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Preliminary stock assessment of yellowfin tuna (*Thunnus albacares*) in the Indian Ocean by SCAA (Statistical-Catch-At-Age) (1950-2017)

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Abstract

We preliminary attempted stock assessments for yellowfin tuna (YFT) in the Indian Ocean using SCAA (Statistical-Catch-At-Age) with available data for 68 years (1950-2017). It is preliminary suggested that YFT stock status (2017) is lightly overfished, i.e., the red zone in the Kobe plot but very close to both MSY levels (F and SSB) with F (2017)/Fmsy=1.08 and SSB (2017)/SSBmsy=0.88.

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1. Introduction

We attempted stock assessments for the yellowfin tuna (*Thunnus albacares*) (YFT) in the Indian Ocean using SCAA (Statistical-Catch-At-Age) with available data for 68 years (1950-2017). ADMB (AD Model Builder) implemented SCAA/ASPM software was used, which was developed by us and Dr Rademeyer (University of Cape Town). This software can conduct both ASPM and SCAA and is available at http://ocean-info.ddo.jp/kobeaspm/aspm/ASPM.zip including Users' manual and case studies.

For this time, we update the last SCAA (Nishida et al, 2015) as a reference or supporting information (if appropriate) for SS3 (Fu et al, 2018) which is the primary stock assessment method in IOTC. Another reason to conduct SCAA is to implement one of SC recommendations on the WPTT program of work (2018-2022) (page 213, SC20 report in 2017) i.e., to develop and compare multiple assessment approaches to determine stock status led by Consultant (Secretariat) and CPCs directly.

It is important to note that results of SCAA (this document) should not be used for management advices because we conducted mainly the base case with minor sensitivities and did not implement full scale sensitivities, diagnostics of results, retrospective analyses nor risk assessments (Kobe II).

2. Ecology and stock structure

YFT is a cosmopolitan species distributed mainly in the tropical and subtropical oceanic waters of the three major oceans, where it forms large schools. Feeding behavior has been extensively studied and it is largely opportunistic, with a variety of prey species being consumed, including large concentrations of crustaceans. It has also been observed that large individuals can feed on very small prey, thus increasing the availability of food for this species. Archival tagging of yellowfin tuna has shown that YFT can mainly dive in normal depth ranges, but in particular cases, dive to very deep (over 1,000 m) probably to feed on meso-pelagic prey (IOTC, 2017; Dargon et al, 2008; Matsumoto, 2013).

In the Indian Ocean, longline catch data indicates that YFT is distributed throughout the entire tropical Indian Ocean. The tag recoveries of the IOTC RTTP-IO provide evidence of large movements of yellowfin tuna, thus supporting the assumption of a single stock for the Indian Ocean. The average distance travelled by yellowfin between being tagging and recovered is 710 nautical miles and shows increasing distances as a function of time at sea.

3. Input information

To implement SCAA, following information are used:

- Fleet types
- Nominal catch by fleet and year;
- CAA (catch-at-age) by year and fleet;
- Plus and minus age group by fleet;
- Seeding values of selectivity by fleet;
- Standardized CPUE(STD_CPUE) by year in the whole Indian Ocean; and
- Biological information by age (LW, growth, maturity schedule)

3.1 Fleet types

We used 7 types of fleet exploiting YFT in the Indian Ocean as listed in Table 1 based on available fleets in CAA prepared by IOTC Secretariat (IOTC, 2018).

Table 1 List of 7 fleets used in the stock assessment by SCAA

No	Code	Fleet
(1)	LL	Tuna longline (deep-freezing)
(2)	LF	Tuna longline (fresh)
(3)	PS	Purse seine
(4)	GIL	Gillnet
(5)	HAND	Hand line
(6)	BB	Pole and Line
(7)	TROL	Troll line (Including negligible catch by other fleets similar selectivity to troll)

3.2 Nominal Catch

Fig. 1 shows the YFT total nominal catch trends (1950-2017) with 2 scenarios (2012-2017) (IOTC, 2018), i.e., High and low Indonesian catch. These 2 scenarios are based on 2 different catch estimations of Indonesian catch, which was pointed out in swordfish stock assessment during WPB15 (IOTC, 2017). Large discrepancies were detected in swordfish catch (to 20%), while for YFT, it is much less ranging 2.5-6.9%. In SCAA, we use the LOW catch as base case and we will not attempt HIGH catch scenario as we consider that HIGH catch will not affect results significantly.

	Diff (%) between High-Low NC
2012	2.5
2013	3.3
2014	3.0
2015	3.1
2016	6.8
2017	6.9

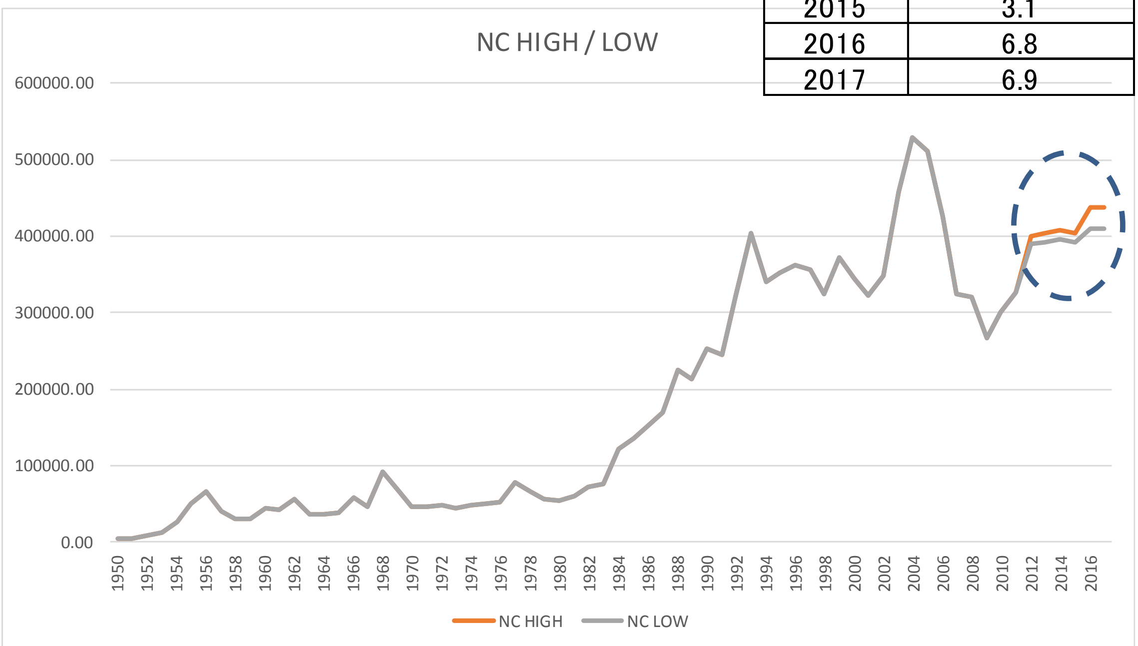


Fig. 1 Trends of nominal catch (1950-2017) with 2 scenarios of recent catch level (2012-2017) due to 2 different Indonesian LL catch estimates (Source: IOTC Secretariat, 2018)

Fig. 2 shows nominal catch (tons) trend by fleet. PS is one of the main fleets with the largest catch after mid 1980's. In recent years, fleets with large catch (in weight) (in order) are by PS, HAND, GILL, LF, TROLL and BB.

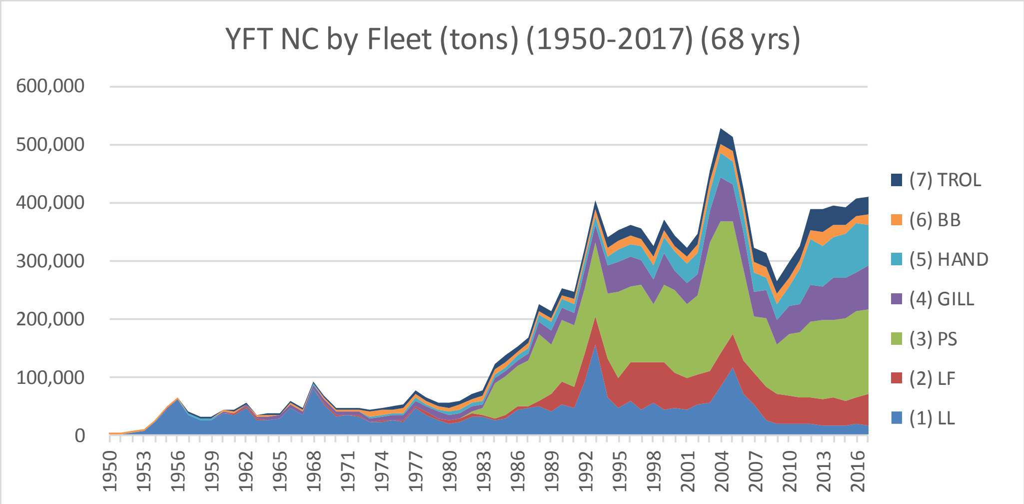


Fig.2 YFT nominal CPUE (tons) (1950-2017) (IOTC, 2018)

3.3 Catch-At-Age (CAA)

(1) Age composition

As CAA provided by the IOTC Secretariat is composed by seven (annual) age (group), we used these seven age (group) (age0-age6+), same as in the last assessments (Nishida et al, 2015). We attempted to use 2 types of CAA by slicing and probability method.

(2) CAA (slicing method)

Fig. 3 shows the catch-at-age (CAA) (all fleet combined) estimated by the IOTC Secretariat (2018). Figs. 4-10 show the CAA trend by fleet.

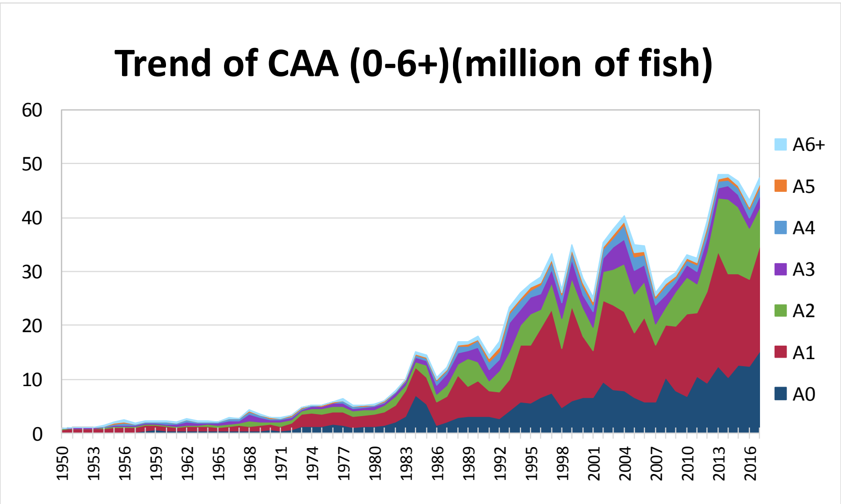


Fig. 3 Trend of YFT CAA estimated by IOTC (2018) (all fleets combined)

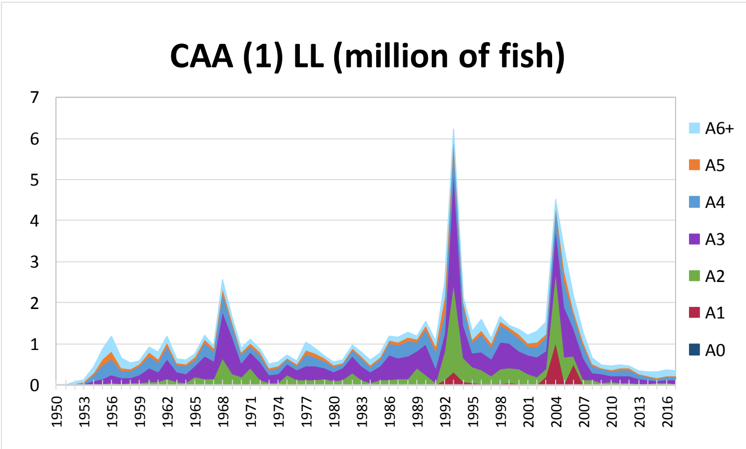


Fig 4. CAA for LL

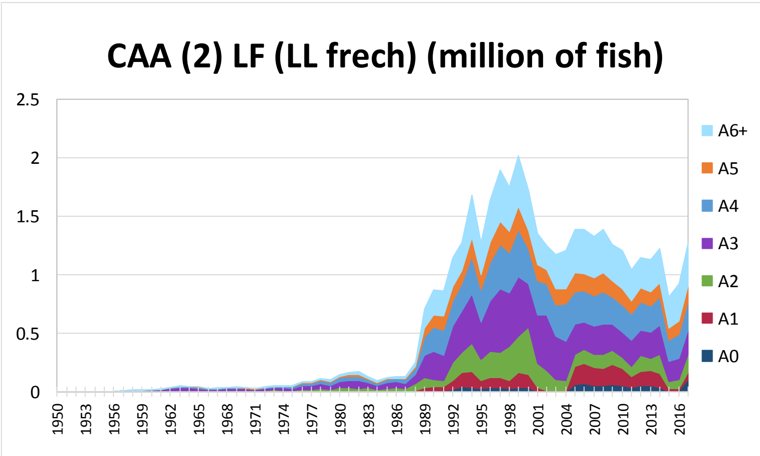


Fig 5. CAA for LF

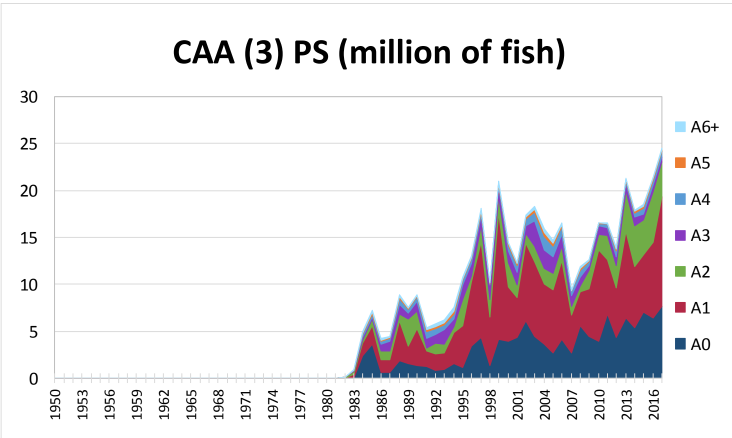


Fig 6. CAA for PS

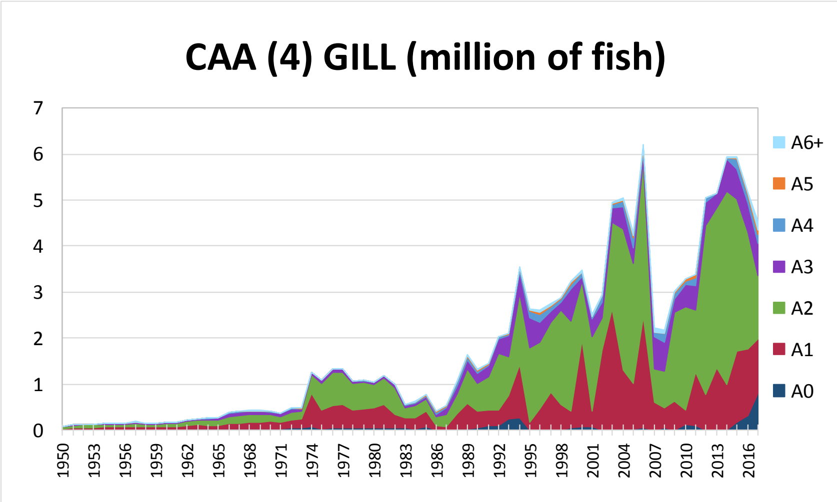


Fig. 7 CAA for GILL

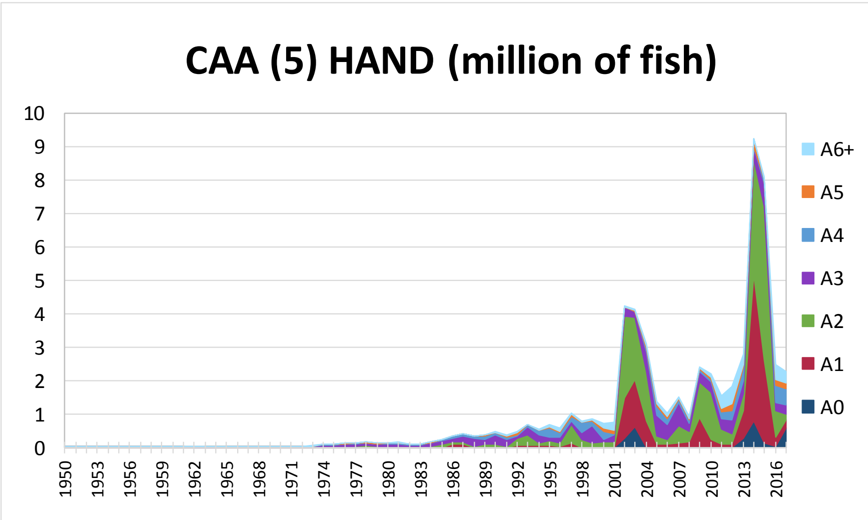


Fig. 8 CAA for HAND

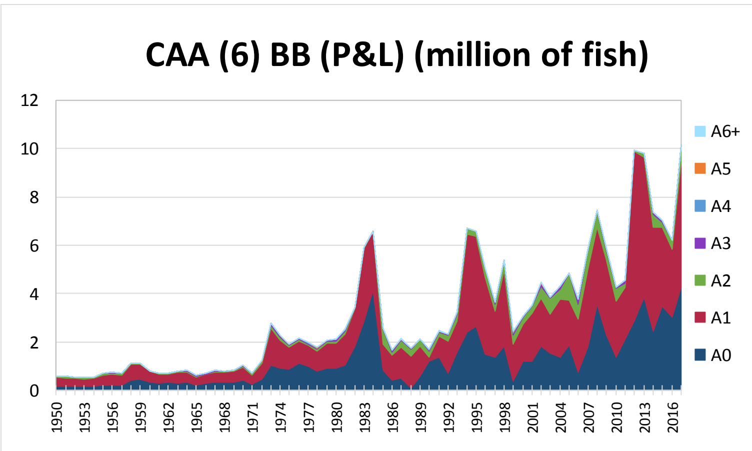


Fig. 9 CAA for BB

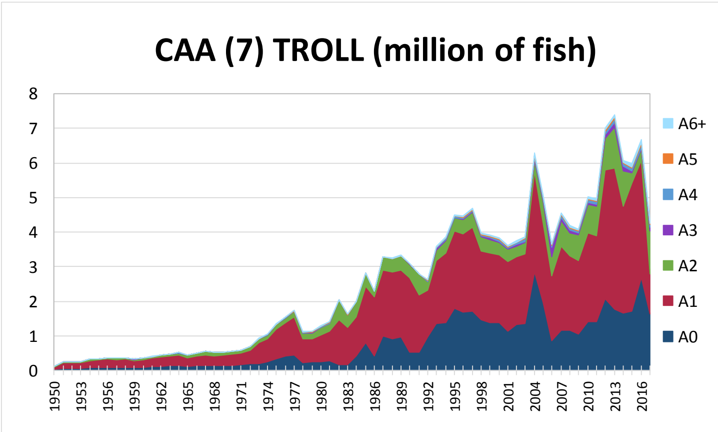


Fig. 10 CAA for TROL

(3) CAA (Probability method)

AS CAA by the slicing method include potential biases because of the knife edge type separation method. Thus, the probability method is attempted to estimate less biased CAA. Using the growth equation by Fonteneau (2008), we used the same probability distribution function applied by SS3 (2015 and 2016), i.e., normal distribution with mean=μ, CV=0.1, SE=0.1μ and error= N (0, 0.1μ). Table 2 shows the age (quarter)-length key for the cut points between quarterly ages.

Table 2

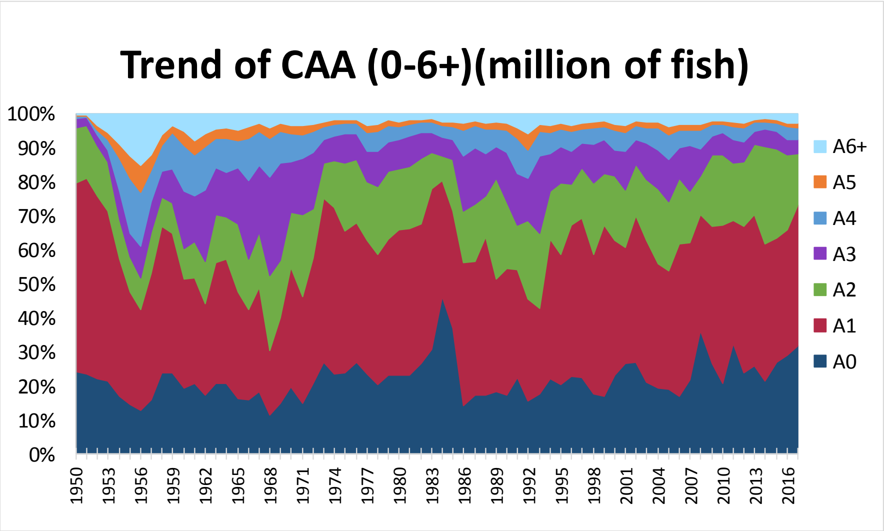
Age (quarter) - Length key based on the growth equation by Fonteneau (2008)

Age	Quarter	LengthFrom	LengthTo	Proportion
0	1	0	22	1
0	2	0	32	1
0	3	0	48	1
0	4	0	52	1
1	1	22	54	1
1	2	32	60	1
1	3	48	68	1
1	4	52	78	1
2	1	54	88	1
2	2	60	98	1
2	3	68	108	1
2	4	78	114	1
3	1	88	120	1
3	2	98	126	1
3	3	108	130	1
3	4	114	132	1
4	1	120	136	1
4	2	126	138	1
4	3	130	140	1
4	4	132	140	1
5	1	136	142	1
5	2	138	142	1
5	3	140	144	1
5	4	140	144	1
6	1	142	252	1
6	2	142	252	1
6	3	144	252	1
6	4	144	252	1

Then we estimated % age compositions in each size range then computed CAS (Catch-at-Size) using total catch number by fleet. Then we computed CAA by accumulating corresponding CAS.

(4) Comparison 2 types of CAA between slicing and probability method

Fig. 11 shows two types of CAA (1950-2017) by slicing and probability method. There are large discrepancies between 2 types. CAA by the probability method has a very large Age 1 composition, while nil composition for Age 0.



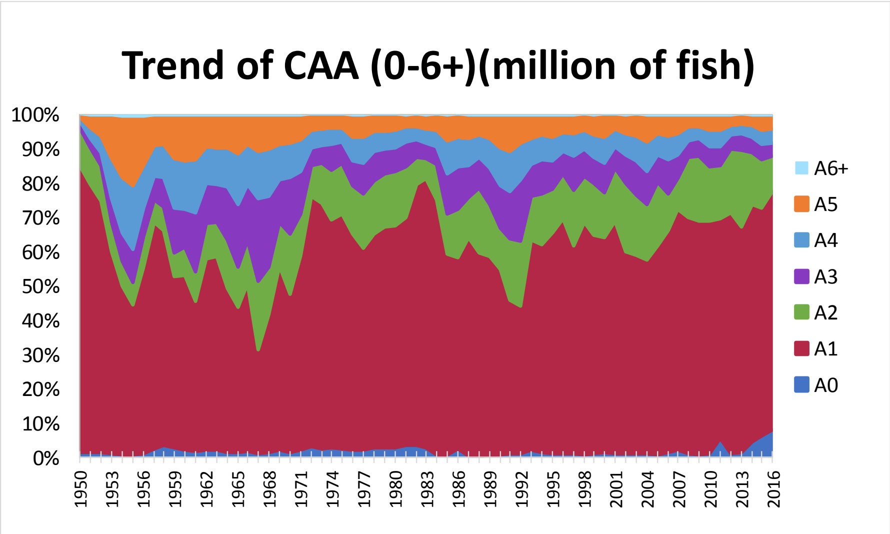


Fig. 11 Two types of CAA

(above: based on slicing method and below: based on probability method)

The major reason of this large discrepancies is as follows: Fig.12 shows probability distributions of 8 (quarter) Ages and ranges of (annual) Age 0 and Age 1 for slicing and probability methods. In the probability method, the range of (annual) Age 0 is about 10-32cm, while Age 1, about for 32-78cm. Number of fish in 10-32 cm is extremely low (27 million fish), while the number for Age 1 is extremely large (797 million fish), i.e., 3% vs. 97%. That is why the composition of Age 0 (probability method) is almost nil as shown in Fig. 11. This problem is caused by probability distributions, i.e., four distributions for (quarterly) Age 0 are much more centralized with very skewed edges than others, which makes the size range of annual Age 0 narrower as 10-32cm.

To improve this situation, we need to explore more appropriate probability distribution functions especially for quarterly Age 1-4 to generate much flatter distributions so that (annual) Age 0 can cover much larger size classes and age compositions will be more realistic. Due to time constraint we could not explore this time, thus we use CAA by the slicing method and we plan to search more plausible probability distribution functions in the future.

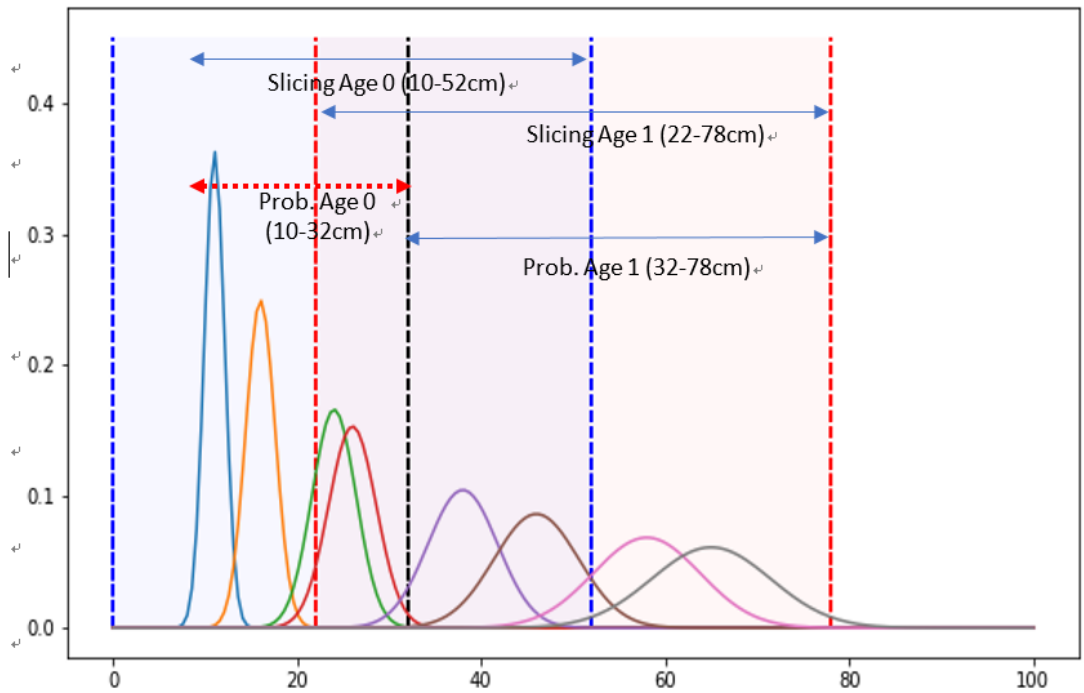


Fig. 12 Probability distributions (*) of quarterly ages and size ranges for (annual) Age 0 and Age 1 by slicing and probability method to estimate CAA. (*) Normal distribution with mean=μ, CV=0.1, SE=0.1μ and error= N (0, 0.1μ)

3.4 Plus and minus group

In running SCAA, plus and minus groups need to assign to implement robust optimization. Based on the CAA information by fleet, we determined plus and minus age groups which CAA by age composition less than 2% of the total number (Table 3) (personal communication with Dr Butterworth).

Table 3 Minus and plus group determined based on compositions of CAA by age.

No	Code	Fleet	Minus group	Plus group	Period of available CAA data
(1)	LL	Tuna longline (deep-freezing)	Age 1-	Age 6+	1950-2017
(2)	LF	Tuna longline (fresh)	Age 1-	Age 6+	1950-2017
(3)	PS	Purse seine		Age 4+	1977-2017
(4)	GIL	Gillnet		Age 4+	1950-2017
(5)	HAND	Hand line		Age 6+	1950-2017
(6)	BB	Pole and Line		Age 2+	1950-2017
(7)	TROL	Troll line		Age 2+	1950-2017

3.5 Seeding values of selectivities

Seeding values of selectivity by fleet need to assign. Seeding values are selected based on the relevant information in the past. Table 4 shows the seeding values

Table 4 Seeding values of selectivity by fleet

(1) LL(frozen)	Age 1-	Age 6+		0.1	0.1	0.9	(1)	1	1
(2) LF (fresh)	Age 1-	Age 6+		0.1	0.1	0.5	(1)	1	1
(3) PS		Age 4+	0.2	0.6	0.6	0.8	(1)		
(4) GILL		Age 4+	0.1	0.1	(1)	0.3	0.2		
(5) HAND		Age 6+	0.2	(1)	1	1	1	1	1
(6) BB		Age 2+	(1)	0.9	0.2				
(7) TROL		Age 2+	0.1	(1)	0.7				

Note: (1) is the highest selectivity (=1) (blanks).

3.6 Standardized CPUE (STD_CPUE)

We used the joint STD LL CPUE (IOTC, 2018 and Holye et al, 2018) (Japan, Korean, Taiwan and Seychelles) available on the IOTC web site. There is different category of STD CPUE series in terms of sub-areas (Fig. 13) and time-period (quarter or annual). As SCAA is annual based and area aggregated stock assessment, we used annual STD CPUE (4 sub areas aggregated) (Fig. 14).

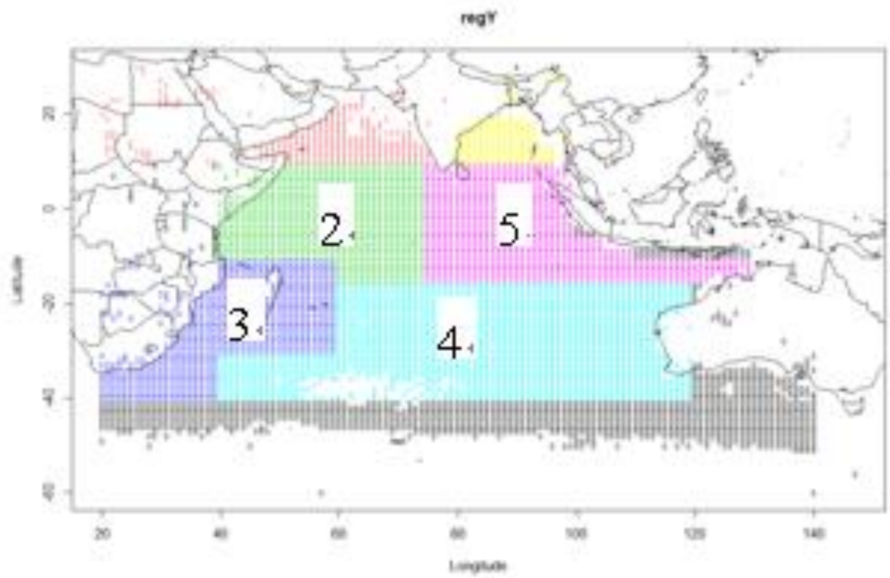
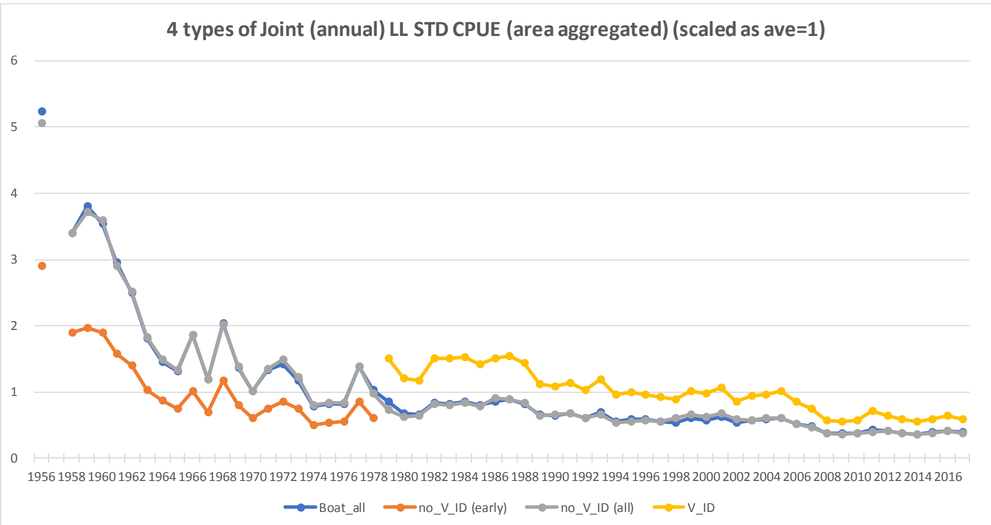


Fig. 13 Four sub areas used in the YFT joint CPUE



Fug 14 Trends of 4 type of joint LL (annual) STD_CPUE (Japan, Korea, Taiwan and Seychelles) (All sub-areas aggregated) (scaled as ave=1)

Within this category, there are 4 types of STD_CPUE, i.e., One Boat (1956-2017), No Vessel ID (1956-1978), No Vessel ID All (1957-2017) and V_ID (1979-2017) without 1957 data. We evaluated the plausible STD_CPUE by checking the correlation between STD_CPUE and catch assuming they are negatively correlated and STD_CPUE with higher r2 is the more plausible. We also examined both LOW and HIGH catch scenarios.

Box 1 shows the results. STD_CPUE based on V_ID (1979-2017) indicates the highest negative correlations (about 50%) for both LOW and HIGH catch scenarios, while r2 for others are low (less than 33%). Therefore, we used STD_CPUE by V_ID for SCAA stock assessment (Fig. 15). It is also noted that both LOW and HIGH catch showed same levels of correlations. This implies that two different catches unlikely affect stock assessment results (Box 1).

We examined EU PS STD_CPUE, but they are optimistic considering the current stock status, thus we did not use.

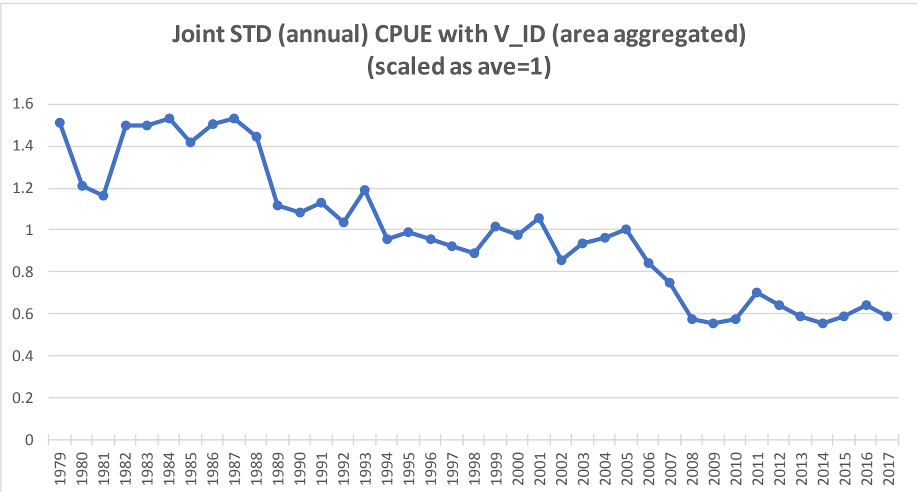
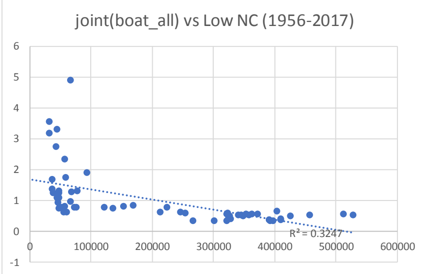
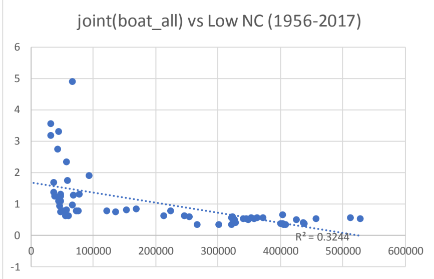
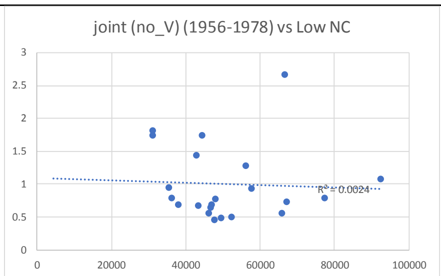
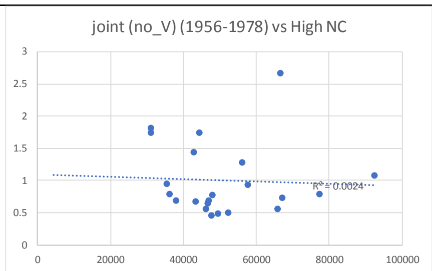
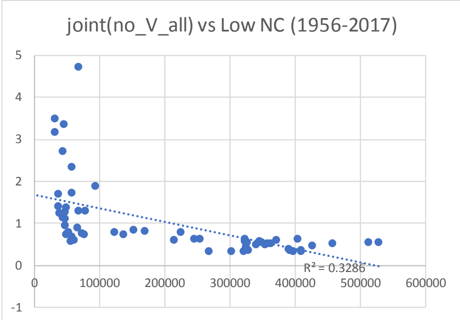
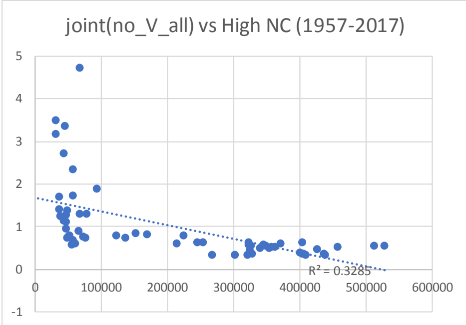
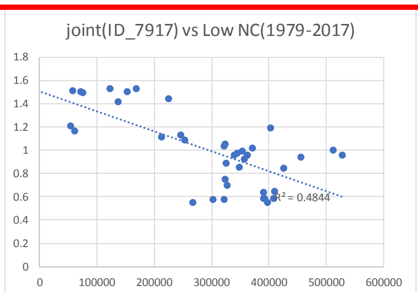
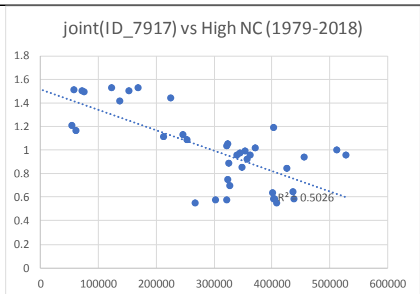


Fig. 15 Trend of joint tuna LL annual STD_CPUE (Japan, Korea, Taiwan and Seychelles) with vessel ID (Call signs) used for SCAA stock assessment.
(scaled as ave.=1)

BOX 1 Relation between joint CPUE vs NC (Low and High catch scenarios)

Joint CPUE	Nominal catch scenario	
	Low NC	High NC
Boat all (1956 - 2017)	 r2=32%	 r2=32%
No V ID (1956 - 1978)	 r2=0%	 r2=0%
No V ID all (1956 - 2017)	 r2=33%	 r2=33%
V ID (1979 - 2017)	 r2=48%	 r2=50% high NC: more plausible?

3.7 Biological information

In SCAA, three types of age-specific biological inputs need to assign, i.e., natural mortality-at-age (*M*), weight-at-age (beginning and mid-year) and maturity-at-age.

(1) Age specific natural mortality (M)

We applied M based on the IOTC tagging recapture data (IOTC 2008b), which was applied to YFT stock assessment by SS3 (Langley et al, 2012). Table 5 shows the M vector by age.

(2) Beginning- and mid-year weight-at-age growth curve

Beginning- and mid-year weights-at-age were estimated as follows: (a) using the growth equation by Fonteneau (2008) (Fig. 16), size-at-age was calculated, then (b) using the length-weight relationship, $GGT=a(FL)^b$ (a=0.0000094007 and b= 3.126843987) (IOTC, 2018) and the conversion factor for (Whole weight) =(GGT)*1.13 (IOTC, 2018), beginning- and mid-year weights-at-age were computed (Table 5).

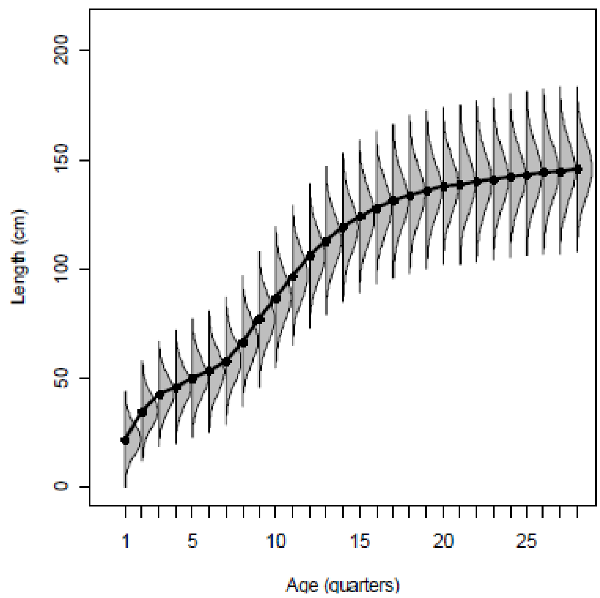


Fig. 16 YFT growth curve (Fonteneau, 2008)

(3) Maturity-at-age

We applied maturity ogives derived by Zudair et al (2000) (Table 5)

(4) Summary of biological parameters (Table 5)

Table 5 Summary of age specific M, weight and maturity

Age	M	Weight-at-age (ton)		Maturity-at-age(%)
		beginning	middle	
0	1.240	0.00017	0.00136	0
1	0.552	0.00218	0.00347	15
2	0.552	0.00841	0.01732	70
3	0.756	0.02792	0.03733	100
4	0.756	0.04432	0.04983	100
5	0.596	0.05286	0.05604	100
6+	0.552	0.05864	0.06077	100

4. SCAA

4.1 Grid search

We attempted SCAA runs using input data described in the previous Section. To search optimum parameters, we conducted the grid search using 72 scenarios (Table 6).

Table 6 Specification of grid search

Parameters	Search range and interval	No of scenarios
h (steepness)	0.7, 0.8 and 0.9	3
Sigma R (SR fluctuation)	0.4, 0.5, 0.6, 0.7 and 0.8	5
(*) Weighting for CAA = [Multiple] x [C] [C] = Coverage (sample number of size) = (number of size measured) / (total catch in number)	1.0 [C], 0.5[C], 0.2[C], 0.1[C] 0.01 [C] and 0.001[C]	6
Total		90

(*) Weighting for CAA by fleet

In SCAA, weightings for CAA by fleet need to assign. The normal (default) weightings for CAA are [C]: coverages of size sample, i.e., (number of size measured)/ (total catch in number) by fleet. We investigated [C] by fleet and Table 7 shows results. As we are interested in other weighting schemes to investigate optimum parameters, we set up 5 additional weightings using different multiples, i.e., 0.5[C], 0.2[C], 0.1[C], 0.01[C] and 0.01[C] (Table 7).

Table 7 Six weighting schemes for CAA using [C]
[C]: coverages of size sample = (number of size measured)/ (total catch in number)

Fleet	1.0 [C]	0.5[C]	0.2[C]	0.1 [C]	0.01[C]	0.001[C]
LL	0.036871	0.018436	0.007374	0.003687	0.000369	0.0000369
LF	0.003889	0.001944	0.000778	0.000389	0.000039	0.0000039
PS	0.234767	0.117384	0.046953	0.023477	0.002348	0.0002348
GILL	0.012511	0.006256	0.002502	0.001251	0.000125	0.0000125
HAND	0.000367	0.000183	0.000073	0.000037	0.000004	0.0000004
BB	0.001366	0.000683	0.000273	0.000137	0.000014	0.0000014
TROL	0.000303	0.000151	0.000061	0.000030	0.000003	0.0000003

4.2 Results

Table 8 shows the SCAA results (last assessed year: 2017) with the last stock assessment by SS3 (2015). Results (SSB/SSBmsy and F/Fmsy) of SCAA are presented by medians of converged scenarios. Fig. 17 shows Kobe plot for SCAA results with the previous result of SS3(2015)

Table 8 Results of SCAA (medians) with SS3(2015)

stock assessment method	last year of stock assessment	Weightings for SCAA (multiple of [C])	number of scanarios converged (out of 15)	SSB/SSBmsy	F/Fmsy
SS3	2015			0.89	1.11
SCAA	2017	1.0	15	1.27	0.59
		0.5	15	1.18	0.67
		0.2	15	1.12	0.73
		0.1	15	1.21	0.7
		0.01	9	1.16	0.78
		0.001	4	0.83	0.96

(Note) SCAA Results (SSB/SSBmsy and F/Fmsy) are the median points of converged scenarios.

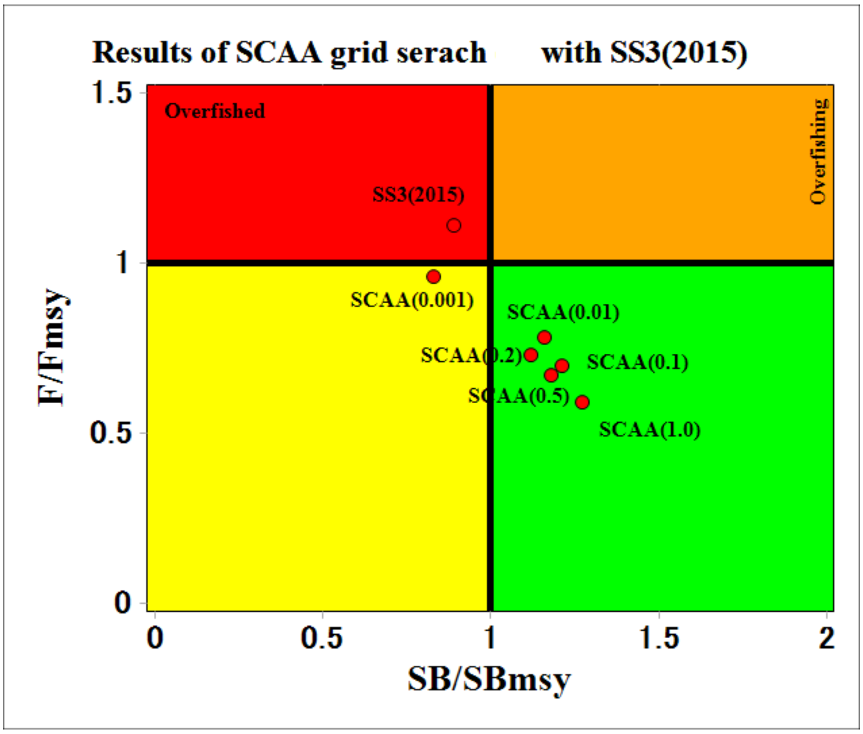


Fig. 17 Results of grid search of SCAA runs (last assessment year: 2017) using 6 different weighting schemes for CAA with the last stock assessment by SS3 (2015).

Considering that recent catch levels for last 6 years (2012-2017) have been stable (around 400,000 tons), the plausible stock status (2017) is unlikely drastically different from the one in 2015. Therefore, we don't consider that stock statuses by 5 scenarios with 1.0, 0.5. 0.2, 0.1 and 0.01 [C] in the green zone of the Kobe plot are plausible as they are optimistic, while the one with 0.001[C] in the yellow zone is likely more plausible.

Then we further investigated SCAA results with 0.001 [C]. Within 0.001 [C], there are 4 scenarios that were converged. Table 9 shows results and Fig. 18 depicted the Kobe plot of these 4 points with SS3(2015). The r2 and the total likelihood of 4 scenarios are almost identical. As the catch levels are stable in the last 6 years (2012-2017) with around 400,000 tons and recruitment is stable (SCAA result), thus we don't expect large changes in the stock status from the last assessment year (2015). Thus, with same levels of goodness of fitness for all 4 scenarios, using the expert judgements, we selected scenario (2), the one close to SS3(2015) as the representative result for SCAA.

Fig. 19 shows the Kobe plot of scenario (2). Fig. 20-21 and Table 10 show its summary.

Table 9 Results of 4 converged SCAA runs with 0.0010 [C]

Scenario no	h (steepness)	Sigma (SR)	SSB0 (1,000 t)	Total likelihood	r2	SSB (1,000 t)	MSY (1,000 t)	SSB/SSBmsy	F/Fmsy
(2)	**0.7**	**0.5**	**4446**	**-70.6**	**0.9**	**1321**	**404**	**0.87**	**1.07**
(4)	0.7	0.7	5517	-70.6	0.9	1504	480	0.81	0.98
(5)	0.7	0.8	6176	-70.6	0.9	1549	533	0.74	0.96
(10)	0.8	0.8	5646	-70.6	0.9	1472	536	0.88	0.84

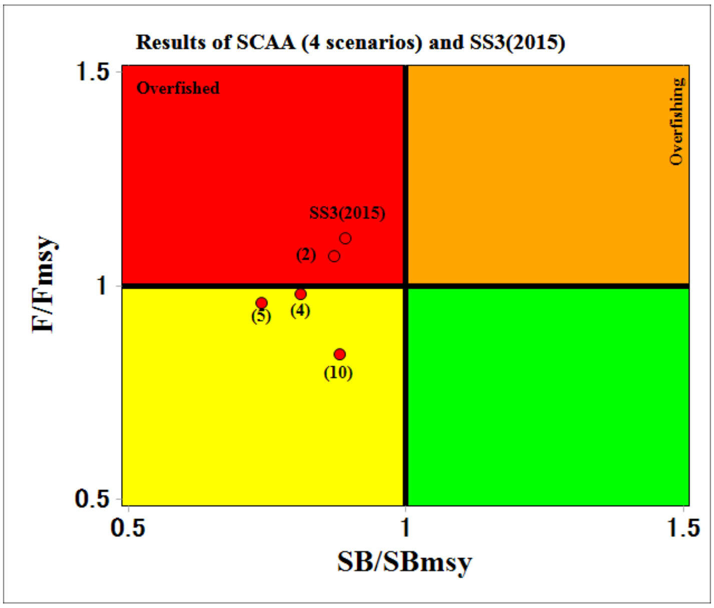


Fig. 18 Kobe plots: SS3(2015) and SCAA (2017) for 4 scenarios of CAA weightings with 0.001 [C]
[C]: coverages of size sample = (number of size measured)/ (total catch in number)

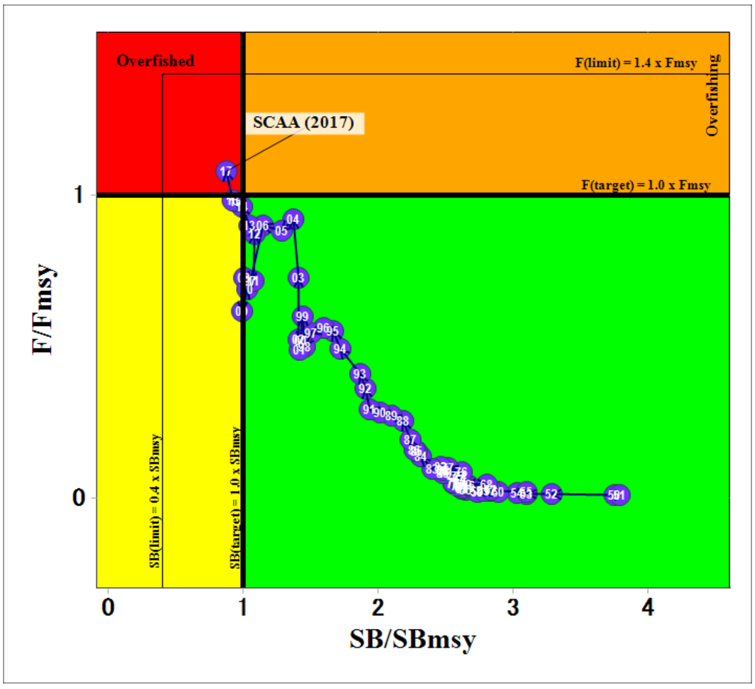


Fig. 19 Kobe plot: Result of scenario (2) of SCAA (2017)

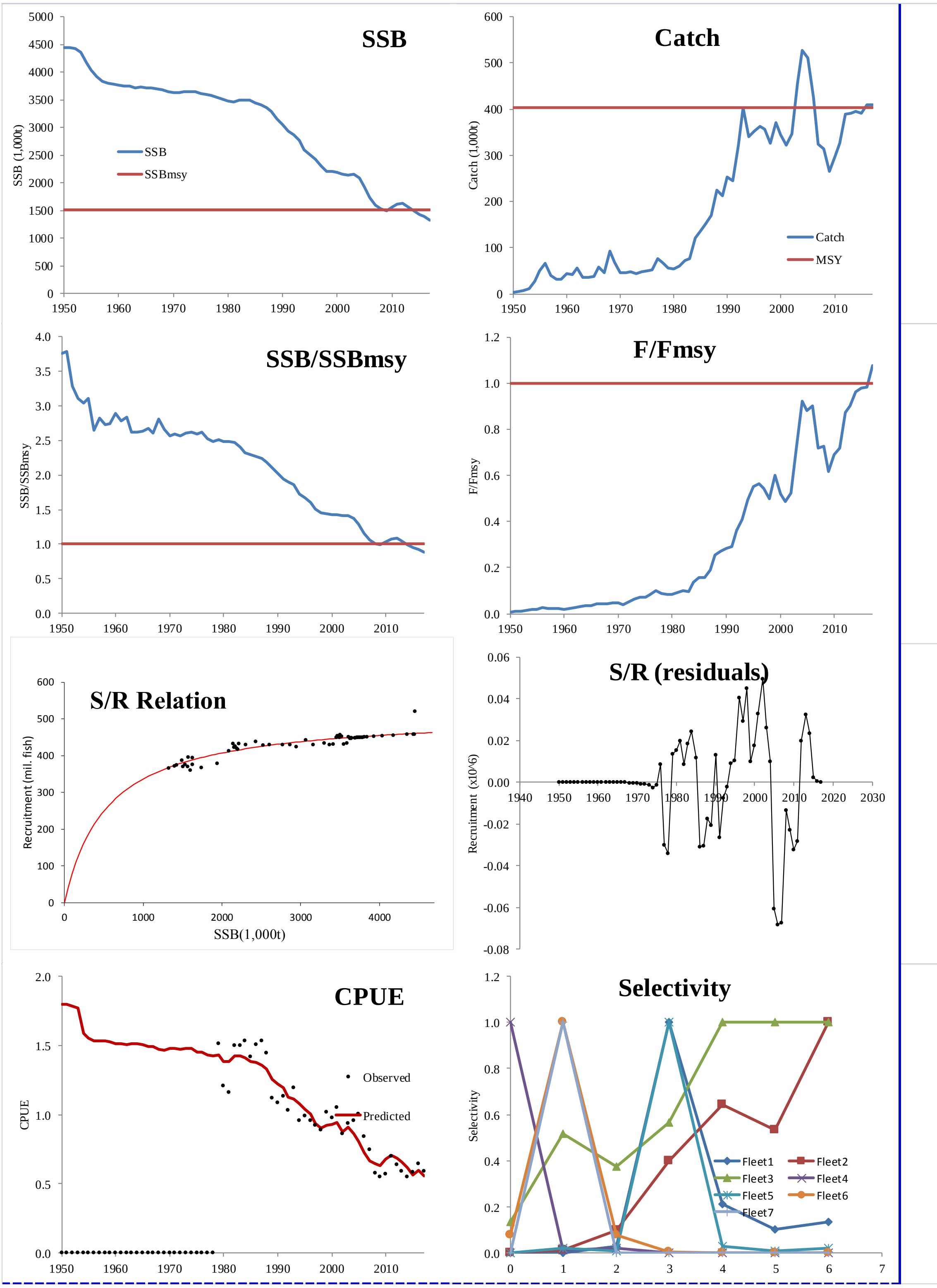


Fig. 20 Result of SCAA (scenario 2) (2017)
Fleet 1-7 (L, LF, PS, GILL, HAND, BB and TROL respectively)

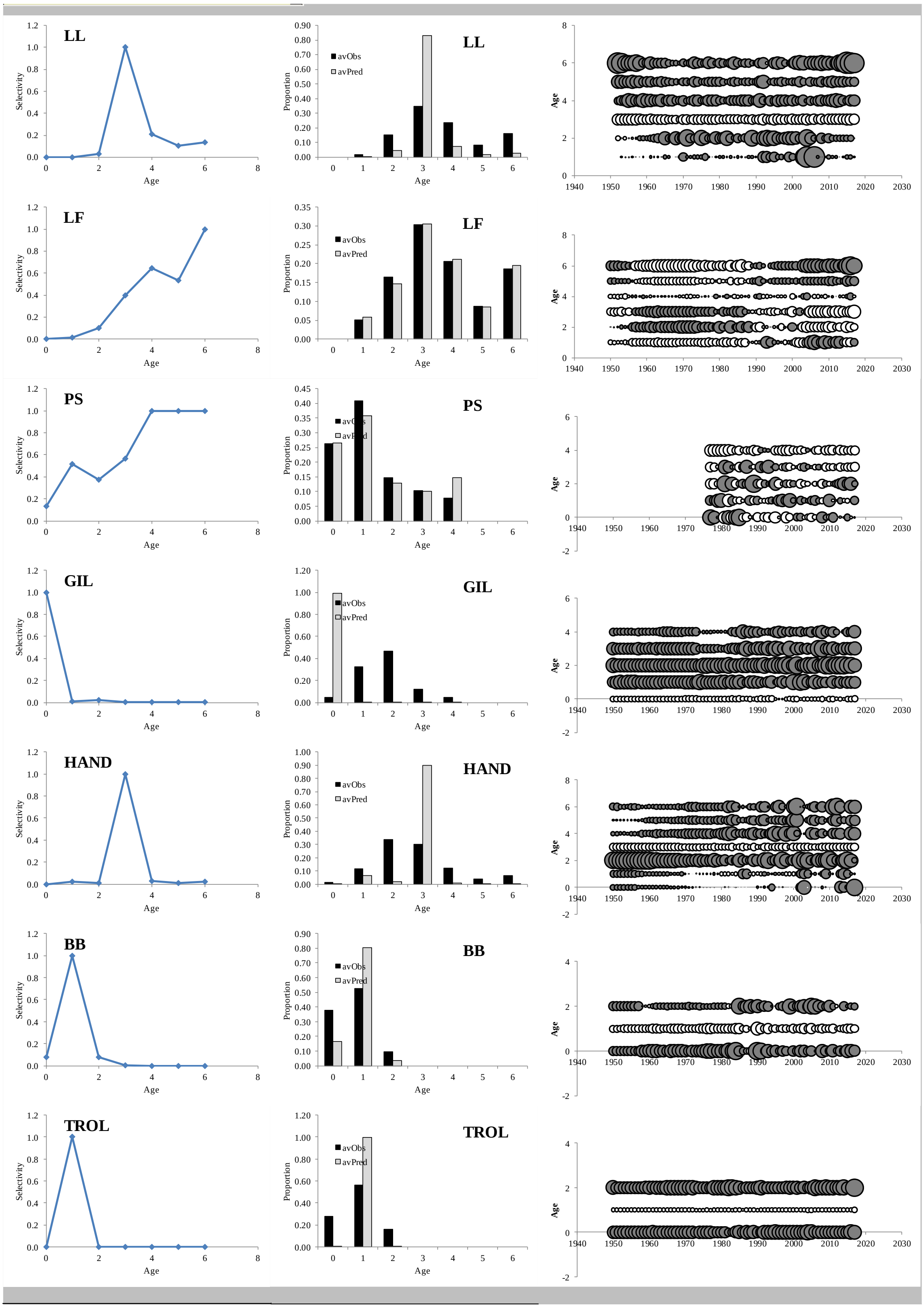


Fig. 21 Estimated selectivity, fitness and bubble plot of residuals by fleet

Table 10 Summary of SCAA YFT stock assessment (2017)

Management Quantity	Indian Ocean
Most recent catch estimate (t) (2017)	409,150
Mean catch over last 5 years (t) (2013–2017)	399,831
h (steepness)	0.7
MSY (1,000t) (80% CI)	404 (n.a.)
Data period (catch)	1950–2017
CPUE series/period	1979-2017
F_{MSY} (80% CI)	0.31 (n.a.)
SB_{MSY} or *B_{MSY} (1,000 t) (80% CI)	1,507 (n.a.)
F_{2017}/F_{MSY} (80% CI)	1.08 (n.a.)
B_{2017}/B_{MSY} (80% CI)	n.a.
SB_{2017}/SB_{MSY} (80% CI)	0.88 (na)
B_{2017}/B_{1950} (80% CI)	n.a.
SB_{2017}/SB_{1950} (80% CI)	0.30 (n.a.)
$SB_{2017}/SB_{current, F=0}$ (80% CI)	n.a.

5. Discussion

(1) CAA

We attempted to develop CAA by the probability method using normal distribution with mean=μ, CV=0.1, SE=0.1μ and error= N (0, 0.1μ). However, normal distributions for younger ages (quarterly age 1-4) are very much centralized with very narrow edges in both sides (See Fig.12, page 10), we have highly biased CAA as a result (too many age 1 compositions). In the future, we need to explore more plausible distributions to reflect real situation.

(2) Weightings for CAA

Plausible weightings for CAA were resulted in very small values. In the past, we assigned arbitrary small number such as 0.01 for CAA weightings for all fleets. But for this time, we used more meaningful values as weightings for CAA, i.e., [C] coverage rates of size samples by fleet and various multiples of [C]. Actual [C] (coverage) varies by fleet, i.e., 0.003 for TROL to 0.23 for PS). Then, after exploring various multiples to [C] (1.0, 0.5, 0.2, 0.1, 0.01 and 0.001). It was resulted that 0.001 (very small fraction) produced the most plausible and optimum SCAA parameters.

The reason why such very small numbers were resulted as most plausible weightings for CAA is as follows: Optimum parameters of SCAA are estimated based on combined likelihoods of CPUE and CAA, and raised CAA are very large number (max 10 million), thus if weightings for CAA are not small enough, likelihoods are mainly driven by CAA and the one for CPUE are not reflected for the parameters optimizations. That is why very small weighting were selected.

(3) Standardized CPUE

We used the joint standardized CPUE by year in the whole Indian Ocean (4 sub-areas aggregated). Four different types of such STD_CPUE are available. It is reasonable that STD_CPUE type with vessel ID (proxy of skipper's ability) was selected as the best. This is because it is the exact refection that skipper's ability very much influence q (catchability) in nominal CPUE producing biases. Thus STD_CPUE with Vessel ID is resulted as the best to remove biases by skipper effects. We explored PS STD_CPUE and realized they were optimistic considering current stock status, thus we did not use PS STD_CPUE.

(4) SCAA Result

The final SCAA result is likely plausible. However, there are a few basic caveats, i.e., there are limited sensitivity runs (all biological parameters were fixed as base case and no sensitivity analyses were conducted), there are no retrospective analyses nor risk assessments (Kobe II). Thus, SCAA result is preliminary, it should not be used for management advices and should be used as reference or supporting information if appropriate.

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