NPFC-2022-TWG CMSA05-WP01

2nd Meeting of the Small Working Group on Operating Model for Chub Mackerel Stock Assessment
August 31 - September 1, 2021 (9am – 1pm Tokyo time)
WebEx

Summary

Agenda Item 1. Opening of the Meeting

The 2nd intersessional meeting of the Small Working Group on Operating Model for Chub Mackerel Stock Assessment (SWG OM) commenced at 9 AM on 31 August 2021, Tokyo time in the format of video conferencing via WebEx. The meeting was attended by Members from Canada (Janelle Curtis), China (Qiuyun Ma, Libin Dai, Heng Zhang), Japan (Shota Nishijima, Kazuhiro Oshima, Momoko Ichinokawa, Naoto Shinohara) and Russia (Oleg Katugin, Vladimir Kulik, Igor Chernienko, Emiliya Chernienko) as well as the Secretariat (Dae-Yeon Moon, Alex Zavolokin, Peter Flewwelling, Mervin Ogawa, Sungkuk Kang). Dr. Joel Rice attended the meeting as an invited expert. The meeting was opened by Dr. Shota Nishijima (Japan) who served as the SWG OM Lead.

Participants agreed that the stock assessment documents presented at this SWG OM meeting will be revised, if needed, after the meeting and submitted to TWG CMSA05 as working papers. In case of document revision, the member responsible for the document submission shall submit a cover letter or document text which describes the revision to be prepended to the original document.

Agenda Item 2. Adoption of Agenda

There were no amendments to the agenda.

Agenda Item 3. Short summary of NPFC CMSA04 meeting relevant to SWG OM

The Lead gave a presentation on the development of an operating model up to the last meeting of the TWG CMSA held in June. He highlighted the key decisions made by the TWG CMSA and outlined mattes to be discussed at this meeting.

Agenda Item 4. Report of the results of candidate stock assessment models

- China (ASAP, BSSPM)
- Japan (SAM, VPA)
- Russia (KAFKA)

China presented an updated stock assessment based on ASAP for operating model for chub mackerel. Model settings were the same as those of the previous stock assessment except average catch-at-age data and mortality-at-age. Estimated catch were fitted well through all 6 scenarios, while the abundance indices fittings were various among different indices. The overall trends of total stock number, spawning stock biomass (SSB), and fishing mortality (F) were much similar among 6 scenarios. There was no significant difference in abundance and fishing mortality estimates among all scenarios.

On the question about a post-hoc analysis, China clarified that it did not apply post-hoc analysis of stock-recruitment relationship.

Participants discussed a need for a standardized method when calculating performance measures including reference points (see agenda item 5 for more details).

China presented preliminary results of BSSPM for operating model for chub mackerel. Only one base case scenario was run because, due to the model assumption of BSSPM, the different natural mortality, maturity and weight matrix could not be considered in the stock assessment.

Participants asked several questions on observation errors in abundance indices, wide credible intervals, bimodal posterior distributions, the applicability of informative prior distributions, and the possibility of retrospective analysis. China clarified that the observation errors were consistent among different abundance indices and agreed that the retrospective analysis would be tried in a future analysis. China argued that the balance of data and prior distributions is important and recognized that some improvements such as setting informative priors and changing MCMC sampling may be effective.

Participants re-affirmed that BSSPM will be used as a candidate stock assessment model after pseudo data are generated by POPSIM.

Japan presented an update of VPA and SAM for operating models for chub mackerel stock assessment. A few model configurations from the previous analysis have been changed to avoid overfitting and stabilize parameter estimation, which will be useful for the application of these models to pseudo-data generated by operating model. Abundance estimates became lower in comparison with previous assessment due to the change in M, but qualitative results have not changed significantly. SAM demonstrated lower retrospective bias than VPA.

Russia provided stock assessment results by KAFKA for different scenarios with a set of biological uncertainties such as natural mortality, weight at age and maturity at age. Scenarios with the highest maturity and weight demonstrated higher SSB values compared to the other scenarios.

Participants requested Russia to update the description of KAFKA model and respond to the questions sent to Russia during the meeting.

It was found that Russia used input data that were different from other members' analyses. Participants agreed that Russia will re-run the KAFKA model and submit the results with detailed model description to the SWG OM members for review by 30 September. Final results should be submitted to the external expert by 7 October.

Participants noted lack of model diagnostics and requested Russia to include model diagnostics of retrospective analysis in its stock assessment document.

Agenda Item 5. Wrap-up of model specifications and outputs

- Confirmation of scenarios analyzed

  Participants viewed 6 scenarios agreed at TWG CMSA04.

- Update of model settings (listed in Annex E in CMSA04 Report, if needed)

  Participants reviewed settings of the stock assessment models used for the conditioning of operating models and revised them (Annex A). A new line "Process error" was added to the table of model settings.

  On the question about Kalman filter of KAFKA, Russia clarified that Kalman filter smooths total number of fish.

Members were requested to review the table of model settings and should report any changes made by each member intersessionally at the TWGCMSA05 meeting.

- Model outputs and comparison of model results based on the determined performance measures

Comparison of model results was not possible due to incorrect data of KAFKA.

- Discussion on the evaluation of model outputs and finalization of prioritization of performance measures

Participants reviewed priority performance measures for evaluating the stock assessment models and revise them (Annex B). Participants agreed to calculate annual F as average F at age weighted by catch weight at age (observed for VPA and KAFKA and estimated for ASAP and SAM).

Japan drafted a document outlining configurations for calculating performance measures to be used by members. It was provisionally determined that the time period for biological parameters and F-at-age for calculating biological reference points would be 2016-2018 and 2017-2019. Japan will update the document with detailed descriptions and circulate it to members by 30 September. Members will review the document and provide feedback by 7 October. The final version of detailed configurations for calculating performance measures is shown in Annex D.

Agenda Item 6. Development of operating model (PopSim-A)

- Progress of OM development (Presentation from Dr. Joel Rice)
- Information necessary for OM

The external expert conducted a preliminary analysis using a VPA result and found that population dynamics simulated by PopSim-A did not match the estimates by VPA because of different settings of recruitment age between PopSim-A (age 1) and VPA (age 0), which should be fixed. The external expert argued the importance of model diagnostics by introducing several methods but did not recommend including an additional performance measure. Participants recognized that some diagnostics will be applied to the model fitted to real data after the OM testing is finished.

Participants discussed whether PopSim-A can treat probability distributions of measurement errors of abundance indices and catch data other than the default settings. The external expert agreed to check the settings of PopSim-A on probability distributions of measurement errors.

Members confirmed necessary input data (e.g., number at age in the initial year, annual recruitment, annual maturity-at-age) and recognized that process errors are not incorporated into PopSim-A. The template of necessary input data is available on the Collaboration website.

The external expert requested members to provide the stock assessments results under the determined scenarios in the format of csv or rdata. China and Japan will send the results with their outline or description to the external expert by 30 September (see Agenda Item 4 for Russia).

Agenda Item 7. Assignments to be done towards the TWG CMSA05 meeting

- Each Member (China, Japan, and Russia)
- The external expert

Participants agreed on the following assignments and timelines towards the TWG CMSA05 meeting:

- China and Japan will submit finalized input data for PopSim, in accordance with the template, to the invited expert (by 30 September 2021)
- Russia will submit input data* for PopSim, in accordance with the template, to the invited expert (by 30 September 2021)

  *Data may require revision
- Russia will submit model configuration and results of KAFKA under the determined scenarios for review by Members (by 30 September 2021)
- Japan will submit the description of a standardized method for calculating performance measures (by 30 September) and Members will review it (by 7 October)
- Members will review the submitted model configuration and results of KAFKA (by 7 October 2021)
- Russia will submit finalized input data of KAFKA, in accordance with the template, to the invited expert (by 7 October 2021)
- Members will share a program code for calculating output performance measures (by 30 October 2021)

In addition, members slightly revised and clarified some tasks in the flowchart as follows:

- Members will fit models to pseudo-data and original six scenarios and calculate performance measures for sending estimates to the expert (by 31 December 2021)

- Members will share the original model estimates and outputs based on the pseudo-data for transparency and double-checking by TWG CMSA (by 31 December 2021)

The timelines for the expert remained unchanged:

- The expert will generate the pseudo data to members (by 30 October 2021)
- Members will fit models to pseudo-data and send estimates to the expert (by 31 December 2021)

The revised flowchart for the development of operating models and testing stock assessment models is attached (Annex C).

Members designated contact points for communication with the external expert:

- Qiuyun Ma (China) qyma@shou.edu.cn
- Shota Nishijima (Japan) nishijimash@affrc.go.jp
- Igor Chernienko (Russia) igor.chernienko@tinro-center.ru
- (cc: Vladimir Kulik (TWG CMSA Chair) vladimir.kulik@tinro-center.ru, Kazuhiro Oshima (TWG CMSA vice-Chair) oshimaka@affrc.go.jp and Alex Zavolokin (Science Manager) azavolokin@npfc.int).

Agenda Item 8. Other matters

Members agreed not to hold an additional intersessional meeting of the SWG OM and to use e-mail correspondence and the Collaboration website for intersessional works.

The Science Manager informed participants about proposed dates of the next TWG CMSA05 meeting – 22-25 February 2022. The dates will be further discussed among TWG CMSA members through correspondence.

Agenda Item 9. Closing of the Meeting

The meeting closed at 14:48 PM on 1 September 2021, Tokyo time.

Annexes

Annex A – Settings of the stock assessment models used for the conditioning of operating models

Annex B – Priority performance measures for evaluating the stock assessment models

Annex C – Flowchart for the development of operating models and testing stock assessment models
Annex D– Detailed configurations for calculating performance measures

Annex A

Settings of the stock assessment models used for the conditioning of operating models

Settings/Models	VPA	SAM	ASAP	KAFKA
General characteristics	Backward calculation, no specific assumption in SR relationship and fisheries selectivity. No errors in catch at age. Penalty in estimating the terminal year's F.	Forward calculation, flexible assumption in SR relationship, and ability to estimate several random effects in fishing mortality	Forward calculation, Beverton-Holt SR relationship (recruitment is 1 age-old), separable assumption in fishing mortality	Backward calculation + Kalman filter, no specific assumption in SR relationship and fisheries selectivity. No errors in catch at age.
Total catch weight	Simple summation of catch at age * weight at age			
Error in total catch weight	No error	Sum of predicted catch number at age (no error)	Lognormal error	No error
Catch at age data	Merged	Merged	Merged	Merged
Error of catch at age or catch composition	No error	Lognormal error	Multinomial	No error
Abundance index fitted	All six abundance indices	All six abundance indices	All six abundance indices	All six abundance indices
Abundance index error	Lognormal error	Lognormal error	Lognormal error	Normal
Estimation of nonlinear parameter of hyper stability/depletion	Yes	Yes (but fixed at 1 for the SSB indices)	No	No
Natural mortality scenario	Previous M values (Takahashi et al. 2019) to be used. M at age 0 is extrapolated at 0.57. Gislason 1 to be used.			
Maturity-at-age scenario	Keeping the three scenario settings (average, highest, lowest)			
Weight-at-age scenario	Keeping the three scenario settings (average, highest, lowest)			
Recruitment age	0	0	1	0

Process error	No error distribution assumed	Random walk for age 0 Fixed at a small value (SD: 0.01) for other ages	Lognormal error from predicted values assuming steepness as 0.99(?) for age 0	Normal error in total number
Stock recruitment assumption	Post-hoc analysis by the standardized method*			
Steepness				
Sigma R				
Fleet configuration	Merged	Merged	Merged	Merged
Selectivity assumption	Independent age specific F	Age specific F with random walk	Age specific selectivity	Age specific fishing rate fi_at=1-exp(-F_at)
Objective function (error structure)	Lognormal observation errors in abundance indices + ridge penalty to reduce retrospective bias	Lognormal observation errors in abundance indices and catch at age, and random effects of lognormal recruitment variability and F random walk process	Lognormal observation errors in abundance indices and total catch, multinomial in catch composition	Normal observation errors in abundance indices
Others			Post-hoc analysis of SR relationship is suggested (if possible)	The feasibility to use the other indices needs confirmation

Note: Shaded rows indicate common settings among all models.

Annex B

Priority performance measures for evaluating the stock assessment models

			Measure Available				
Measure	**Necessity**	Priority	VPA	ASAP	KAFKA	SAM	BSSPM
State Variables							
B (whole years)	Compulsory	Yes	Yes	Yes	Yes	Yes	Yes
R (whole years)	Compulsory	Yes	Yes	Yes	Yes	Yes	No
F (whole years)	Compulsory	Yes	Yes	Yes	Yes	Yes	No
Exploitation Rate			Yes	Yes	Yes	Yes	Yes
Biological Reference Points							
F%SPR	Compulsory, if possible	Yes	Yes	Yes	Yes	Yes	No
F0.1, FMAX	Compulsory, if possible	Yes	Yes	Yes	Yes	Yes	No
B_{MSY}	Compulsory, if possible	Yes	Yes*	Yes*	Yes*	Yes	Yes
F_{MSY}	Compulsory, if possible	Yes	Yes*	Yes*	Yes*	Yes	Yes
Depletion Statistics							
SSB/max(SSB) (periods**)	Compulsory	TBD	Yes	Yes	Yes	Yes	No
B/max(B) (periods**)	Compulsory	Yes	Yes	Yes	Yes	Yes	Yes
SSB/median(SSB) (periods**)	Compulsory	TBD	Yes	Yes	Yes	Yes	No
B/median(B) (periods**)	Compulsory	Yes	Yes	Yes	Yes	Yes	Yes
***Relevant Time period for Depletion Statistics*	*Average by decade, 1970's-2020.*						
Retrospective analysis (e.g.Mohn's rho) 7 years	Compulsory	Yes	Yes	Yes	Yes	Yes	Yes

Notes and Questions:

Biological reference points will be calculated by a standardized method.

The time period for the biological reference points is 2017-2019 and 2016-2018.

How to rank or utilize the results in comparison of the performance measures.

Weighted average F by catch-weight-at-age will be used as the performance measure of F (catch-at-age will be based on observed one for VPA and KAFKA and on estimated one for ASAP and SAM).

Check the performance of SSB & B.

**by post hoc analysis*

c

Annex C

Flowchart for the development of operating models and testing stock assessment models

1. Real data for stock assessment

Data available

- Each member will submit available data (*by SC04 meeting, April 2019*)
- SWG will format the data and compile the data *by 1st July 2019*

2. Fit with several models

Some stock assessment models (VPA, ASAP, KAFKA, SAM) **proposed as the candidates for the stock assessment are used**

- Start from 1st July 2019

3. Estimated parameters

- Members will submit working papers (WP) on results of each stock assessment model and WPs with description of data submitted (no later than one month before TWG CMSA03 meeting)
- SWG will present and compare the estimated results and TWG will review them
- SWG will make a table of assumptions and parameters used in the SA models
- TWG will review data submitted
- TWG will determine scenarios for operating models (for free assumption cases)

by the end of TWG CMSA03

- Secretariat will seek an external expert intersessionally and invite her/him to the TWG CMSA04 meeting
- The expert will suggest the rules for prioritization of the performance measures for review by TWG CMSA04*
- Members will rerun the stock assessment models based on the determined scenarios (TWG CMSA04 report, Annex X)
- Model description and results of BSSPM based on base-case scenario will be provided

SWG OM02 will review the results (late August 2021)

- Additional timelines agreed at SWG OM02, 31 Aug-1 Sep 2021 (see below)

4. Generation of pseudo data sets

- The expert will generate the pseudo data according to the scenarios determined and distribute pseudo data to members* (by 30 October 2021)
- **Exclude extremely unrealistic pseudo data (crash or outburst...) *** (according to the paragraph 7 of the protocol of OM Development)

5. Fit with several models

The candidates of the stock assessment models

VPA, ASAP, KAFKA, SAM, BSSPM

- Members will fit models to pseudo-data and original six scenarios and calculate performance measures for sending estimates to the expert (by 31 December 2021)
- Members will share the original model estimates and outputs based on the pseudo-data for transparency and double-checking by TWG CMSA (by 31 December 2021)

6. Estimates in the SA models

Check the performance of the candidate stock assessment models*

- Consultant will analyze model estimates, check the performance of the candidate stock assessment models and draft a report for the TWG CMSA (by 15 February 2022)

TWG CMSA05 will review the results (spring 2022)

* By an external expert

Additional timelines agreed at SWG OM02, 31 Aug-1 Sep 2021

- China and Japan will submit finalized input data for PopSim to the invited expert (by 30 September)
- Russia will submit input data* for PopSim to the invited expert (by 30 September 2021)
  * Data may require revision
- Russia will submit model configuration and results of KAFKA under the determined scenarios for review by Members (by 30 September 2021)
- Members will review the submitted model configuration and results of KAFKA (by 7 October 2021)
- Russia will submit finalized input data of KAFKA to the invited expert (by 7 October 2021)

Other matters

- Japan will submit the description of a standardized method for calculating performance measures (by 30 September) and Members will review it (by 7 October)
- Members will share a program code for calculating output performance measures (by 30 October 2021)

Annex D

Detailed configurations for calculating performance measures

Table 1. Symbols

N_{ay}	Numbers of fish at age a and year y	Estimated
F_{ay}	Fishing mortality coefficient age a and year y	Estimated
c_{ay}	Observed catch number at age a and year y	Given
C_{ay}	Estimated catch number at age a and year y ($C_{ay} = c_{ay}$ in VPA or KAFKA that does not consider error in catch at age)	Estimated
w_{ay}	Weight (g) of individual fish at age a and year y	Given
g_{ay}	Maturity rate at age a and year y	Given
M_a	Natural mortality rate at age a	Given
A	Plus group age	Given (=6)
TN_y	Total numbers of fish in year y. When process error of total number of fish (ϵ_y) is considered (KAFKA), $TN_y = \sum_{a=0}^{A} N_{ay} + \epsilon_y$. In other cases (VPA, SAM, and ASAP), $TN_y = \sum_{a=0}^{A} N_{ay}$.	Estimated

Table 2. Definition of important statistics

SB_y	Spawning biomass at year y	$\sum_{a=0}^{A} N_{ay}w_{ay}g_{ay}$ (VPA, SAM, and ASAP) $TN_y w_{ave_y} g_{ave_y}$ (KAFKA)
TB_y	Total biomass at year y	$\sum_{a=0}^{A} N_{ay}w_{ay}$ (VPA, SAM, and ASAP) $TN_y w_{ave_y}$ (KAFKA)
R_y	Number of recruits at year y	N_{0y}
AF_y	F at age weighted by catch weight at age	$\frac{\sum_{a=0}^{A} w_{ay}\ C_{ay}F_{ay}}{\sum_{a=0}^{A} w_{ay}\ C_{ay}}$
w_{ave_y}	Average weight at year y for calculating total and spawning biomass in KAFKA	$\frac{\sum_{a=0}^{A} c_{ay}w_{ay}}{\sum_{a=0}^{A} c_{ay}}$
g_{ave_y}	Average maturity at year y for calculating total and spawning biomass in KAFKA	$\frac{\sum_{a=0}^{A} c_{ay}g_{ay}}{\sum_{a=0}^{A} c_{ay}}$
E_t	Exploitation rates in year y (expected catch at age is used)	$\frac{\sum_{a=0}^{A} w_{ay}C_{ay}}{TB_y}$
$F_{a,1618}$	Fishing mortality coefficient at age a representing recent (2016-2018) fishing impacts	$\frac{1}{3}\sum_{y=2016}^{2018} F_{ay}$
$S_{a,1618}$	Selectivity at age a representing recent (2016-2018) selectivity (the maximum age = 1)	$\frac{F_{a,1618}}{F_{A,1618}}$

$w_{a,1618}$	Weight at age a representing recent (2016-2018) fish weight	$\frac{1}{3}\sum_{y=2016}^{2018} w_{ay}$
$g_{a,1618}$	Maturity at age a representing recent (2016-2018) maturity rate	$\frac{1}{3}\sum_{y=2016}^{2018} g_{ay}$
$F_{a,1719}$	Fishing mortality coefficient at age a representing the most recent (2017-2019) fishing impacts	$\frac{1}{3}\sum_{y=2017}^{2019} F_{ay}$
$S_{a,1719}$	Selectivity at age a representing the most recent (2017-2019) selectivity (the maximum age = 1)	$\frac{F_{a,1718}}{F_{A,1718}}$
$w_{a,1719}$	Weight at age a representing the most recent (2017-2019) fish weight	$\frac{1}{3}\sum_{y=2017}^{2019} w_{ay}$
$g_{a,1719}$	Maturity at age a representing the most recent (2017-2019) maturity rate	$\frac{1}{3}\sum_{y=2017}^{2019} g_{ay}$

Table 3. Definition of performance measures

	Parameters
State variables	
B (whole years)	TB_y (y=1970, ⋯, 2019)
R (whole years)	R_y (y=1970, ⋯, 2019)
F (whole years)	AF_y (y=1970, ⋯, 2019)
Exploitation rate (whole years)	E_y (y=1970, ⋯, 2019)
Biological Reference Points * In the following equations, the subscript of cur represents both of 1618 and 1719 (e.g. $F_{a,cur}$ means both of $F_{a,1719}$ and $F_{a,1618}$) * Recent selectivity $S_{a,cur}$ and recent biological parameters of $M_{a,cur}$, $w_{a,cur}$ and $g_{a,cur}$ are used for the calculation of BRP, basically. * The biological reference points of fishing mortality coefficient are given as a vector from age 0 to A ($F_{a,ref}$) and their selectivity is assumed to $S_{a,cur}$ * We define F_{ref} (without subscript of a) as $F_{A,ref}$ (i.e., F reference point at the plus group age) and have two analyzed periods: $F_{a,ref1618} = S_{a,1618}F_{ref1618}$ and $F_{a,ref1719} = S_{a,1719}F_{ref1719}$ * We have six kinds of F reference points (see below) and therefore 12 parameters to be estimated in	

total: $F_{20\%SPR,1618}$, $F_{20\%SPR,1719}$, $F_{30\%SPR,1618}$, $F_{30\%SPR,1719}$, $F_{40\%SPR,1618}$, $F_{40\%SPR,1719}$, $F_{0.1,1618}$, $F_{0.1,1719}$, $F_{MAX,1618}$, $F_{MAX,1719}$, $F_{MSY,1618}$, and $F_{MSY,1719}$ * Baranov catch equation is used for SAM and ASAP, and Pope's approximation is used for VPA and KAFKA	
F%SPR (F20%SPR, F30%SPR, and F40%SPR)	F value at which spawning biomass per recruit (SBR) is X% of SBR at F=0. Equilibrium relative number at age (assuming the number of recruits as 1) is expressed as: $$n_{cur,a}(F) = \begin{cases} 1, & a = 0 \\ \exp\left[-\sum_{i=0}^{a-1}\left(M_i + S_{i,cur}F\right)\right], & 1 \le a \le A-1 \\ \dfrac{\exp\left[-\sum_{i=0}^{A-1}\left(M_i + S_{i,cur}F\right)\right]}{1 - \exp\left(-M_A - S_{A,cur}F\right)}, & a = A \end{cases}$$ Here, the fish number at plus group is summed up into infinity by using the formula for equipartition series. SBR is calculated as follows: $$SBR(F) = \sum_{a=0}^{A} w_{a,cur}\, g_{a,cur}\, n_{a,cur}(F)$$ $F_{X\%SPR}$ is F value that gives (Mangel et al. 2013); $$\frac{SBR(F)}{SBR(0)} = X\ \%.$$ The percentages of 20, 30, 40% are calculated.
F0.1	F value at which the slope of YPR curve is 0.1 of that at the origin. When the Baranov fishing equation is adopted, yield per recruit (YPR) is calculated as: $$YPR(F) = \sum_{a=0}^{A} \frac{S_{a,cur}\, F}{M_a + S_{a,cur}\, F}\left(1 - \exp\left(-M_a - S_{a,cur}F\right)\right) \times w_{a,cur} \times n_{a,cur}(F)$$ When the Pope's approximation is adopted, YPR is calculated as: $$YPR(F) = \sum_{a=0}^{A}\left\{1 - \exp\left(-S_{a,cur}\, F\right)\right\} \times w_{a,cur} \times n_{a,cur}(F) \times \exp\left(-\frac{M_a}{2}\right)$$ $F_{0.1}$ is the F value that makes the marginal yield per recruit (the slope of the yield-per-recruit curve, the YPR function) 10% of the slope at the origin as; $$\frac{Marginal\ yield\ per\ recruit(F)}{Marginal\ yield\ per\ recruit(0)} = \frac{\frac{\partial}{\partial F} YPR(F_{0.1})}{\frac{\partial}{\partial F} YPR(0)} = 0.1.$$
F_{MAX}	F value that maximizes YPR(F). F_{MAX} satisfies $\frac{\partial}{\partial F} YPR(F_{MAX}) = 0$.
F_{MSY}	F value that maximizes sustainable yield. - Stock-recruitment relationship parameters are estimated from SB_y and R_y

	(y=1970, ⋯, 2019) - The estimation of stock-recruitment relationship uses a normal distribution at log scale: $\log R_y \sim Normal(\log \hat{R}_y, \sigma_R^2)$ - Beverton-Holt (BH) with the assumption of steepness of 0.5, 0.7, 0.9 - Hockey-stick (HS) with the restriction of breaking point being within the range of estimated $SB_{1970:2019}$ When the BH stock-recruitment relationship is adopted, the predicted recruitment ($\hat{R}$) is expressed as: $$\hat{R} = \frac{\alpha\, SB}{1 + \beta\, SB}$$ The parameters α and β can be expressed by steepness (h) and equilibrium unfished recruitment (R_0) as: $$\alpha = \frac{4h}{SBR(0)(1-h)}\, and\ \beta = \frac{5h-1}{(1-h)SB_0}$$ Sustainable yield is calculated as: $$SY(F) = \ YPR(F)\frac{\alpha\, SBR(F) - 1}{\beta\, SBR(F)}.$$ F_{MSY} is the F value that maximizes the sustainable yield (SY). The hockey-stick stock-recruitment relationship is expressed as: $$\hat{R} = \begin{cases} \alpha\, SB, & SB < \beta \\ \alpha\, \beta\,, & SB \geq \beta \end{cases}$$ Sustainable yield is calculated as: $$SY(F) = \begin{cases} YPR(F)\alpha\beta, & F \leq F^* \\ 0, & F > F^* \end{cases}.$$ Note that the hockey-stick relationship does not have an equilibrium with positive abundance when the F value is larger than the threshold F^*, where $\alpha\, SBR(F^*)$=1. F_{MSY} is the F value that maximizes the sustainable yield (SY).
B_{MSY}	$B_{MSY,1618}$ and $B_{MSY,1719}$, equilibrium total biomass when F is equal to $F_{MSY,1618}$, and $F_{MSY,1719}$, respectively. When the BH stock-recruitment relationship is adopted: $$B_{MSY} = \sum_{a=0}^{A} w_{a,cur} \times R_{MSY} \times n_{a,cur}(F_{MSY}) = \sum_{a=0}^{A} w_{a,cur} \times \frac{\alpha SBR(F_{MSY}) - 1}{\beta SBR(F_{MSY})} \times n_{a,cur}(F_{MSY}).$$ When the Hockey-stick stock-recruitment relationship is adopted: $$B_{MSY} = \sum_{a=0}^{A} w_{a,cur} \times R_{MSY} \times n_{a,cur}(F_{MSY}) = \sum_{a=0}^{A} w_{a,cur} \times \alpha\beta \times n_{a,cur}(F_{MSY})$$

SB_{MSY}	$SB_{MSY,1618}$ and $SB_{MSY,1719}$, equilibrium spawning stock biomass when F is equal to $F_{MSY,1618}$, and $F_{MSY,1719}$, respectively. When the BH stock-recruitment relationship is adopted: $$SB_{MSY} = \frac{\alpha\, SBR(F_{MSY}) - 1}{\beta}$$ When the Hockey-stick stock-recruitment relationship is adopted: $$SB_{MSY} = \alpha\, \beta\, SBR(F_{MSY})$$
Relative fishing impact (optional)	Current F relative to F reference point can be an important measure for evaluating model performance and, therefore, is included as an 'optional' performance. The relative fishing impacts (RF) are $RF_{20\%SPR,1618}$, $RF_{20\%SPR,1719}$, $RF_{30\%SPR,1618}$, $RF_{30\%SPR,1719}$, $RF_{40\%SPR,1618}$, $RF_{40\%SPR,1719}$, $RF_{0.1,1618}$, $RF_{0.1,1719}$, $RF_{MAX,1618}$, $RF_{MAX,1719}$, $RF_{MSY,1618}$, and $RF_{MSY,1719}$.
F_{cur}/F_{ref}	The ratio of current F (2016-2018 and 2017-2019) to F reference point shown in above.
Depletion statistics	
SSB/max(SSB)	$\frac{1}{10}\sum_{k=y}^{y+9}\frac{SB_k}{SB_{max}}$ (y = 1970, 1980, 1990, 2000, 2010), where $SB_{max} = \max SB_{1970:2019}$
B/max(B)	$\frac{1}{10}\sum_{k=y}^{y+9}\frac{TB_k}{TB_{max}}$ (y = 1970, 1980, 1990, 2000, 2010), where $TB_{max} = \max TB_{1970:2019}$
SSB/median(SSB)	$\frac{1}{10}\sum_{k=y}^{y+9}\frac{SB_k}{SB_{median}}$ (y = 1970, 1980, 1990, 2000, 2010), where $SB_{median} = \text{median}\, SB_{1970:2019}$
B/median(B)	$\frac{1}{10}\sum_{k=y}^{y+9}\frac{TB_k}{TB_{median}}$ (y = 1970, 1980, 1990, 2000, 2010), where $TB_{median} = \text{median}\, TB_{1970:2019}$
Retrospective analysis	
Mohn's rho	$$\rho = \frac{1}{7}\sum_{i=1}^{7}\left(\frac{X_{2019-i}^{R} - X_{2019-i}}{X_{2019-i}}\right),$$ where X_y is the estimate in year y when the full data up to 2019 are used and X_y^R is the estimate in year y when the data later than y are removed. Total biomass (TB),

	spawning stock biomass (*SB*), average fishing mortality coefficient weighted by catch weight at age (*AF*) and exploitation rate (*E*) are used as the abundance estimate *X*.

References

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