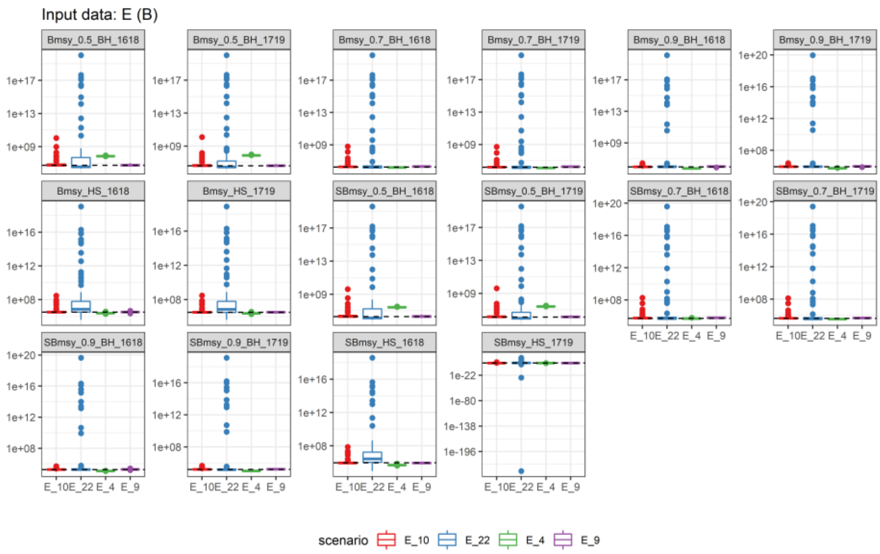
SBmsy_HS_1618
SBmsy_HS_1719
scenario D_17 D_19 D_23 D_6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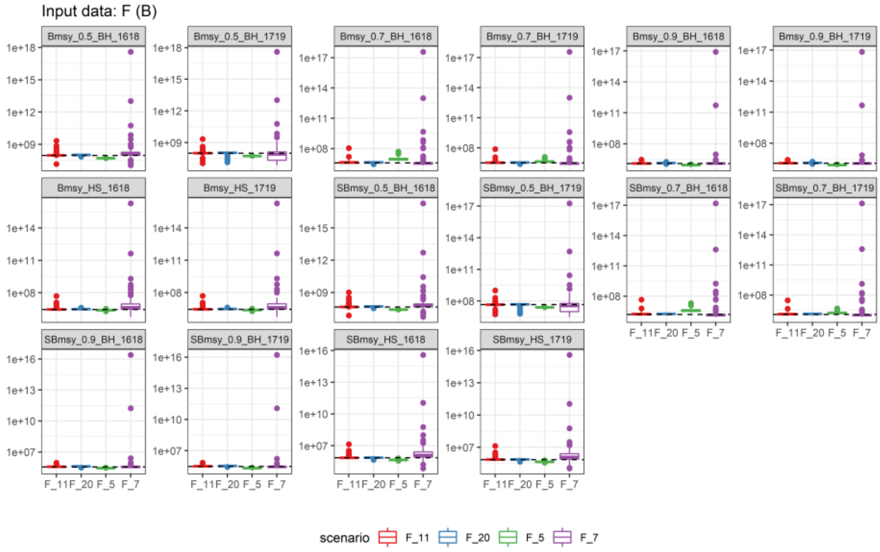
Bmsy_0.5_BH_1719
Bmsy_0.7_BH_1618
Bmsy_0.7_BH_1719
Bmsy_0.9_BH_1618
Bmsy_0.9_BH_1719
Bmsy_HS_1618
Bmsy_HS_1719
SBmsy_0.5_BH_1618
SBmsy_0.5_BH_1719
SBmsy_0.7_BH_1618
SBmsy_0.7_BH_1719
SBmsy_0.9_BH_1618
SBmsy_0.9_BH_1719
SBmsy_HS_1618
SBmsy_HS_1719
scenario E_10 E_22 E_4 E_9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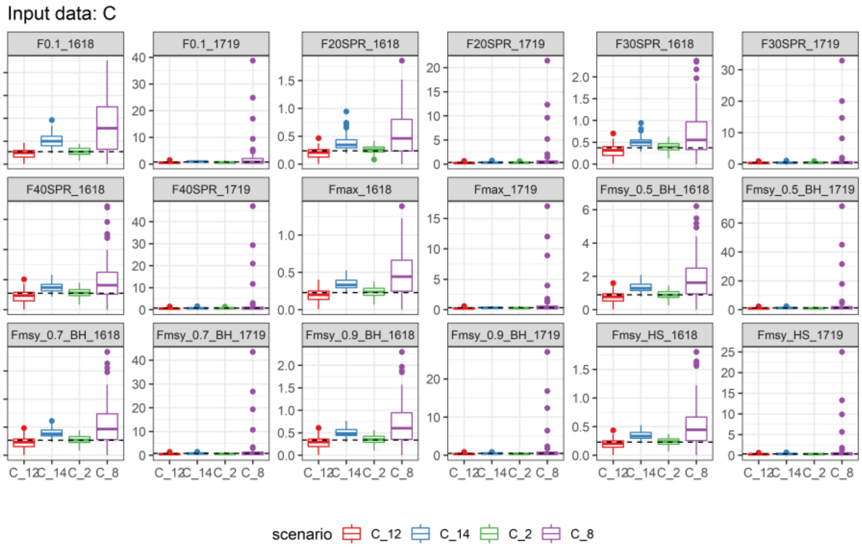
Bmsy_0.5_BH_1719
Bmsy_0.7_BH_1618
Bmsy_0.7_BH_1719
Bmsy_0.9_BH_1618
Bmsy_0.9_BH_1719
Bmsy_HS_1618
Bmsy_HS_1719
SBmsy_0.5_BH_1618
SBmsy_0.5_BH_1719
SBmsy_0.7_BH_1618
SBmsy_0.7_BH_1719
SBmsy_0.9_BH_1618
SBmsy_0.9_BH_1719
SBmsy_HS_1618
SBmsy_HS_1719
F_11 F_20 F_5 F_7
scenario F_11 F_20 F_5 F_7

Fig. 4: Relative fishing impacts (ratio of current F to F reference points) with VPA from scnario (input data) A to F. The dashed lines indicate the values in fitting VPA to the real data under scenarios A to F.


Input data: C
F0.1_1618
F0.1_1719
F20SPR_1618
F20SPR_1719
F30SPR_1618
F30SPR_1719
F40SPR_1618
F40SPR_1719
Fmax_1618
Fmax_1719
Fmsy_0.5_BH_1618
Fmsy_0.5_BH_1719
Fmsy_0.7_BH_1618
Fmsy_0.7_BH_1719
Fmsy_0.9_BH_1618
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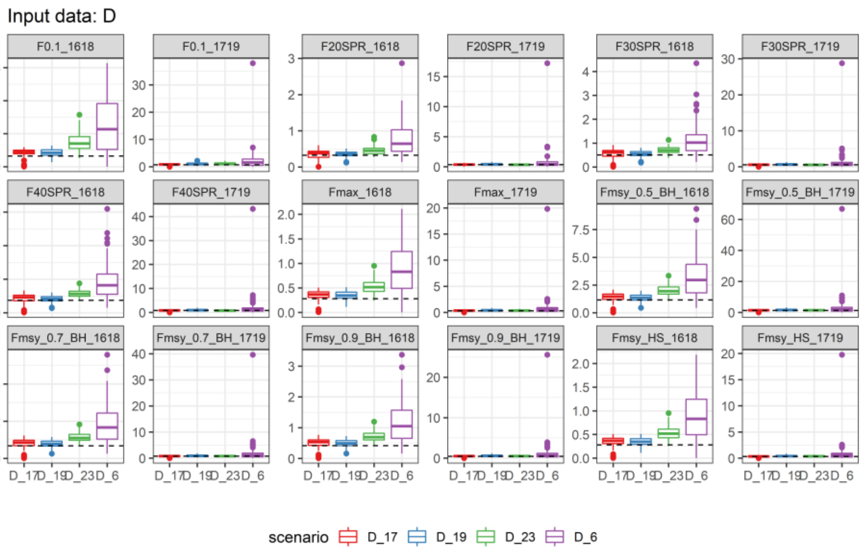
Fmsy_HS_1618
Fmsy_HS_1719
scenario C_12 C_14 C_2 C_8


Input data: D
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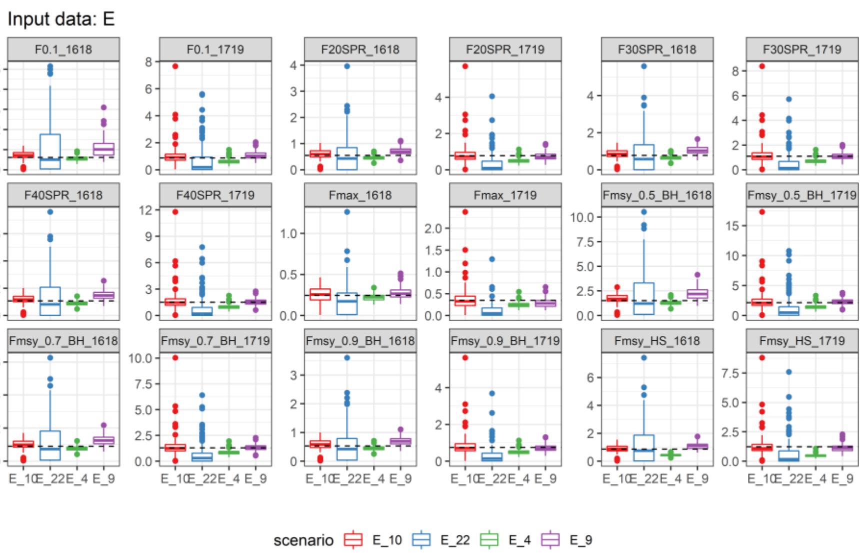
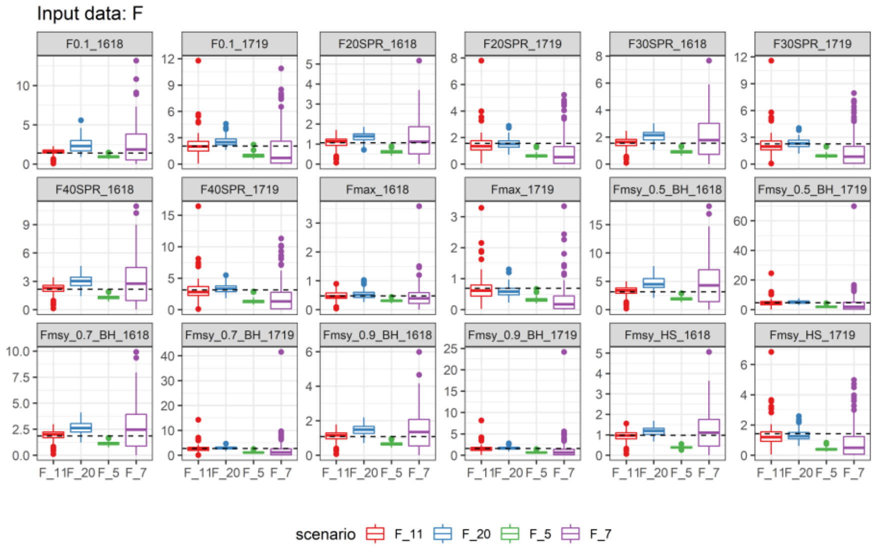
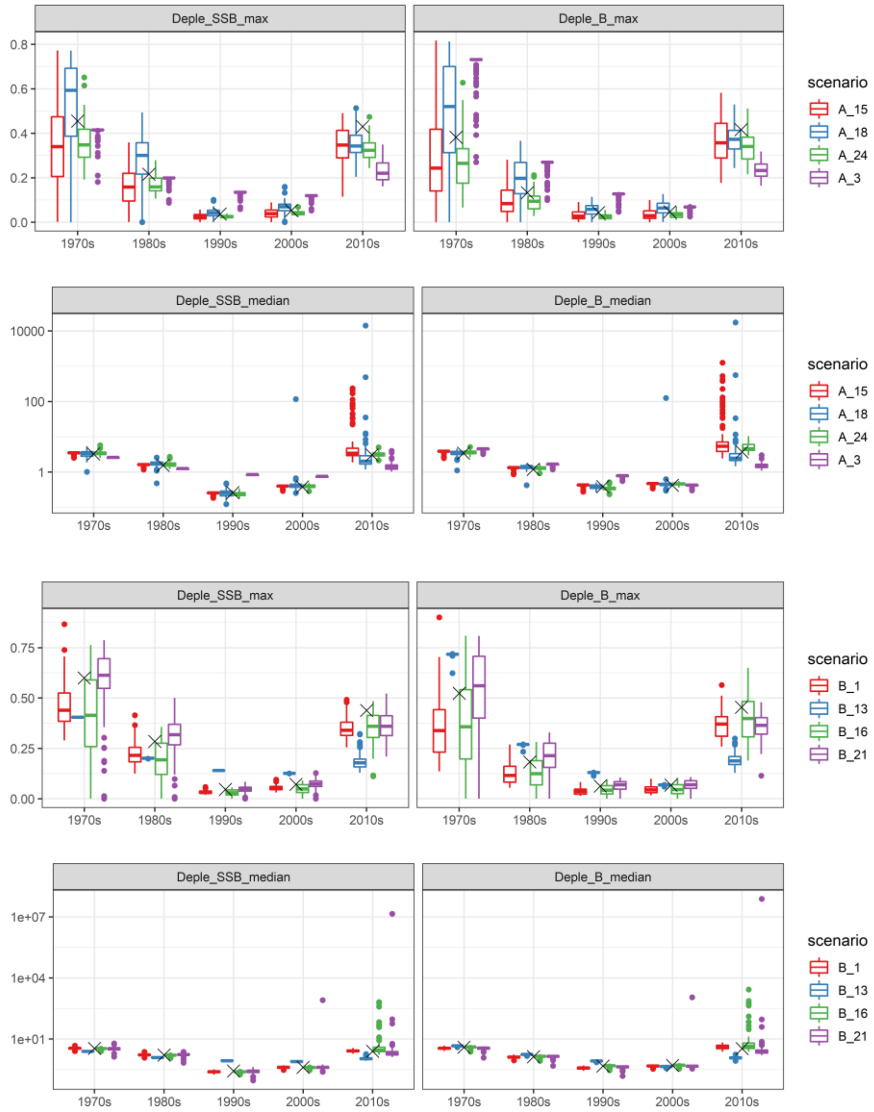
F0.1_1719
F20SPR_1618
F20SPR_1719
F30SPR_1618
F30SPR_1719
F40SPR_1618
F40SPR_1719
Fmax_1618
Fmax_1719
Fmsy_0.5_BH_1618
Fmsy_0.5_BH_1719
Fmsy_0.7_BH_1618
Fmsy_0.7_BH_1719
Fmsy_0.9_BH_1618
Fmsy_0.9_BH_1719
Fmsy_HS_1618
Fmsy_HS_1719
scenario D_17 D_19 D_23 D_6

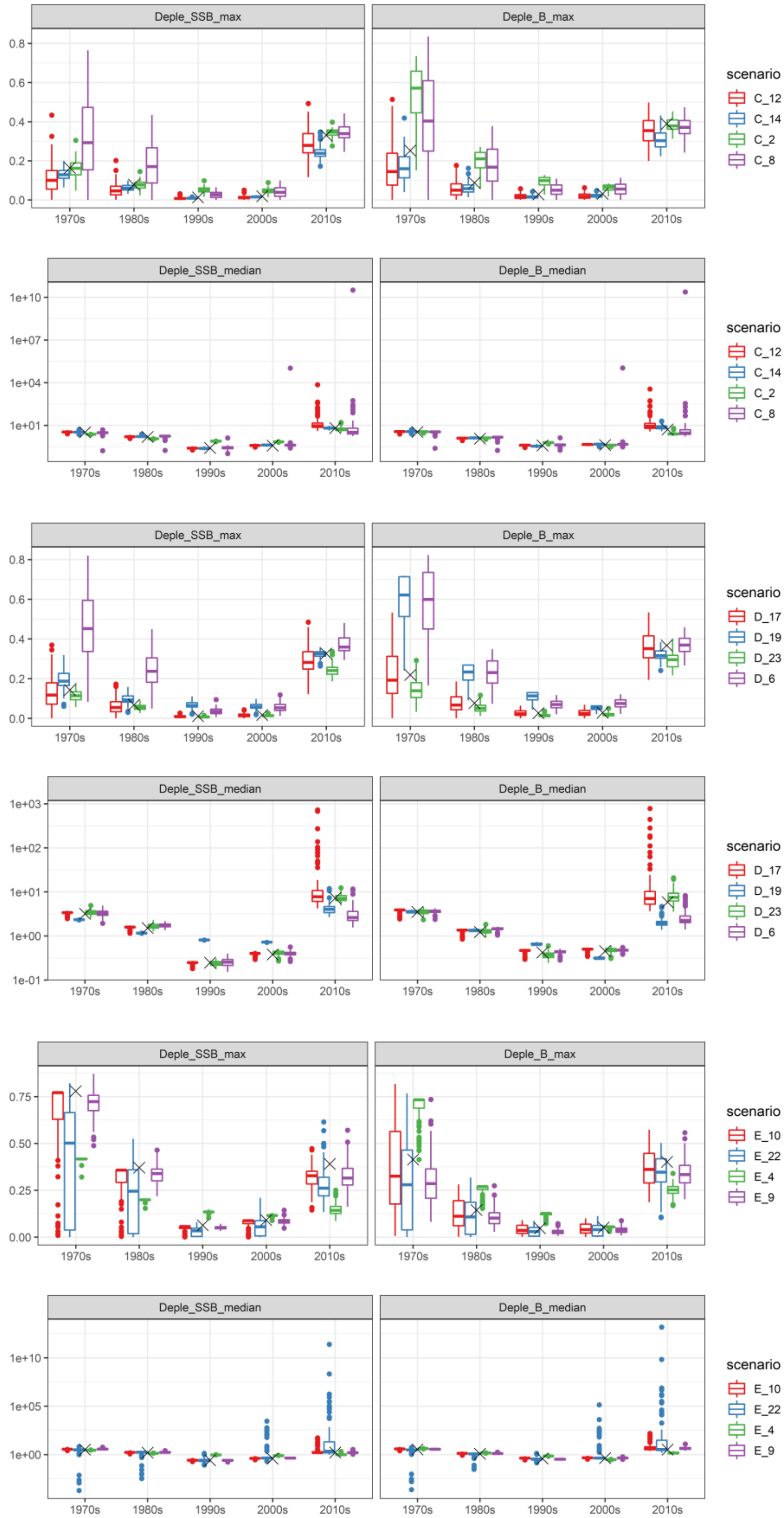

Input data: E
F0.1_1618
F0.1_1719
F20SPR_1618
F20SPR_1719
F30SPR_1618
F30SPR_1719
F40SPR_1618
F40SPR_1719
Fmax_1618
Fmax_1719
Fmsy_0.5_BH_1618
Fmsy_0.5_BH_1719
Fmsy_0.7_BH_1618
Fmsy_0.7_BH_1719
Fmsy_0.9_BH_1618
Fmsy_0.9_BH_1719
Fmsy_HS_1618
Fmsy_HS_1719
scenario E_10 E_22 E_4 E_9



Input data: F
F0.1_1618
F0.1_1719
F20SPR_1618
F20SPR_1719
F30SPR_1618
F30SPR_1719
F40SPR_1618
F40SPR_1719
Fmax_1618
Fmax_1719
Fmsy_0.5_BH_1618
Fmsy_0.5_BH_1719
Fmsy_0.7_BH_1618
Fmsy_0.7_BH_1719
Fmsy_0.9_BH_1618
Fmsy_0.9_BH_1719
Fmsy_HS_1618
Fmsy_HS_1719
F_11 F_20 F_5 F_7
scenario F_11 F_20 F_5 F_7

Fig. 5: Depletion statistics with VPA from scenario A to F. The points of 'X' indicate the values in fitting VPA to the real data under scenarios A to F. Note that the relative values to median are log-transformed for visualization of large ranges.




Deple_SSB_max
Deple_B_max
0.8
0.6
0.4
0.2
0.0
1970s
1980s
1990s
2000s
2010s
scenario
C_12
C_14
C_2
C_8
Deple_SSB_median
Deple_B_median
1e+10
1e+07
1e+04
1e+01
Deple_SSB_max
Deple_B_max
scenario
D_17
D_19
D_23
D_6
Deple_SSB_median
Deple_B_median
1e+03
1e+02
1e+01
1e+00
1e-01
Deple_SSB_max
Deple_B_max
0.75
0.50
0.25
0.00
scenario
E_10
E_22
E_4
E_9
Deple_SSB_median
Deple_B_median
1e+10
1e+05
1e+00

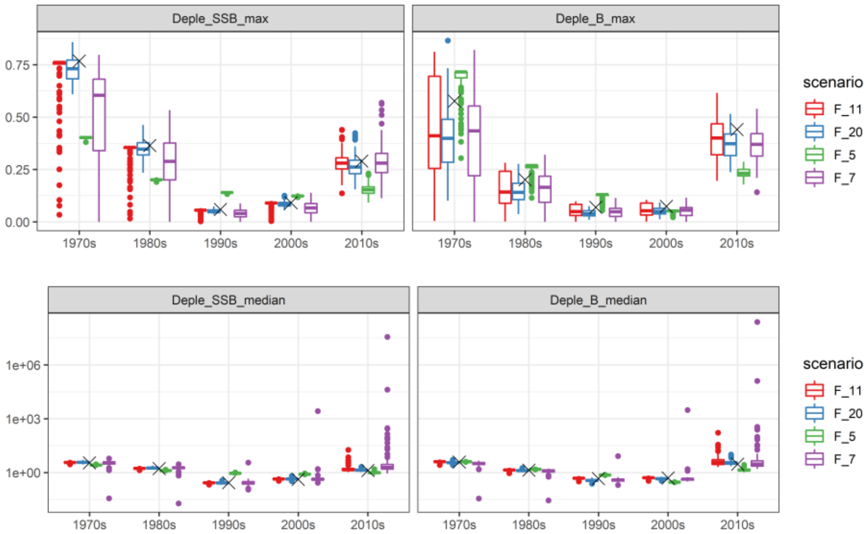

Deple_SSB_max
Deple_B_max
0.75
0.50
0.25
0.00
1970s
1980s
1990s
2000s
2010s
scenario
F_11
F_20
F_5
F_7
Deple_SSB_median
Deple_B_median
1e+06
1e+03
1e+00

Fig. 6: Frequencies of models that were used for SAM fitting for each pseudo dataset. Model "−1" indicates failure to estimate or converge.

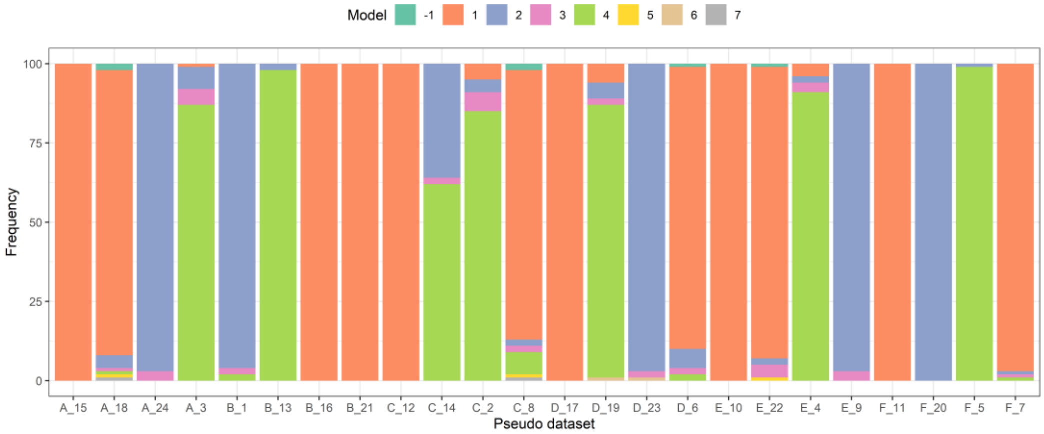
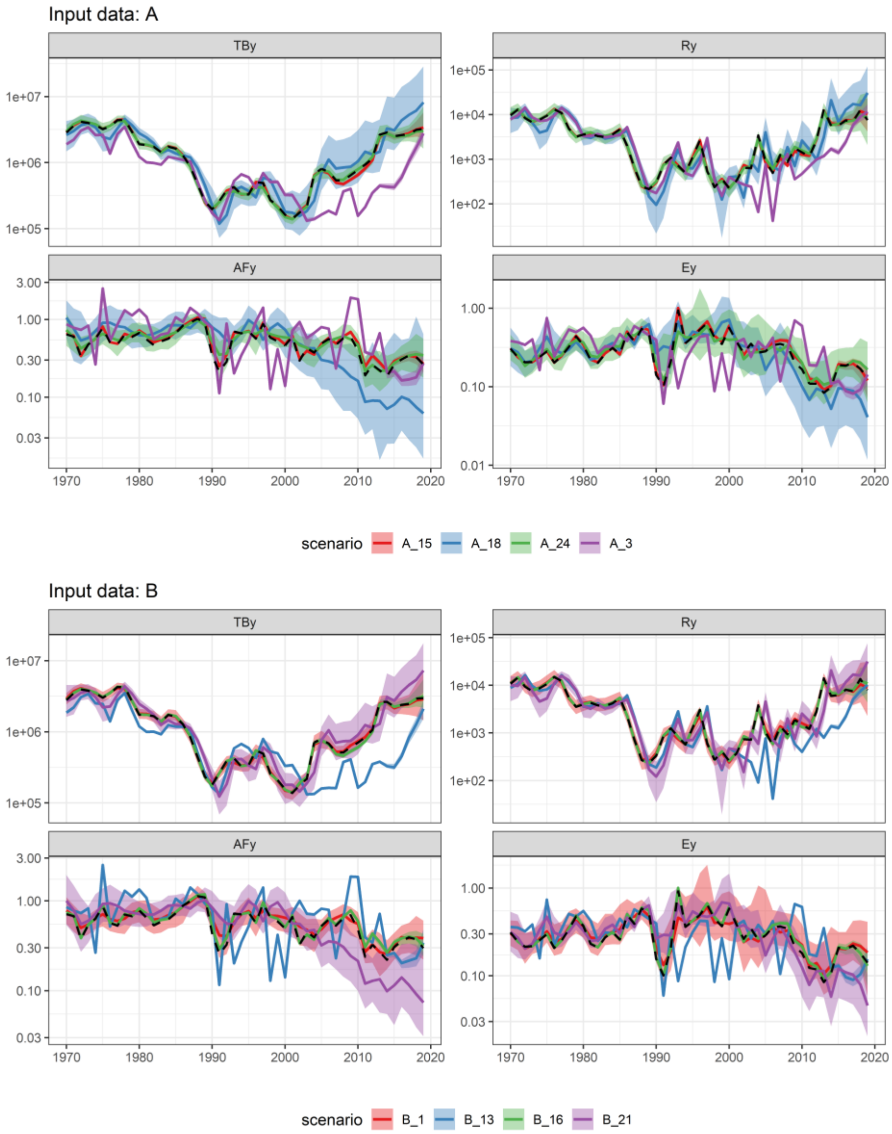
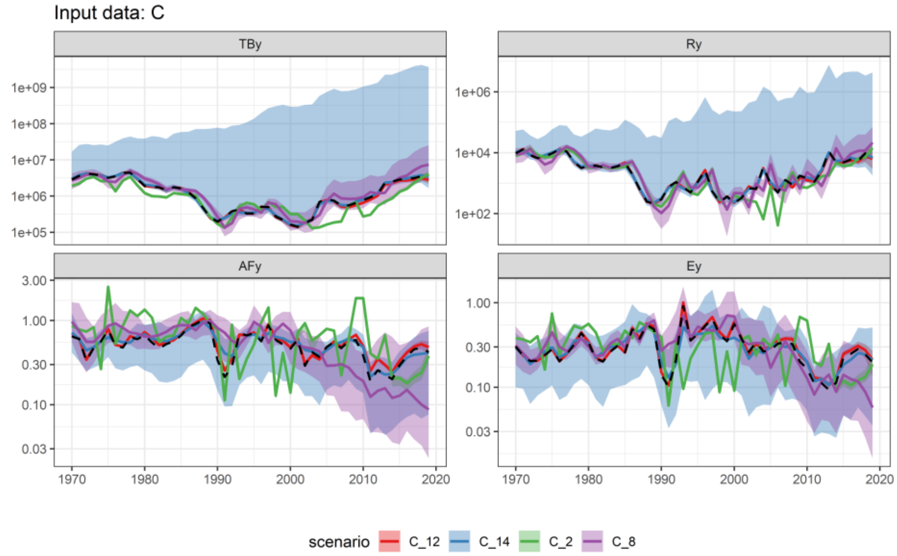
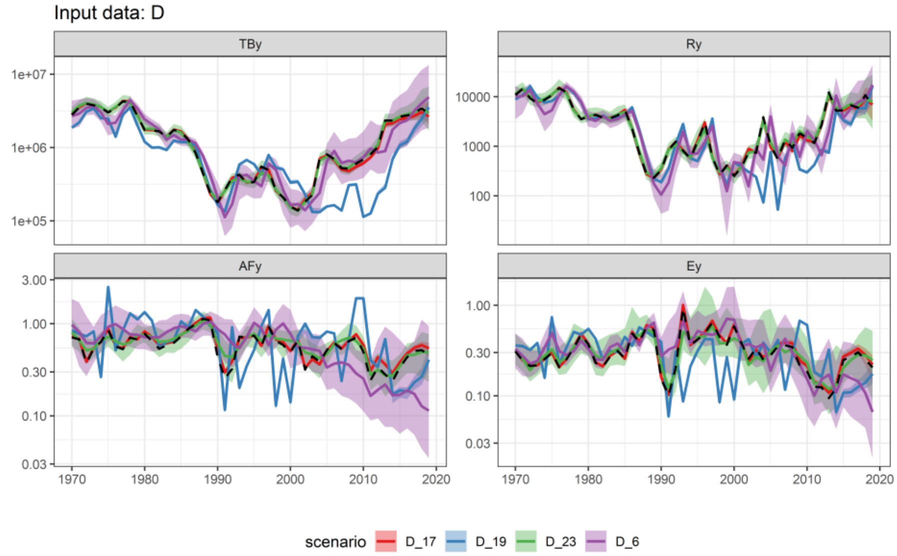
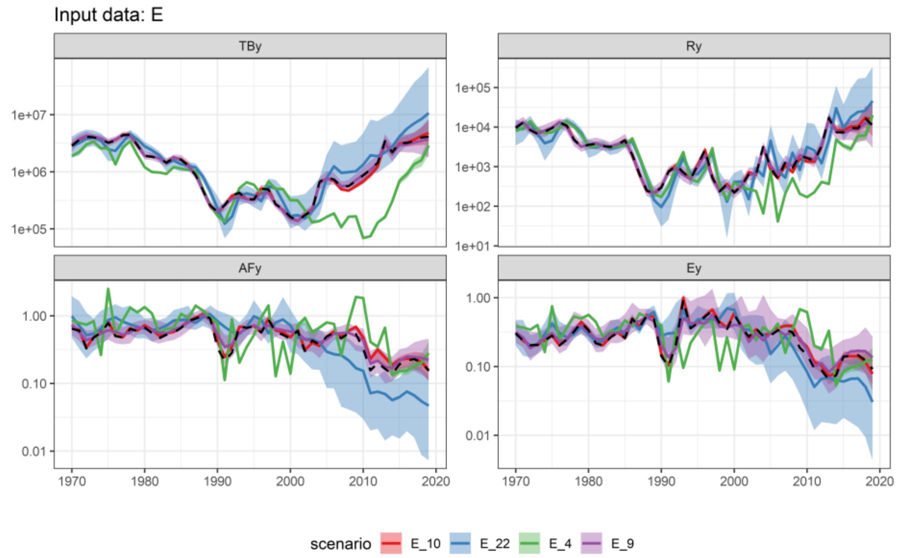


Fig. 7: Time series of state variables (TBy: total biomass, Ry: the number of recruits, AFy: F at age weighted by catch weight at age, and Ey: exploitation rate) with SAM from scnario (input data) A to F. The coloured lines indicates the median values among iterations per dataset while the shadowed areas indicate 95% intervals. The dashed lines indicate estimates when we fitted SAM to the real data under scenarios A to F. Note that the *y*-axes are log-transformed for visualization of large intervals.




Input data: C
TBy
Ry
AFy
Ey
scenario
C_12
C_14
C_2
C_8


Input data: D
TBy
Ry
AFy
Ey
scenario
D_17
D_19
D_23
D_6


Input data: E
TBy
Ry
AFy
Ey
scenario
E_10
E_22
E_4
E_9

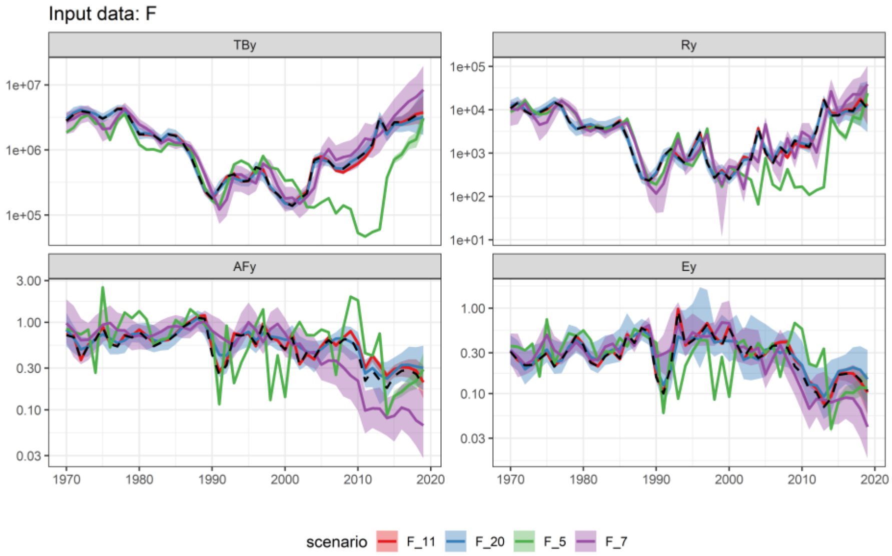
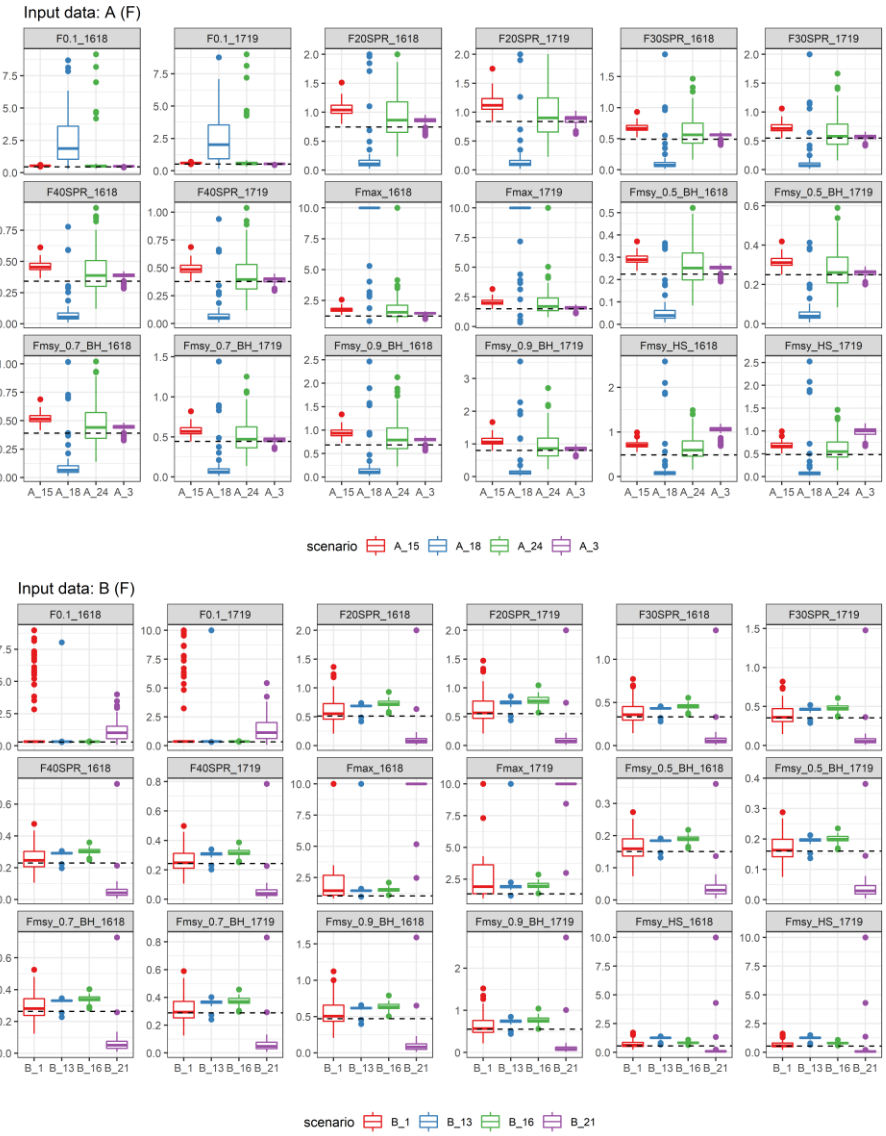
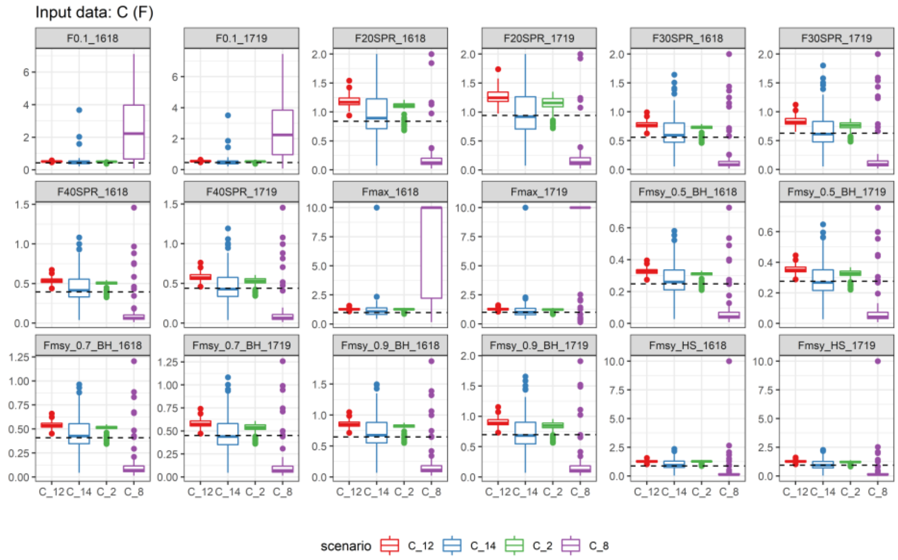
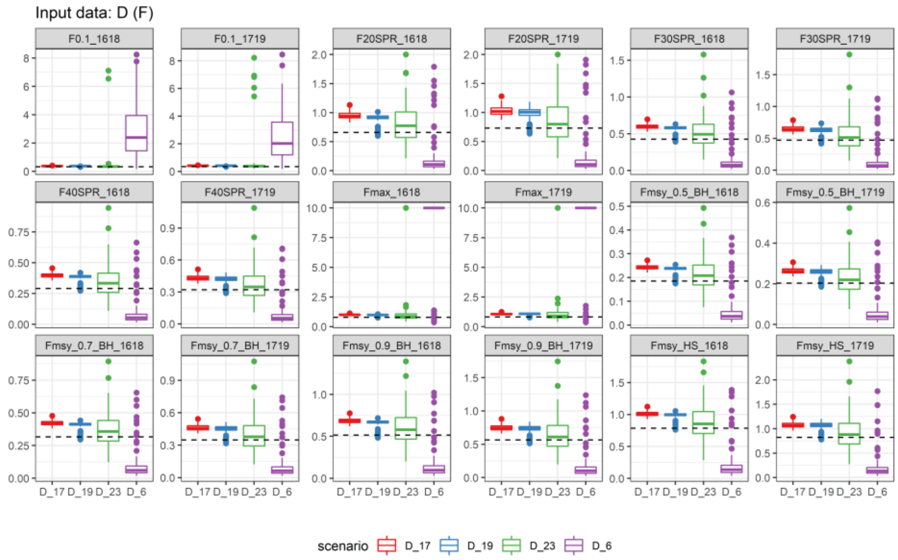
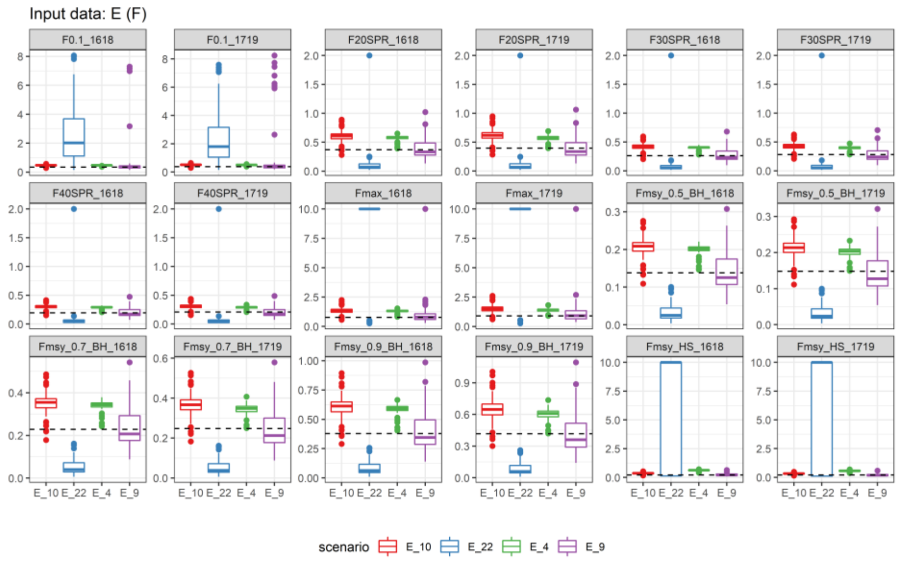

Input data: F
TBy
Ry
AFy
Ey
1e+07
1e+06
1e+05
1e+05
1e+04
1e+03
1e+02
1e+01
3.00
1.00
0.30
0.10
0.03
1.00
0.30
0.10
0.03
1970
1980
1990
2000
2010
2020
scenario
F_11
F_20
F_5
F_7

Fig 8: BRPs related to fishing mortality with SAM from scnario (input data) A to F. The dashed lines indicate the values in fitting SAM to the real data under scenarios A to F.




Input data: C (F)
F0.1_1618
F0.1_1719
F20SPR_1618
F20SPR_1719
F30SPR_1618
F30SPR_1719
F40SPR_1618
F40SPR_1719
Fmax_1618
Fmax_1719
Fmsy_0.5_BH_1618
Fmsy_0.5_BH_1719
Fmsy_0.7_BH_1618
Fmsy_0.7_BH_1719
Fmsy_0.9_BH_1618
Fmsy_0.9_BH_1719
Fmsy_HS_1618
Fmsy_HS_1719
C_12 C_14 C_2 C_8
scenario C_12 C_14 C_2 C_8


Input data: D (F)
F0.1_1618
F0.1_1719
F20SPR_1618
F20SPR_1719
F30SPR_1618
F30SPR_1719
F40SPR_1618
F40SPR_1719
Fmax_1618
Fmax_1719
Fmsy_0.5_BH_1618
Fmsy_0.5_BH_1719
Fmsy_0.7_BH_1618
Fmsy_0.7_BH_1719
Fmsy_0.9_BH_1618
Fmsy_0.9_BH_1719
Fmsy_HS_1618
Fmsy_HS_1719
D_17 D_19 D_23 D_6
scenario D_17 D_19 D_23 D_6


Input data: E (F)
F0.1_1618
F0.1_1719
F20SPR_1618
F20SPR_1719
F30SPR_1618
F30SPR_1719
F40SPR_1618
F40SPR_1719
Fmax_1618
Fmax_1719
Fmsy_0.5_BH_1618
Fmsy_0.5_BH_1719
Fmsy_0.7_BH_1618
Fmsy_0.7_BH_1719
Fmsy_0.9_BH_1618
Fmsy_0.9_BH_1719
Fmsy_HS_1618
Fmsy_HS_1719
E_10 E_22 E_4 E_9
scenario E_10 E_22 E_4 E_9

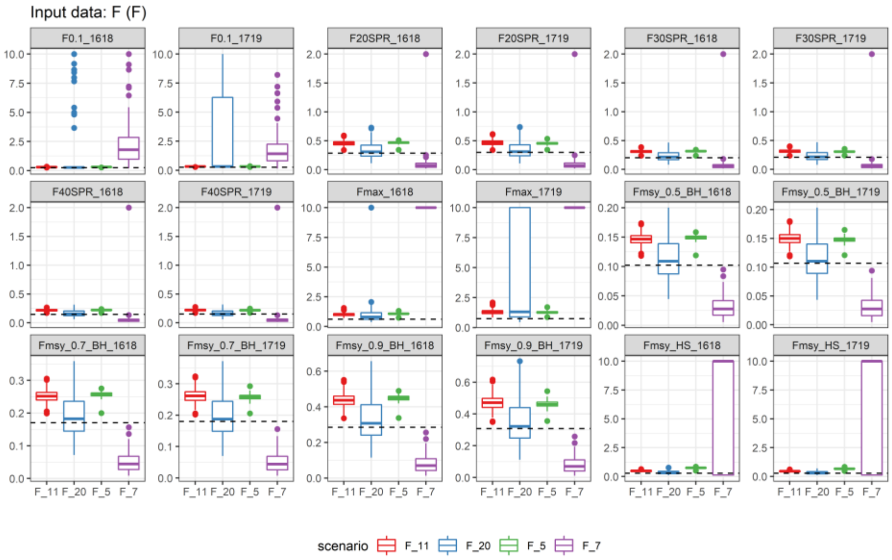
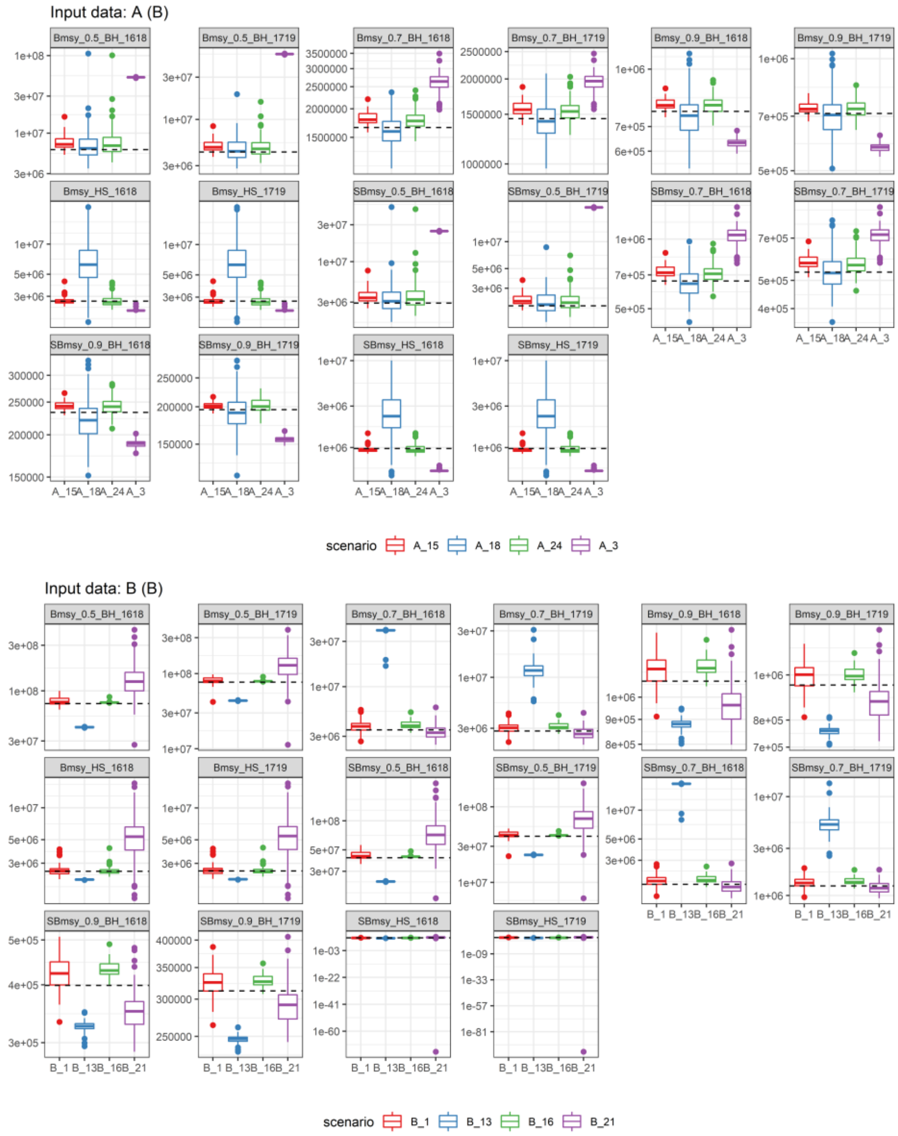
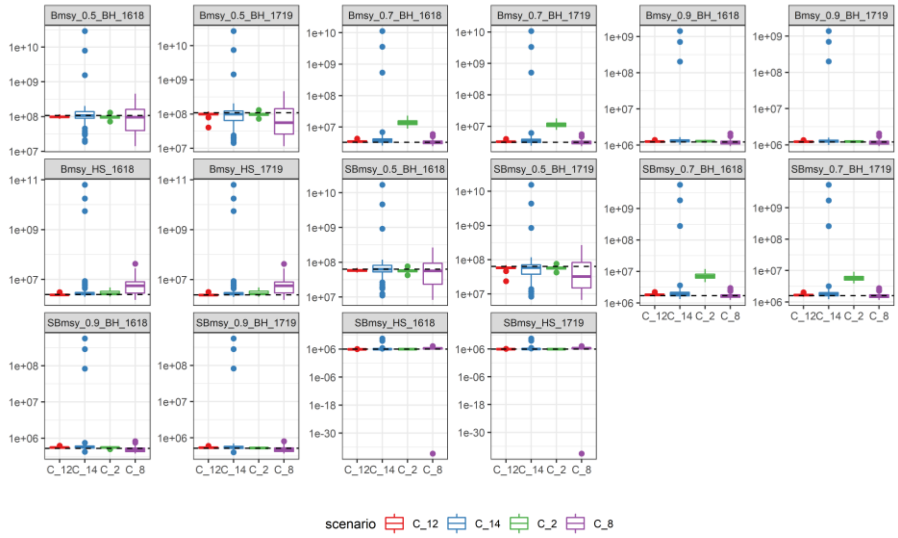

Input data: F (F)
F0.1_1618
F0.1_1719
F20SPR_1618
F20SPR_1719
F30SPR_1618
F30SPR_1719
F40SPR_1618
F40SPR_1719
Fmax_1618
Fmax_1719
Fmsy_0.5_BH_1618
Fmsy_0.5_BH_1719
Fmsy_0.7_BH_1618
Fmsy_0.7_BH_1719
Fmsy_0.9_BH_1618
Fmsy_0.9_BH_1719
Fmsy_HS_1618
Fmsy_HS_1719
F_11 F_20 F_5 F_7
scenario F_11 F_20 F_5 F_7

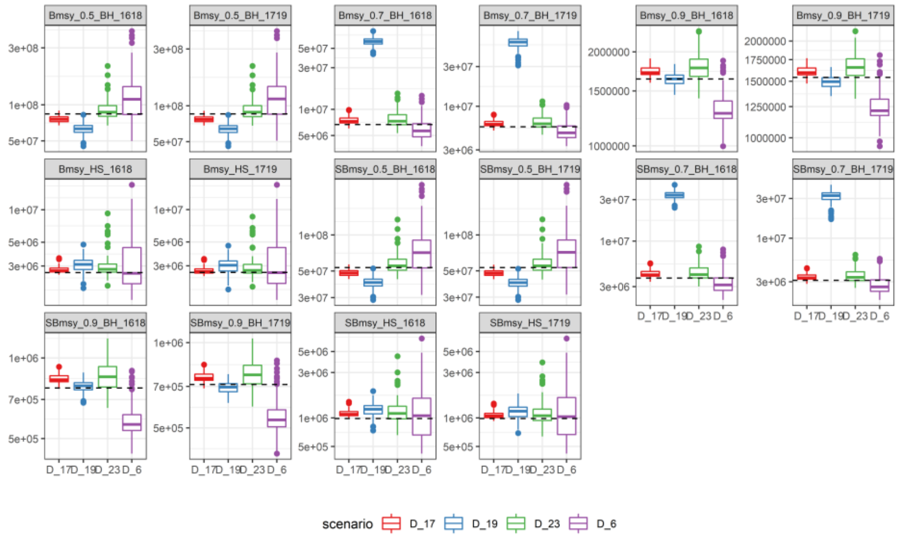
Fig 9: BRPs related to total biomass and spawning stock biomass with SAM from scnario (input data) A to F. The dashed lines indicate the values in fitting SAM to the real data under scenarios A to F.



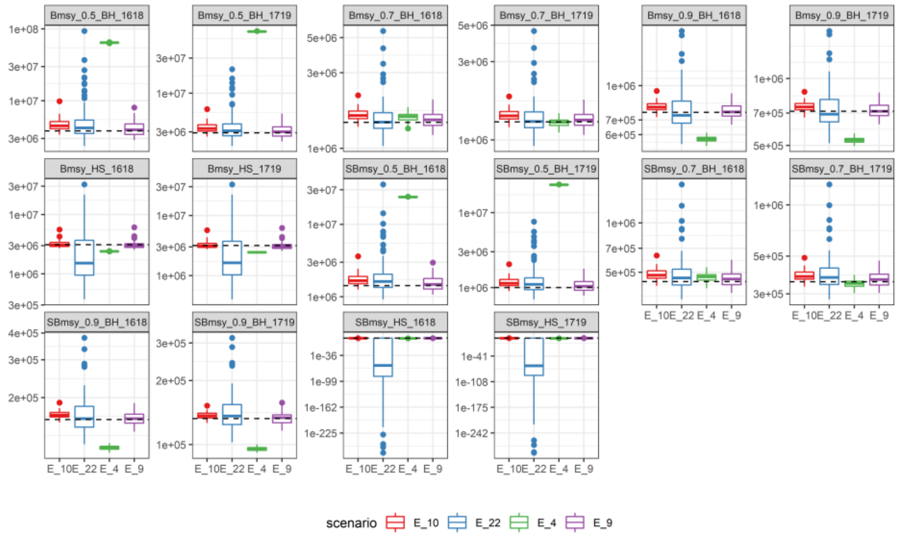
Input data: C (B)



Input data: D (B)



Input data: E (B)



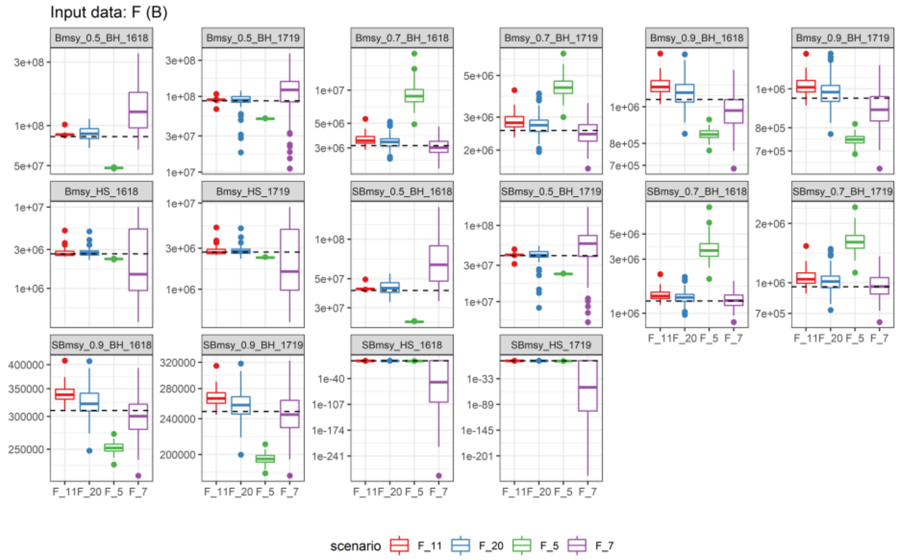
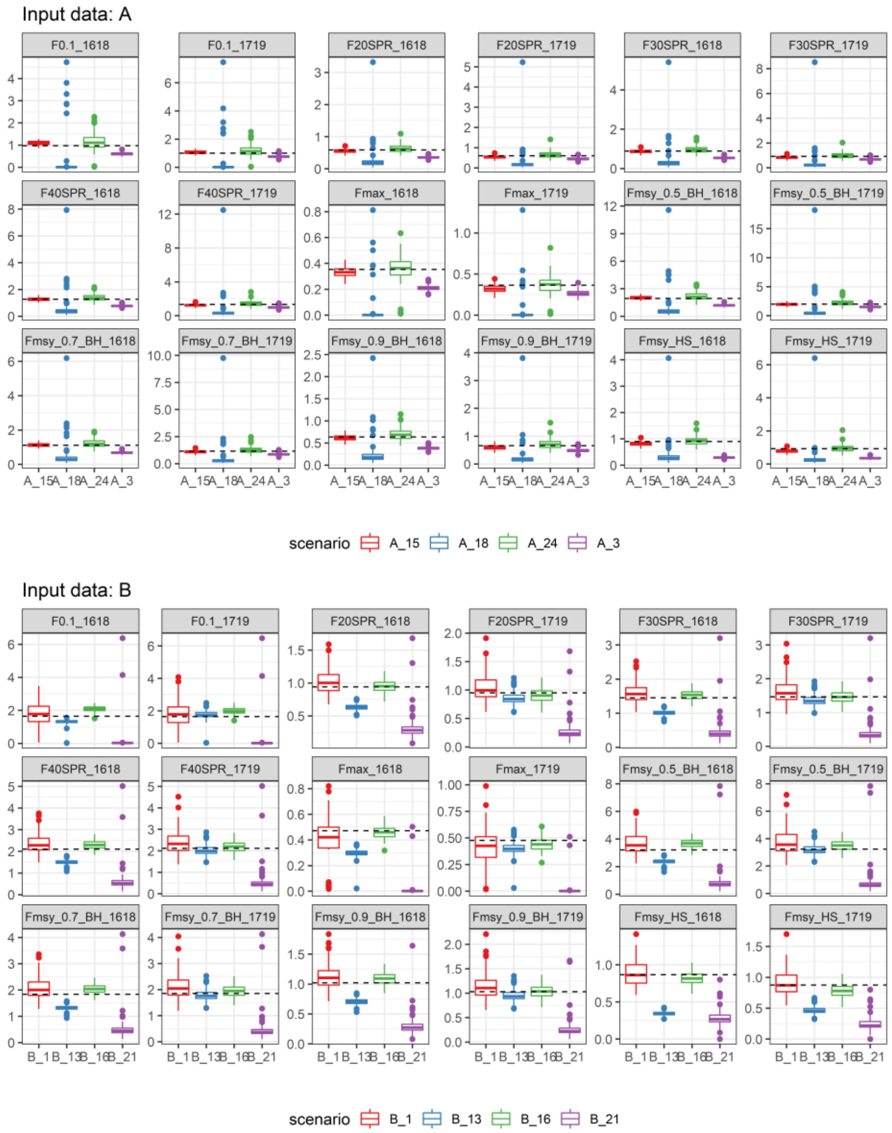
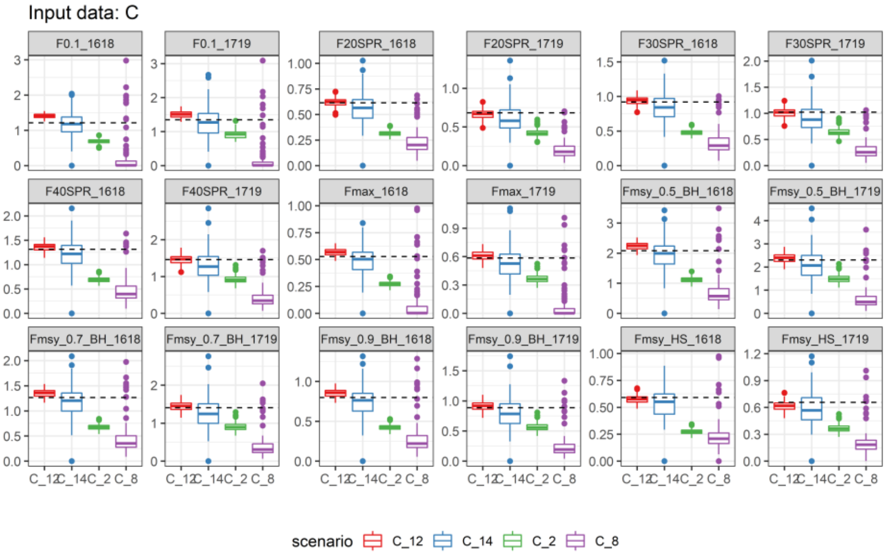
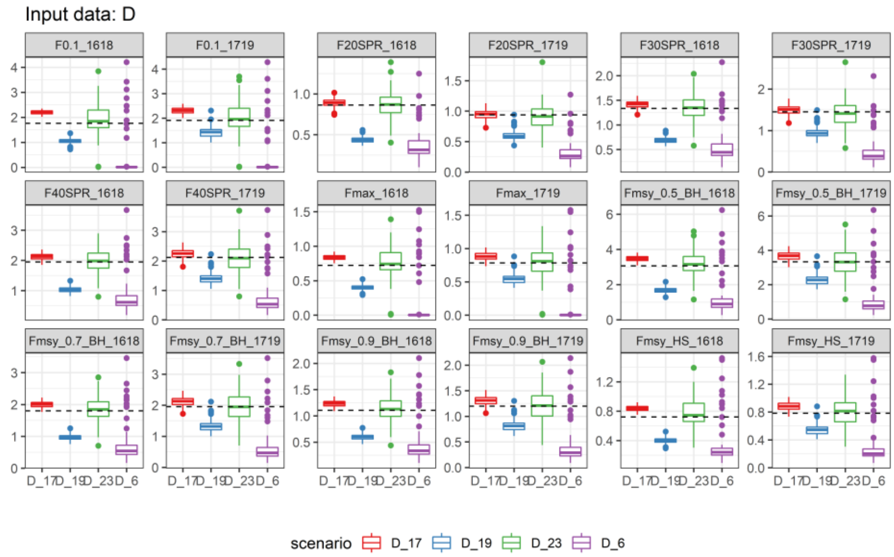
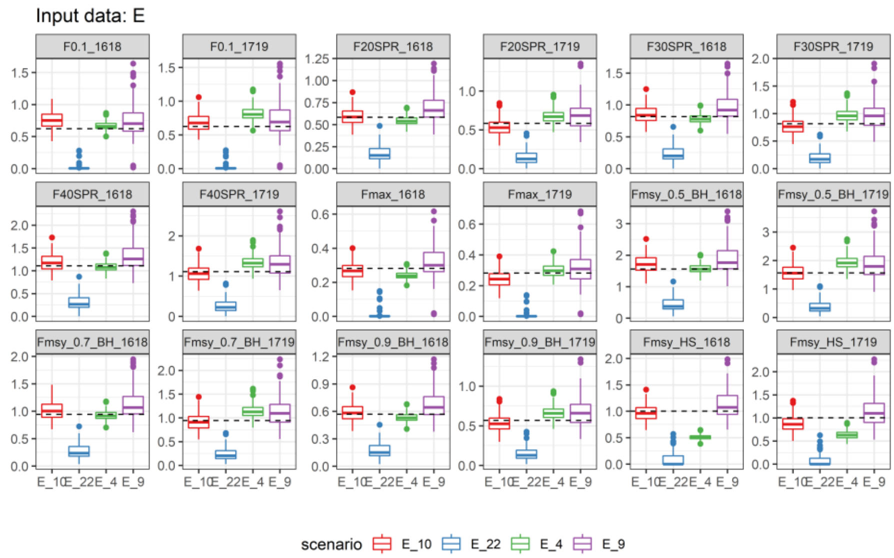

Input data: F (B)
Bmsy_0.5_BH_1618
Bmsy_0.5_BH_1719
Bmsy_0.7_BH_1618
Bmsy_0.7_BH_1719
Bmsy_0.9_BH_1618
Bmsy_0.9_BH_1719
Bmsy_HS_1618
Bmsy_HS_1719
SBmsy_0.5_BH_1618
SBmsy_0.5_BH_1719
SBmsy_0.7_BH_1618
SBmsy_0.7_BH_1719
SBmsy_0.9_BH_1618
SBmsy_0.9_BH_1719
SBmsy_HS_1618
SBmsy_HS_1719
F_11 F_20 F_5 F_7
scenario F_11 F_20 F_5 F_7

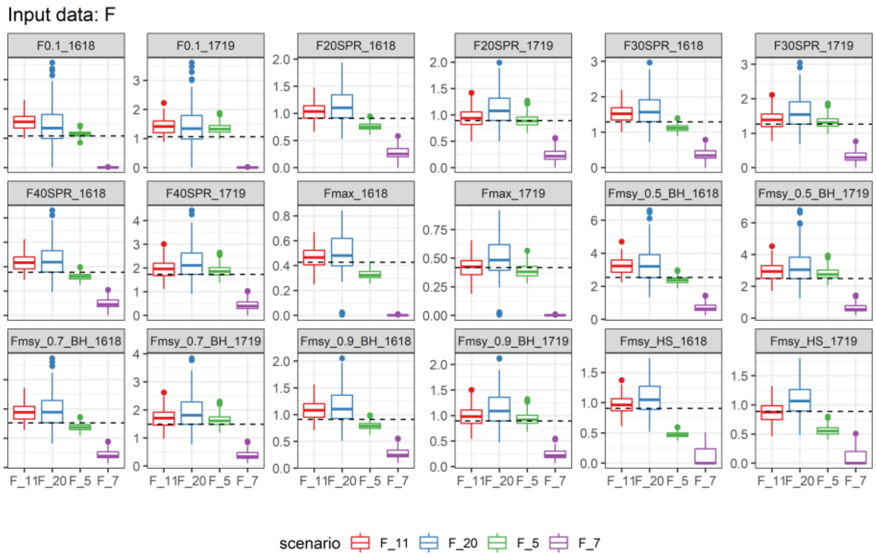
Fig. 10: Relative fishing impacts (ratio of current F to F reference points) with SAM from scnario (input data) A to F. The dashed lines indicate the values in fitting SAM to the real data under scenarios A to F.




Input data: C
F0.1_1618
F0.1_1719
F20SPR_1618
F20SPR_1719
F30SPR_1618
F30SPR_1719
F40SPR_1618
F40SPR_1719
Fmax_1618
Fmax_1719
Fmsy_0.5_BH_1618
Fmsy_0.5_BH_1719
Fmsy_0.7_BH_1618
Fmsy_0.7_BH_1719
Fmsy_0.9_BH_1618
Fmsy_0.9_BH_1719
Fmsy_HS_1618
Fmsy_HS_1719
scenario C_12 C_14 C_2 C_8

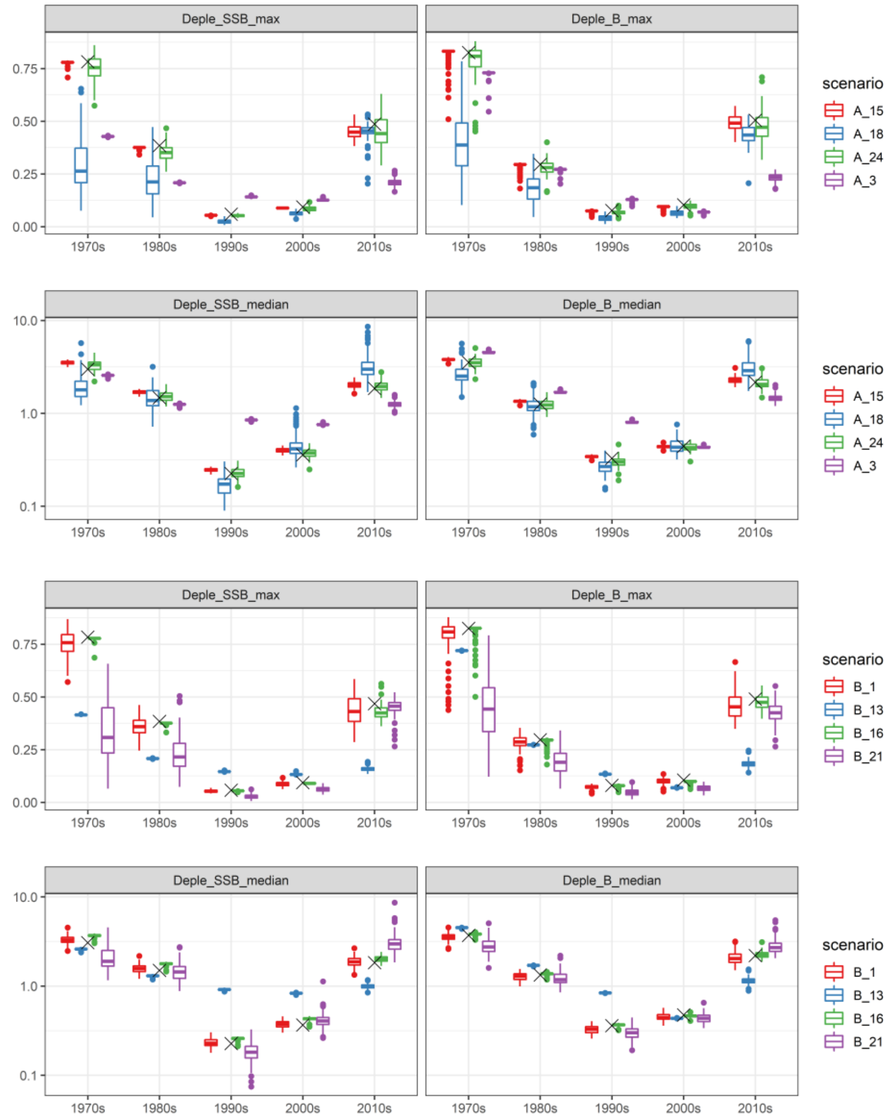

Input data: D
F0.1_1618
F0.1_1719
F20SPR_1618
F20SPR_1719
F30SPR_1618
F30SPR_1719
F40SPR_1618
F40SPR_1719
Fmax_1618
Fmax_1719
Fmsy_0.5_BH_1618
Fmsy_0.5_BH_1719
Fmsy_0.7_BH_1618
Fmsy_0.7_BH_1719
Fmsy_0.9_BH_1618
Fmsy_0.9_BH_1719
Fmsy_HS_1618
Fmsy_HS_1719
scenario D_17 D_19 D_23 D_6

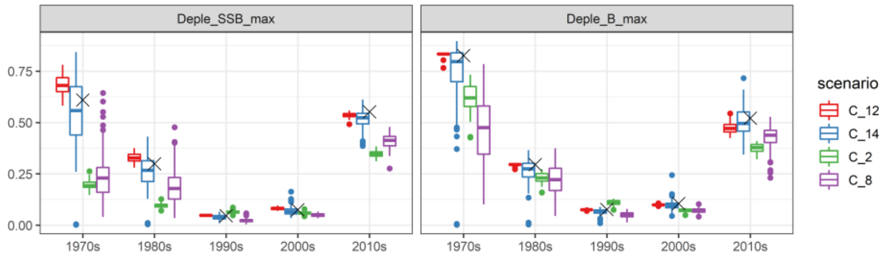

Input data: E
F0.1_1618
F0.1_1719
F20SPR_1618
F20SPR_1719
F30SPR_1618
F30SPR_1719
F40SPR_1618
F40SPR_1719
Fmax_1618
Fmax_1719
Fmsy_0.5_BH_1618
Fmsy_0.5_BH_1719
Fmsy_0.7_BH_1618
Fmsy_0.7_BH_1719
Fmsy_0.9_BH_1618
Fmsy_0.9_BH_1719
Fmsy_HS_1618
Fmsy_HS_1719
scenario E_10 E_22 E_4 E_9

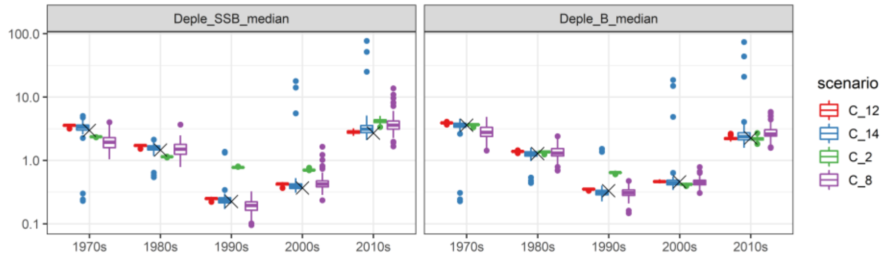


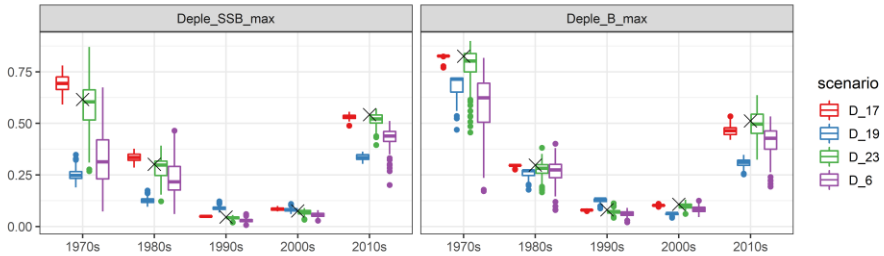
Input data: F
F0.1_1618
F0.1_1719
F20SPR_1618
F20SPR_1719
F30SPR_1618
F30SPR_1719
F40SPR_1618
F40SPR_1719
Fmax_1618
Fmax_1719
Fmsy_0.5_BH_1618
Fmsy_0.5_BH_1719
Fmsy_0.7_BH_1618
Fmsy_0.7_BH_1719
Fmsy_0.9_BH_1618
Fmsy_0.9_BH_1719
Fmsy_HS_1618
Fmsy_HS_1719
F_11 F_20 F_5 F_7
scenario F_11 F_20 F_5 F_7

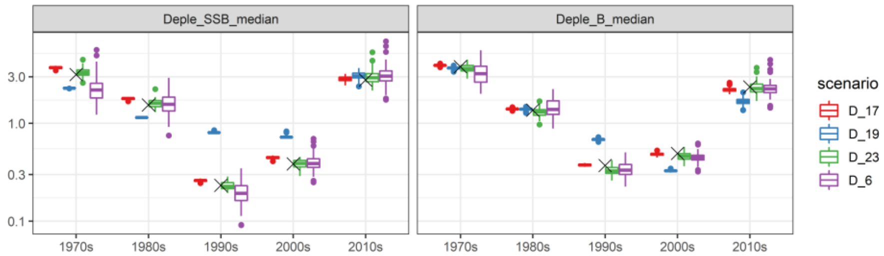
Fig. 11: Depletion statistics with SAM from scenario A to F. The points of ‘X’ indicate the values in fitting SAM to the real data under scenarios A to F. Note that the relative values to median are log-transformed for visualization of large ranges.

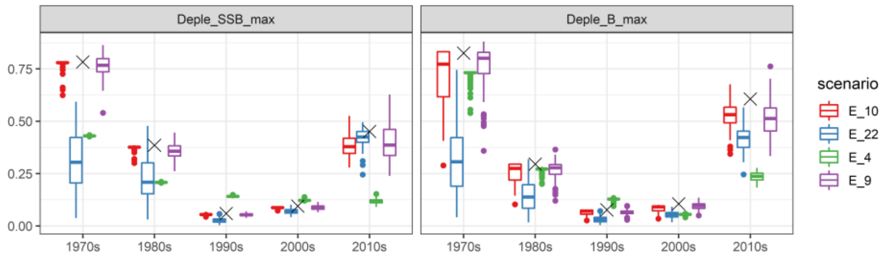


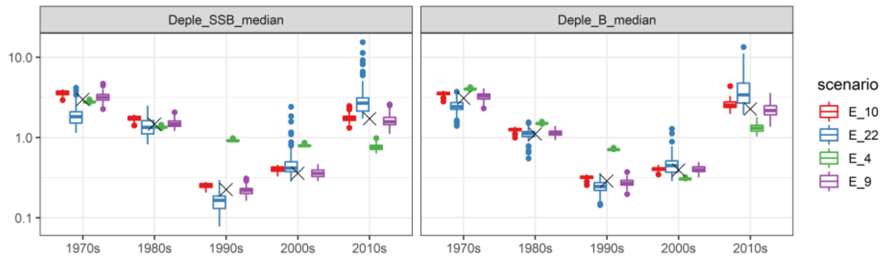

Deple_SSB_max
Deple_B_max
0.75
0.50
0.25
0.00
1970s
1980s
1990s
2000s
2010s
scenario
C_12
C_14
C_2
C_8

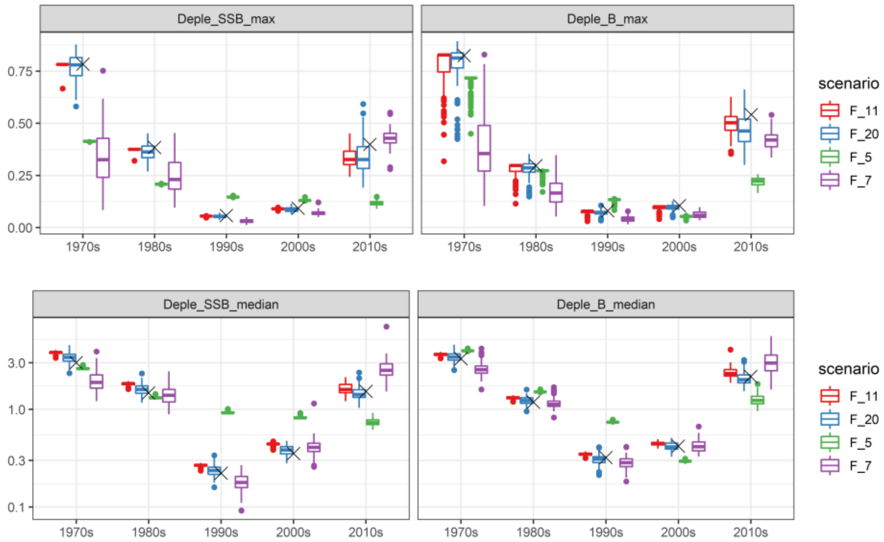

Deple_SSB_median
Deple_B_median
100.0
10.0
1.0
0.1
1970s
1980s
1990s
2000s
2010s
scenario
C_12
C_14
C_2
C_8


Deple_SSB_max
Deple_B_max
0.75
0.50
0.25
0.00
1970s
1980s
1990s
2000s
2010s
scenario
D_17
D_19
D_23
D_6


Deple_SSB_median
Deple_B_median
3.0
1.0
0.3
0.1
1970s
1980s
1990s
2000s
2010s
scenario
D_17
D_19
D_23
D_6


Deple_SSB_max
Deple_B_max
0.75
0.50
0.25
0.00
1970s
1980s
1990s
2000s
2010s
scenario
E_10
E_22
E_4
E_9


Deple_SSB_median
Deple_B_median
10.0
1.0
0.1
1970s
1980s
1990s
2000s
2010s
scenario
E_10
E_22
E_4
E_9



Deple_SSB_max
Deple_B_max
Deple_SSB_median
Deple_B_median
0.75
0.50
0.25
0.00
3.0
1.0
0.3
0.1
1970s
1980s
1990s
2000s
2010s
scenario
F_11
F_20
F_5
F_7