Preliminary stock assessments of Indian Ocean albacore tuna using Statistical-Catch-At-Size (SCAS) (1950-2020)[1]

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Abstract

- Using the SCAS software, a preliminary stock assessment was attempted with the following specification, i.e., four scenarios incorporating nine different variants for the model uncertainties.
- Four scenarios are a combination of two assumptions; (a) two types of use in CPUEs, i.e., Western Indian Ocean (IO) (R1+R3) (say 2CPUE) or Whole IO (R1+R2+R3+R4) (say 4CPUE) and (b) the relative weight to CAS against CPUE (0.05 and 0.1), i.e., CASW(0.05) and CASW(0.1) for short. The four scenarios were named as 2CPUE_CASW(0.05), 2CPUE_CASW(0.1), 4CPUE_CASW(0.05) and 4CPUE_CASW(0.1).
- Nine different variants for the model uncertainties is a combination of three levels of σ_R (0.5, 0.6 and 0.7) and three levels of *h* (steepness, 0.7, 0.8 and 0.9).
- As convergence was not met in optimization when the original models with 11 fleet and 9 CAS (full spec) were employed, reduced 8 fleets and 8 CAS models were used with an aggregated definition of combined OT fleets (whole IO) from 4 regional OT fleets, and convergence was achieved in all four of those scenarios.
- Based on the retrospective analyses, two scenarios, [A] 2CPUE_CASW(0.1) and [B] 4CPUE_CASW(0.05), were considered to be the most plausible and were used in subsequent evaluations.
- Based on various comparisons of results between the two selected scenarios [A] and [B], scenario [A] seems to be more plausible than [B] by the following three reasons; (a) MSY (78K t) in [B], is likely too high comparing to the current catch (41K t), which is almost twice; and (b) the stock status [B] (SSB ratio=1.83 & F ratio=0.57) is likely too optimistic considering general decreasing/constant trends of the joint CPUE except increasing trends in recent years in R3+R4 (Eastern IO) due to the sharp increased catch, which implied that CPUE standardization may not reflect the intrinsic CPUE trends. In fact, there are nil correlation between catch and joint CPUE in R4, and (c) on the view point of consistency from the last stock assessment (2019).
- The selected best scenario [A] 2CPUE_CASW(0.1) suggests that the current stock status (2020) is in the orange zone (Kobe plot) (SSB ratio=1.26 and F ratio=1.12) (not overfished but overfishing), MSY(58K ton), and depression(0.28).

Contents

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1. INTRODUCTION

We attempted the preliminary stock assessments of the Indian Ocean albacore using Statistical-Catch-At-Size (SCAS) software (1950-2020) (Nishida *et al*., 2020). We followed the input information agreed in the data preparatory meeting IOTC-WPTmT(DP) held in April, 2022 (IOTC, 2022). The main objective to conduct SCAS (a simpler version of SS3) to provide the reference information to SS3 (main assessment model). It should be well noted that SSB in the SCAS software includes both male and female, while that in SS3 is only for female.

2. Input information

Stock structure

One single stock is assumed in the whole the Indian Ocean.

Time step

Annual basis.

Area

A definition of four sub-areas is used (Fig. 1).

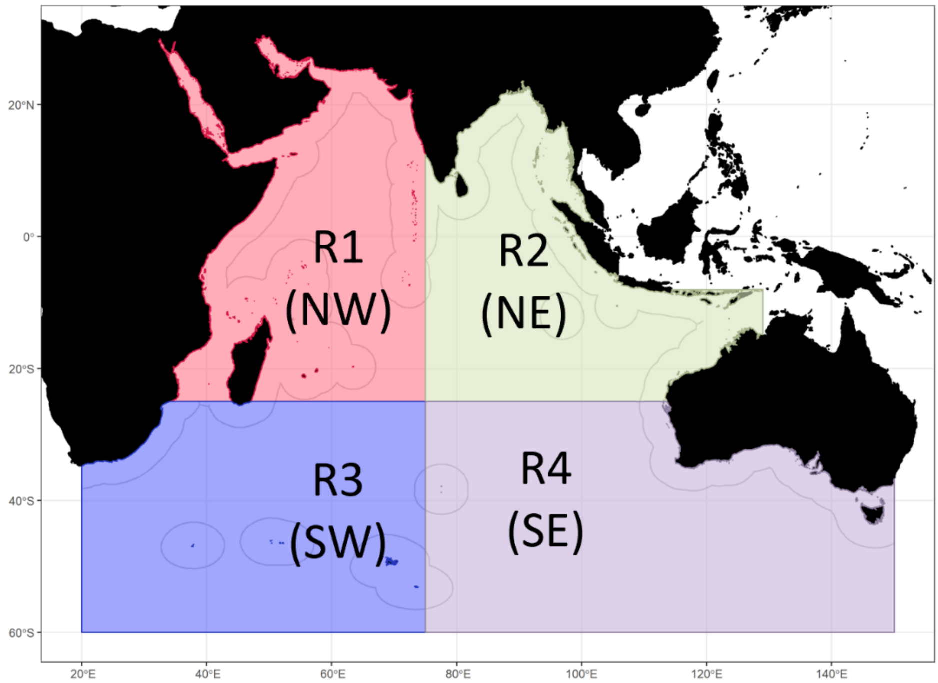


Fig. 1 Four areas used for the SCAS stock assessments.

Fleets

11 fleets are used (Table 1).

Table 1. Definition of 11 fleets.

Fleet ID	Code	Gear name	area
F1	LL1	Longline	R 1
F2	LL2	Longline	R 2
F3	LL3	Longline	R 3
F4	LL4	Longline	R 4
F5	DN3	Driftnet	R 3
F6	DN4	Driftnet	R 4
F7	PS1	Purse seine	R 4
F8	OTH1	Other gears	R 1
F9	OTH2	Other gears	R 2
F10	OTH3	Other gears	R 3
F11	OTH4	Other gears	R 4

Nominal catch

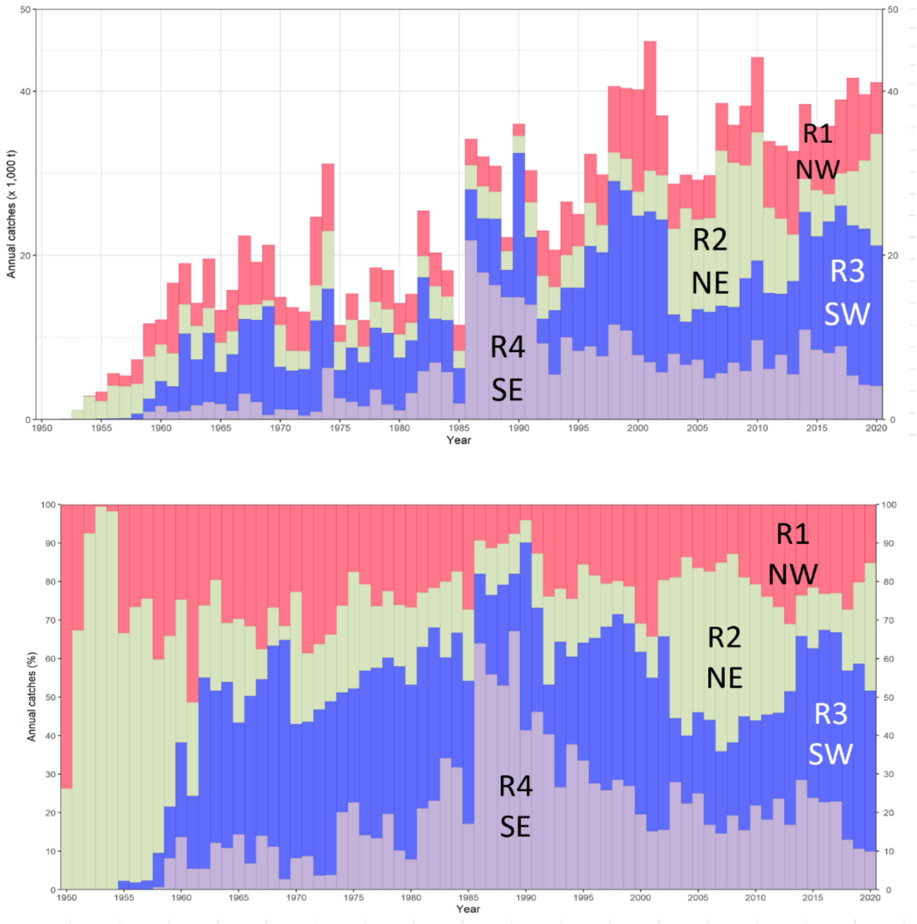


Fig. 2 Annual nominal catches by area (IOTC-2022-WPTmT08(AS)-DATA03).

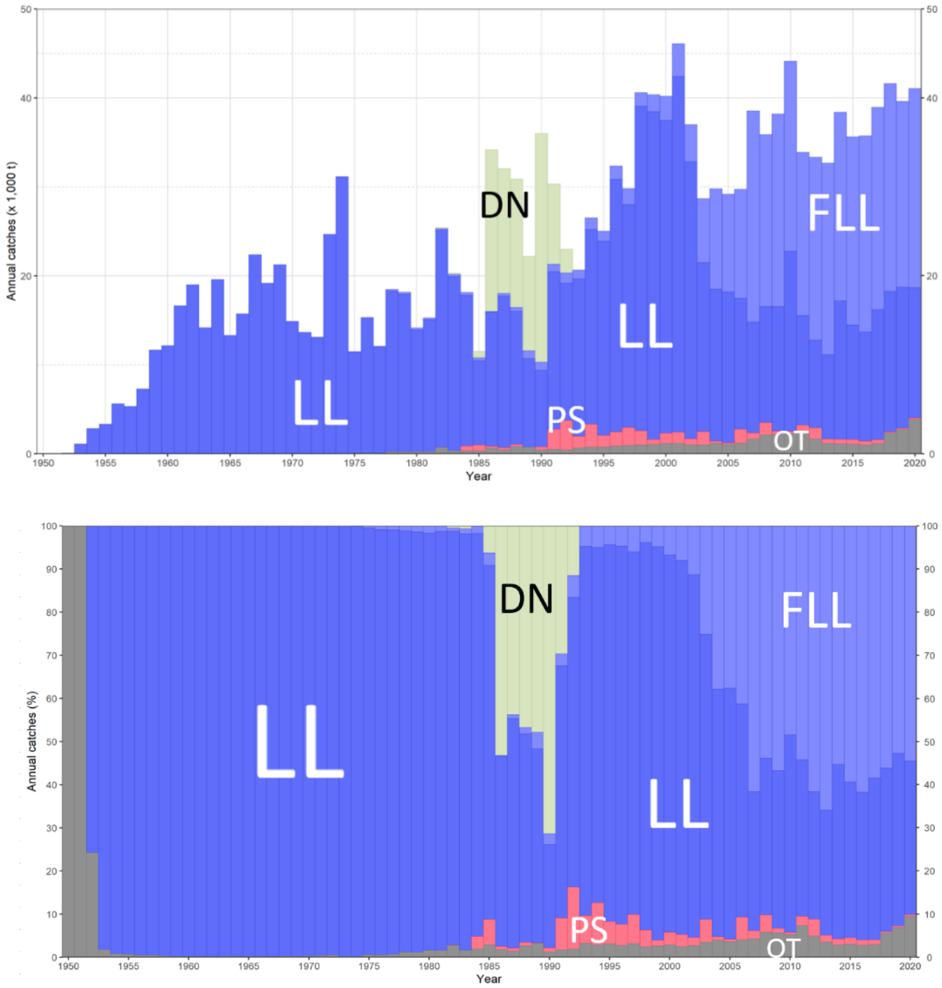


Fig. 3 Annual nominal catches by fleet (IOTC-2022-WPTmT08(AS)-DATA03).

Standardized joint annual longline CPUE

The joint tuna longline CPUE (Japan, Korean and Taiwan) (1975-2020) by area and quarter was estimated by Kitakado *et al*. (2022). Annual based joint CPUE were provided by Kitakado (Personal Communication). Fig 4 shows the scatter plots (catch vs. joint CPUE) by area and the predicted 95% confidence intervals (CI). The points outside of the 95% CIs are defined as the outliers and removed from the joint CPUE series. There are 2, 3, 2 and 3 outlier points in the areas R1-R4 respectively. Fig. 5 shows the annual joint CPUE trends (1975-2020) (left) and those without the outliers (right). It is noted that there were nil differences in the results of the SCAS assessments with and without outliers. It is noted that DN(drift gillnet) CPUE was not used in the SCAS assessment, while it was used in SS3.

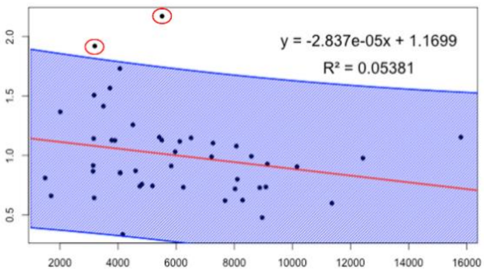
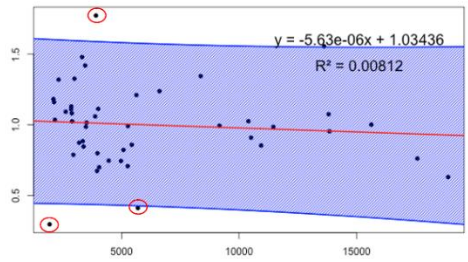
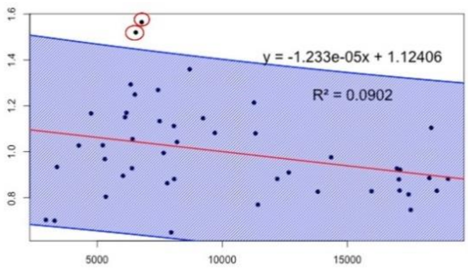
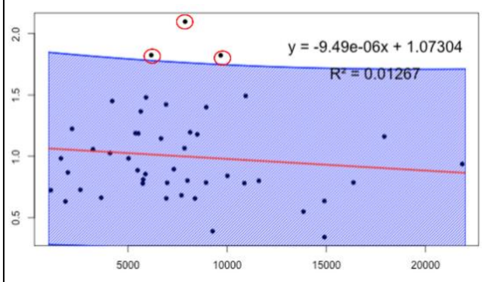
	Western IO		Eastern IO
R1		R2	
R3		R4	

Fig 4. Scatter plots of catch vs. joint CPUE by area (R1-R4) and outliers defined those outside of the 95% predicted CI envelop.

Life span

14 years old is applied, which is based on otolith reading (North Pacific). 14+ is treated as a plus group, thus 15 year-classes (0-14+) are assumed internally in the SCAS assessment.

Sex ratio

Male : Female = 1:1 is assumed for all ages.

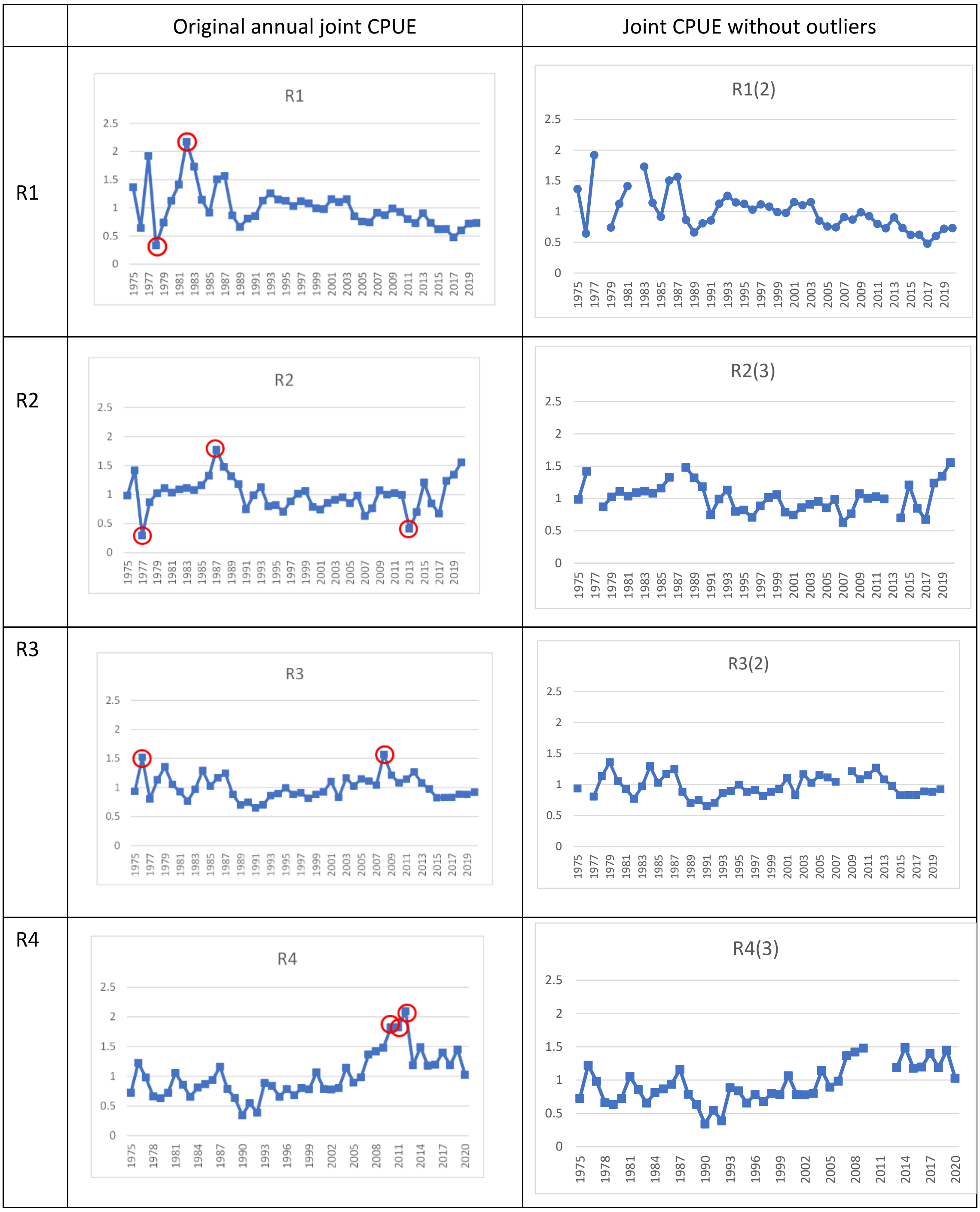


Fig 5. Trends of the scaled standardized annual joint CPUE of the Asian tuna longline fisheries (Japan, Taiwan and Korea) (1975-2020). The average value is scaled as 1.

Left: Trends of all data series (points with red circles are defined as outliers).

Right: Trends of data series without the outliers

LW relation

Fig. 6 shows the LW relations derived by Kitakado *et al*. (2019) , i.e., $W = (0.69 \times 10^{-5}) * L^{3.2263}$, which is used in the SCAS assessments. Other two LW relations by Dhurmeea *et al*. (2016) (a new study in the Indian Ocean) and Penny (1994) (used in the past stock assessments) are presented as references.

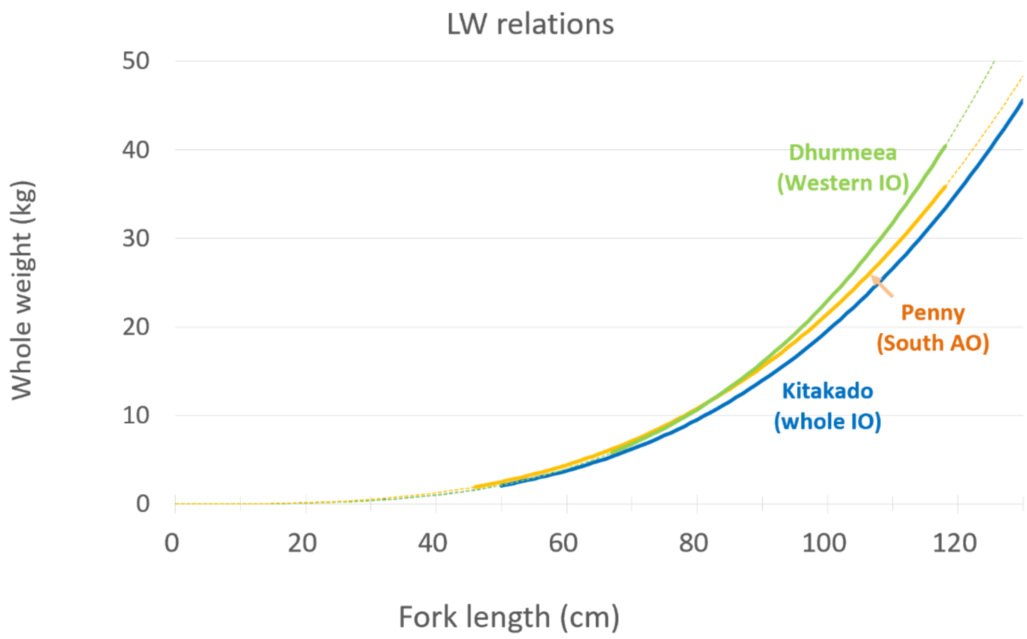


Fig. 6 The LW relation derived by Kitakado *et al.* (2019) , i.e., $W = (0.69 \times 10^{-5}) * L^{3.2263}$ used in the SCAS stock assessments (Other 2 are shown as references).

Growth equation

Fig. 7 shows the growth equations by sex estimated by Farley *et al.* (2019) and Chen *et al* (2012). In the SCAS assessments, we used the sex combined one by Fraley et al (2019) as the current SCAS software cannot handle the growth equations by sex. We computed the average growth equations between two. The one by Chen *et al*. (2012) was used in the past stock assessments shown as a reference.

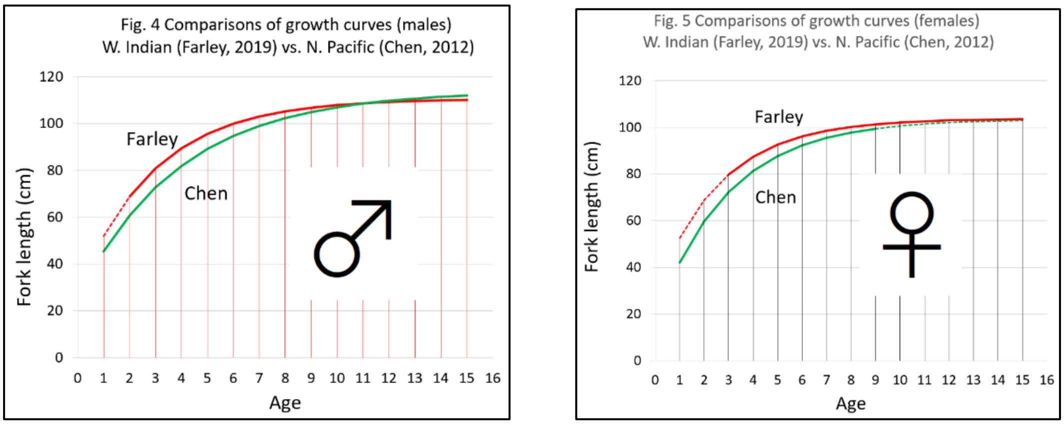


Fig. 7 Average growth equations between male and female by Fraley *et al.* (2019) used in the SCAS stock assessment (see below). The one by Chen *et al.* (2012) used in the past stock assessments is shown as a reference.

[♂] L(t)=110.6 [1-e-0.34 (t+0.87)]

[♀] L(t)=103.8 [1-e-0.38 (t+0.86)]

[♂♀] L(t)=107.2 [1-e-0.36 (t+0.87)]

Natural mortality

Constant value (M=0.3) for all ages used in the North Atlantic and North Pacific, are applied in the SCAS stock assessments.

Fecundity-at-age

Fecundity is assumed to be proportional to female weight at age (by individual).

Selectivity

Table 2 shows the models used for selectivity by fleet and area.

Table 2. Selectivity used by fleet and area.

Fleet #	Code	Gear name	Area	Selectivity (model)
F1	LL1	Longline	R1	Logistic
F2	LL2	Longline	R2	Logistic
F3	LL3	Longline	R3	Double logistic
F4	LL4	Longline	R4	Double logistic
F5	DN3	Driftnets	R3	Double logistic
F6	DN4	Driftnets	R4	Double logistic
F7	PS1	Purse seine	R4	Logistic
F8	OTH1	Other gears	R1	Double logistic
F9	OTH2	Other gears	R2	Double logistic
F10	OTH3	Other gears	R3	Double logistic
F11	OTH4	Other gears	R4	Double logistic

Maturity-At-Age

Fig. 8 shows the Maturity-At-Age by Dhurmeea *et al.* (2016) (Indian Ocean), Farley *et al*. (2014) (South Pacific Ocean) and Bard *et al*. (1981) (North Atlantic Ocean). Fraley *et al*. (2014) was agreed to use as a base case in the data preparatory meeting (IOTC, 2022). Other two are shown as references.

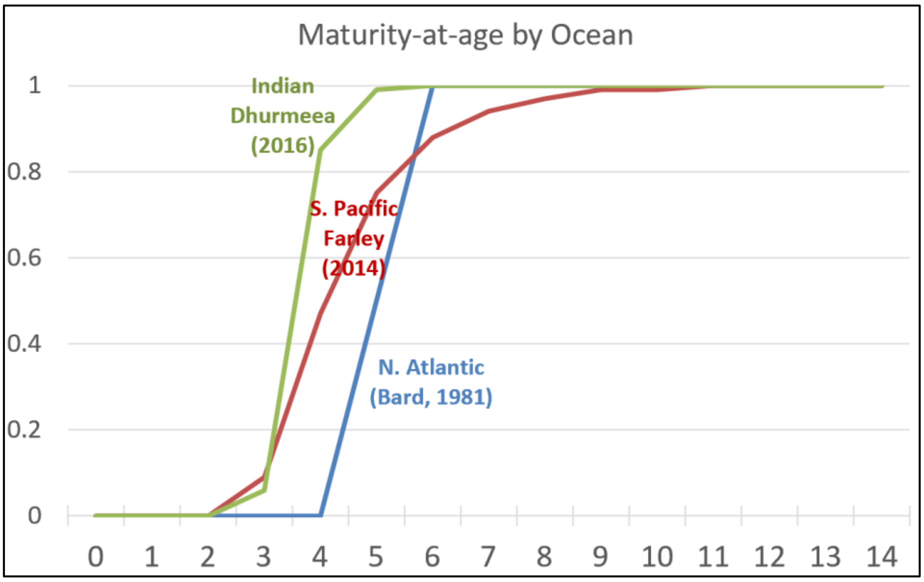


Fig. 8 The Maturity-At-Age by Farley *et al.* (2014) used in the SCAS assessments.

3. Stock assessments

3.1 Specification

Using the SCAS software, a preliminary stock assessment was attempted by the following specification, i.e., four scenarios incorporating nine different variants for the model uncertainties.

Four scenarios are a combination of the following two assumptions; (a) two types of use in CPUEs, i.e., Western Indian Ocean (IO) (R1+R3) (say 2CPUE) or Whole IO (R1-R4) (say 4CPUE) and (b) the relative weight to CAS against CPUE (0.05 and 0.1), i.e., CASW(0.05) and CASW(0.1) for short. These two values (0.1 and 0.05) were selected as they are likely plausible but sensitive to results of the SCAS assessments based on the preliminary investigations. The four scenarios were named as 2CPUE_CASW(0.05), 2CPUE_CASW(0.1), 4CPUE_CASW(0.05) and 4CPUE_CASW(0.1).

Then in each scenario, the model uncertainty was explored using nine different variants. i.e., a combination of three levels of σ_R (0.5, 0.6 and 0.7) and three levels of *h* (steepness, 0.7, 0.8 and 0.9).

3.2 Eleven (11) fleets model

Initially we attempted the SCAS assessments using the full specs, i.e., 11 fleets with 9 CAS (LL1-LL4, DN3-4, PS1, OT1-2). However, we could not get any convergences, i.e., *Warning -- Hessian does not appear to be positive definite*. To solve this problem, we simplified and reduced to 8 CAS (LL1-LL4, DN3-4, PS1, OT) by pooling OT1 and OT2 as one OT because we considered that CAS (OT1 and OT2) include uncertainties due to various types of gears (size frequencies), which may affect results. Nevertheless, we still could not get any convergences.

3.3 Eight (8) fleets model

We then further simplified and reduced to the 8 fleets model pooling all catches of the OT1-OT4 fleets and treated as one OT fleet (all areas combined) because we considered that OT1-OT4 included the uncertainties explained above. Using the 8 CAS (LL1-LL4, DN3-4, PS1, OT), we could get convergences for all 4 scenarios. We also attempted the 7 CAS (LL1-LL4, DN3-4, PS1) without CAS (OT), but it was not converged. Thus we decided to proceed stock assessments using the 8 fleets with 8 CAS model. Table 3 shows the situation on convergences in the 8 and 11 fleets model.

Table 3 Summary of situation on convergences in the 8 and 11 fleet models for different CAS, CPUE and the relative weight to CAS against CPUE (CASW) under 9 different variants of uncertainties with σ_R(0.5, 0.6 and 0.7) and h(steepness)(0.7, 0.8 and 0.9).

Fleet	CAS	CASW (Relative weight to CAS against CPUE)	2CPUE (R1+R3) Western IO	4CPUE (R1+R2+R3+R4) Whole IO
11 fleets (LL1-LL4, DN3-DN4,PS1 and OT1-OT4)	9 CAS (LL1-LL4, DN3-4, PS1 and OT1-2)	0.1 and 0.05	not converged	not converged
	8 CAS (LL1-LL4, DN3-4, PS1 and OT)	0.1 and 0.05	not converged	not converged
8 fleets (LL1-LL4, DN3-DN4, PS1 and OT)	8 CAS (LL1-LL4, DN3-4, PS1 and OT)	0.1	**2CPUE_CASW(0.1)** 5 variants were converged	**4CPUE_CASW(0.1)** 5 variants were converged
		0.05	**2CPUE_CASW(0.05)** 9 variants were converged	**4CPUE_CASW(0.05)** 5 variants were converged

(Note) There were no convergences in the 8 fleets model with 7 CAS without OT.

Fig. 9 shows the Kobe plots showing the stock statuses (2020) in 4 difference scenarios considering uncertainties on 9 different variants by 3 levels of σ_R (0.5, 0.6 and 0.7) and 3 levels of steepness *h* (0.7, 0.8 and 0.9). Boxes 1-2 show the results of the retrospective analyses for 4 scenarios.

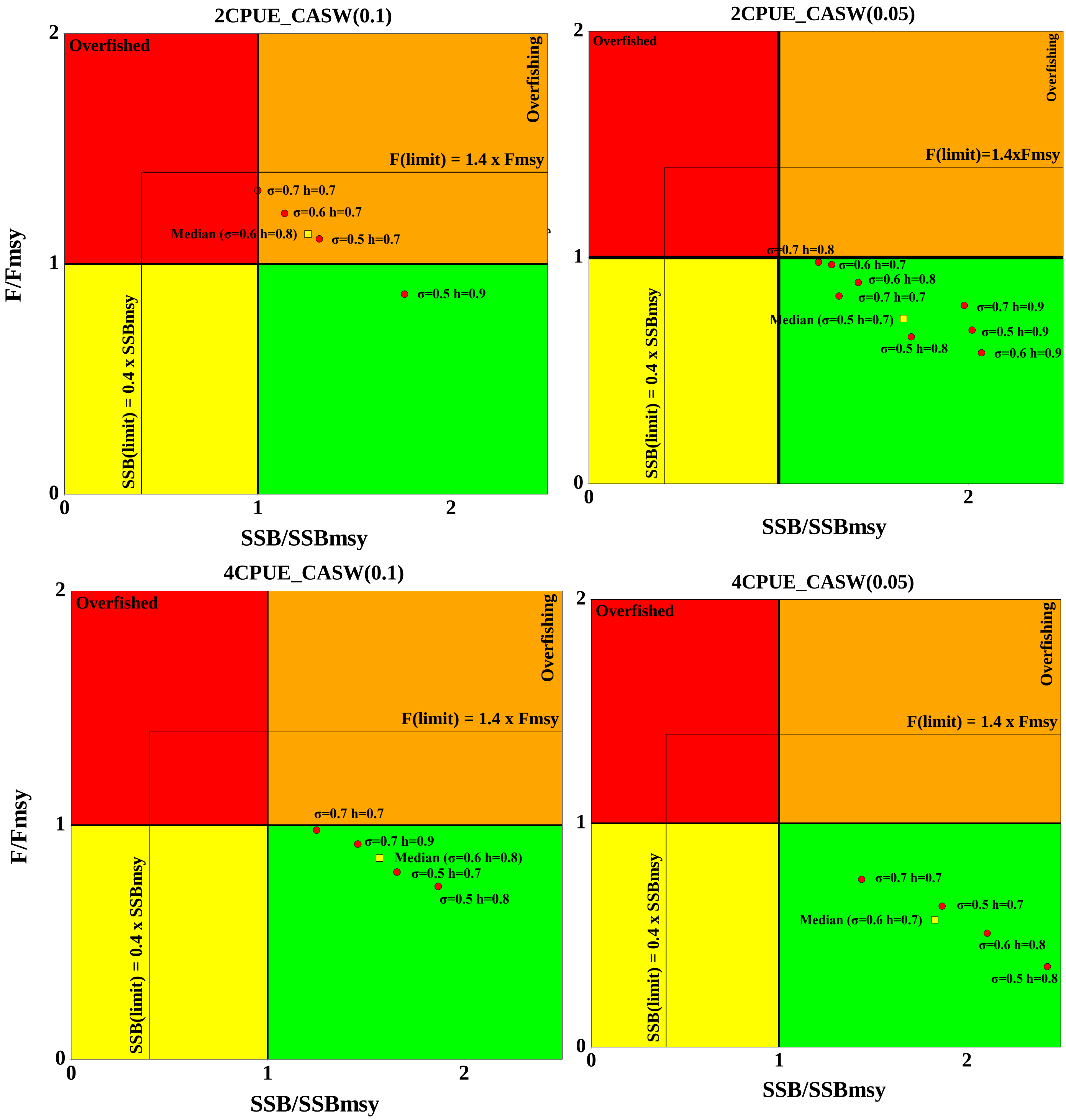


Fig. 9 The stock statuses (2020) in 4 scnarios with uncertainties on 9 different variants by 3 levels of σ_R (0.5, 0.6 and 0.7) and 3 levels of steepness *h* (0.7, 0.8 and 0.9). The results for model variants with convergence are presented. The representative stock status in each scenario is defined by the median (central) point (yellow rectangles) considering the locations among all points.

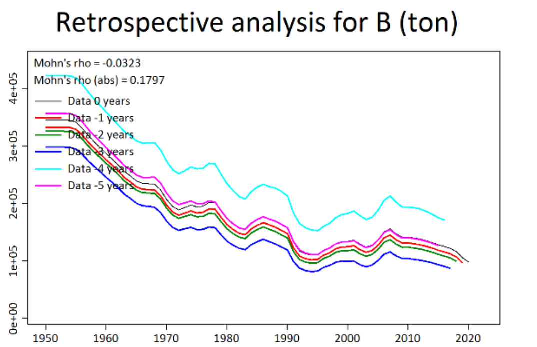
Box 1. Retrospective analyses

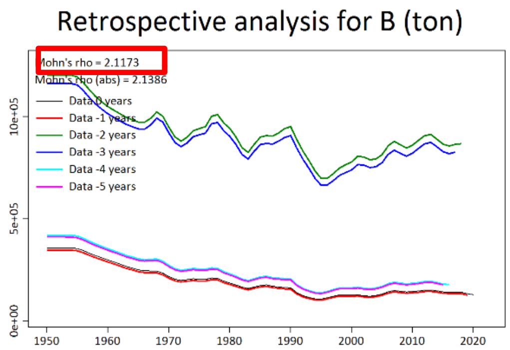
CASW(0.1) (B: SSB ♂♀ combined)

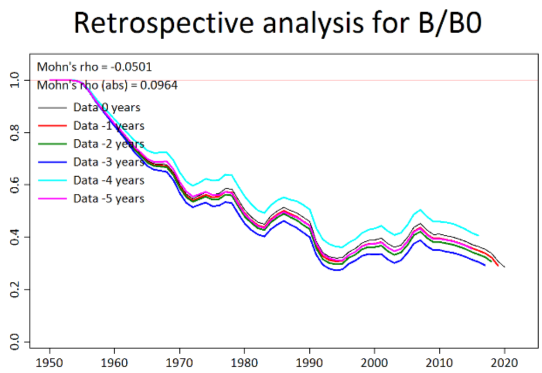
(Note) Plausible range of the Mohan' rho (long-lived species): -0.22 to 0.30 (Carvalho et al, 2021).

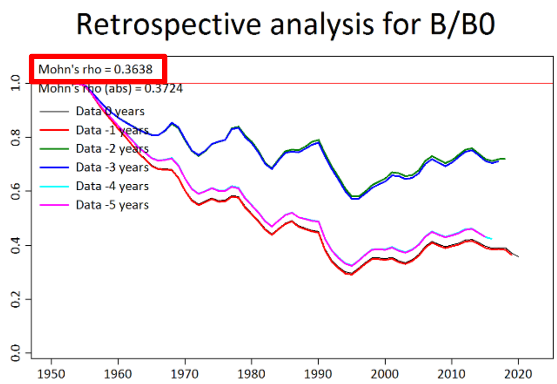
Red rectangles indicate those outside of this rage.

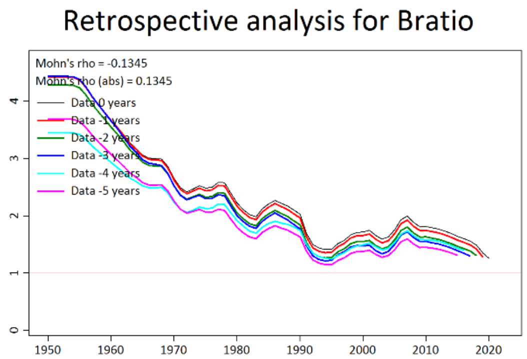
2CPUE_CASW(0.1)	4CPUE_CASW(0.1)

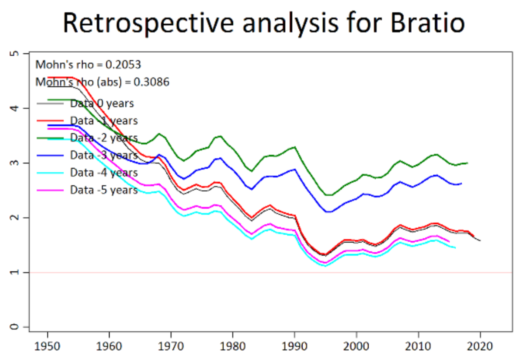


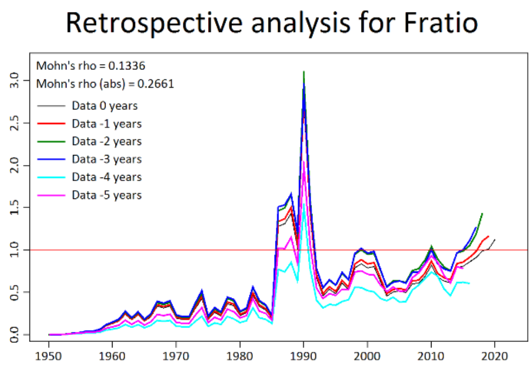


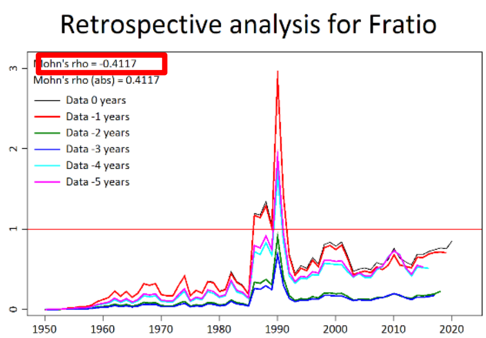










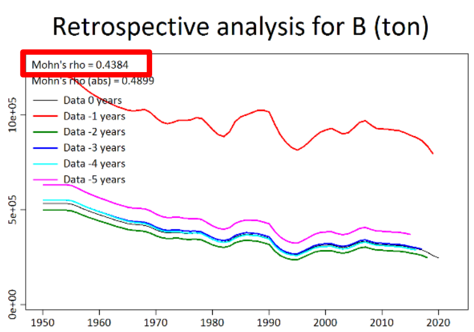


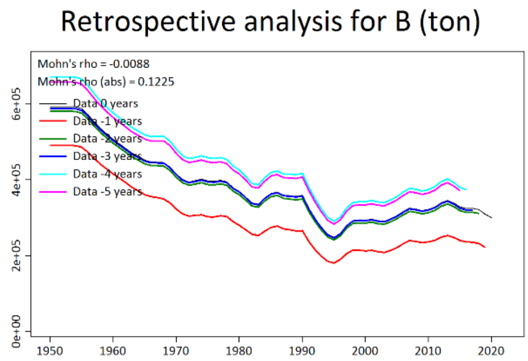
Box 2. Retrospective analyses

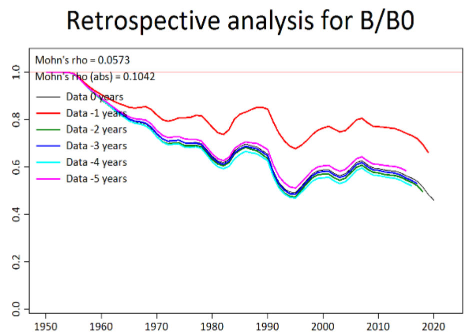
CASW(0.05) (B: SSB ♂♀ combined)

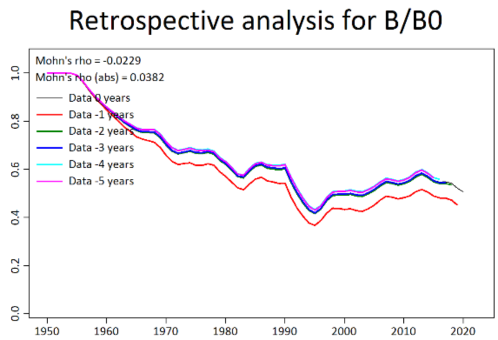
(Note) Plausible range of the Mohan' rho (long-lived species): -0.22 to 0.30 (Carvalho et al, 2021).
Red rectangles indicate those outside of this rage.

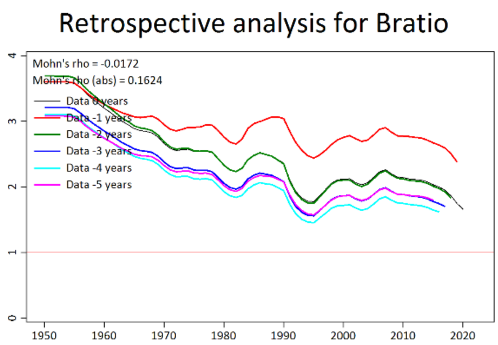
2CPUE_CASW(0.05)	4CPUE_CASW(0.05)

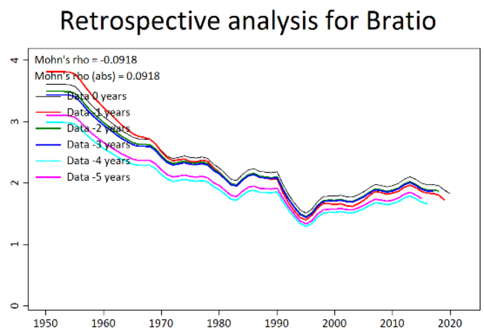


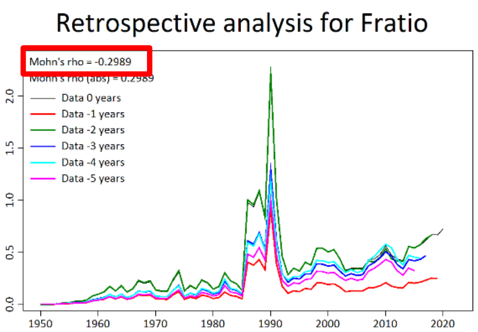












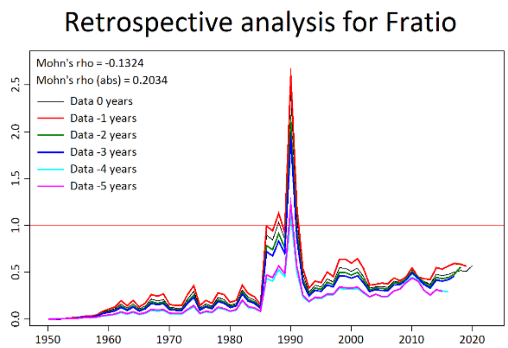


Fig. 10 shows comparisons of the Mohan's Roh values among 4 scenarios for SSB(♂♀), Depression, SSBratio and Fratio. From Fig. 9, it is clear that 2CPUE_CAS(0.1) and 4CPUE_CAS(0.05) fit much better than other two considering the plausible Mohan's Rho values and retrospective patterns shown in Box 1 and Box 2.

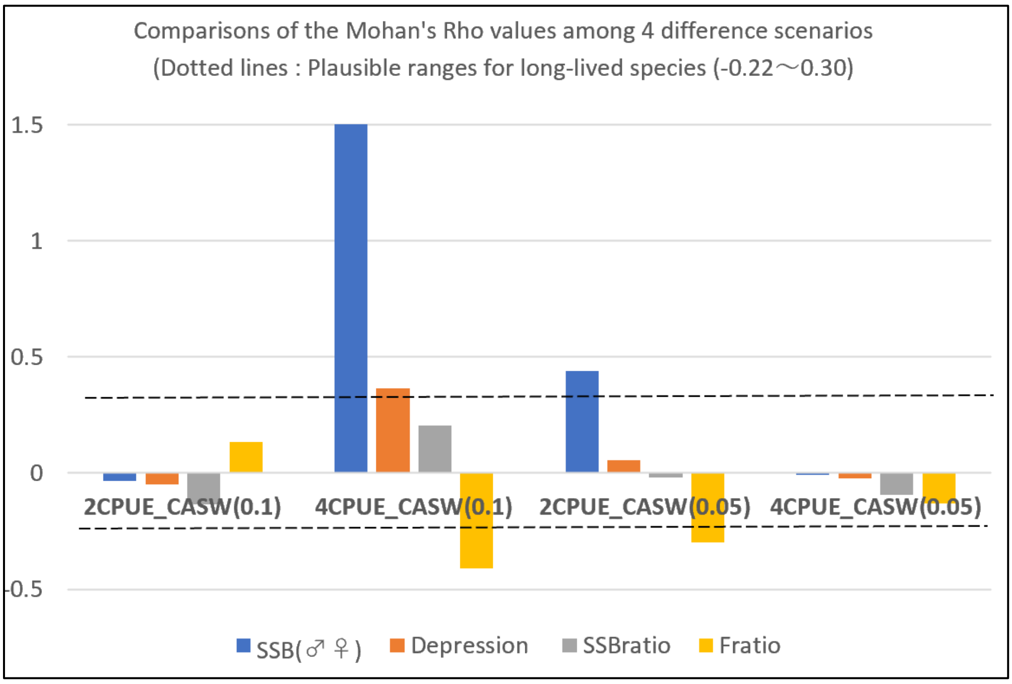


Fig. 10 Comparisons of the Mohan's Rho values among 4 scenarios

3.3 Results (8 fleets model)

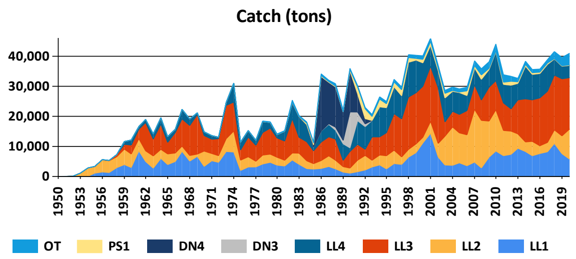
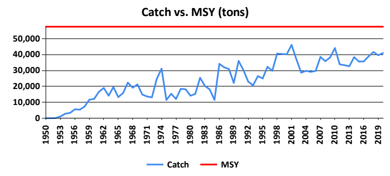
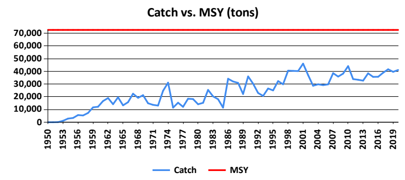
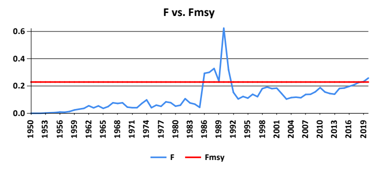
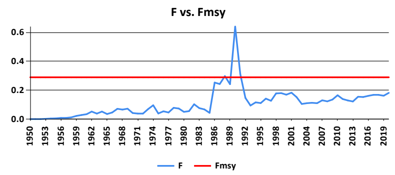
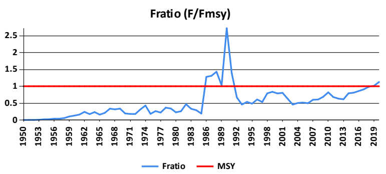
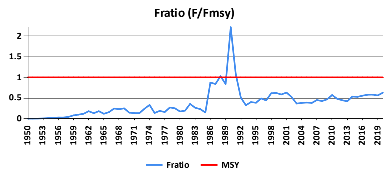
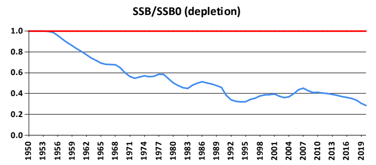
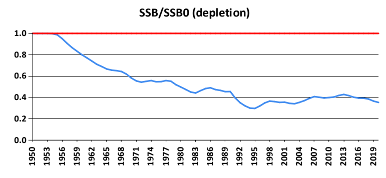
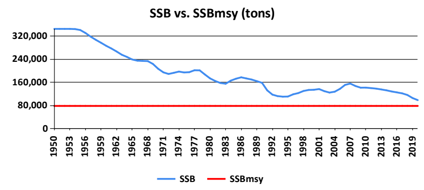
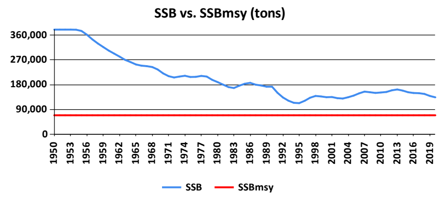
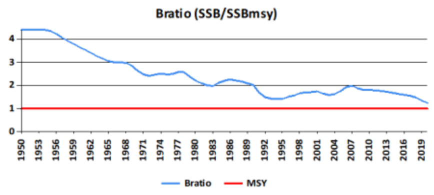
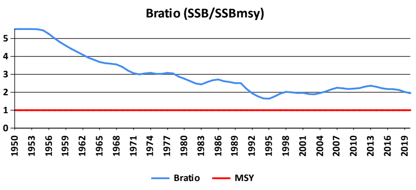
Based on the discussion in previous sections, we decided to proceed further evaluations on the two most plausible scenarios, i.e., [A] 2CPUE_CASW(0.1) and [B] 4CPUE_CASW(0.05). Boxes 3-7 and Fig. 11 show comparisons of various results between two scenarios, i.e.,

Comparison of estimations between 2 scenarios on

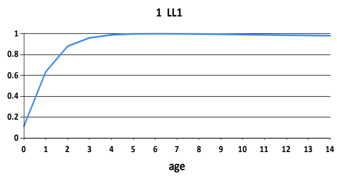
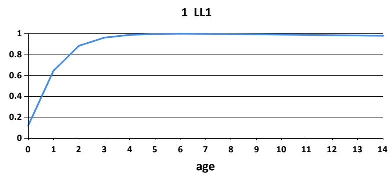
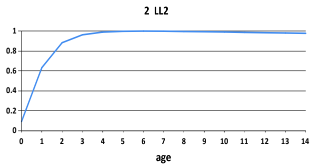
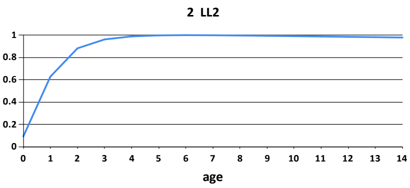
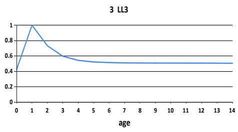
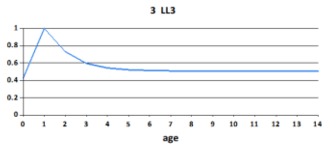
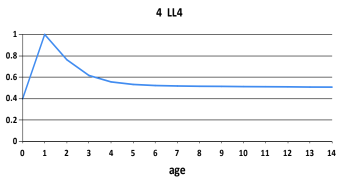
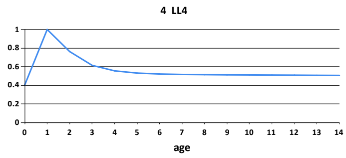
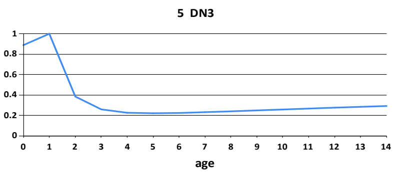
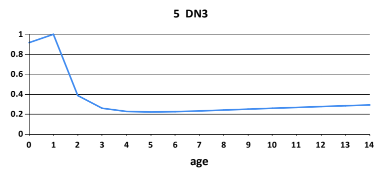
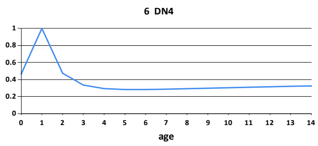
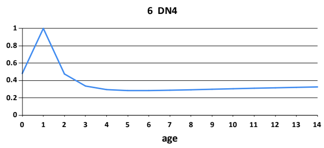
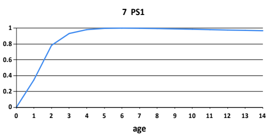
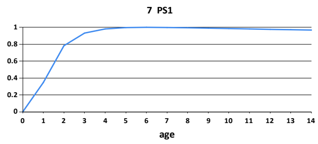
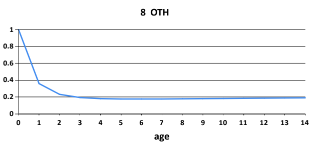
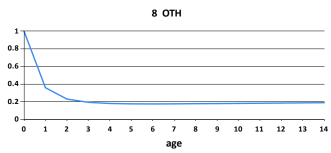
Box 3	Population parameters (MSY, F, SSB and depletion)
Box 4	Estimated selectivity
Box 5	Observed and predicted size frequencies
Box 6	Observed and predicted joint CPUE
Box 7	Recruitments, residuals, and SR relations
Fig. 11	Kobe plots with uncertainties in 2020

Table 4 shows the grand summary of the comparisons between the two scenarios, [A] 2CPUE_CASW(0.1) and [B] 4 CPUE_CASW(0.05).

Box 3 Comparison of estimated key quantities (MSY, F, SSB and depletion) between the two scenarios.

Scenario	[A] 2CPUE_CASW(0.1)	[B] 4CPUE_CASW(0.05)
Catch by fleet		
Catch vs. MSY		
F vs. Fmsy		
Fratio		
Depletion		
SSB Vs. SSBmsy		
SSB ratio		

Box 4 Comparison of estimated selectivity curves between the two scenarios

<table>
<tr><th>Scenario</th><th>[A] 2CPUE_CASW(0.1)</th><th>[B] 4CPUE_CASW(0.05)</th></tr>
<tr><td>LL1</td><td></td><td></td></tr>
<tr><td>LL2</td><td></td><td></td></tr>
<tr><td>LL3</td><td></td><td></td></tr>
<tr><td>LL4</td><td></td><td></td></tr>
<tr><td>DN3</td><td></td><td></td></tr>
<tr><td>DN4</td><td></td><td></td></tr>
<tr><td>PS1</td><td></td><td></td></tr>
<tr><td>OT</td><td></td><td></td></tr>
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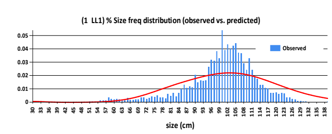
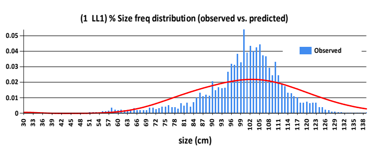
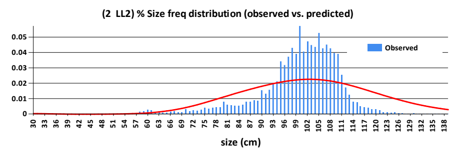
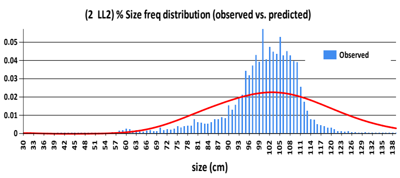
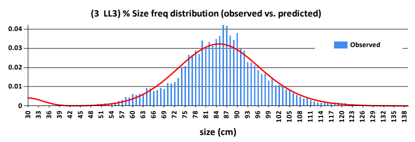
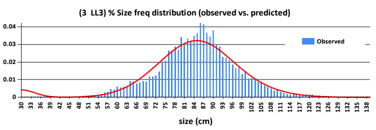
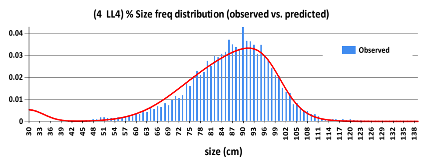
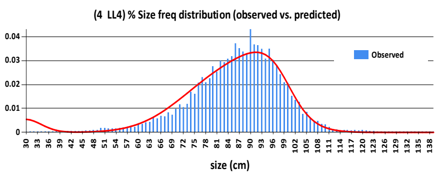
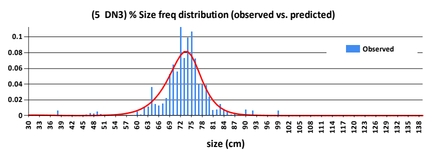
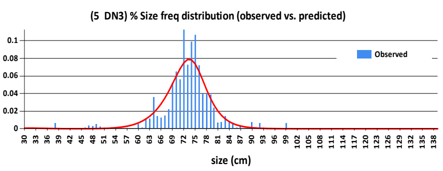
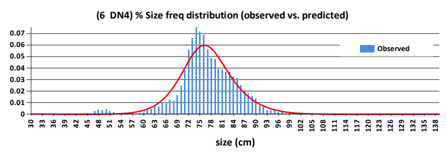
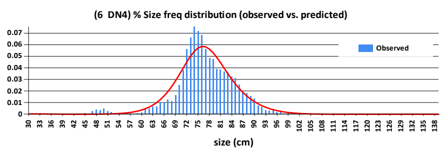
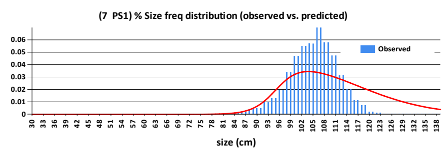
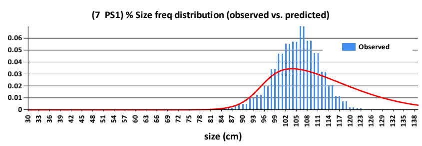
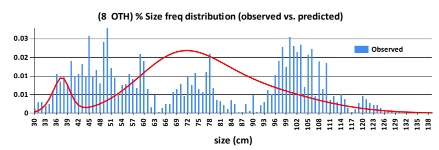
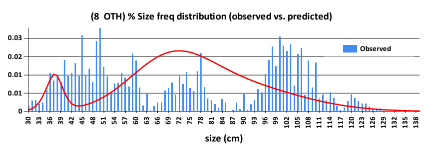
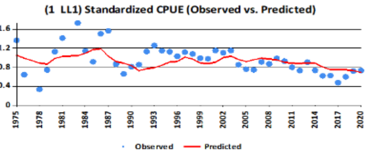
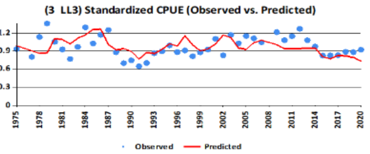
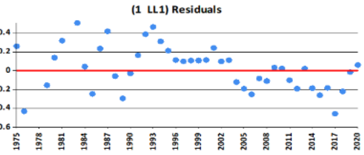
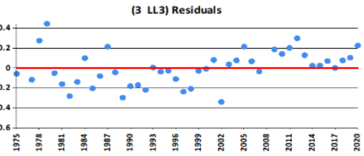
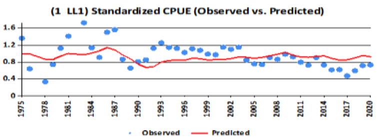
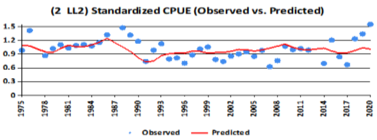
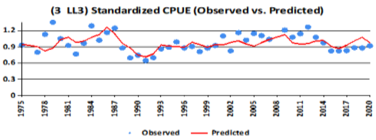
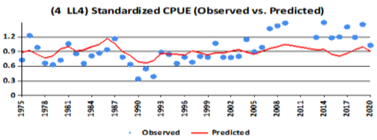
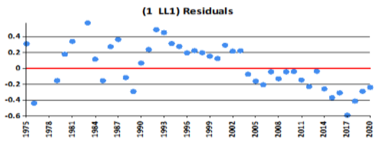
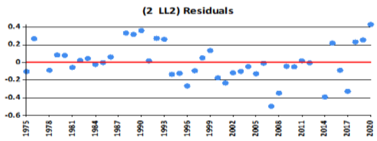
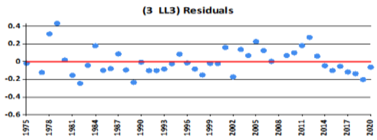
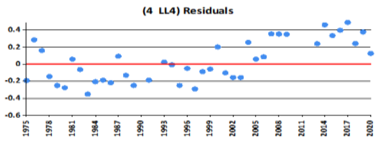
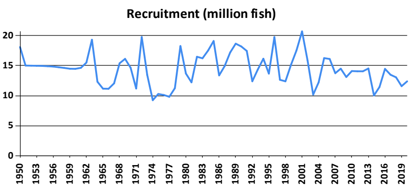
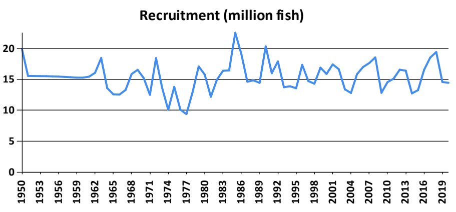
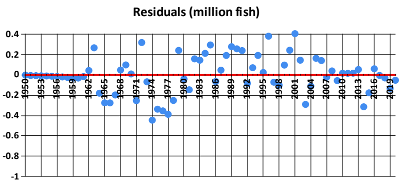
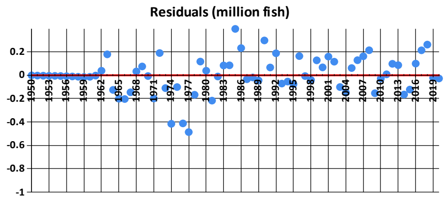
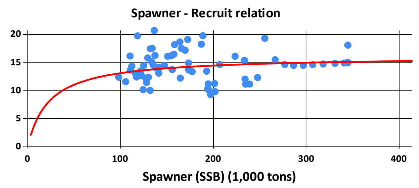
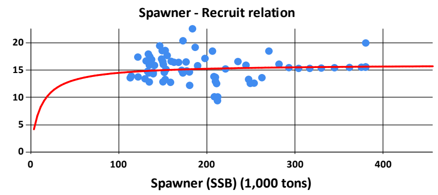
Box 5 Comparisons of observed and predicted size frequencies between the two scenarios

Scenario	[A] 2CPUE_CASW(0.1)	[B] 4CPUE_CASW(0.05)
LL1		
LL2		
LL3		
LL4		
DN3		
DN4		
PS1		
OT		

Box 6 Comparisons of observed and predicted abundance indices between the two scenarios

Scenario	Observed vs. Predicted	Residuals
[A] 2CPUE_CASW(0.1)	 	 
[B] 4CPUE_CASW(0.05)	   	   

Box 7 Comparisons of the results of recruitments, residuals and SR relations between the two scenarios

Scenario	[A] 2CPUE_CASW(0.1)	[B] 4CPUE_CASW(0.05)
Recruitment (million fish)		
Residuals of Recruitment		
SR relation		

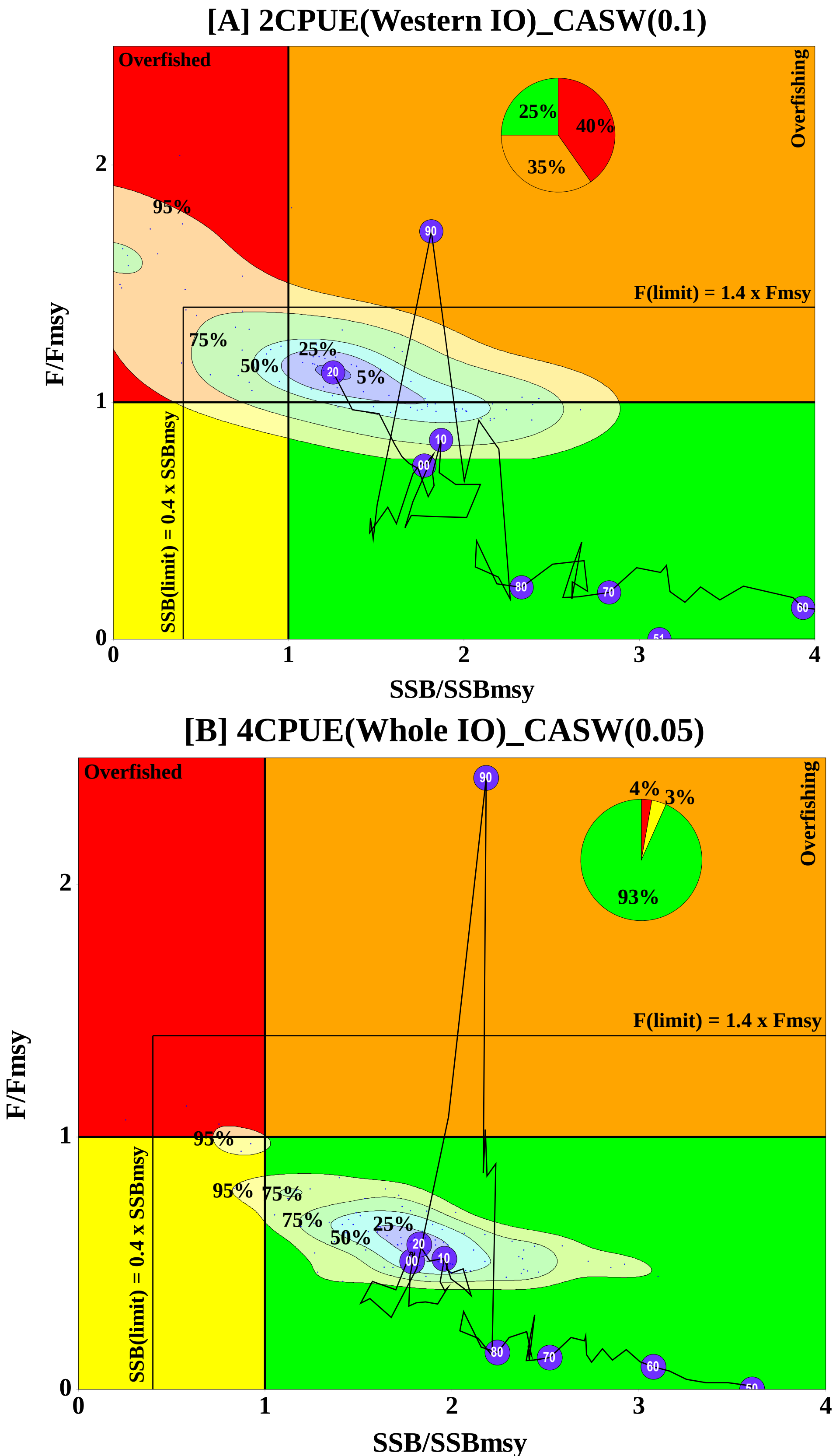
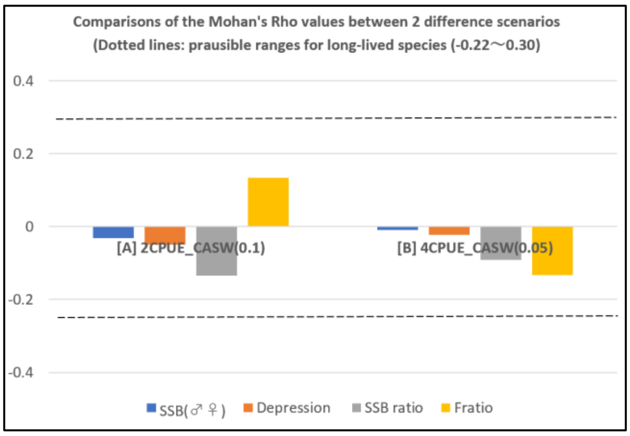


Fig. 11 Comparisons of the Kobe plots with trajectories and uncertainties in the final year (2020) between two scenarios based on the dynamic MSY option (see page 24 on the discussion about constant vs. dynamic MSY).

Table 4 Summary of results of two plausible scenarios

Items with red rectangles indicate large difference between 2 scenarios.
(SSB includes both male and female)

	8 fleets & 8 CAS model (LL1-LL4+DN3-DN4+PS1+OT)	
Scenario	[A] 2CPUE_CASW(0.1)	[B] 4CPUE_CASW(0.05)
	Key results	
Steepness	0.8	0.7
σ_R	0.6	0.6
Catch (2020) (1,000t)	41	
MSY (1,000t)	58	78
SSB0 (1,000t)	345	593
SSBmsy (1,000t)	78	164
SSB ratio (2020)	1.26	1.83
F ratio (2020)	1.12	0.57
Phase of the Kobe plot (probability)	Orange (35%)	Green (93%)
Fmsy	0.23	0.17
Depression	0.28	0.51
	Likelihood (crude reference as two scenarios have slightly different specs and CPUE)	
Total	-785	-486
	CPUE	
All	11	26
CPUE1	8.8	12
CPUE2		3.8
CPUE3	1.8	0.36
CPUE4		9.1
	CAS	
CAS(all)	-561	-275
CAS (LL1)	-79	-39
CAS (LL2)	-89	-44
CAS (LL3)	-152	-73
CAS (LL4)	-136	-67
CAS (DN3)	-4.6	-2.3
CAS (DN4)	-25	-12
CAS (PS1)	-71	-35
CAS (OT)	-4.5	-2.1
	SR	
SR_fits	37	35
	Catch	
Catch_fits	-271	-271
	Retrospective analyses	
Mohan's Rho values		

4. Discussion

4.1 Stock status

We discuss the stock status in 2020 using results of 2 plausible scenarios in the 8 fleets with 8 CAS model based on the comparisons made in the previous sections, then provide our suggestions. For the effective discussion, we further made the grand summary of qualitative comparisons between 2 scenarios (Table 5) based on the qualitative results presented in the previous section.

Table 5 Summary of qualitative comparisons between 2 scenarios

Scenario		[A] 2CPUE_CASW(0.1)	[B] 4CPUE_CASW(0.05)
CPUE Area		Western IO (R1+R3)	Whole IO (R1+R2+R3+R4)
Retrospective analyses			Slightly better fits
Likelihood *(crude reference as two scenarios have slightly different specs& CPUE)*	Total	Better fits	
	CPUE	Better fits	
	SR	Similar	
	CATCH	Similar	
Kobe plot (Fig.10, page 20)	Stock status (2020)	Orange zone (SSB ratio=1.26 & Fratio=1.12) Close to the green zone	Green zone (SSB ratio=1.83 & Fratio=0.57) Optimistic
	Uncertainties (confidence surface) (2020)	Larger	Smaller
MSY(1,000t)		58	78
Selectivity		Reasonable fits except OT	

Based on this comparison, we consider that both results are reasonable, although both have problems of uncertainties in their results. However, we consider that the scenario [A] 2CPUE_CASW(0.1) is more plausible than [B] 4CPUE_CASW(0.05) by the following three reasons, although [A] has larger uncertainties (larger confidence surface) in the 2020 stock status and [B] slightly fits better than [A] according to the results of retrospective analyses.

(1) MSY (78K t) [B] is likely too high comparing to the current catch (41K t) which is almost twice.

(2) The stock status [B] (SSB ratio=1.83 and F ratio=0.57) is likely too optimistic considering trends of the joint CPUE i.e., Generally the joint CPUE in the whole Indian Ocean (R1-R4) show decreasing or constant trends except recent years in R2+R4 (Eastern IO) showing the sharp increasing trends (Fig 12). It is noted that the data preparatory meeting (IOTC, 2022) suggested that the recent CPUE due to sharp increased catch in R3 and R4 may not be realistic, which imply that CPUE standardization may not reflect the intrinsic CPUE trends. In fact, there are nil correlations between catch and joint CPUE in R4 (r^2=1.2%) (Fig. 4, page 5).

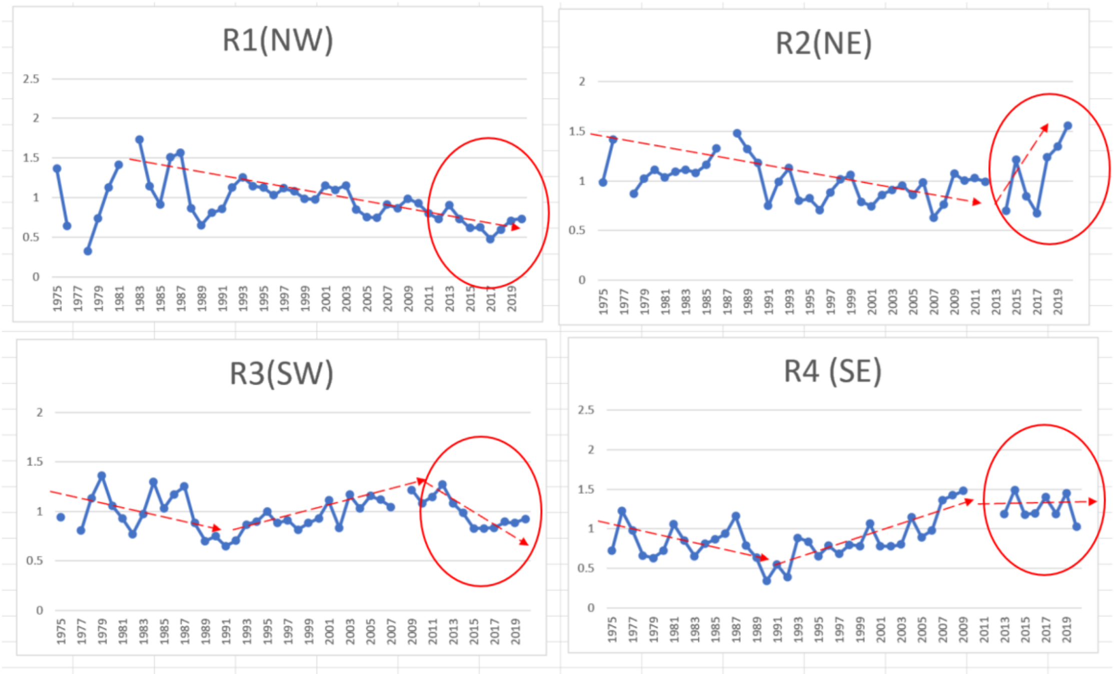


Fig. 12 Characteristics of joint annual CPUE trends in four areas.

(3) To understand differences of estimated stock statuses among SS3 and SCAS, we compared 4 results, i.e., SS3(2017) (Langley, 2019) and SCAS(2020)(this paper) with CPUE2 (R1+R3) (Western IO) and SS3 (2020)(Rice, 2022) and SCAS (2020) (this paper) with CPUE4 (R1+R2+R3+R4) (Whole IO). Fig. 13 shows the comparisons. We cannot compare them precisely as the input information and specifications among 4 stock assessments are different, especially SCAS is the annual basis with 8 fleets which are different from SS3 (quarterly basis with the 11 fleets). However, there are clear

differences in the stock statuses between 2CPUE and 4 CPUE. The reason of the different is clear as 2CPUE (R1+R3) show the decreasing or constant trend producing the pessimistic stock statuses, while 4CPUE(R1+R2+R3+R4) including (R2+R4) (Eastern IO) with increasing trends in recent years, which produced more optimistic stock statuses.

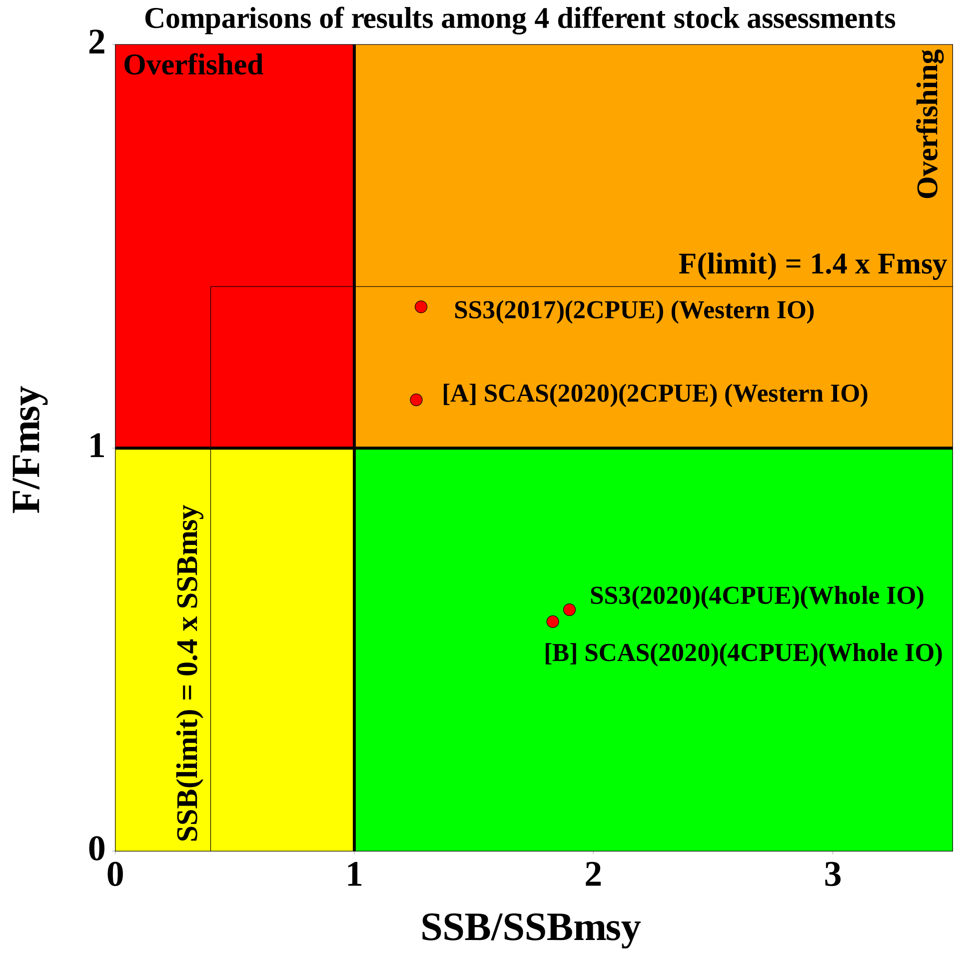


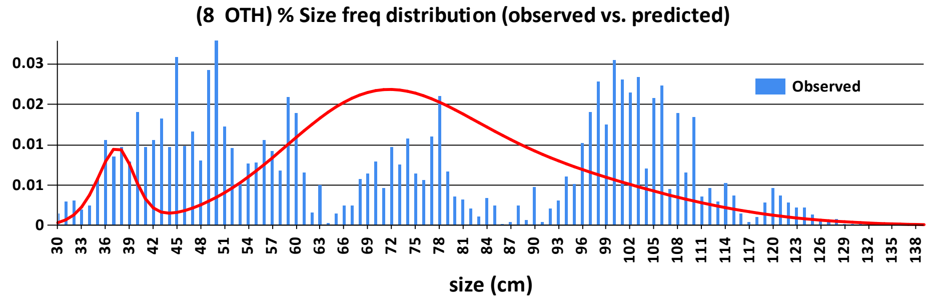
Fig. 13 Comparisons of stock statuses among results of four different stock assessments

With these three reasons we suggest that the scenario [A] 2CPUE_CASW(0.1) is considered to be the most plausible scenario, hence it is suggested that the stock status of the Indian Ocean albacore in 2020 is in the orange zone in the Kobe plot (SSB ratio=1.26 and F ratio=1.12) (not overfished but overfishing), MSY(58K ton), and depression(0.28).

4.2 Technical issues (future works)

(1) As we have some difficulties to get convergences in the 11 fleets model, we will investigate this matter in the near future.

(2) We had difficulty to fit predicted size frequencies to the observed one for the OT fleet (see the graph below). As the size frequency distribution (OT) include various size frequencies in different ranges from different types of gears, it is unlikely ideal to use one homogenous OT fleet. In the future, it may be ideal that the OT catch/CAS data will be re-classified to other gear type categories. A simple method for example, is to separate from OT to OT(LL type), OT(DN type), OT(PS type) etc., then include them to LL(CAS/catch), DN(CAS/catch) and PS(CAS/catch), so we will not worry about the problem of OT(mixed gear types) data. Although OT catch are very small, we recognized that CAS (OT) are very sensitive to the SCAS assessment results, thus we need to improve this problem as explained above.



(3) We realized that values of relative weights to CAS against CPUE (CASW) are very sensitive to the SCAS assessment results. For example, 0.1 and 0.05 in our case, produced quite different results. In the future, we need to apply hindcasting analyses to evaluate the optimum and plausible CASW values.

(4) Based on the comparison of the Kobe plot between constant and dynamic MSY options (Fig. 14), we understand that the constant MSY option (red line) produces much higher jump in 1990 during the gillnet peak catch, which is unlikely realistic, while the dynamic MSY option (black line) could mitigate such jump, which is likely more plausible. Thus we used the dynamic MSY option and produced the resultant Kobe plots in Fig. 11, page 21. Please note that two options (constant and dynamic MSY) are available in the SCAS software.

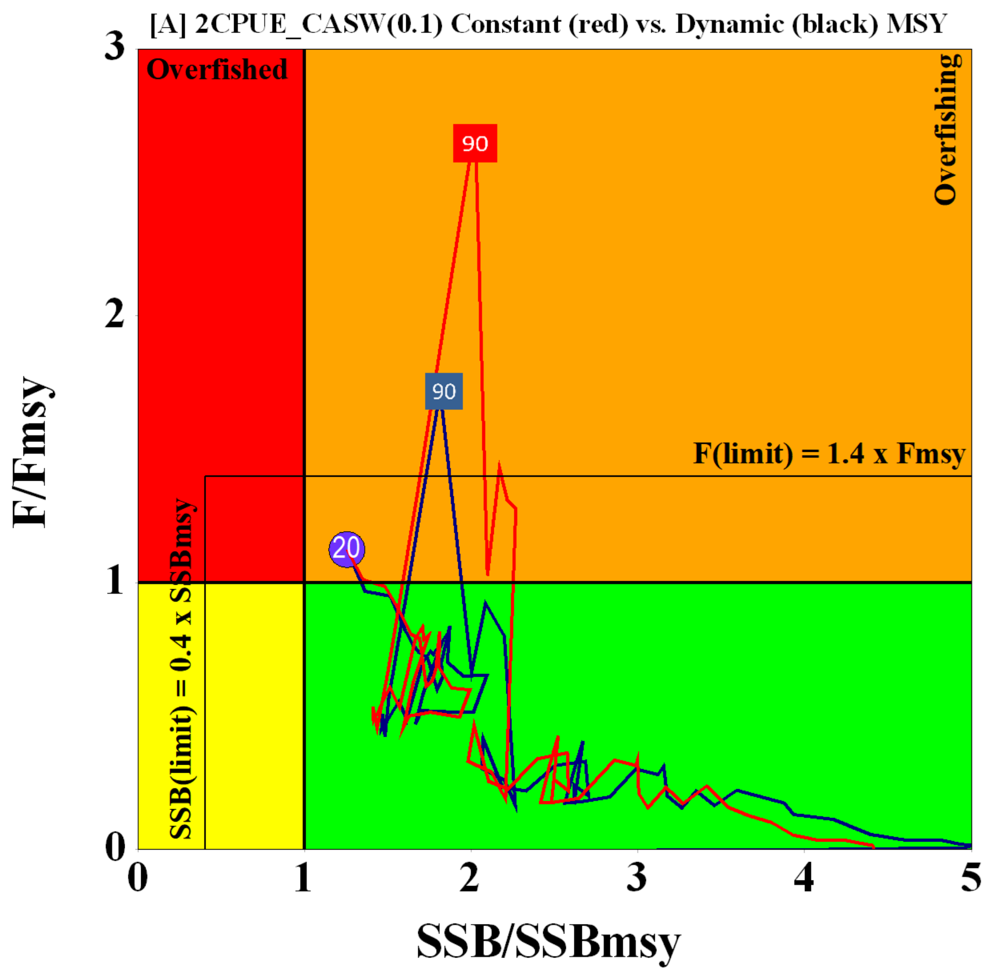


Fig. 14 Comparison of the Kobe plots between constant (red line) and dynamic (black line) MSY options in the SCAS assessments for the selected (best) scenario 2CPUE_CASW(0.1).

(5) In the future we need to include two additional diagnostics (Jitter and ASPM analyses) in the SCAS software as they are not available in the current version as shown in Fig. 15.

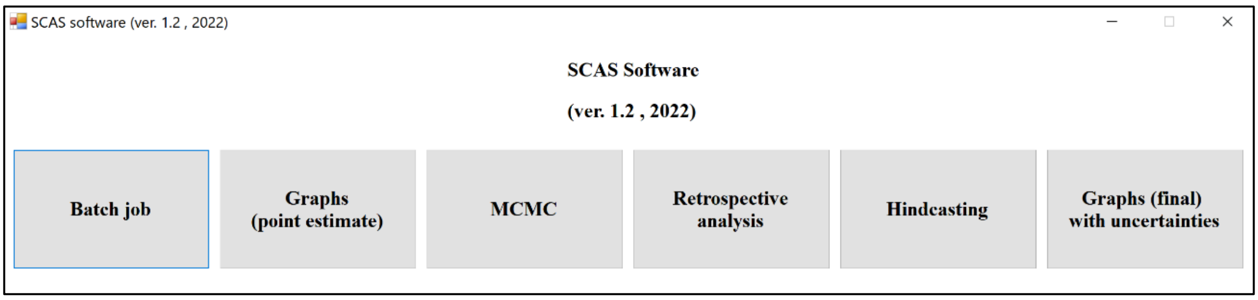


Fig. 15 Six menus available in the current version of the menu-driven SCAS software (after Nishida *et al.*, 2021)

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