Stock assessment of bigeye tuna (*Thunnus obesus*) in the Indian Ocean using Statistical-Catch-At-Age (SCAA)

Tom Nishida [1/], Toshihide Kitakado [2/] and Takayuki Matsumoto[1/]

1/ National Research Institute of Far Seas Fisheries, Japan Fisheries Research and Education Agency, Shimizu, Shizuoka, Japan
2/ Tokyo University of Marine Science and Technology, Tokyo, Tokyo, Japan

November, 2016

Abstract

We attempted stock assessments for the Indian Ocean bigeye tuna by SCAA (Statistical–Catch-At-Age) considering the possible regime shift before and after 1978/79. The reason why we considered the regime shift is that trends of standardized CPUE before and after 1978/79 are highly heterogeneous. In this connection, we examined three periods in SCAA runs, i.e., (a) All period (1954-2015), (b) New regime (I) (1978-2015) and (c) (II) (1979-2015). We made different runs (27, 81 and 81 scenarios respectively) by varying plausible values of h (steepness), B0/K and Sigma R (SR relations). It was suggested that SCAA by all period (a), did not provide the realistic results, while SCAA by two new regimes (b) and (c), plausible although they provided different stock statuses. Then using all converged runs in (b) and (c) (total 54 scenarios) and considering relevant uncertainties, we selected the median point as the representative (selected) result of the SCAA stock assessment, i.e., the 55th run in (c) new regime hypothesis starting 1979. The representative run suggests that the 2015 status stock is in the yellow zone of the Kobe plot (not overfishing but overfished), i.e., F_{2015}/F_{msy}=0.82 and SSB_{2015}/SSB_{msy}=0.95. In this study we also explored to evaluate slicing and probability based CAA (Catch-At-Age).

Contents

Submitted to the IOTC WPTT18 (November 5-16, 2016), Victoria, Seychelles

1. Introduction

We attempt to assess the bigeye tuna (*Thunnus obesus*) (BET) stock in the Indian Ocean using the ADMB implemented Statistical-Catch-At-Age (SCAA) software (CAA based), which also can conduct Age-Structured Production Model (ASPM) (selectivity based). Details on the ADMB implemented SCAA/ASPM software are described in the users' manual (IOTC-2014-WPTT16-54). We assume that BET in the Indian Ocean is a single stock. As the SS3 assessment is avaiable (Langley, 2016) (IOTC-WPTT18-2016-20), we try to use same input information as much as possible, so that results between SS3 and SCAA can be comparable to some extent.

2. Input data

To implement SCAA, five types of information are needed, i.e., BET annual nominal catch by fleet, standardized (STD) CPUE, CAA (catch-at-age) by fleet and biological information. Details of these information are described as follows

2.1 Fleet types

We use 7 fleet types available in the nominal catch and CAA provided by the IOTC Secretariat (Table 1).

Table 1 Seven types of fleets used in the BET stock assessment by SCAA

IOTC code	Description	Depth
LL	LL (frozen)	Mid water
LF	LL (fresh)	Sub-surface
PS (LOG)	PS (Log school)	Surface to sub surface
PS (FREE)	PS (Free school)	Surface to sub surface
BB	Pole and Line (Bait Boat)	Surface
LINE	GILL/LL+HAND/TROLL+HAND+LLCO	Surface to sub surface
OTH	GILL + TROLL + other minor artisanal gears	Surface to sub surface

2.2 Nominal catch (weight and number) by fleet (Figs. 1-2)

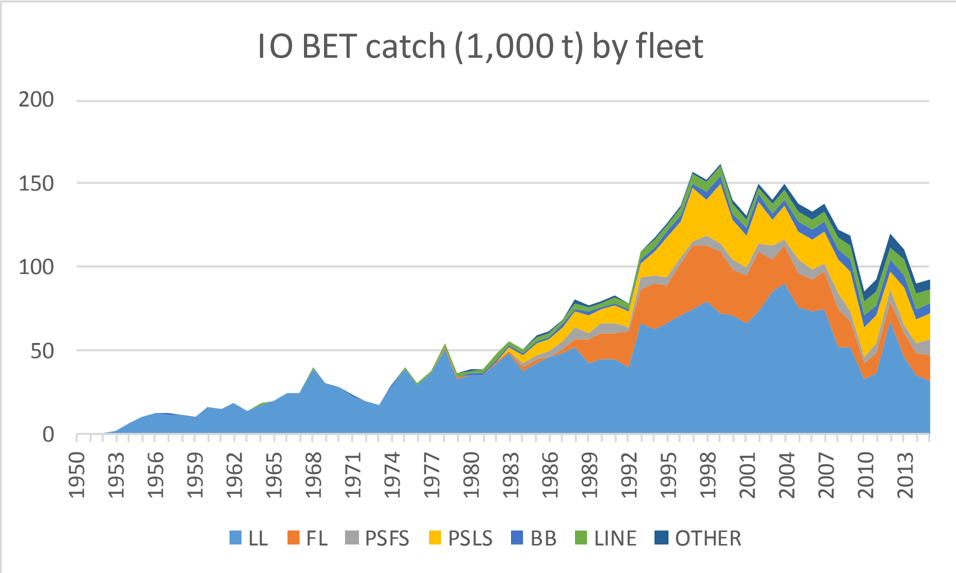


Fig. 1 IO BET catch (1,000 tons) by fleet (1950-2015)

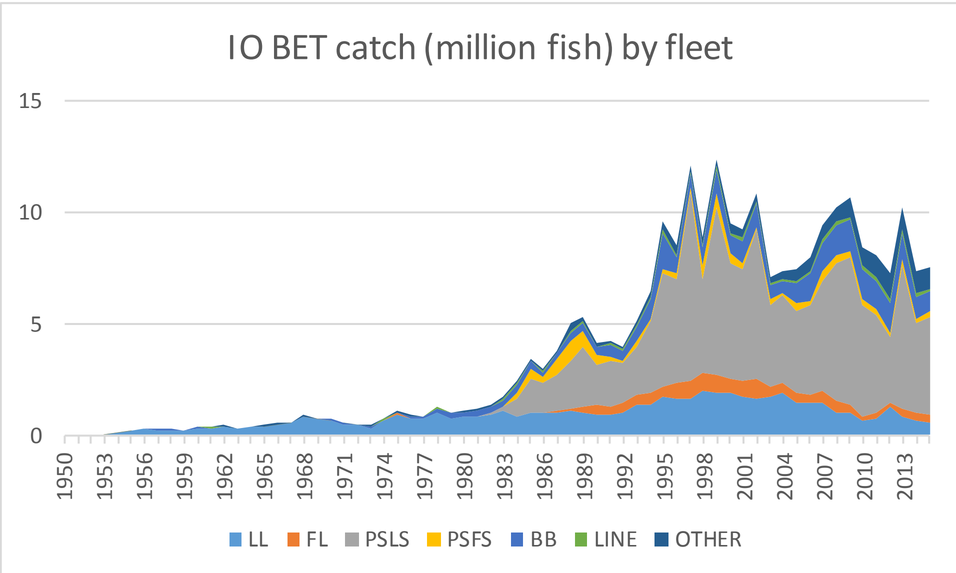


Fig. 2 IO BET catch (million fish) by fleet (1950-2015)

2.3 Standardized CPUE (STD_CPUE)

Three types of standardized CPUE are available, i.e., Japan (Matsumoto et al, 2016), Taiwan (Yeh and Chang, 2016) and Joint (Japan + Taiwan + Korea combined) (Table 2) (Hoyle et al, 2016). From the previous assessments, it was learned that STD_CPUE in the tropical region represented the plausible signals as it had the better relation to the catch. So we will compare of three standardized CPUE in the tropical area (Fig. 3). For Japan standardized CPUE, we use those based on set by set data. We use the annual based standardized CPUE.

From Fig. 3 all three standardized CPUE show similar trends. Only significant discrepancy is that Japan STD_CPUE show the increasing trends in recent years, while Joint and Taiwan STD_CPUE decreasing trends. After the piracy stopped in 2011, Taiwan LL and PS resume their operations off Somalia where is the good BET fishing grounds. Thus it is likely that the stock has been impacted strongly. In addition, Japan LL still does not operate off Somalia, thus its CPUE might not reflect such impact. Therefore, we used the joint STD_CPUE as a base case.

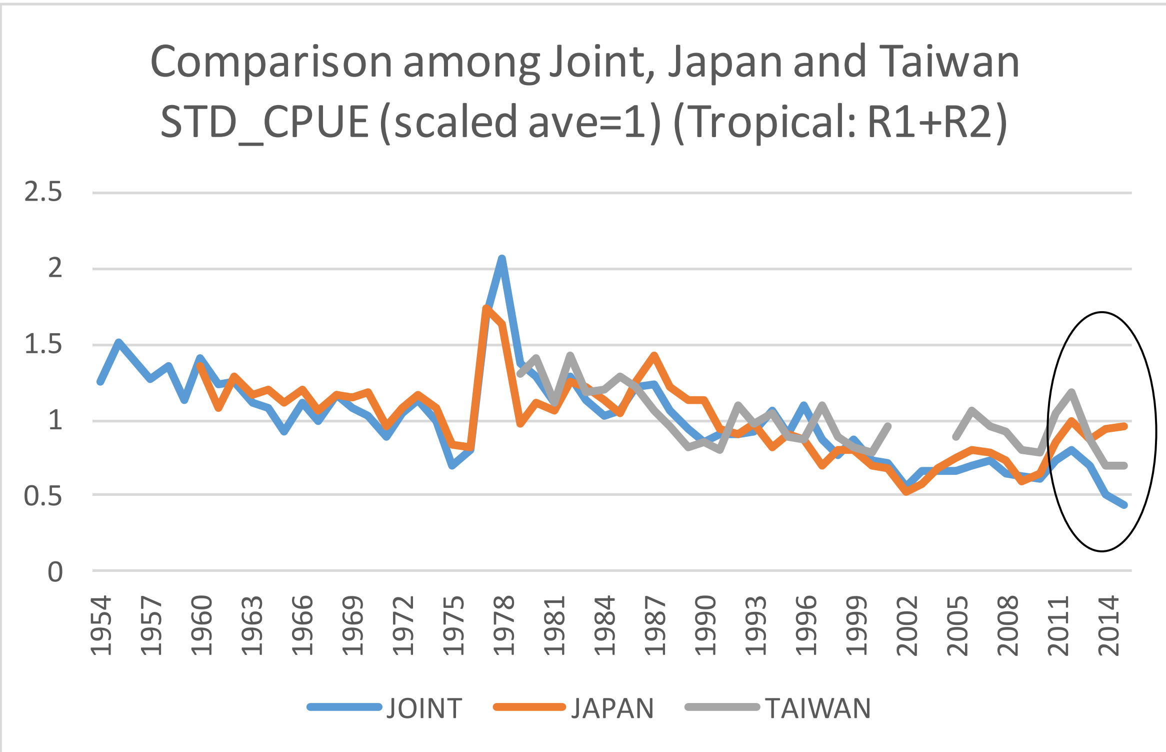
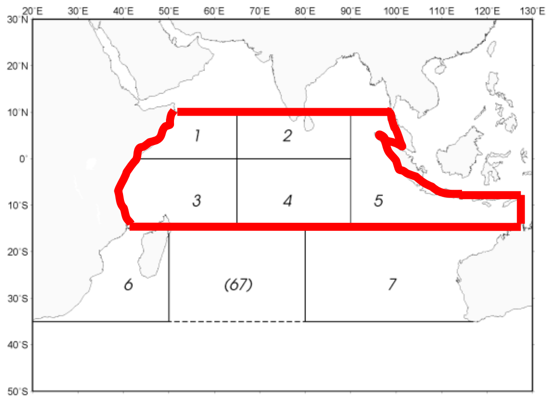
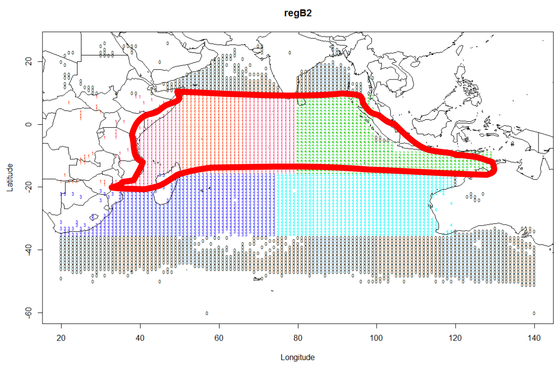
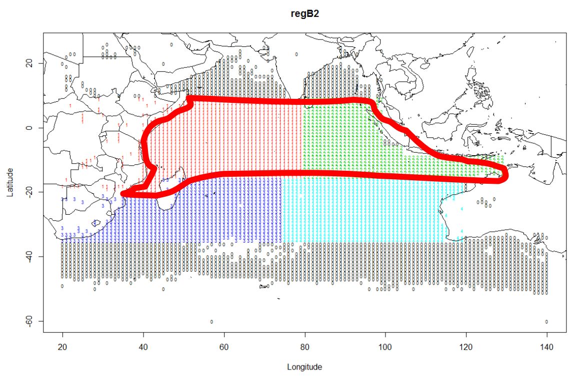


Fig. 3 Comparison among Joint, Japan and Taiwan STD_CPUE (scaled ave.=1) (Tropical: R1+R2)

Table 2 Available annual standardized CPUE. Tropical joint CPUE will be used in the stock assessments

	Years	Area	Major Specs
Japan	1960-2015	Tropical (1-5), South (6-7) and Whole (1-7)  	● Set by set data ● L5 effect ● Correction of Targeting = no of hooks between float
Taiwan	1979-2001 2005-2015	4 separate areas  	● 5x5 Q data ● Correction of Targeting = cluster analyses
Joint	1954-2015	R1+R2 combined  	● Japan + Taiwan + Korea combined ● Set by set with vessel ID (after 1979?) ● Correction of Targeting = cluster analyses

2.4 Catch-At-Age (CAA)

CAA data based on the slicing method have been provided by the Secretariat. However, it is well recognized that the slicing method provide biases to estimate CAA. Thus for this time, we also attempt to estimate CAA based on the probability method and compare with CAA by the slicing method.

(1) CAA based on the slicing method

The IOTC Secretariat provided CAA using the slicing method, which was developed by Herrera (former IOTC data coordinator) (IOTC-WPTT13-07). Box 1 (left) shows the original CAA provided by the Secretariat. However, CAA by BB, LINE and OTH are not plausible as they have abnormal spikes and shapes in the trends.

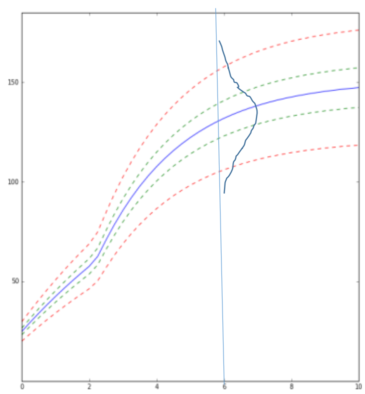
After consulting the Secretariat on these problems, it was found that there were some substitution process problems as the situation has been changed from 2007 when the initial document developed by Herrera (IOTC-WPTT13-07). Then the Secretariat revised CAA considering the current situation. Box 1 (right) shows the revised CAA by fleet, which are more plausible and useful for stock assessments especially for BB, LINE and OTH. We noticed that the CAA level of LL (frozen) was also different between two CAAs

(2) Probability method

For this time, we attempt to develop the probability method considering the SE (Standard Error) in the growth curve by Everson et al (2014). As the SE from the original data are not available, CV=0.1 is used as SE (Langley, 2016). Then, we estimate probabilities of the age composition by size, which are multiplied by CAS to compute CAA (BOX 3 and Figs. 4-6). Fig. 9 shows the resultant CAA by fleet.

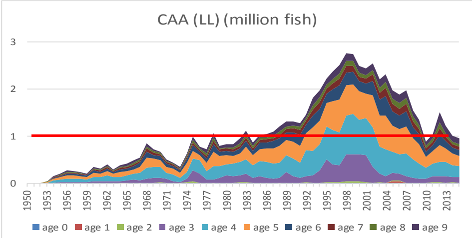
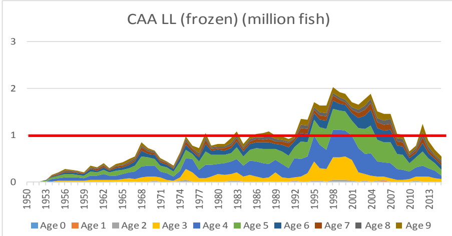
Fig. 4 Probability of size distribution
to the particular age
in the growth equation

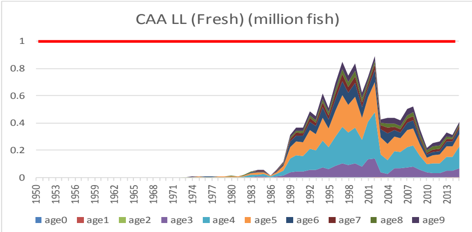
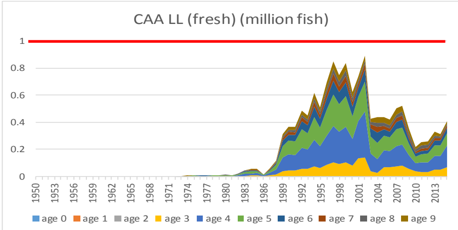
mean=μ, CV=0.1 and SE=0.1μ
Error= N(0, 0.1μ)

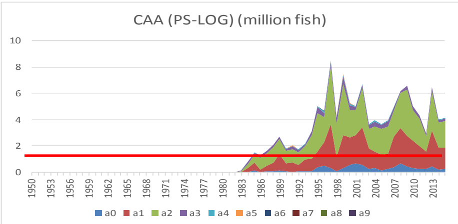
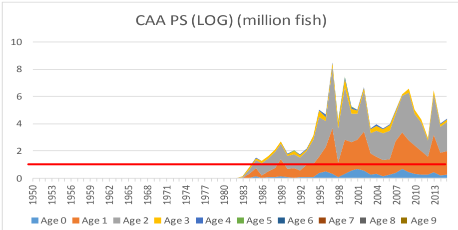


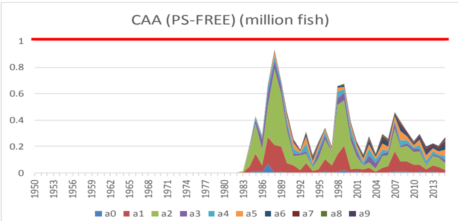
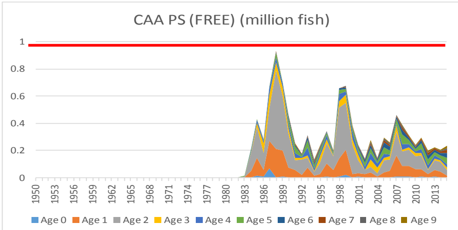
Red: 95% CI
Green: quantile
blue: average

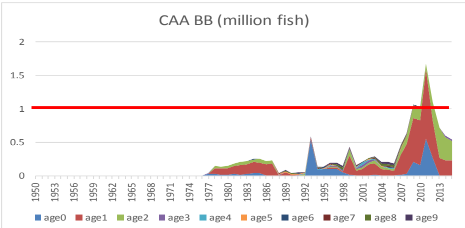
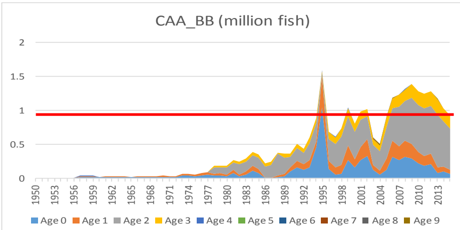
<table>
<tr><td colspan="3">Box 1 Discrepancy between Initial CAA vs Revised CAA (red line indicate one million fish)</td></tr>
<tr><td></td><td>Initial CAA</td><td>Revised CAA</td></tr>
<tr><td>LL (frozen)

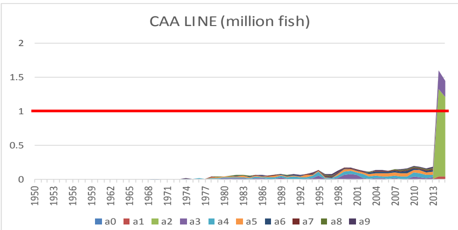
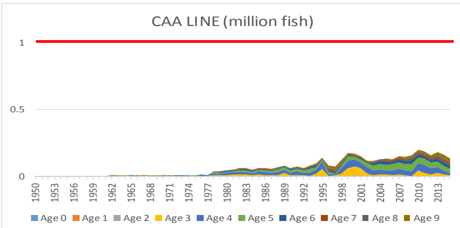
Discrepancy in the level</td><td></td><td></td></tr>
<tr><td>LL (Fresh)

OK</td><td></td><td></td></tr>
<tr><td>PS (LOG)

OK</td><td></td><td></td></tr>
<tr><td>PS (FREE)

OK</td><td></td><td></td></tr>
<tr><td>BB

Large discrepancy</td><td></td><td></td></tr>
<tr><td>LINE

Large discrepancy (2014-15)</td><td></td><td></td></tr>
<tr><td>OTH

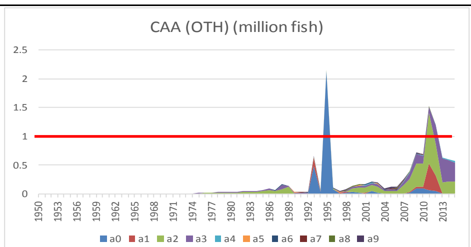
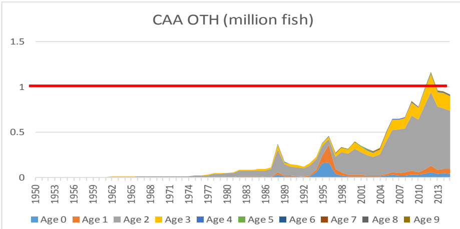
Large discrepancy</td><td></td><td></td></tr>
</table>

Fig. 5 Schematic diagram to compute the probabilities of age compositions
using the growth equation by Everson et al (2012)
Age 2=58cm 2.5=71cm 3.0=86cm 3.5=98cm and 4.0=116cm
in case of age 3(86cm)➔ Pr (age 2)=10%, Pr (age 3)=80% and Pr (age 4)=10%

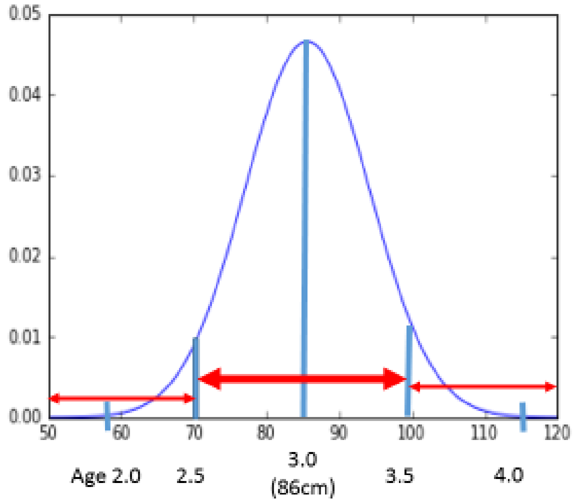
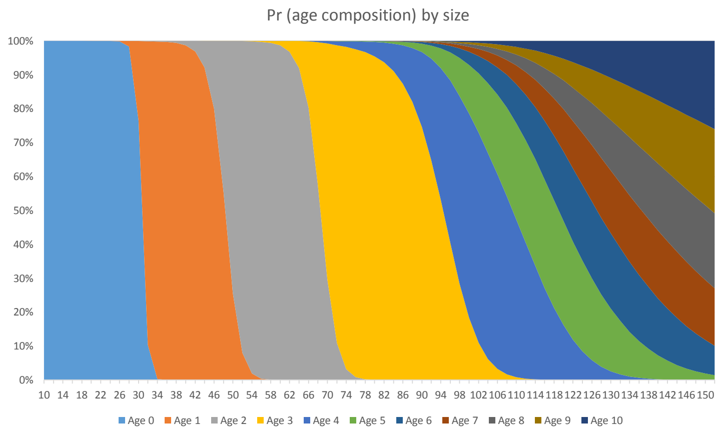


Fig. 6 Probability of age compositions by size (2cm)
based on the growth equation by Everson et al (2012)



CAA by fleet= ∑ CAS (Catch-At-Size) x Pr (age composition)

Fig. 7 CAA by fleet (million fish) (probability method)

LL (frozen)

LF (fresh)

PSLS (log school)

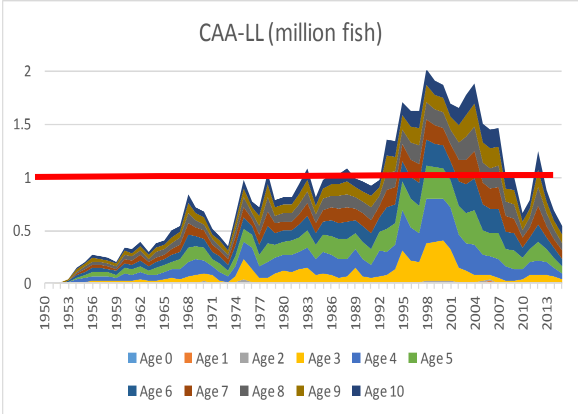
PSFS (Free school)

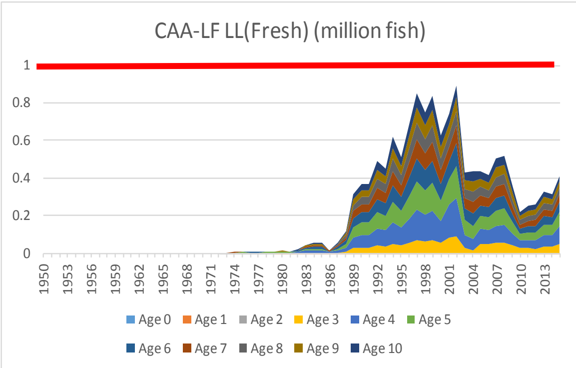
BB (Pole and Line)

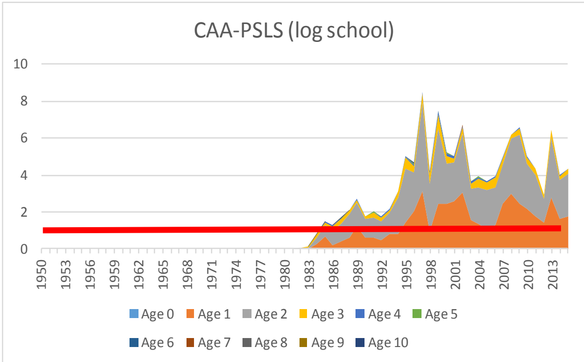
LINE (Mixed gears)

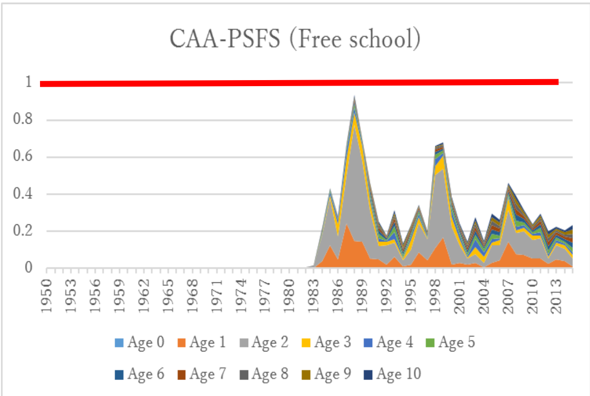
OTH (others)

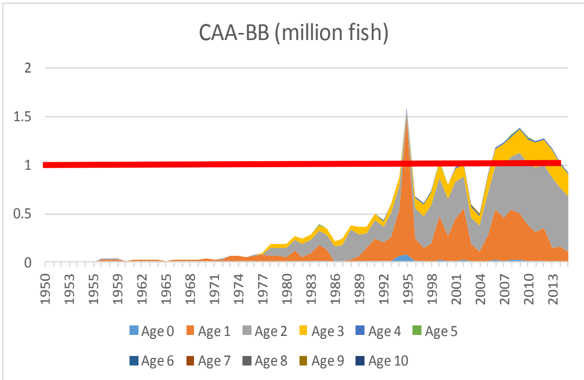
The horizontal red line represents the 1 million fish level.

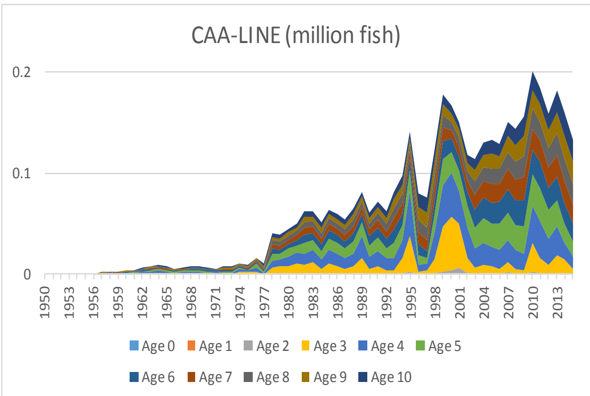


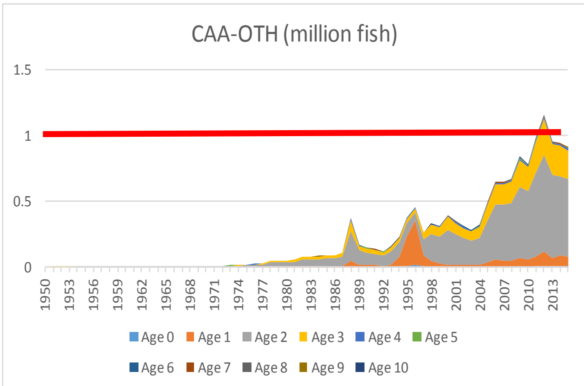












2.5 Plus & minus group and Seeding values of selectivities

In running SCAA, plus and minus groups need to be set up, in order to implement robust optimization. Based on the CAA information by fleet, we determined plus and minus groups which CAA by age composes less than 2% of the total CAA. Seeding values of selectivity by fleet are also needed to run SCAA. Table 3 and 4 show results by slicing and probability method respectively.

Table 3 Minus & plus group and seeding values of selectivity by fleet (slicing method)

No	Fleet code	Fleet	Minus group	Plus group	Period of available CAA data	Age	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10
						Q age	2.5	6.5	10.5	14.5	18.5	22.5	26.5	30.5	34.5	38.5	42.5
(1)	LL	Tuna longline (frozen)	Age 3-	Age 10+	1952-2015					0.5	0.9		1	1	1	1	1
(2)	LF	Tuna longline (fresh)	Age 3-	Age 10+	1973-2015					0.9		1	1	1	1	1	1
(3)	PSLS	Purse seine (log school)	Age 1-	Age 3+	1978-2015				0.7	0.1							
(4)	PSFS	Purse seine (free school)	Age 1-	Age 10+	1978-2015				0.4	0.3	0.8	1	1	1	1	1	1
(5)	BB	Pole and Line (Bait boat)	Age 0	Age 3+	1957-2015		0.3	0.9		0.1							
(6)	LINE	Local LL, troll and hand lines	Age 3-	Age 10+	1950-2015					0.7	0.9		1	1	1	1	1
(7)	OTH	Other surface fisheries (Danish seine)	Age 1-	Age 4+	1950-2015				0.3	0.2	0.8						

Note: highest selectivity (=1) specified as blanks (yellow markers)

Table 4 Minus & plus group and seeding values of selectivity by fleet (probability method)

No	Fleet code	Fleet	Minus group	Plus group	anchor age	Period of available CAA data	Age	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9
							Q age	2.5	6.5	10.5	14.5	18.5	22.5	26.5	30.5	34.5	38.5
(1)	LL	Tuna longline (frozen)	Age 3-	Age 9+	Age 5	1952-2015					0.5	0.9		1	1	1	1
(2)	LF	Tuna longline (fresh)	Age 3-	Age 9+	Age 4	1973-2015					0.5		1	1	1	1	1
(3)	PSLS	Purse seine (log school)	Age 0	Age 3+	Age 1	1978-2015		0.1		0.5	0.2						
(4)	PSFS	Purse seine (free school)	Age 0	Age 8+	Age 1	1978-2015		0.2		0.5	0.4	0.9	0.6	0.6	0.6	0.6	
(5)	BB	Pole and Line (Bait boat)	Age 0	Age 3+	Age 2	1957-2015		0.2	0.8		0						
(6)	LINE	Local LL, troll and hand lines	Age 3-	Age 9+	Age 4	1950-2015					0.6		1	1	1	1	1
(7)	OTH	Other surface fisheries (Danish seine)	Age 0	Age 4+	Age 1	1950-2015		0.05		0.2	0.4	0.9					

Note: highest selectivity (=1) specified as blanks (yellow markers)

2.6 Biological information

In SCAA, three types of age-specific biological inputs are needed, i.e., natural mortality-at-age (*M*), weights-at-age (beginning and mid-year) and proportion maturity-at-age.

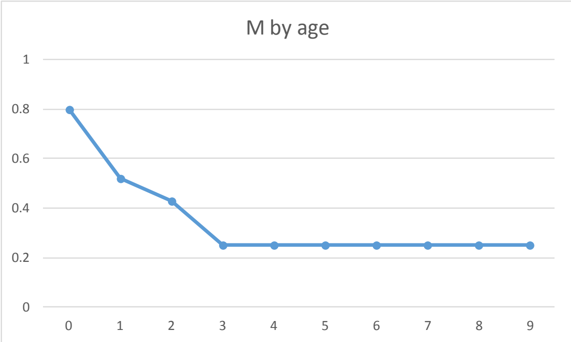
(1) Natural mortality vector (*M*)

We applied annual M vectors used in the recent ICCAT assessments (ICCAT, 2015), derived by the Lorenz curve (Box 2).

BOX 2 M by age

Natural mortality by age

#age	0	1	2	3	4	5	6	7	8	9
	0.80	0.52	0.43	0.25	0.25	0.25	0.25	0.25	0.25	0.25



(2) Beginning- and mid-year weights-at-age

Using the growth curve derived by Everson et al (IOTC-2012-WPTT14-23) (Box 3) and the LW relationships (Box 4), we computed weight-at-age by 0.5 year (Box 5).

Box 3 Indian Ocean BET growth equation (Everson et al, 2012)

Growth curve

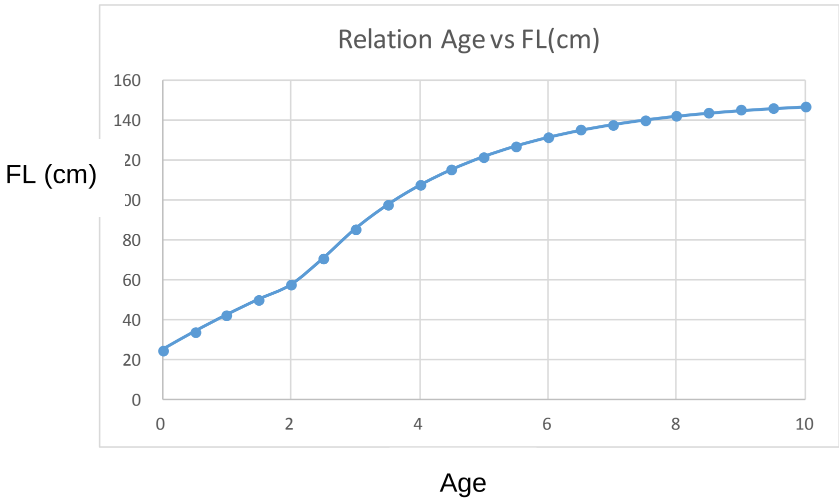
$$l(a) = L_\infty \left[1 - \exp\left(-k_2(a - a_0)\right)\left\{\frac{1 + \exp\left(-\beta(a - a_0 - \alpha)\right)}{1 + \exp(\alpha\beta)}\right\}^{-(k_2 - k_1)/\beta}\right]$$

l: Length (FL)

a: Age

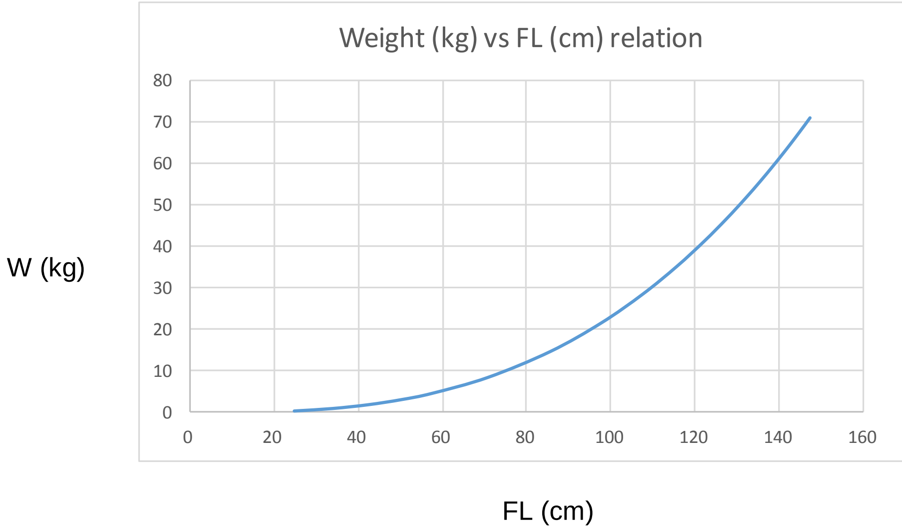
parameters

$$L_\infty = 150.9, a_0 = -1.2, k_1 = 0.15, k_2 = 0.41, \alpha = 3.4, \beta = 20$$



Box 4 LW relation by Nakamura and Uchiyama (1966)

$$W(kg) = 2.661*10^{-5}*(FL: cm)^{2.901}$$



Box 5 BET Weights-at-age (tons) in the Indina Ocaen

Beginning of the year weights by age (tons)

# age	0	1	2	3	4	5	6	7	8	9
	0.000409	0.001928	0.004671	0.014793	0.028685	0.041465	0.051721	0.059369	0.064832	0.068633

Middle of the year weights by age (tons)

# age	0	1	2	3	4	5	6	7	8	9
	0.001012	0.003153	0.008513	0.021706	0.035346	0.046933	0.055850	0.062340	0.066909	0.070059

(3) Maturity-at-age (Box 6)

Box 6 Maturity at-age of in the Indian Ocean based on Shono (2009) and Age-length key

Shono (2009) assume that age 2 is no maturation and 6 fully matured then derived the equation to compute the probability of maturation by length.

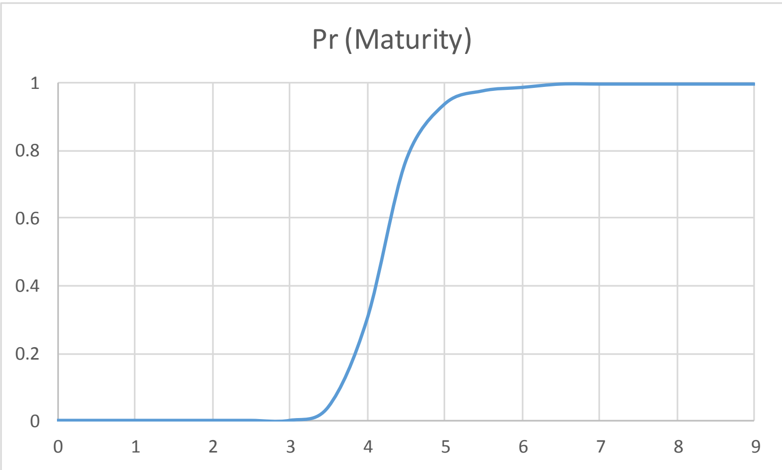
$$Ma(L) = \frac{1}{1+\exp\{-0.25*(L-110.888)\}}$$ Shono (2009)

, where Ma(L) is the probability of maturity by size.

Then Ma(L) is converted to age by the growth curve (Everson et al, 2012) and probabilities by age are computed as below:

Proportion maturity by age

# age	0	1	2	3	4	5	6	7	8	9
	0	0	0	0.04	0.77	0.98	1	1	1	1



3. SCAA

3.1 Periods for assessments considering the regime shift

From the catch trends, there is nil catch from 1950-1953 and joint STD_CPUE are available (1954-2015), hence we will use the data from 1954-2015 (62 years) for stock assessment. In addition, there is the inconsistency in STD_CPUE trend before and after 1978/79 (Fig. 8). The trends after 1978/79 might be the new regime. The cause of this gap has been discussed many times in the past, but the clear reason is still unknown.

In addition, vessel ID is used from 1980 in the joint CPUE, hence the quality of STD_CPUE before and after 1980 may be different to some extent. This can be understood by the study made by Otsuyama and Kitakado (2016) (WPTT18-19), i.e., Bayesian state-space production models for the Indian Ocean bigeye tuna and their predictive evaluation. They used the joint standardized CPUE and found that the q (catchability) in the 1st period (regime) (1960-1979) is larger than the one in the new regime (1979-2015), i.e., $q_{1960-1978} = 2.5*10^{-6} > q_{1979-2015} = 2.3*10^{-6}$. Normally, it should be reversed as the technological progress in gears and vessels have much advanced in later years.

Thus we attempt to set up three hypothetical periods (Table 5). The reason to include (c) is that CPUE in 1978 is too high comparing in 1979, which may not plausible, thus we also attempt SCAA using the data from 1979 by assuming the new regime might start from 1979.

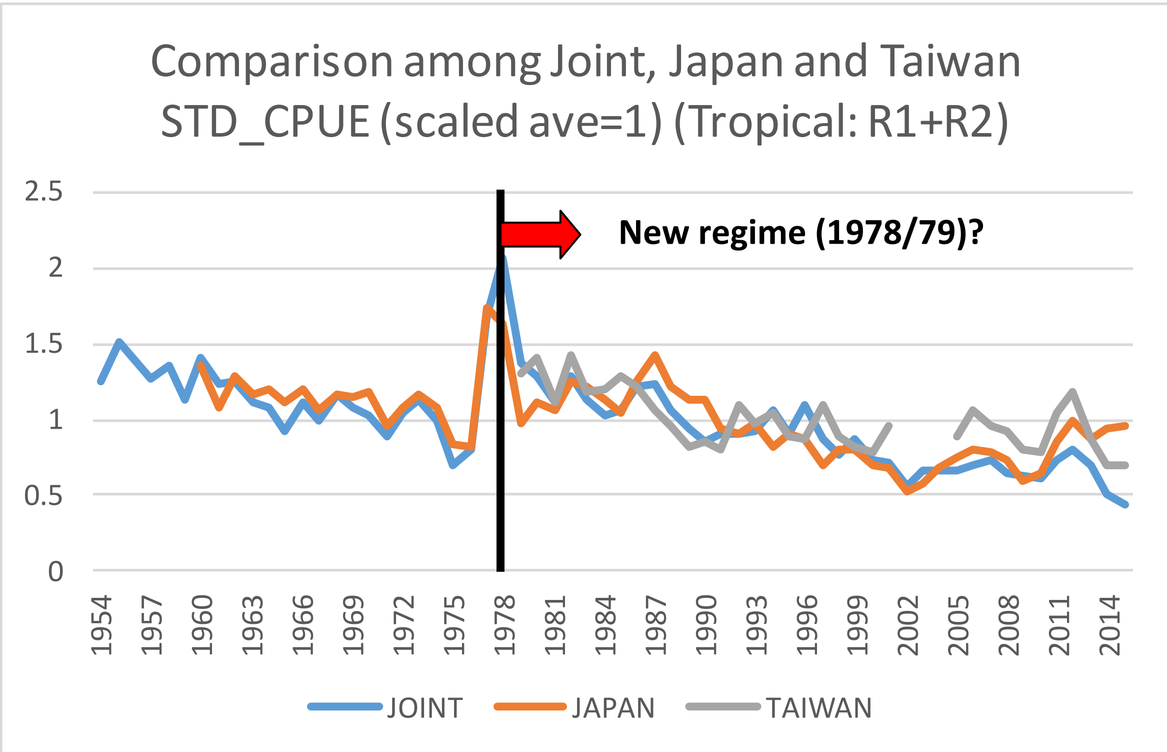


Fig. 8 STD_CPUE trends and the new regime after 1978

Table 5 Three periods to be examined in the SCAA stock assessments

Period	Regime	Years
1	One (no new regime)	1954-2015
2	New (I) starting 1978	1978-2015
3	New (II) starting 1979	1979-2015

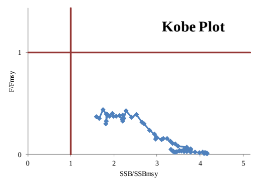
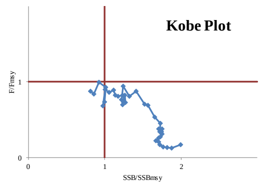
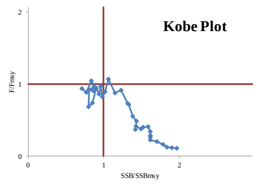
3.2 Initial runs to examine CAA and regime shift

As a first step, we attempt SCAA runs using 6 scenarios in order to examine 2 CAA (slicing vs. Probability) and 3 periods (All period: 1954-2015, New regime I: 1978-2015 and II: 1989-2015) with the following default parameter values (Box 7). The results are shown in Table 6. We exclude those with CAA using the slicing method as they are not converged and selectivities are not plausible. Thus we have three different periods for further SCAA runs.

BOX 7 Default values used for the initial runs

- Sigma R (SR) =0.4
- Steepness =0.8
- Weight CAA (all fleet) = 0.1
- CV (CPUE)=0.1
- Biological parameters (Box 2-6)
- Plus/minus group and anchor values for CAA based on probability and slicing method (Tables 3 and 4)

Table 6 Six scenarios for the initial runs to search base case

Scenario no	CAA	Period for Catch and Joint CPUE (tropical)	B0/K	Seeding values: Initial Biomass (t)	Results (Kobe plot) NC: Not converged
1	Probability	All period (one regime) 1954-2015	1	3 million (14.9 in $\log_e$)	NC Selectivity is not plausible
2	Slicing				
3	Probability	New regime (I) 1978-2015	0.5	2 million (14.5 in $\log_e$)	NC Selectivity is not plausible
4	Slicing				
5	Probability	New regime (II) 1979-2015			NC (Selectivity is not plausible)
6	Slicing				

3.3 Runs for three period and sensitivities runs

(1) All period (1954-2015): 27 scenarios (54/1 to 54/27) (numbers with yellow markers are used as the default values (BOX 7) in the initial runs.

B0/K : 1 way (1.0)
Steepness : 3 ways (0.7, 0.8, 0.9)
Sigma(SR) : 3 ways (0.4, 0.6, 0.8)
Weight CAA : 3 ways (0.05, 0.1, 0.15)
25 scenario converged

Table 7 Results of SCAA runs for All period (one regime) (1954-2015)
25 out of 27 scenarios are converged.

No	Scnerio no	B0/K	h (steepness)	Sigma (SR)	WT (CAA)	Total likelihood	R	(1,000 t)				
								SSB(1954)	SSB(2015)	MSY	SSB/SSBmsy	F/Fmsy
1	54/1	1	0.7	0.4	0.05	-137	0.85	2,666	1,064	138	1.3	0.59
2	54/2	1	0.7	0.4	0.1	-174	0.71	3,533	1,518	178	1.4	0.43
3	54/3	1	0.7	0.4	0.15	-220	0.63	4,313	3,670	358	1.46	0.35
4	54/4	1	0.7	0.6	0.05	-142	0.85	3,778	1,535	188	1.32	0.46
7	54/7	1	0.7	0.8	0.1	-181	0.74	9,979	4,243	465	1.39	0.19
8	54/8	1	0.7	0.8	0.15	-228	0.66	14,059	5,984	651	1.39	0.14
9	54/9	1	0.8	0.4	0.05	-137	0.85	2,512	1,001	148	1.46	0.51
10	54/10	1	0.8	0.4	0.1	-173	0.71	3,401	1,474	194	1.58	0.36
11	54/11	1	0.8	0.4	0.15	-219	0.63	4,208	1,916	237	1.67	0.29
12	54/12	1	0.8	0.6	0.05	-141	0.85	3,554	1,441	200	1.49	0.4
13	54/13	1	0.8	0.6	0.1	-178	0.73	5,281	2,254	289	1.56	0.27
14	54/14	1	0.8	0.6	0.15	-225	0.65	6,993	3,063	378	1.6	0.2
15	54/15	1	0.8	0.8	0.05	-143	0.85	5,747	2,385	310	1.52	0.27
16	54/16	1	0.8	0.8	0.1	-180	0.74	9,359	3,987	493	1.56	0.17
17	54/17	1	0.8	0.8	0.15	-228	0.66	13,281	5,681	696	1.57	0.12
18	54/18	1	0.9	0.4	0.05	-136	0.85	2,402	956	158	1.7	0.43
19	54/19	1	0.9	0.4	0.1	-172	0.70	3,313	1,447	211	1.86	0.3
20	54/20	1	0.9	0.4	0.15	-218	0.62	4,143	1,909	260	1.97	0.23
21	54/21	1	0.9	0.6	0.05	-141	0.85	3,397	1,376	214	1.73	0.34
22	54/22	1	0.9	0.6	0.1	-177	0.73	5,116	2,194	313	1.83	0.22
23	54/23	1	0.9	0.6	0.15	-224	0.65	6,830	3,015	412	1.89	0.16
24	54/24	1	0.9	0.8	0.05	-143	0.85	5,437	2,253	328	1.77	0.23
25	54/25	1	0.9	0.8	0.1	-180	0.74	8,943	3,819	526	1.83	0.14

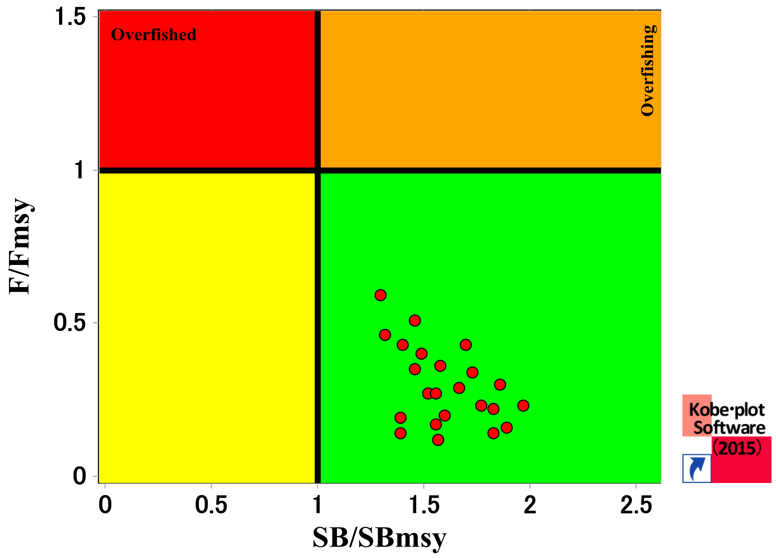


Fig. 9 Kobe plot on base + sensitivity SCAA runs for all period (one regime) (1954-2015) showing uncertainties (25 scenarios of out of 27 are converged)

(2) New phase (1978-2015): 81 scenarios (78/1 to 78/81) (number with yellow markers are the base case)

B0/K	: 3 ways	(0.5, 0.6, 0.7)
Steepness	: 3 ways	(0.7, 0.8, 0.9)
Sigma(SR)	: 3 ways	(0.4, 0.6, 0.8)
Weight CAA	: 3 ways	(0.05, 0.1, 0.15)

Table 8 Results of SCAA runs for New regime (I) (1978-2015)
18 out of 81 scenarios (78/01 to 78/81) are converged.

No	Scenario No	B0/K	h (steepness)	Sigma(SR)	WT(CAA)	Total likelihood	R	(1,000 t)				
								SSB(1978)	SSB(2015)	MSY	SSB/SSBmsy	F/Fmsy
1	78/1	0.5	0.7	0.4	0.05	-76	0.80	1,982	321	118	0.52	1.38
2	78/2	0.5	0.7	0.4	0.1	-96	0.50	1,982	403	113	0.65	1.17
3	78/10	0.5	0.8	0.4	0.05	-73	0.80	1,982	325	134	0.59	1.09
4	78/13	0.5	0.8	0.6	0.05	-75	0.84	1,982	456	127	0.75	0.95
5	78/14	0.5	0.8	0.6	0.1	-99	0.64	1,982	363	126	0.66	1.12
6	78/19	0.5	0.9	0.4	0.05	-68	0.77	1,982	343	150	0.71	0.84
7	78/22	0.5	0.9	0.6	0.05	-79	0.80	1,982	322	146	0.67	0.95
8	78/23	0.5	0.9	0.6	0.1	-98	0.59	1,982	381	140	0.8	0.86
9	78/28	0.6	0.7	0.4	0.05	-80	0.80	1,982	389	115	0.63	1.22
10	78/37	0.6	0.8	0.4	0.05	-78	0.80	1,982	394	130	0.72	0.97
11	78/40	0.6	0.8	0.6	0.05	-84	0.80	1,982	386	127	0.7	1.06
12	78/46	0.6	0.9	0.4	0.05	-75	0.78	1,982	410	146	0.86	0.75
13	78/49	0.6	0.9	0.6	0.05	-83	0.80	1,982	389	142	0.82	0.85
14	78/55	0.7	0.7	0.4	0.05	-84	0.80	1,982	464	112	0.76	1.09
15	78/64	0.7	0.8	0.4	0.05	-82	0.80	1,982	469	127	0.86	0.87
16	78/67	0.7	0.8	0.6	0.05	-87	0.80	1,982	460	123	0.84	0.95
17	78/73	0.7	0.9	0.4	0.05	-80	0.79	1,982	481	142	1.02	0.69
18	78/76	0.7	0.9	0.6	0.05	-86	0.80	1,982	463	138	0.98	0.76

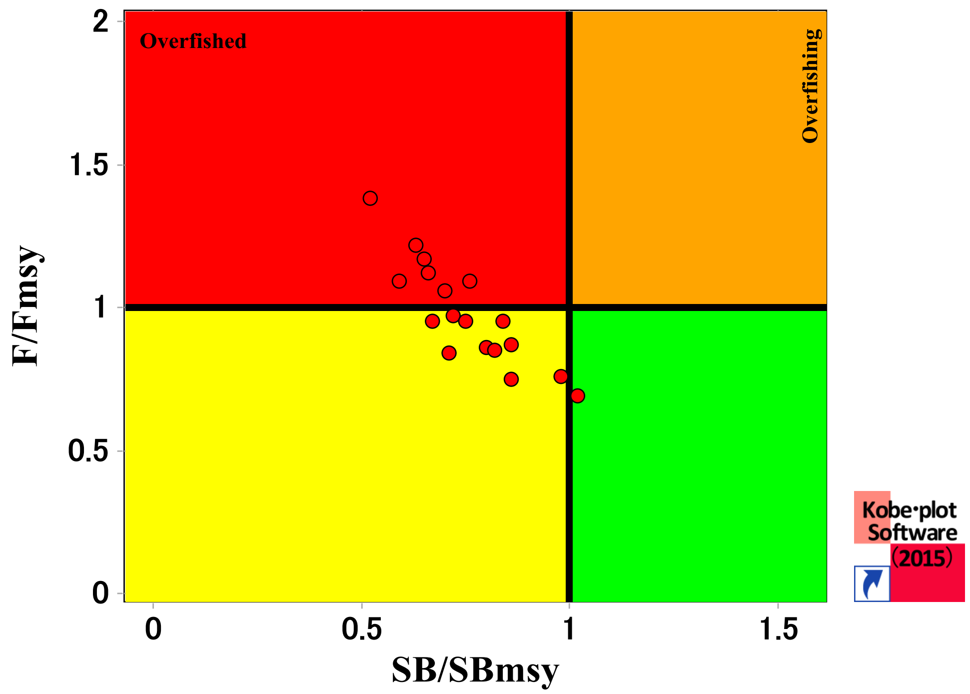


Fig. 10 Kobe plot for base + sensitivity SCAA runs for New regime (I) (1978-2015) showing uncertainties (18 scenarios of out of 81 are converged)

(3) New phase (II) (1979-2015): 81 scenarios (79/1 to 79/81) (number with yellow markers are the base case)

B0/K : 3 ways (0.5, 0.6, 0.7)
Steepness : 3 ways (0.7, 0.8, 0.9)
Sigma(SR) : 3 ways (0.4, 0.6, 0.8)
Weight CAA : 3 ways (0.05, 0.1, 0.15)

Table 9 Results of SCAA runs for New regime (II) (1979-2015). 36 out of 81 scenarios are converged.

No	Scenario No	B0/K	h (steepness)	Sigma(SR)	WT(CAA)	Total likelihood	R	(1,000 t) SSB(1979)	SSB(2015)	MSY	SSB/SSBmsy	F/Fmsy
1	79/1		0.7	0.4	0.05	-83	0.85	2,105	411	122	0.63	1.13
2	79/2		0.7	0.4	0.1	-105	0.85	2,414	478	136	0.64	1.04
3	79/3		0.7	0.4	0.15	-132	0.51	2,944	748	159	0.82	0.72
4	79/10		0.8	0.4	0.05	-81	0.84	1,849	359	123	0.7	1.01
5	79/11	0.5	0.8	0.4	0.1	-101	0.84	2,148	422	139	0.71	0.93
6	79/19		0.9	0.4	0.05	-79	0.84	1,650	324	124	0.8	0.89
7	79/20		0.9	0.4	0.1	-97	0.84	1,940	380	141	0.81	0.81
8	79/22		0.9	0.6	0.05	-85	0.85	2,323	463	165	0.83	0.72
9	79/23		0.9	0.6	0.1	-109	0.85	3,061	637	207	0.88	0.59
10	79/24		0.9	0.6	0.15	-138	0.60	4,350	1,112	284	1.09	0.37
11	79/28		0.7	0.4	0.05	-87	0.85	2,161	522	121	0.78	0.96
12	79/29		0.7	0.4	0.1	-111	0.85	2,459	604	135	0.8	0.89
13	79/30		0.7	0.4	0.15	-139	0.64	3,058	899	163	0.96	0.63
14	79/37		0.8	0.4	0.05	-86	0.85	1,947	466	125	0.87	0.85
15	79/39		0.8	0.4	0.15	-136	0.55	2,918	909	176	1.14	0.51
16	79/40	0.6	0.8	0.6	0.05	-90	0.85	2,687	671	164	0.91	0.68
17	79/42		0.8	0.6	0.15	-146	0.72	4,780	1,396	273	1.07	0.38
18	79/46		0.9	0.4	0.05	-84	0.85	1,786	426	130	1.6	0.7
19	79/47		0.9	0.4	0.1	-106	0.85	2,072	503	146	1.02	0.67
20	79/49		0.9	0.6	0.05	-89	0.85	2,487	618	171	1.05	0.59
21	79/50		0.9	0.6	0.1	-115	0.85	3,211	829	212	1.4	0.48
22	79/51		0.9	0.6	0.15	-144	0.69	4,606	1,377	295	1.27	0.31
23	79/55		0.7	0.4	0.05	-90	0.86	2,261	656	124	0.94	0.81
24	79/57		0.7	0.4	0.15	-144	0.70	3,218	1,087	168	1.1	0.55
25	79/64		0.8	0.4	0.05	-89	0.85	2,070	597	130	1.05	0.71
26	79/65		0.8	0.4	0.1	-114	0.85	2,363	694	144	1.7	0.63
27	79/66		0.8	0.4	0.15	-142	0.66	3,092	1,081	183	1.28	0.45
28	79/67		0.8	0.6	0.05	-92	0.86	2,878	865	172	1.1	0.57
29	79/68	0.7	0.8	0.6	0.1	-120	0.86	3,621	1,120	208	1.13	0.48
30	79/69		0.8	0.6	0.15	-150	0.75	5,130	3,206	345	1.25	0.32
31	79/73		0.9	0.4	0.05	-88	0.85	1,930	554	136	1.21	0.61
32	79/74		0.9	0.4	0.1	-112	0.85	2,220	650	152	1.24	0.56
33	79/75		0.9	0.4	0.15	-141	0.61	3,028	1,097	200	1.54	0.36
34	79/76		0.9	0.6	0.05	-91	0.86	2,697	808	180	1.27	0.48
35	79/77		0.9	0.6	0.1	-119	0.86	3,431	1,060	221	1.31	0.41
36	79/78		0.9	0.6	0.15	-149	0.73	4,967	1,715	313	1.48	0.26

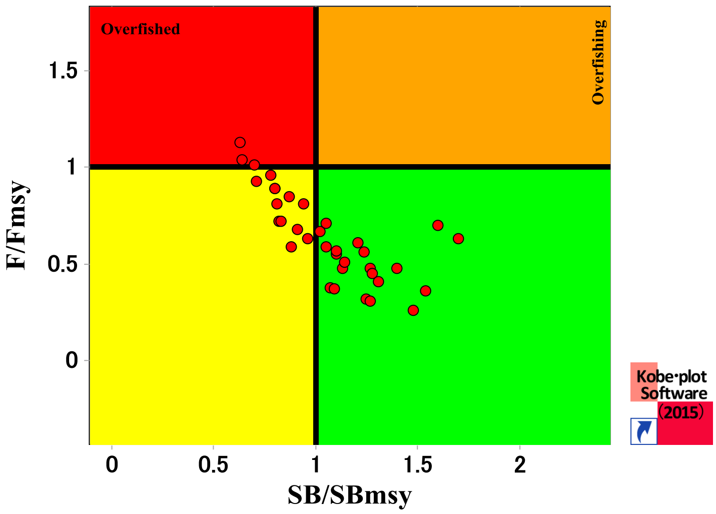
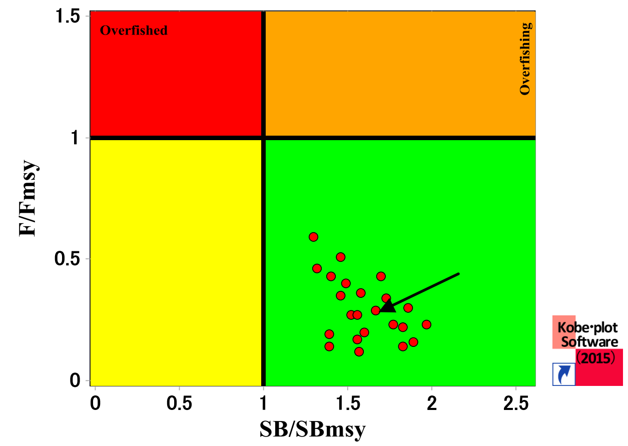
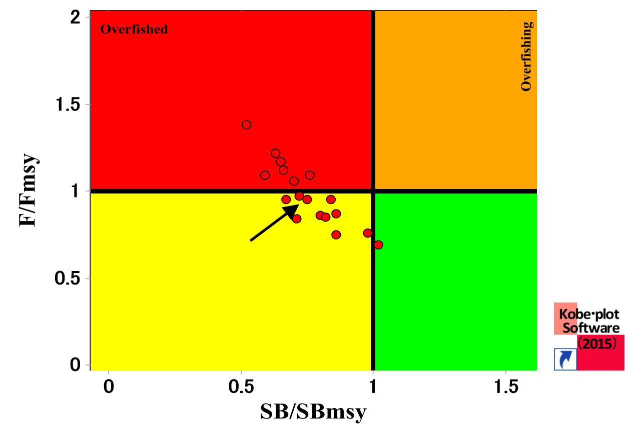
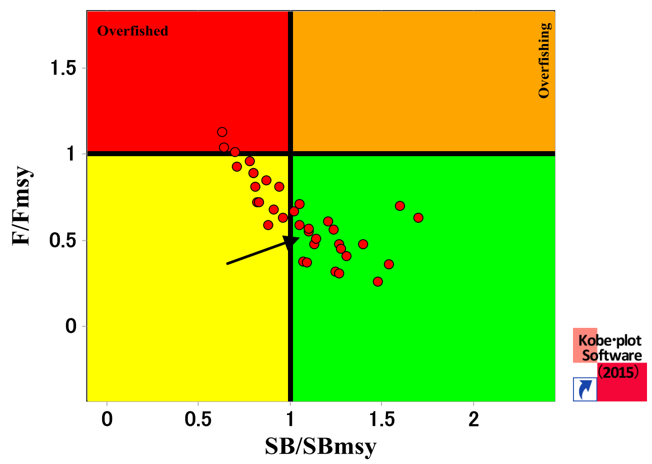


Fig. 11 Kobe plot for base + sensitivity SCAA runs for New regime (II) (1979-2015) showing uncertainties (36 scenarios of out of 81 are converged)

3.4 Results of SCAA runs for three periods

Box 8 shows comparisons of Kobe plots of three SCAA base cases results including the median points (indicated with arrows) as the representative of each base case. Based on the comments we will use results of the new phases (I)+(II) for the further analyses.

BOX 8 Results of SCAA runs for three different periods

Period	Kobe plots (arrow indicate the median)	Comments
All period (one regime) (1954-2015) 25 runs out of 27 were converged		Considering the current situation of catch, effort and CPUE, this result is unlikely plausible. Thus, this base case is not used for further analyses.
New regime (I) (1978-2015) 18 runs out of 81 were converged		Considering the current situation of catch, effort and CPUE, both results are likely plausible. Thus, these two base cases will be used for analyses.
New regime (II) (1979-2015) 36 runs out of 81 were converged		

3.5 Selection of the representative result of SCAA stock assessment

We consider that both Results in New regimes I and II are plausible (Fig. 12), thus we incorporate both uncertainties and select the median among all points (54 runs) with converged results as the representative of the SCAA runs. As a result, the scenario no. 79/55 is selected.

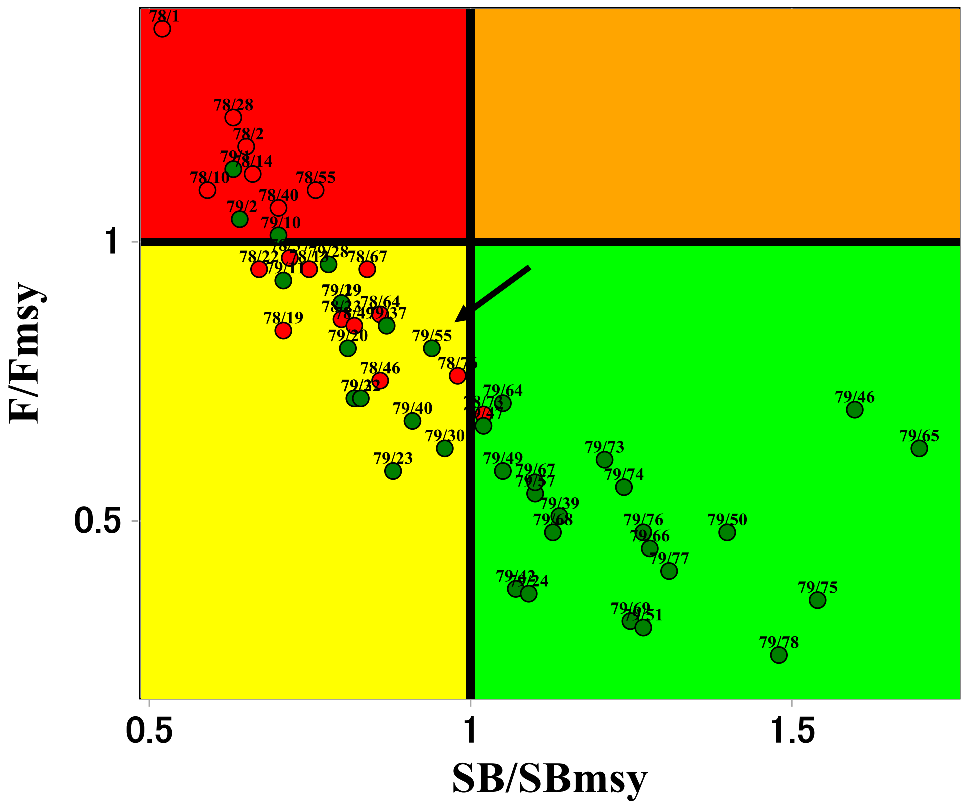


Fig. 12 Kobe plots of two base cases in the new regime hypothesis with scenario numbers

The scenario 79/55 (median point) is selected as the representative of SCAA runs in the new regime hypothesis (green dots for the new regime I: 1978-2015 and red dots for new regime II: 1979-2015)

3.6 Result of the scenario 79/55 in the new regime (II) (Fig. 13-15 and Table 1)

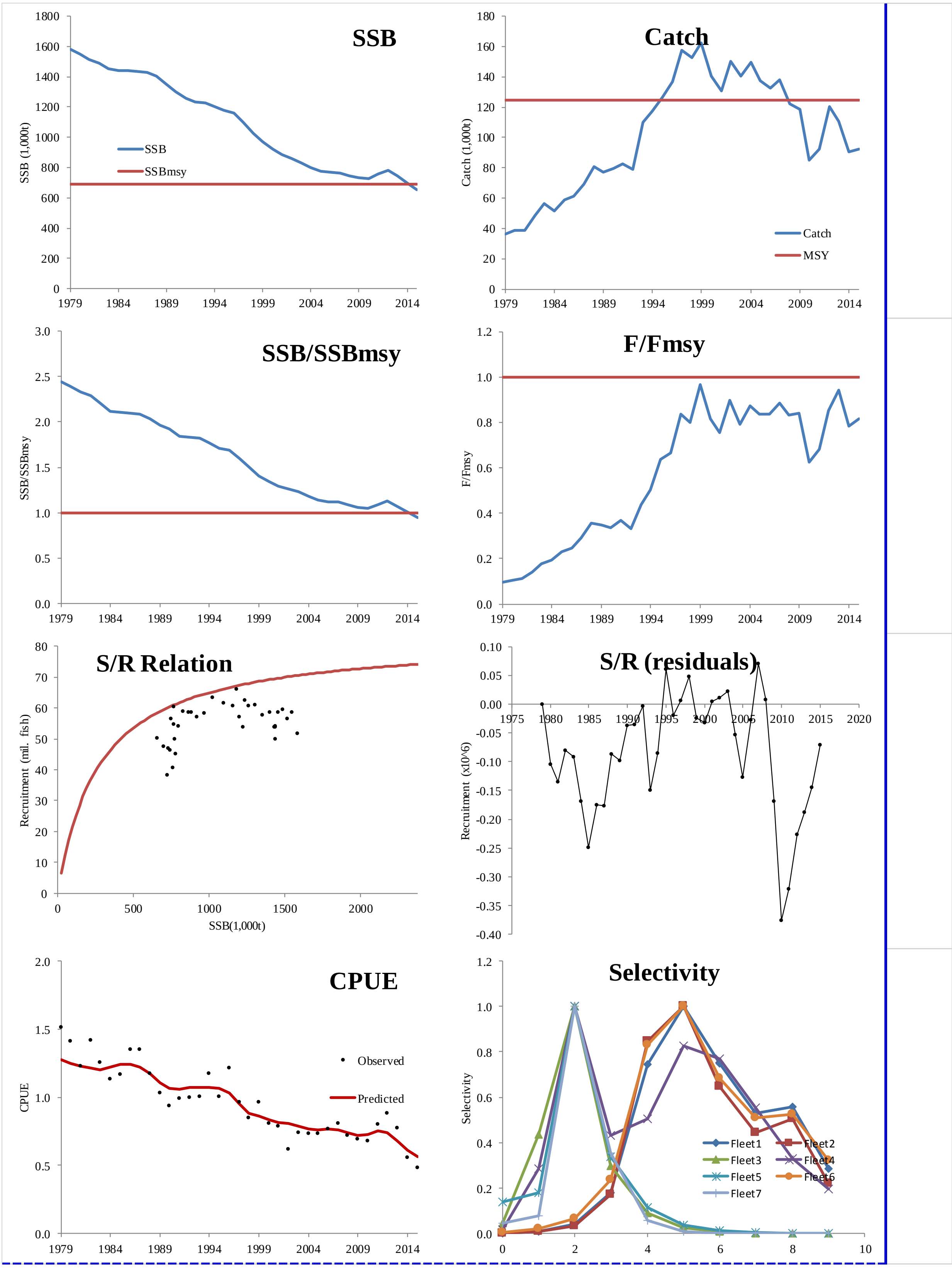


Fig. 13 Result of the final SCAA run in the scenario 79/55

in the new regime hypothesis (II) (1979-2015)

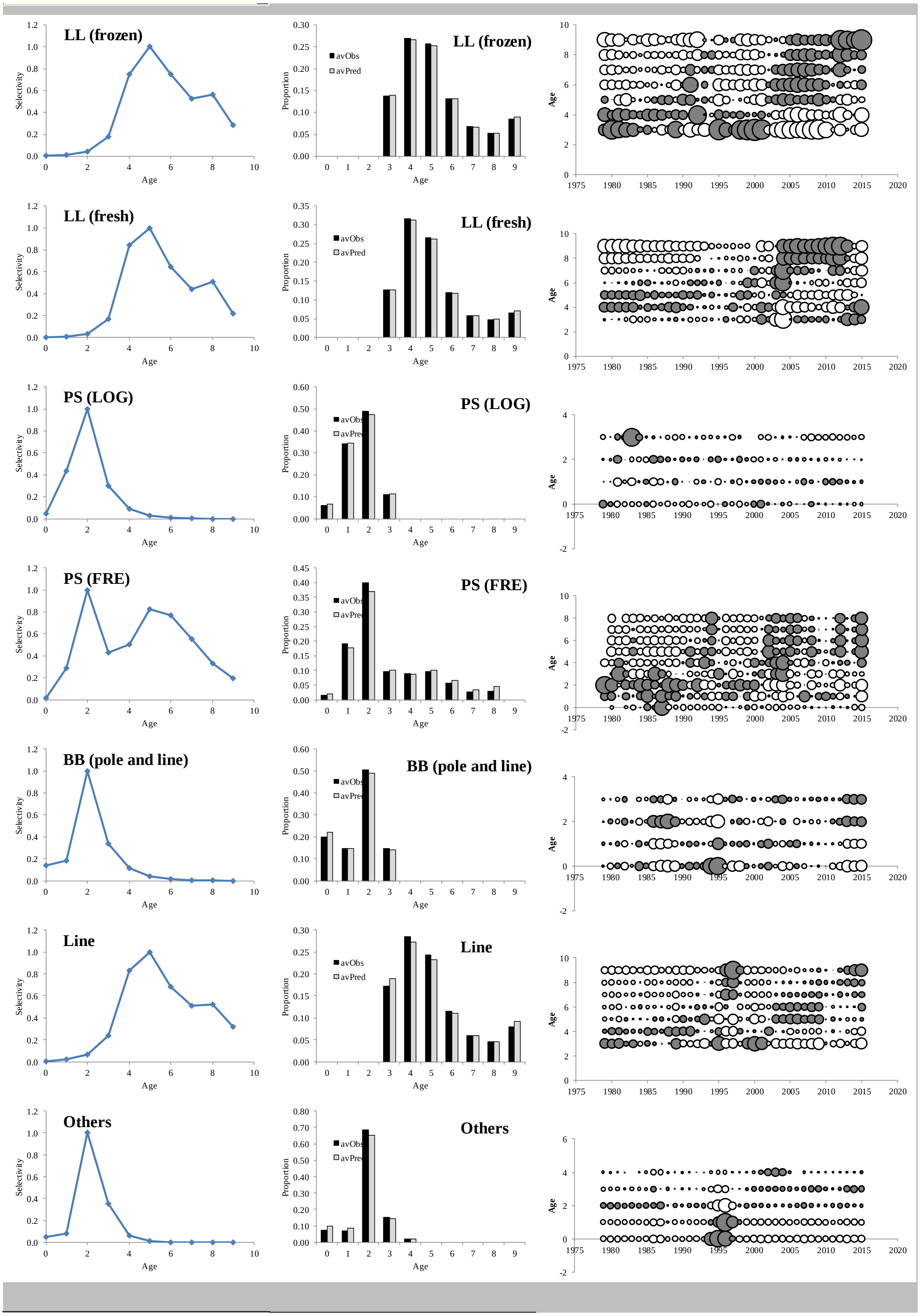


Fig. 14 Estimated selectivity by fleet in the final SCAA run (scenario no 79/55)

in the new regime hypothesis (II) (1979-2015)

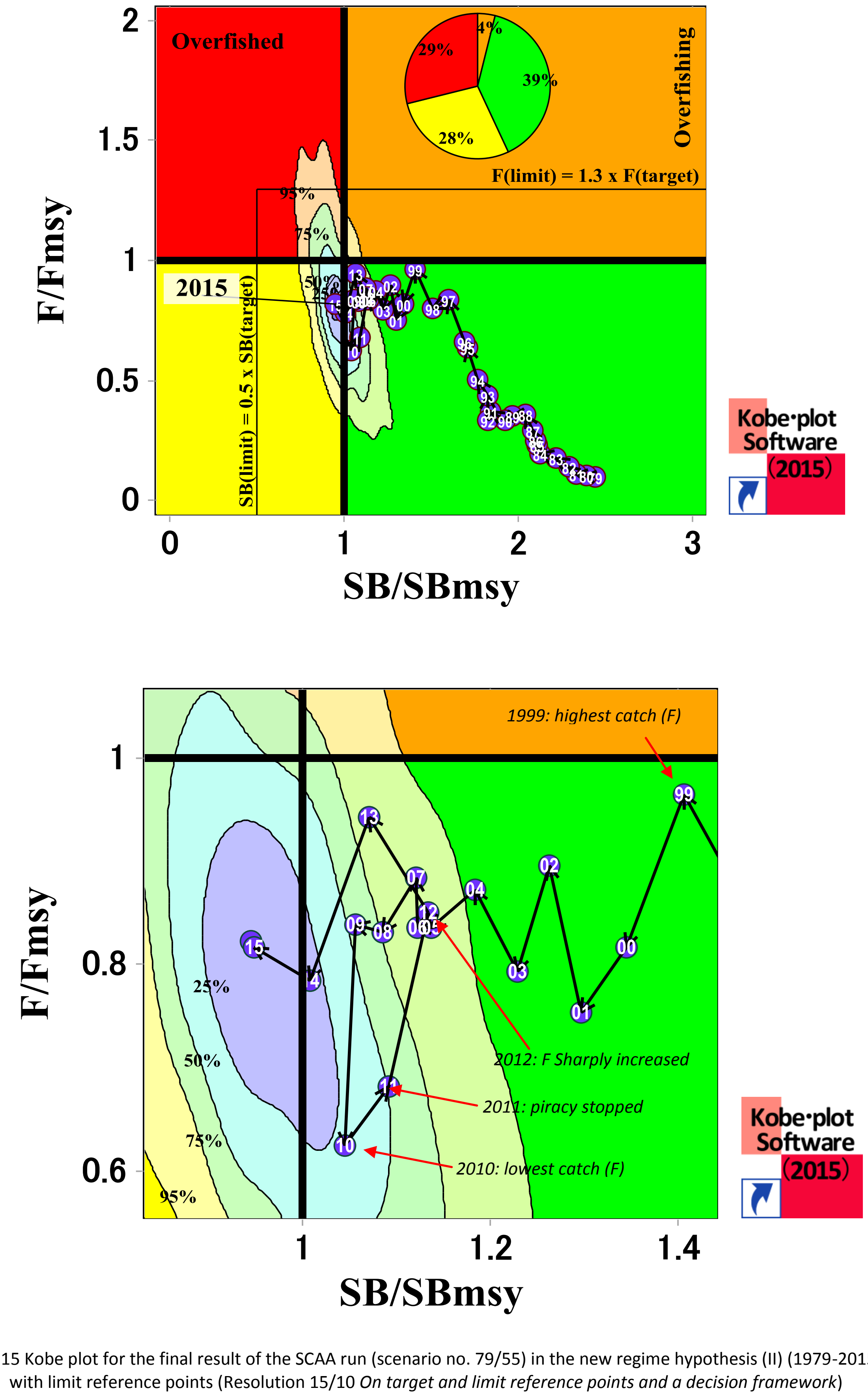


Fig. 15 Kobe plot for the final result of the SCAA run (scenario no. 79/55) in the new regime hypothesis (II) (1979-2015) with limit reference points (Resolution 15/10 *On target and limit reference points and a decision framework*) and the composition of uncertainties (based 1,000 re-sampling by MCMC) in the quadrants of the Kobe plot *(above: standard plot and below: magnified including relations with events)*

Table 10 Indian Ocean bigeye stock status summary based on the SCAA analyses

Management quantity	SCAA
Most recent catch estimate (t) (2015)	92,736
Mean catch over last 5 years (t) (2012–2015)	101,515
MSY (1,000 t) (80% CI)	124 (101–147)
Data period (catch)	1979-2015
CPUE series	Joint (tropical area)
CPUE period	1979-2015
F_{2015}/F_{MSY} (80% CI)	0.82 (0.55–1.09)
$B_{current}/B_{MSY}$ (80% CI)	n.a.
SB_{2015}/SB_{MSY} (80% CI)	0.95 (0.75–1.15)
B_{2012}/B_{1952} (80% CI)	n.a.
SB_{2015}/SB_{1979} (80% CI)	0.42 (n.a.)
$SB_{2012}/SB_{current, F=0}$	n.a.

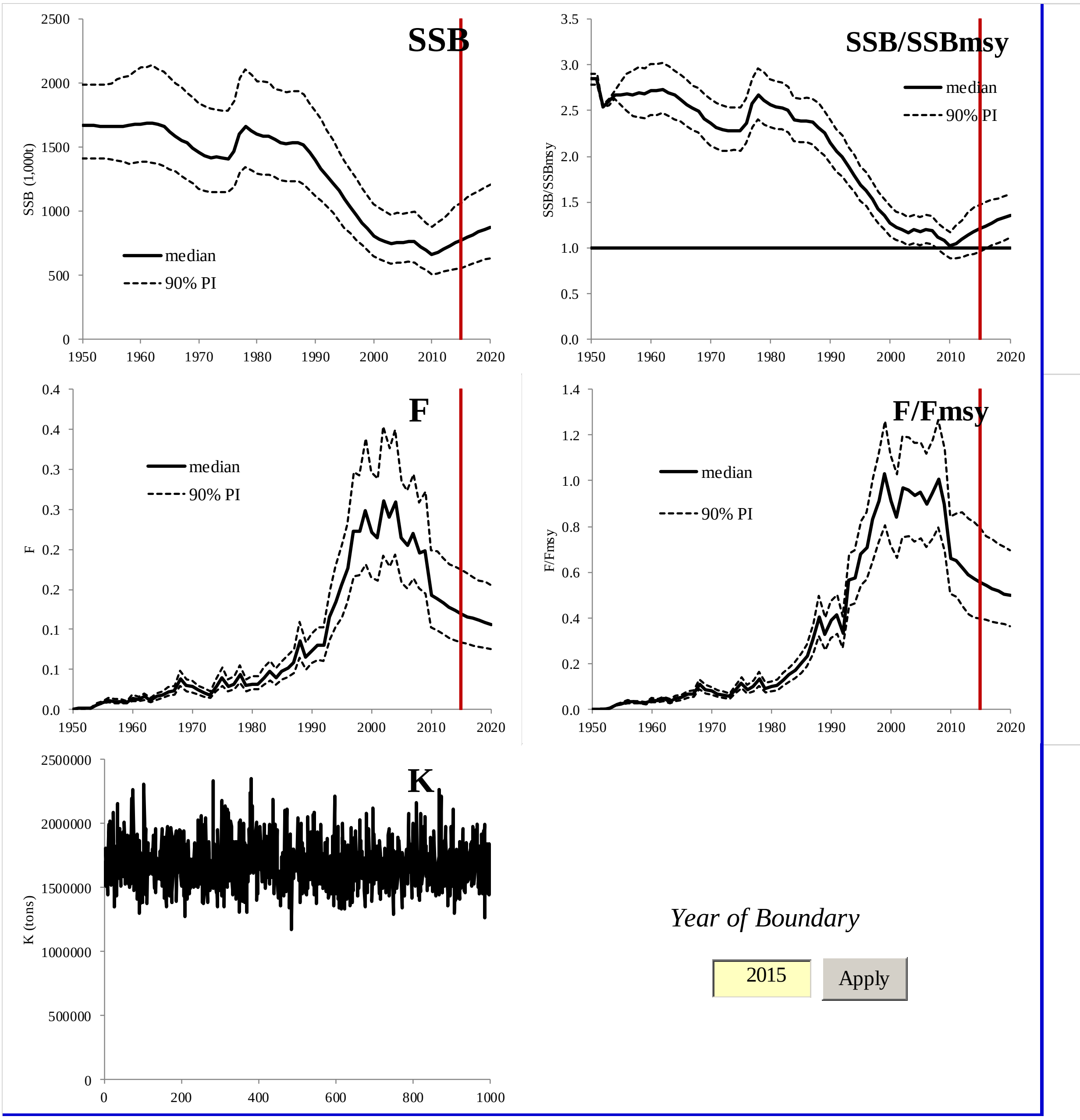


Fig. 16 Result of deterministic projection based on 2015 catch for 7 fleets in the final SCAA run (scenario 79/55) under the new regime hypothesis (II) (1979-2015)

3.7 Discussion

The selected representative results are likely plausible and show the current stock status, i.e., the 2015 status stock is in the yellow zone of the Kobe plot (not overfishing but overfished), i.e., F_{2015}/F_{msy}=0.82 and SSB_{2015}/SSB_{msy}=0.95. However, there are three major caveats in the SCAA results, i.e., (a) SR are not well fits, (b) Usage of slicing based CAA and (c) SCAA results (1979-2015) are similar to other stock assessments (SS3, ASPIC and etc.) using the entire period. Thus results should be looked with caution.

Acknowledgements

We sincerely thank to Fabio Fiorellato, Fisheries Officer (Data coordinator) (IOTC) for providing the nominal catch and Catch-At-Age (CAA) data of bigeye tuna in the Indian Ocean. We also thank to Yu-Min Yeh (Taiwan) and Simon Hoyle (Consultant) to provide the standardized CPUE.

References

Everson, J. P., Million, J., Sardenne, F. and Croizier, G.L. (2012) (IOTC-2012-WPTT14-23) Updated growth estimates for skipjack, yellowfin and bigeye tuna in the indian ocean using the most recent tag-recapture and otolith data

Herrera, A. M., and Pierre, L. (2007) (IOTC-WPTT13-07b) Preparation of catch-at-size and catch-at-age files for the stock assessments of tropical tunas.

Hoyle, S., et al (2016) (IOTC–2016–WPTT18–14) Collaborative study of tropical tuna CPUE from multiple Indian Ocean longline fleets in 2016.

Langley, A. (2016) (IOTC–2016–WPTT18–20) Stock assessment of bigeye tuna in the Indian Ocean for 2016

Matsumoto, T., et al (2016) (IOTC–2016–WPTT18–17) Stock and risk assessments of bigeye tuna in the Indian Ocean based on ASPIC.

Matsumoto, T. et al (2016) (IOTC–2016–WPTT18–13) Japanese longline CPUE for bigeye tuna in the Indian Ocean standardized by GLM

Nishida, T., et al (2014) (IOTC-2014-WPTT16-54) Users' manual: ADMB implemented SCAA/ASPM software.

Merino, G., Kell L. and Murua, H. (2016) (IOTC–2016–WPTT18–16) Assessment of Indian Ocean bigeye (Thunnus obesus) using a biomass dynamic model

Otsuyama K. and Kitakado T. (2016) (IOTC–2016–WPTT18–19) Bayesian state-space production models for the Indian Ocean bigeye tuna and their predictive evaluation.

Yeh, Y. and Chang S. (2016) (IOTC–2016–WPTT18–34) Updated CPUE standardizations for bigeye and yellowfin tuna caught by Taiwanese longline fishery in the Indian Ocean using generalized linear model.

Zhu, J. (IOTC–2016–WPTT18–15) Stock assessment of Indian Ocean bigeye tuna (Thunnus obesus) using Age-Structured Assessment Program (ASAP)