Stock assessments of albacore (*Thunnus alalunga*) in the Indian Ocean using Statistical-Catch-At-Age (SCAA)

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Abstract

The SCAA run with Taiwan standardized LL CPUE (core area) likely produces plausible results, i.e., (a) SB/SBmsy=1.14 and F/Fmsy=0.65. This indicates that albacore stock in the Indian Ocean is in the healthy condition as the spawning stock biomass is 14% higher than its MSY level and F is 35% lower than the MSY level. However, SCAA runs with joint CPUE (Korea, Japan and Taiwan) produced implausible results, i.e., the stock status is too optimistic. These discrepancies need to be elucidated and the plausible standardized CPUE need to be used in the stock assessments in the future.

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1. INTRODUCTION

We attempted the stock assessment on albacore (*Thunnus alalunga*) (ALB) in the Indian Ocean by AD Model Builder implemented Statistical-Catch-At-Age (SCAA) (Nishida *et al*) (2015) using available information for 65 years from 1950-2014. It is essential and important to have a few stock assessments from simple model (e.g. ASPIC), medium model (e.g. VPA), simple integrated models (e.g. SCAA, SCAS, etc.) to full integrated models (e.g. SS3 and MFCL), so that we can compare results under different structure of the dynamic models and evaluate results. If we can get similar results, we have more certainty (confident) in the stock status even there are large uncertainties in the data and models.

2. INPUT INFORMATION

To implement SCAA, we used ALB annual nominal catch by fleet, standardized CPUE (STD_CPUE), CAA (catch-at-age) by fleet and biological information. Below are descriptions of the data used in the SCAA runs.

2.1 Stock structure

In the Pacific and the Atlantic Ocean, two (north and south) stocks hypothesis has been used and stock assessments have been conducted for each stock. As for the Indian Ocean, it has a very small northern part, thus a single stock hypothesis has been applied, although there is some knowledge on intermingled areas with Pacific and Atlantic stocks in its eastern and western end respectively. Nevertheless, we assume a single stock hypothesis for the 2016 stock assessment as in the past.

2.2 Fleet

Considering the features of ALB fisheries in the Indian Ocean and the IOTC data sets, we define 4 types of fleets (gears), i.e., tuna longline fisheries (LL), and drift gillnet fisheries in high seas (GILL) by Taiwan,China, purse seine fisheries (PS) and others(OTH). OTH includes small scale surface fisheries such as troll, pole and lines, lines, gillnet (off shore) and other minor fisheries.

2.3 Nominal catch by gear

We used the nominal catch data by fleet complied by the IOTC Secretariat. Fig. 1 shows the trends of catch by fleet type (in weight).

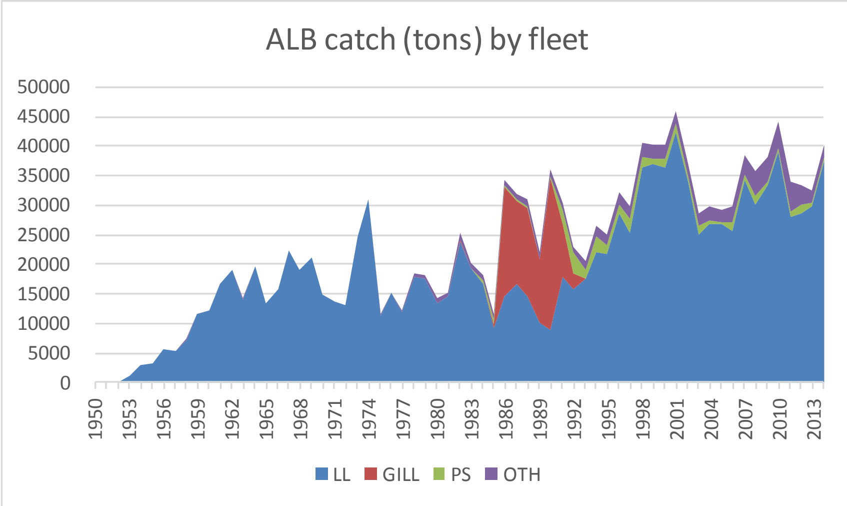


Fig. 1 Trend of albacore tuna catch in the Indian Ocean by fleet (in weight).
(Source: IOTC Secretariat, 2016)

2.3 Plus group age

The IOTC Secretariat provide CAA (age 0-20+) by fleet. According to IOTC-2014-WPTmT-16, plus group age are different among tuna RFMOs (Fig. 2) including IOTC used in the past. We need to decide scientifically valid plus group for our case.

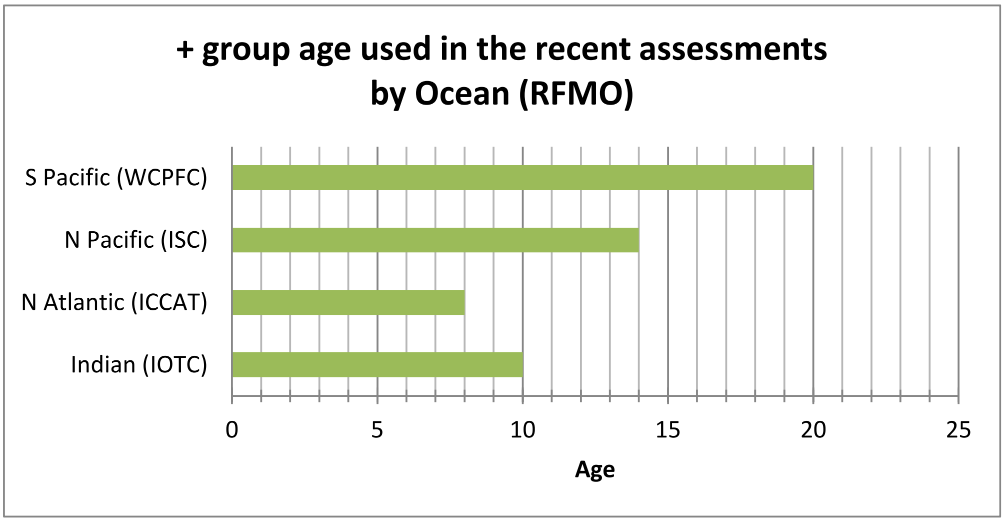


Fig. 2 Plus group used in recent stock assessments in different tuna RFMOs

The IOTC Secretariat provide CAA (age 0-20+) by fleet and we explore optimum plus group using this CAA. Based on personal communications with three professors, Butterworth (Cape Town University), Hiramatsu (Tokyo University) and Shono (Kagoshima University), they suggest three rough clues to decide the optimum plus age group:

(i) If the age determination is difficult from some age (for example, due to limitations to read otolith for), that age and older ages should be pooled as the plus group.

(ii) There will be biases in the stock assessment results if the population in plus group is more than 20% or less than 2% of the total population.

(iii) If 0 catch is included in the plus group in any year, it will be difficult to conduct assessments.

Then we investigated these three criteria to decide the optimum plus group age. Regarding criterion (i), Fig. 3 shows the growth curve agreed in the last WPTmT05 (2014). It is likely that age 15 is the reliable maximum age. Thus age 15 is the possible candidate the plus group age.

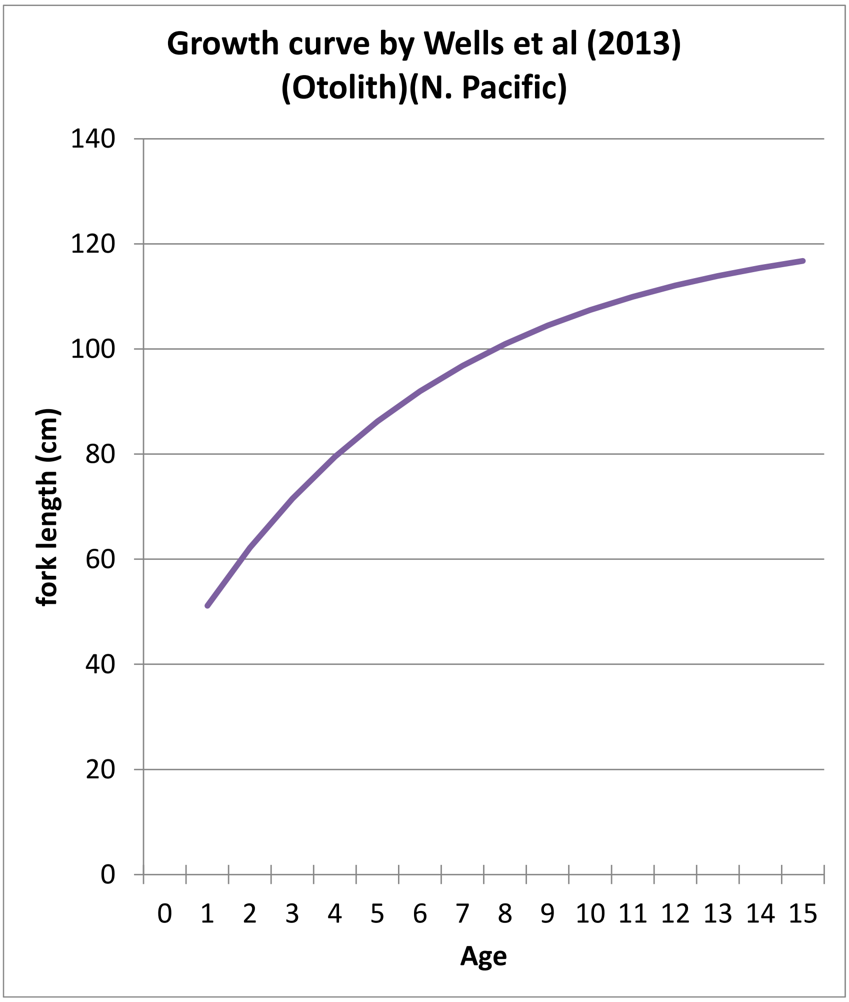


Fig. 3 Estimated growth curve by otolith (Well et al, 2013)

Regarding the criteria (ii), age 15+ satisfied the 2% criterion (Fig.4). Regarding (iil), we investigated 0 (zero) catch in CAA then we found years 1950-1951(Table 1), there are 0 catch in Age 15+ or younger plus age groups. This we will use the data from 63 years (1952-2014). As a conclusion, we define Age 15+ is the optimum plus group.

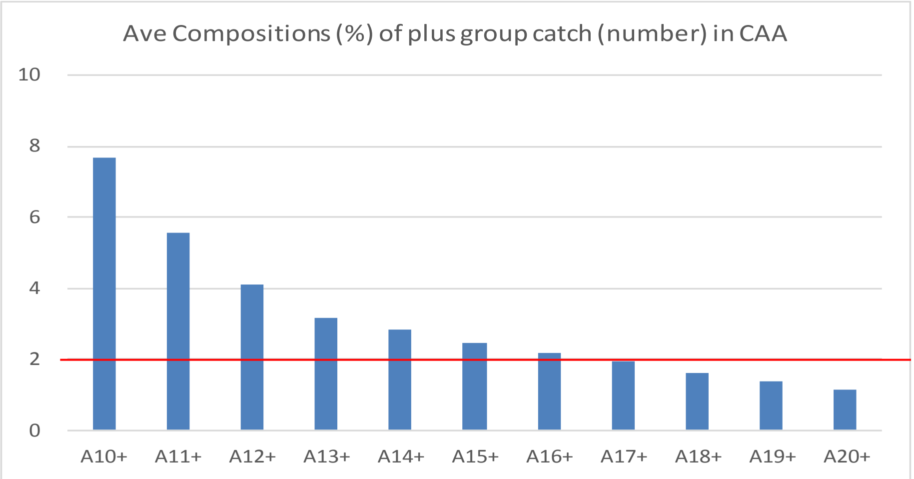


Fig. 4 Compositions (%) of the plus group in the total catch

(The red line shows the 2% level)

Table 1 Number of catch by year and age (1950-1951 include 0 catches)

	Age 09	Age 10	Age 11	Age 12	Age 13	Age 14	Age 15	Age 16	Age 17	Age 18	Age 19	Age 20
1950	0	0	0	0	0	0	0	0	0	0	0	0
1951	0	0	0	0	0	0	0	0	0	0	0	0
1952	388	325	169	47	5	12	4	8	5	4	4	12
1953	6,233	3,184	1,293	415	47	81	17	32	22	14	22	52
1954	16,963	12,382	5,701	2,395	508	326	64	67	73	50	59	175
1955	17,231	10,975	6,753	3,205	841	667	397	182	129	125	132	848
1956	29,315	17,177	9,549	4,599	1,083	970	645	438	499	471	233	881
1957	27,234	18,203	10,223	3,583	973	710	402	373	495	506	243	1,008
1958	36,520	25,564	13,474	5,729	1,416	1,296	828	777	740	842	480	1,710
1959	76,933	32,098	18,553	5,305	1,627	1,328	859	920	919	968	575	1,969
1960	109,713	31,341	26,909	5,638	1,408	1,418	796	790	767	803	483	1,732

2.4 CAA

(1) General trends

The IOTC Secretariat provided CAA by fleet. Figs. 5-8 show CAA by age or age group.

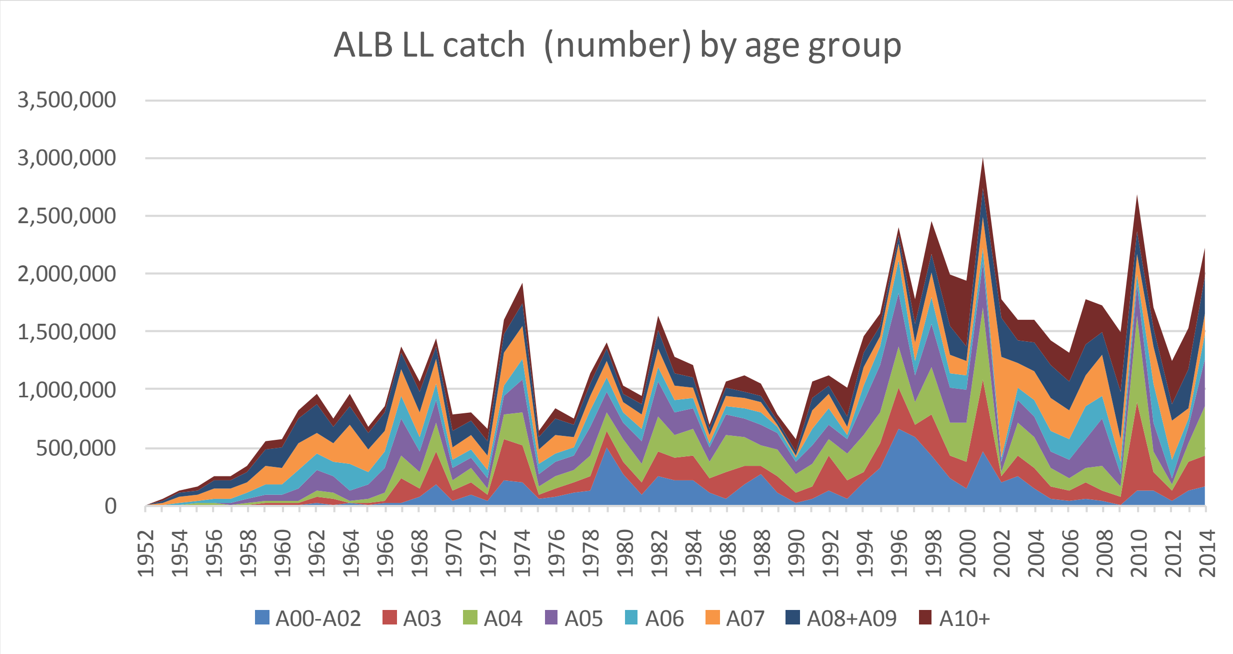


Fig. 5 CAA for LL

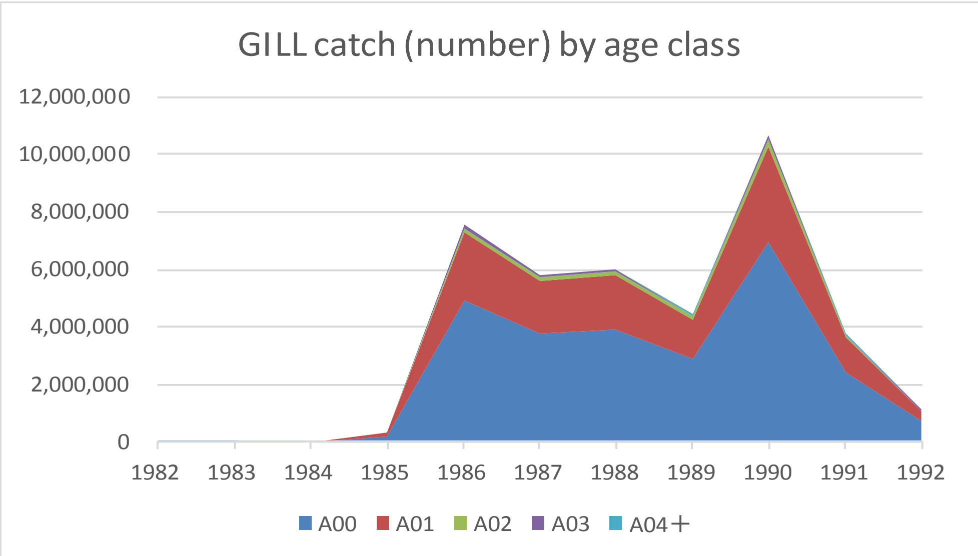


Fig. 6 CAA for GILL (Taiwan,China)

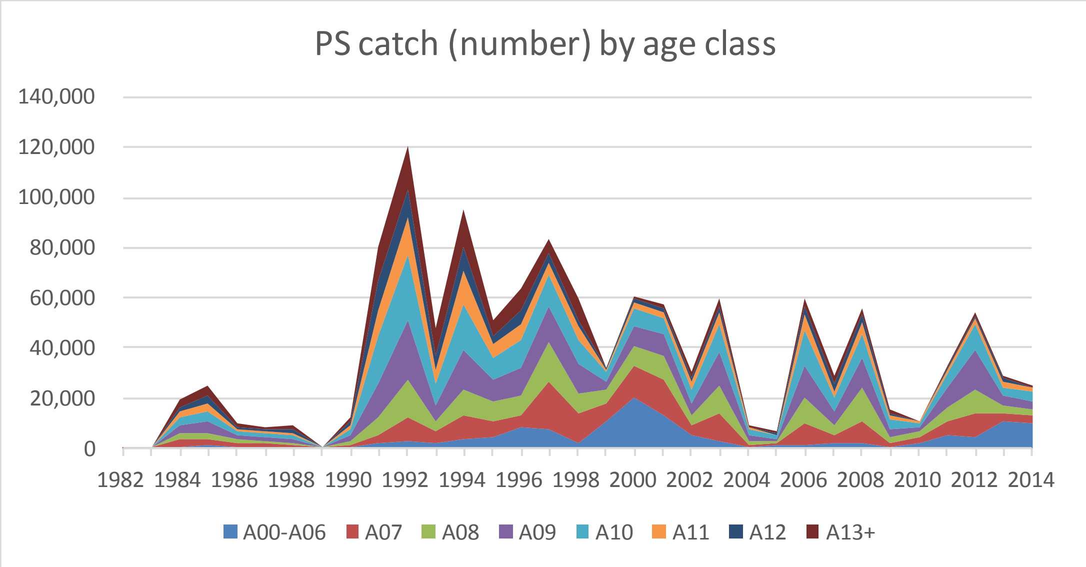


Fig. 7 CAA for PS

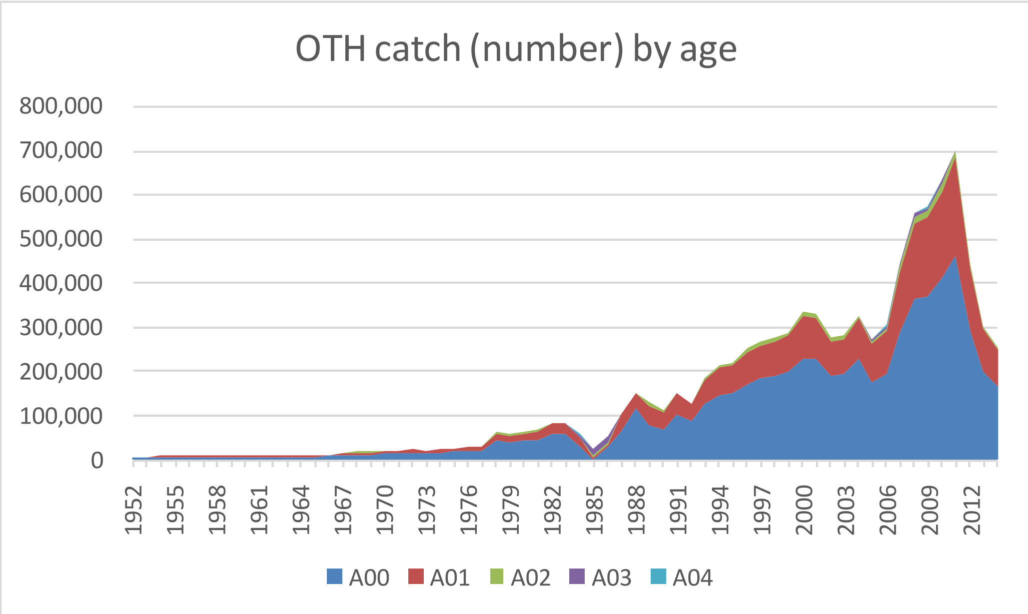


Fig 8 CAA for OTH

(2) Problem of CAA for GILL and revised GILL CAA

Size data for GILL by Taiwan,China (1986-1992) are not available. Thus the IOTC Secretariat used average weight =2.4 Kg (Gillnet fisheries in the South Pacific) and created CAA using same age compositions (patterns) of OTH fleet (1986-1992). This made serious underestimated size/age structures based on the study by Fonteneau (2016) who compared actual size frequency summary and of GILL by Taiwan,China (1986-1992) (Table 2) (Lee and Liu, 1995) (IPTP) (Figs. 9 and 10).

Table 2 **The Indian albacore size frequencies data of Taiwanese gillnet fishery from 1986 to 1992.**

Size (cm)	*Number of fish*						
	1986	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
44	8	2	15	33	6	13	1
48	11	1	23	61	14	22	0
52	0	1	4	16	3	6	0
56	2	1	4	26	3	12	0
60	12	14	24	84	32	159	10
64	42	9	38	88	112	228	32
68	125	103	143	185	355	470	105
72	328	295	355	373	899	1279	258
76	248	231	324	199	539	822	91
80	155	251	372	141	248	370	51
84	114	153	252	69	180	171	33
88	54	43	112	25	64	54	15
92	21	17	28	17	11	26	5
96	5	1	11	6	13	11	4
100	5	3	6	0	6	3	0
104	0	0	2	0	1	4	0
108	0	0	1	0	1	2	0
112	0	0	1	0	1	0	0
116	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0

Data sources: Tuna Research Center, Institute of Oceanography, National Taiwan University

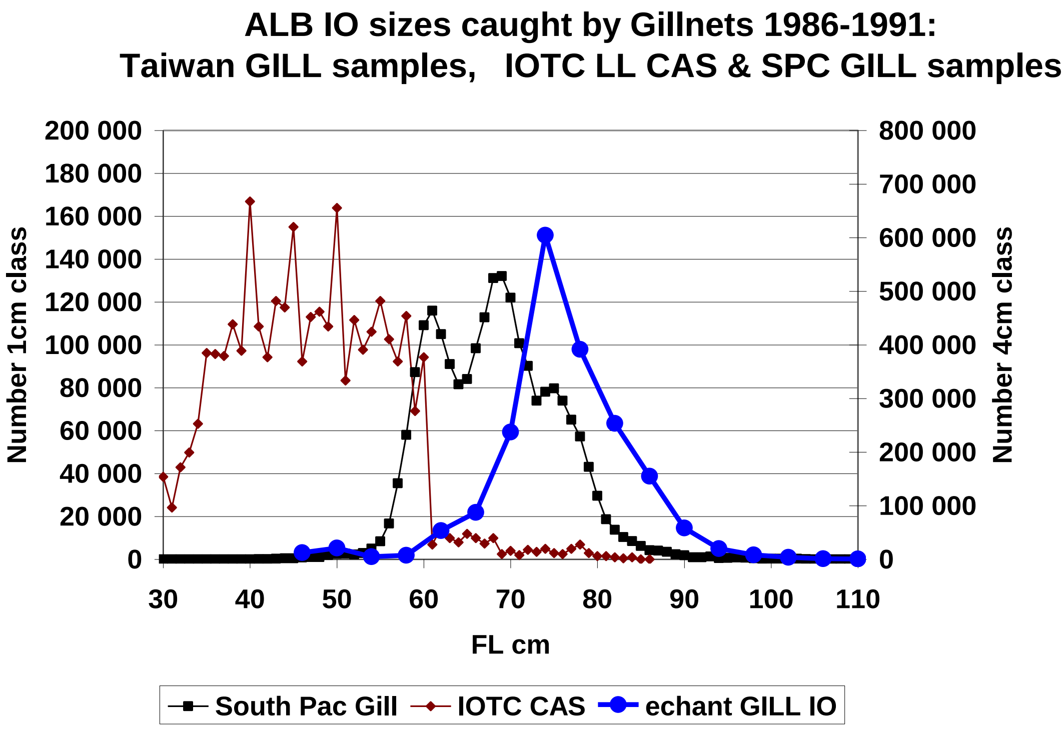


Fig. 9 Average sizes (1986-1991 period) of ALB caught by Gillnets fisheries in 3 data set: submitted by Taiwan in 1993, estimated by IOTC and from SPC south Pacific (Fonteneau,2016)

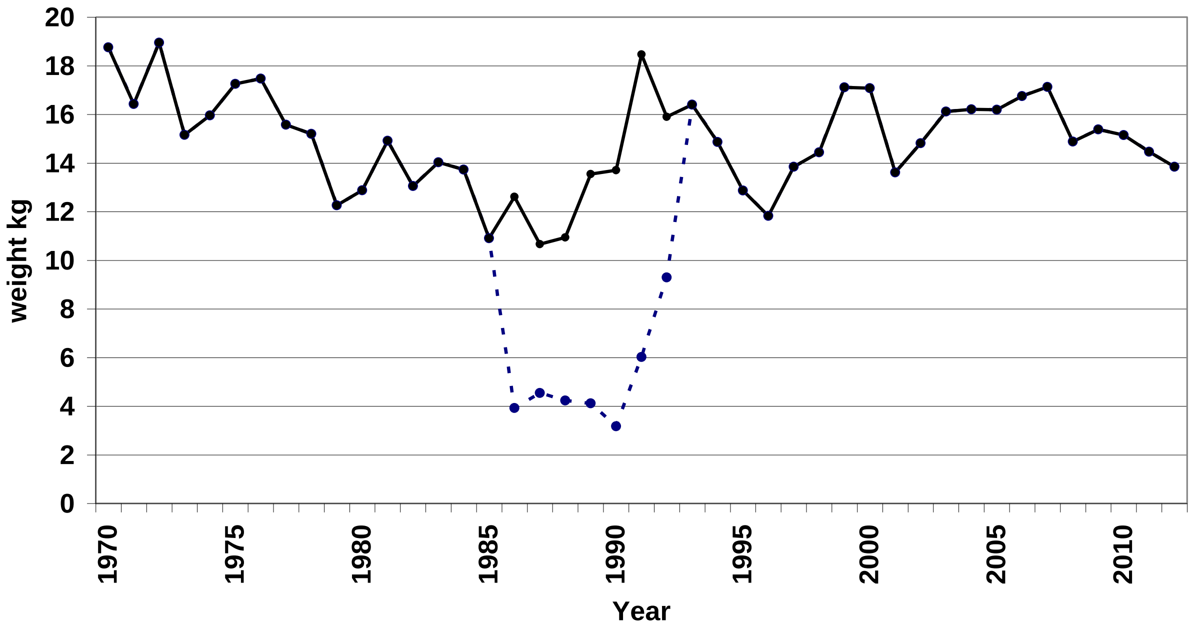


Fig. 10 Average weight of ALB caught by ALB fisheries: estimated by the IOTC with wrong Gillnet sizes, and based on real Taiwanese size data(Fonteneau,2016)

To improve the situation, we estimated GILL annual CAA using total annual number of fish (GILL catch in ton)/(average ALB weights) (1986-1992) and % size frequency distribution based on Table 2 (Fig. 11).

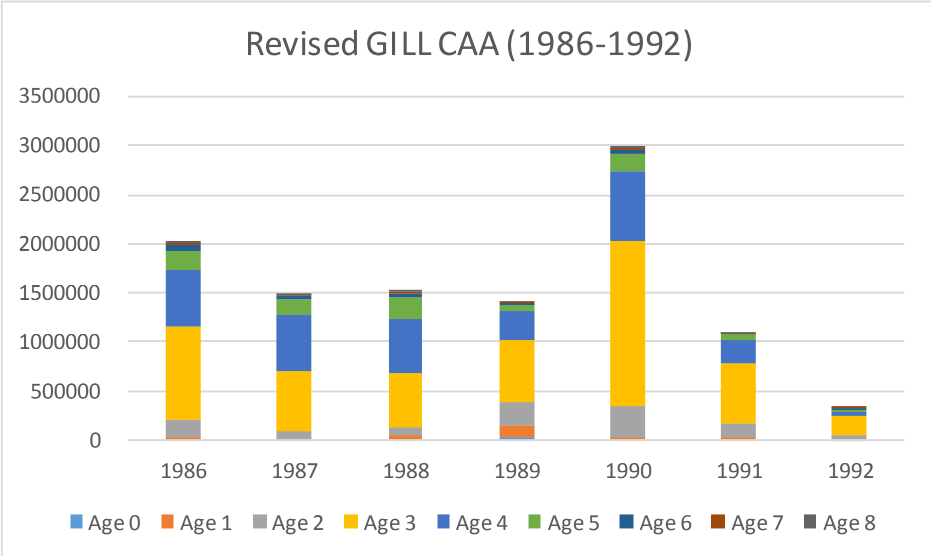


Fig. 11 Revised GILL CAA

(3) Plus and minus group and seeding values of selectivity

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 (Table 2). We also set up the seeding values of selectivity and the anchored values (age with the highest selectivity=1) (Table 3).

Table 3 Minus and plus group (*), age specific seeding values for selectivity and the anchored age with the highest selectivity (=1).

No	Code	Fleet	Minus group	Plus group	Period of available CAA data	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15 +
(1)	LL	Tuna longline	Age 1-	Age 15+	1952-2014		0	0.2	0.4	0.8	(1)	1	1	1	1	1	1	1	1	1	1
(2)	GILL	Gillnet (Taiwan)	Age 1-	Age 6+	1982-1992		0.1	0.2	(1)	0.5	0.2	0.1									
(3)	PS	Purse seine	Age 5-	Age 15+	1982-2014						0.1	0.2	0.9	(1)	0.9	0.2	0.1	0.1	0.1	0.1	0.1
(4)	OTH	Other fleets	Age 0	Age 3+	1952-2014	0.0	0.2	(1)	0.2												

(*) based on compositions of CAA by age.

2.4 CPUE

(1) Introduction

There are a number of standardized LL CPUE available in the WPTmT06 (Table 4).

Table 4 Available standardized CPUE in WPTmT06 (2016)

Fleet (LL)	Area	Years	Season	IOTC-2016 -WPTmP06	Authors
Korea (*)	All	1965-2015	Annual	29	Lee et al
Japan	North, SE and SW	1959-2014 1962-2014	Annual	15	Matsumoto
Taiwan, China	Core (S Central) and Whole	1980-2014	Annual	17	Chang *et al*
Korea+Japan +Taiwan,China combined	Whole (S Central) and 4 sub areas	1958-2014	Annual Quarter	19	Hoyle *et al*

(*) nominal CPUE

We did no use standardized CPUE by Japan and 3 fleets combined CPUE in SCAA stock assessments because of 2 reasons: (a) implausible increasing trends in recent years (Japan and Korea) and (b) implausible sharp drops in 1950's by apparent high CPUE in the virgin stock, which causes have been well documented after Myers and Worm paper (2003) regarding depletion of tuna resources. Hence, tuna RFMOs recommended not to use the early period of tuna longline CPUE by Japan (especially 1950's) (Figs. 12-13).

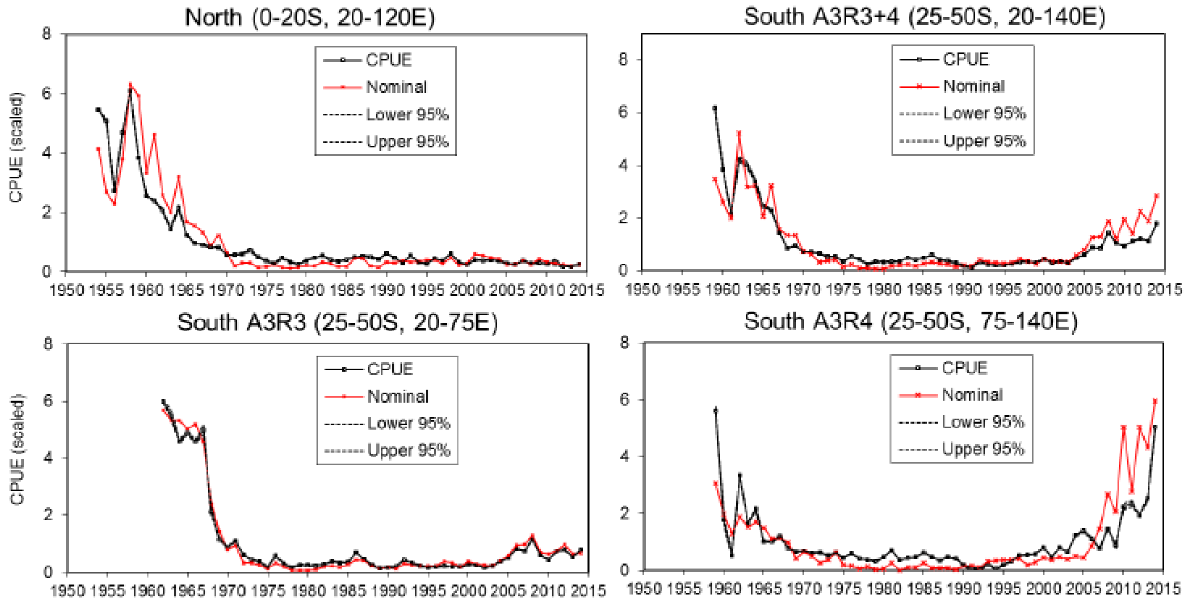


Fig. 12 Standardized CPUE of Japan LL (Matsumoto, 2016)

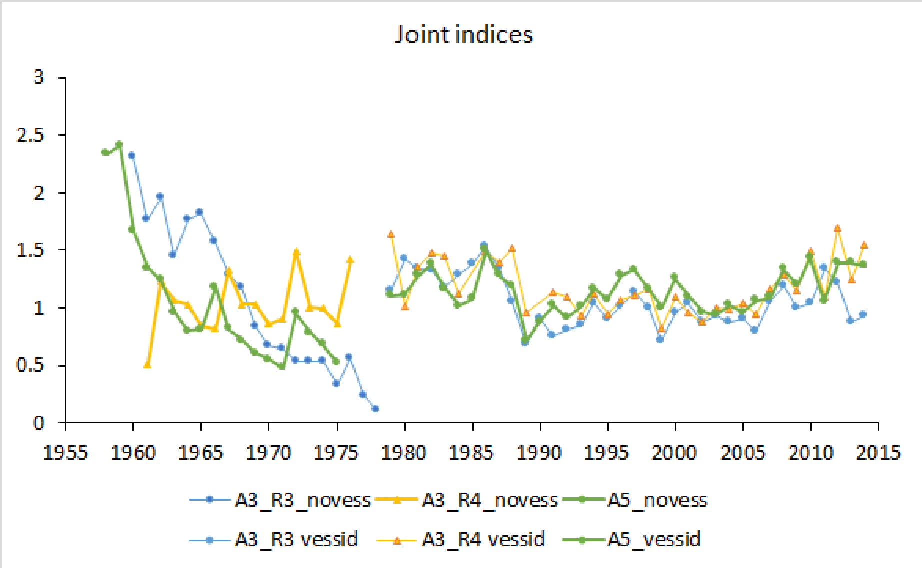


Fig. 13 Combined standardized CPUE of Korea+Japan+Taiwan,China LL fleets

Because of these 2 causes, we concluded that relations between catch and standardized CPUE are not realistic (positively correlated) for Japan (Fig. 14). As for the combined CPUE (Fig. 15), apparent high 3 CPUE points (1958-1961) make the apparent realistic relation (negative correlation between catch and standardized CPUE) (left, Fig. 16), but without these 3 points, there are no relation between catch and standardized CPUE (right of Fig. 16).

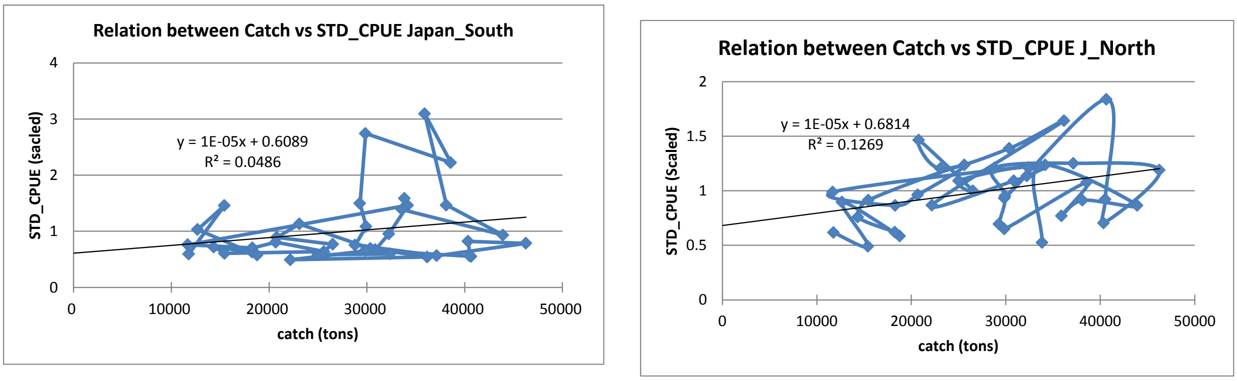


Fig. 14 Positive relation between catch and standardized CPUE (Japan LL)

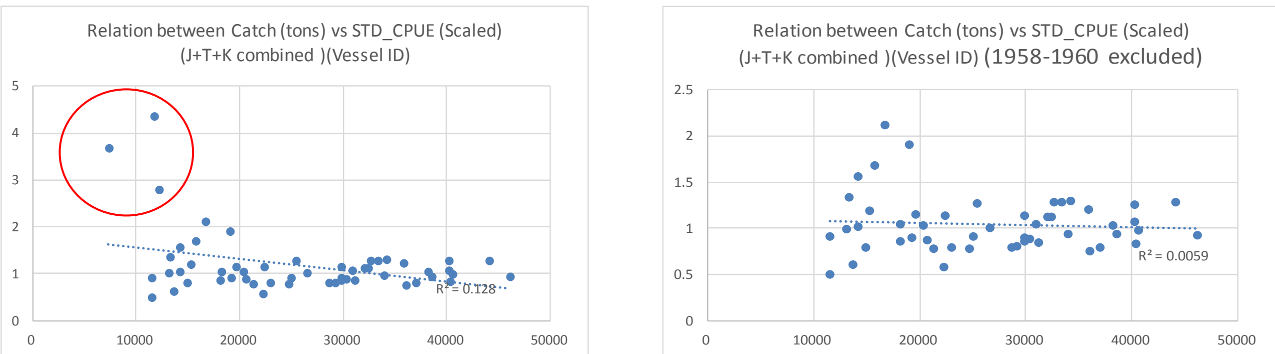


Fig. 15 Relation between catch vs standardized CPUE (3 fleets combined) (1958-2007)
(Left) with 3 apparent high CPUE points (1958-1969) (negative and apparent plausible relation)
and (right) without these three points (no relation)

Hence we use standardized CPUE in the core area (Fig. 16) by Taiwan, China as in the past, in order to keep consistent stock assessments. However, when we compare nominal and standardized CPUE (Fig, 17), standardized CPUE is seriously flattened which is unlikely realistic. In the last WPTmT05 (2014), we have standardized CPUE with plausible contrasts (Fig. 18) like the nominal CPUE in 2016.

The major reason why trends of standardized CPUE of Taiwan,China between 2014 and 2016 have large discrepancies is that they used different approaches to correct targeting biases, i.e., in 2014, they used species composition, while in 2016, cluster analyses. At this stage, we don't know which approach provides more effective targeting bias corrections.

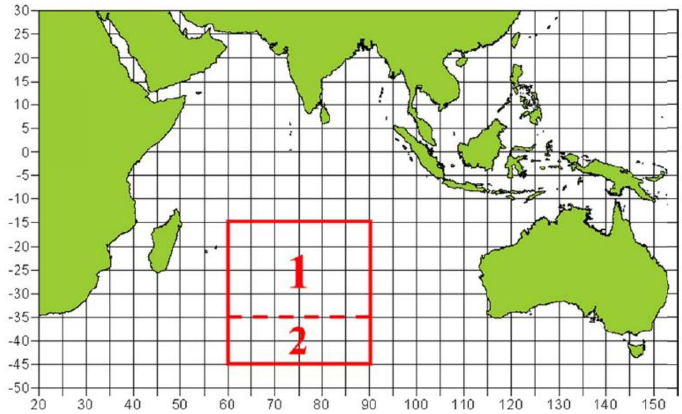


Fig. 16 Core area used in LL CPUE standardization (Taiwan,China)

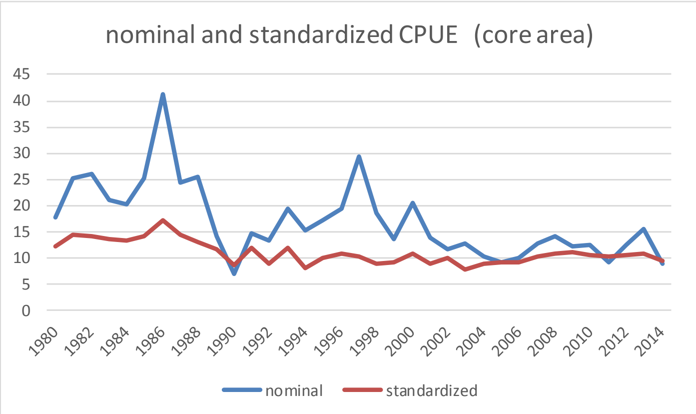


Fig. 17 standardized and nominal LL CPUE of Tawain,China

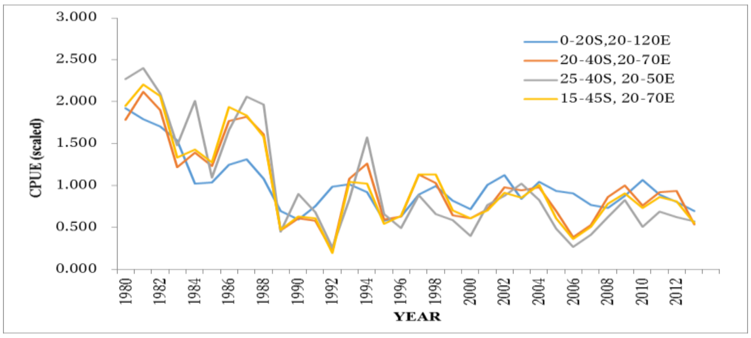


Fig. 18 Standardized LL CPUE of Tawain,China used in the last WPTmT05 (2014)

Fig. 19 shows the relation between catch and standardized CPUE (upper) and also nominal CPUE (lower), which show the plausible relations.

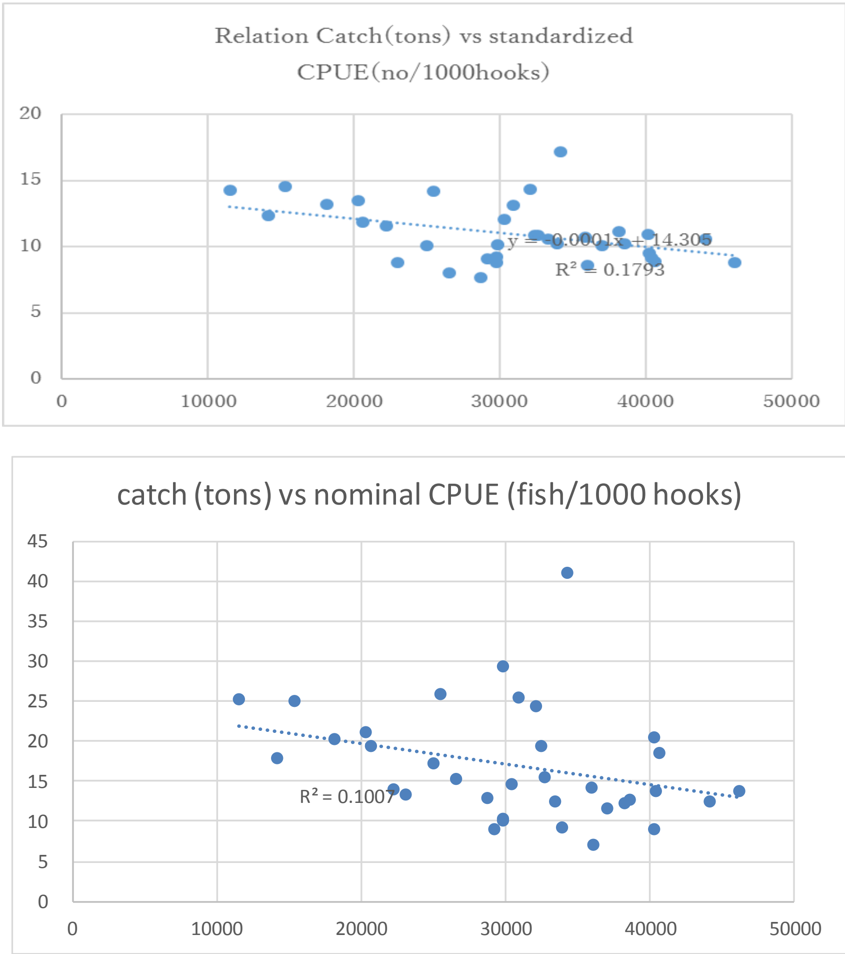
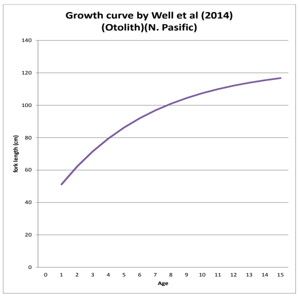


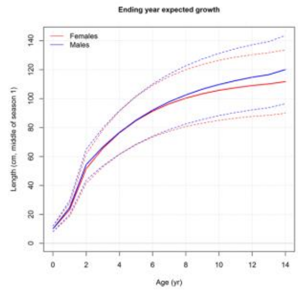
Fig 19 Relation between catch vs standardized (upper) and nominal(lower) CPUE (Taiwan,China) (1980-2014) showing the plausible negative correlations

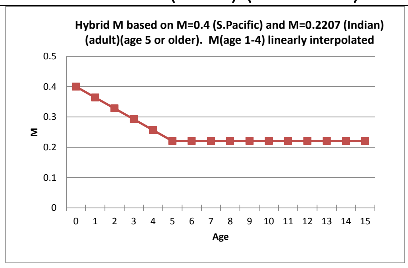
2.5 Biological information

In the 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. In the last WPTmT05 (2014), biological parameters in Table 5 was agreed.

Box 1 Agreed biological parameters in WPTmT05 (2014)

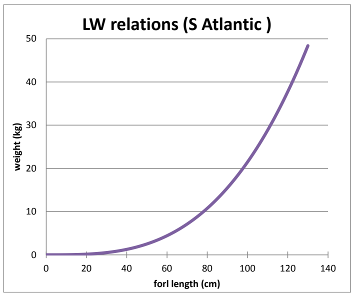
<table>
<tr><th>Parameters</th><th colspan="2">Contents</th></tr>
<tr><td>(1) Stock structure</td><td colspan="2">Single</td></tr>
<tr><td>(2) Sex ratio</td><td colspan="2">1:1</td></tr>
<tr><td>(3) Growth equation</td><td>

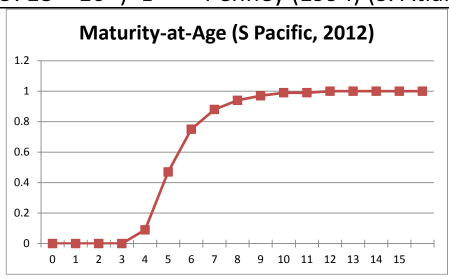
$L(t)=124.10\,[1-e^{-0.164\,(t+2.2390)}]$
Wells et al (2013) (N. Pacific)</td><td>

Chen et al (2012)
Sex based growth curve</td></tr>
<tr><td>(4) M by age</td><td>

Hybrid of Lee and Liu (1992) (Indian)(0.22) and M=0.4 (S Pacific)

NOT used for this time WPTmT06 (2016)</td><td>M=0.2,0.3 and 0.4

M=0.3 and M=0.25
Are used for this time
At WPTmT06 (2016)</td></tr>
<tr><td>(5) LW relation</td><td colspan="2">

$W = (1.3718 \times 10^{-5})*L^{3.0973}$ Penney (1994) (S. Atlantic)</td></tr>
<tr><td>(6) Maturity-at-age</td><td colspan="2">

Age (0-15):0, 0, 0, 0, 0.09, 0.47, 0.75, 0.88, 0.94, 0.97, 0.99, 0.99, 1, 1, 1
Farley et al (2012) (S. Pacific)</td></tr>
<tr><td>(7) Plus group age (last age)</td><td colspan="2">Age 15+ (see Section</td></tr>
</table>

(1) M

For this time, we used different M from in Table 1 by the following reasons. Fig. 20 shows M by Ocean (RFMO). Fonteneau (2016) suggested that M=0.2 (Indian Ocean) is too low and we think that M=0.3-0.6 (N. Atlantic) is too high considering ALB biological futures. Thus we use M=0.3 as a base case and M=0.25 as the sensitivity considering that 2 studies suggested M in the Indian Ocean =0.2. Although 0.2 are possibly too low, but real M in the Indian Ocean may be lower than in other Oceans because of its different (favorable) environmental conditions.

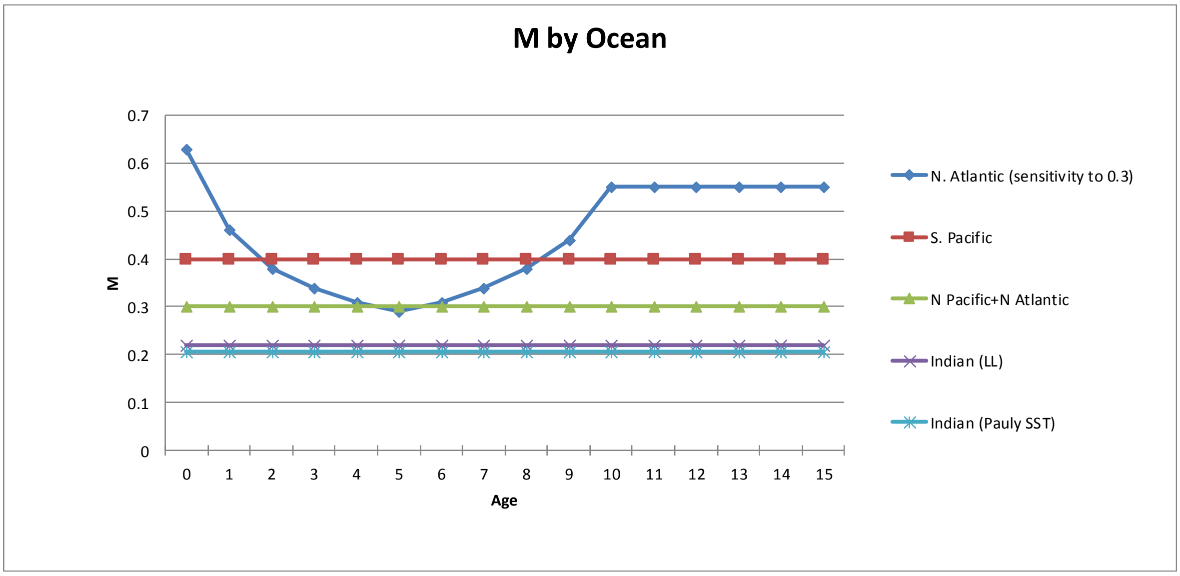


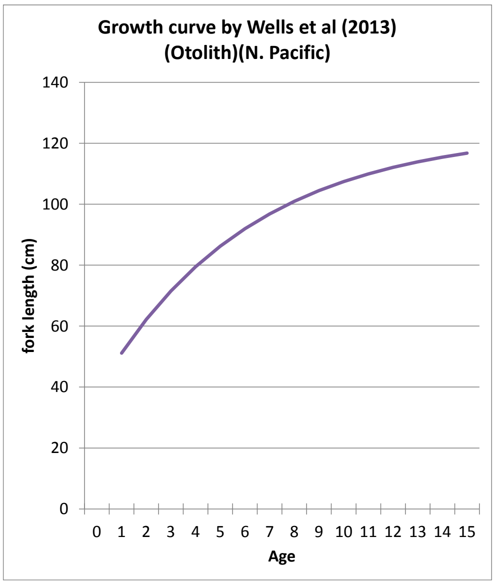
Fig. 20 Age specific M by Ocean (tuna RFMO)

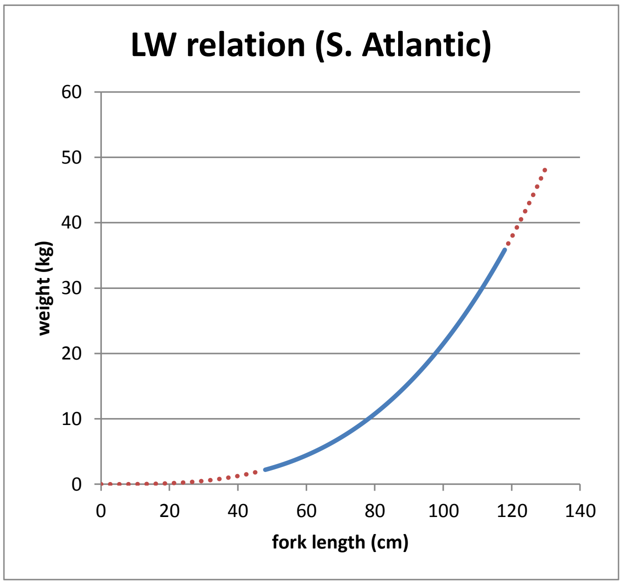
(2) Beginning- and mid-year weights-at-age

Beginning- and mid-year weights-at-age are computed as explained in Box 2.

Box 2 Computation process of beginning- and mid-year weights-at-age as follow:

(a) using the growth equation by Wells et al (2013), size-at-age was calculated, (b) using the length-weight relationship, W = $(1.3718 \times 10^{-5}) * L^{3.0973}$ by Penney (1994) (S Atlantic), weight-at-age was calculated as shown in Table below.





Age (beginning of year)	weight (kg)	Age (middle of year)	weight (kg)
0	1.1	0.5	1.8
1	2.7	1.5	3.7
2	4.9	2.5	6.2
3	7.6	3.5	9.1
4	10.5	4.5	12.1
5	13.6	5.5	15.1
6	16.6	6.5	18.0
7	19.4	7.5	20.8
8	22.1	8.5	23.4
9	24.6	9.5	25.7
10	26.8	10.5	27.8
11	28.8	11.5	29.7
12	30.6	12.5	31.4
13	32.1	13.5	32.8
14	33.5	14.5	34.1
15	34.7	15.5	35.2
16	35.7	16.5	36.2
17	36.6	17.5	37.0
18	37.4	18.5	37.7
19	38.1	19.5	38.3
20	38.6	20.5	38.9

(3) Maturity-at-age

We assume that the fecundity is proportional to maturity. We use maturity–at-age based on biological data in the South Pacific Ocean by Farley et al (2012) (Table 5) and the estimation method by Hoyle (2008).

Table 5 Maturity-at-age based on Farley (2012) and Hoyle (2008)

Age	0	1	2	3	4	5	6	7	8	9	10	11	12+
Maturity –at-age	0	0	0	0	0.09	0.47	0.75	0.88	0.94	0.97	0.99	0.99	1

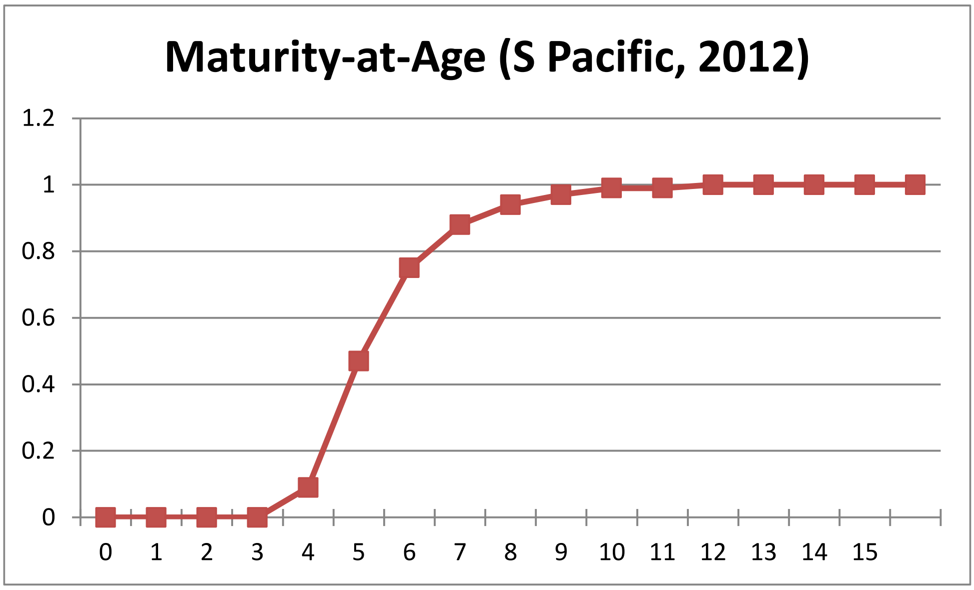


Fig. 21 Maturity-at-age (S Pacific) based on Hoyle (2008) and Farley (2012)

3. SCAA runs

3.1 Initial run

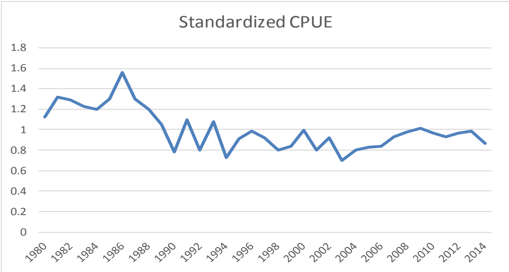
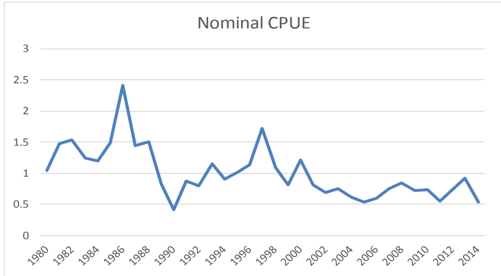
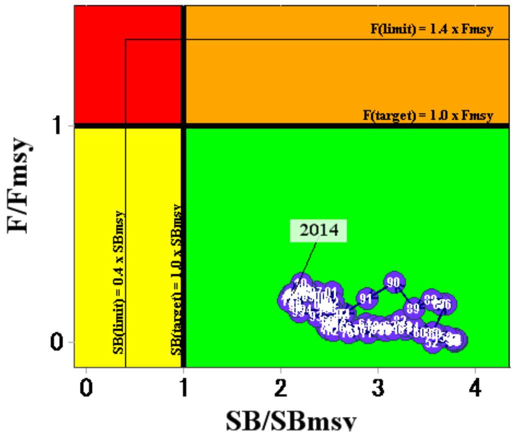
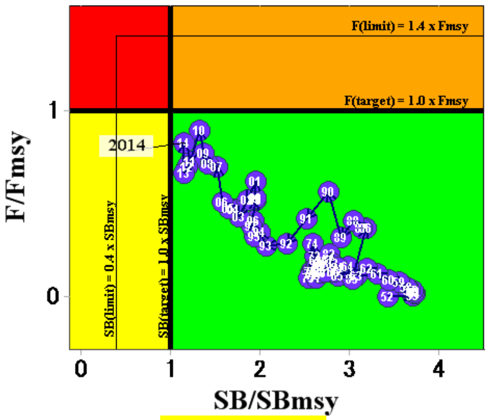
Using 4 fleets model, nominal and standardized LL CPUE of Taiwan,China (area core) and M=0.25 and 0.3, sigma (CAA)=0.5, Steepness=0.7, B0/K=1, we ran SCAA. However, SCAA stopped after the data were read and before program read.

After extensive investigations, we realized that GILL CAA (Taiwan,China) have only 10 years (1987-1992) thus no CAA after 1993, which caused this problem. The same problem was experienced in the ICCAT yellowfin tuna SCAA stock assessments just last month (Satoh et al., 2016). We plan to improve this problem in the near future.

3.2 Second runs

To solve this problem temporarily, we combined GILL and OTH, so that we can have CAA for all the period (1952-2014). However, selectivities in 3 period need to estimated, (a) 1952-1981 (OTH only), (b) 1986-1992 (GILL+OTH combined) and (c) 1993-2014 (OTH only).

After we re-set up the input data set, we re-attempted SCAA runs. Box 3 shows the results using Kobe plots. We consider that the best base case is with M=0.3 (Age 0-1) and M=0.25 (Age 2+-15) using nominal CPUE in the core area.

Box 3 Results of the SCAA base + selectivity runs (B0/K=1), Optimum parameters estimated : Sigma (CAA)=0.5 and steepness=0.7		
M	Standardized CPUE	Nominal CPUE
		
base 0.30	 Too optimstic (Implauisble)	Not converged
Sensi- tivity 0.3 (A01) 0.25 (A2- 15+)	Not converged	 most plausibl

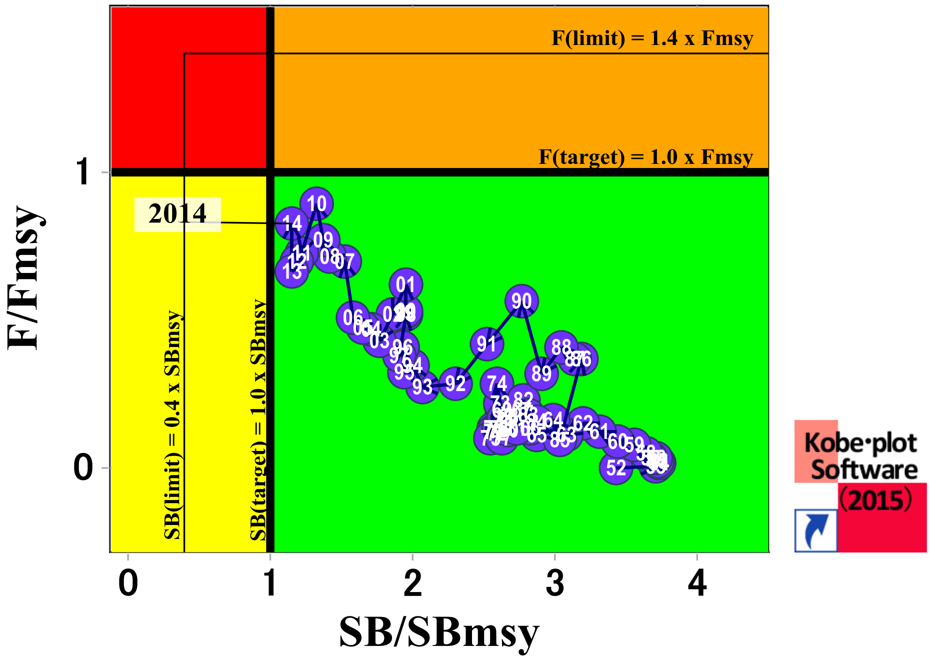
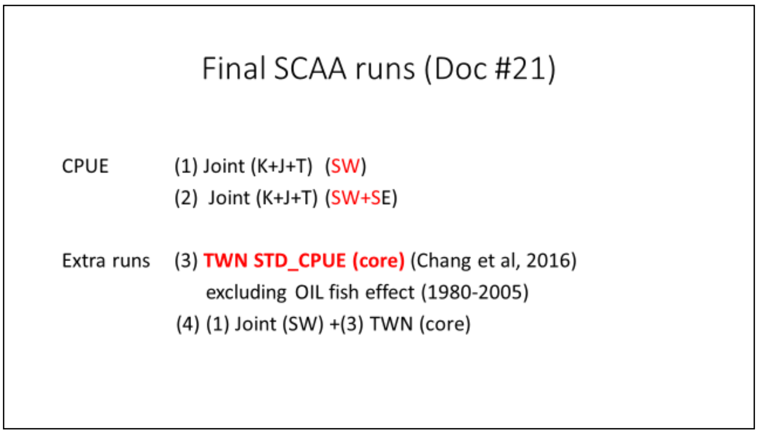


Fig. 22 Result of the (best) base case run

3.3 Final runs

After extensive discussion in the WPTmP06 meeting, it was agreed to use the joint CPUE in SW area (1979-2014) and SE area (1979-2005). This is because CPUE in SW area is not affected by high CPUE increase trends by Japan and Korea and CPUE in SE without 2006-2014 are also not affected as well. In addition, we made 2 additional runs with 2 different CPUE shown PowerPoint slides below. All the results are also shown in the following PowerPoint slides, Box 4 and Table 6. We consider that SCAA run (3) Taiwan standardized CPUE (core) with 1980-205 produce the best stock status. Please note that after the discussion in the meeting, there is no oil fisheries targeting effect in the core area thus they are not relevant in PowerPoints slides. However, we still think that recent CPUE levels are not certain, thus we tested the Taiwan CPUE without the recent years as planned in scenario (3) and (4).



Final SCAA runs (Doc #21)

Specs

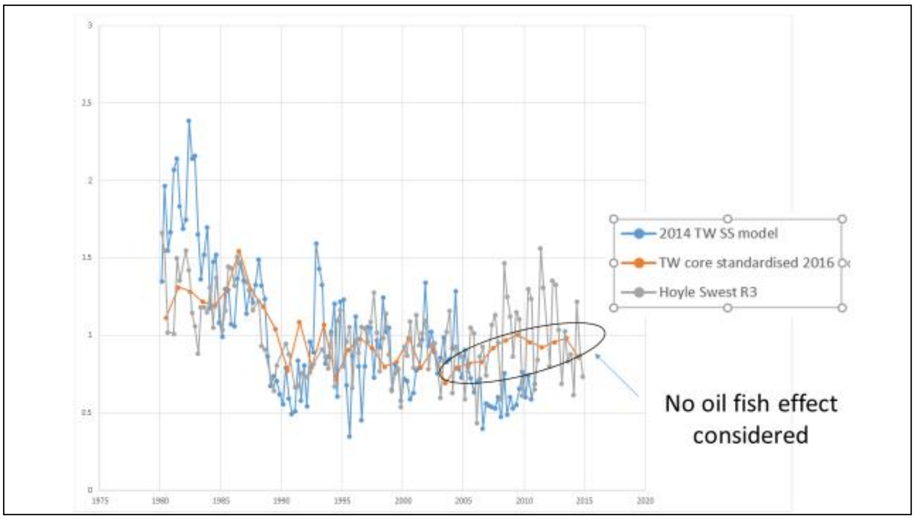
Grid search (96 runs)

- Steepness (4) 0.7+0.8+0.9
- Sigma R (4) 0.5+0.6+0.7+0.8
- Weighting CAA (3) 0.01+0.11+0.21

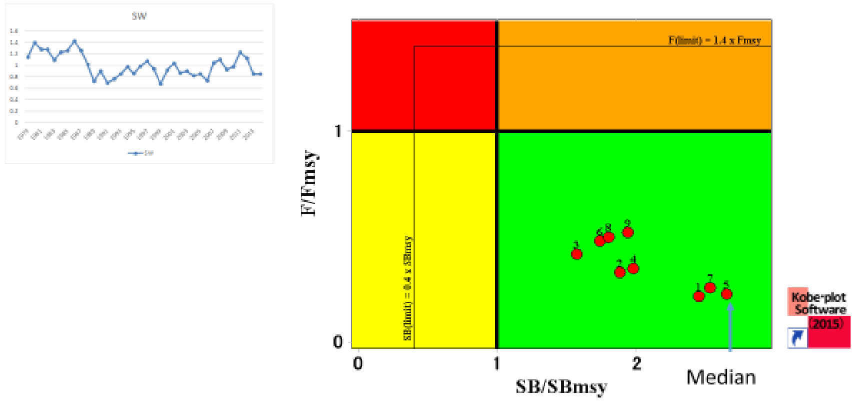
M 0.3 (age 0+1) and 0.25 (age 2-15+)

Incorporating (single) Taiwan CPUE effect

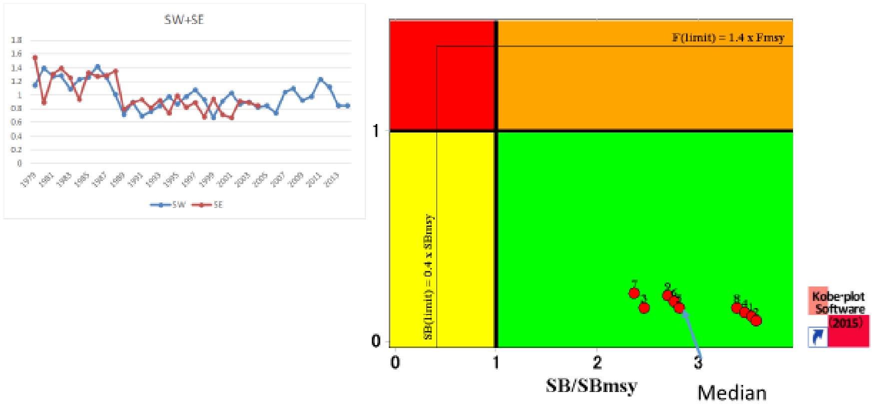
- Taiwan standardized CPUE (core) :
  ➔ **we consider the most plausible signals**
- Apply Taiwan standardized CPUE (core) by **Chang and Yeh (2016)** **without oil fish effect**



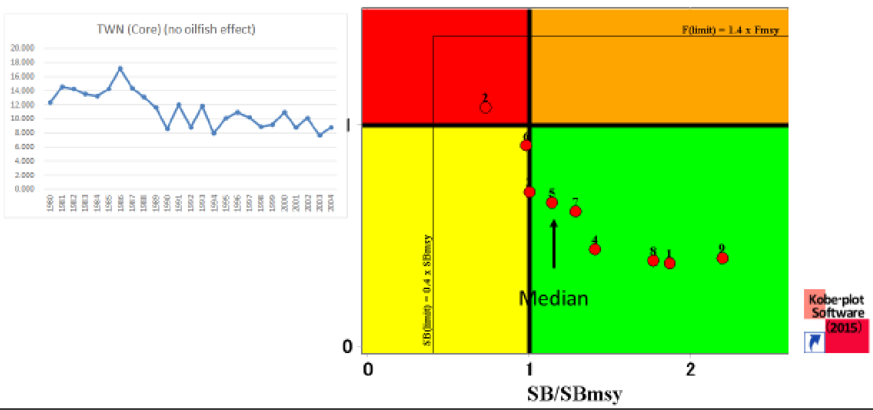
Results : (1) Joint CPUE (SW) (9 best runs)

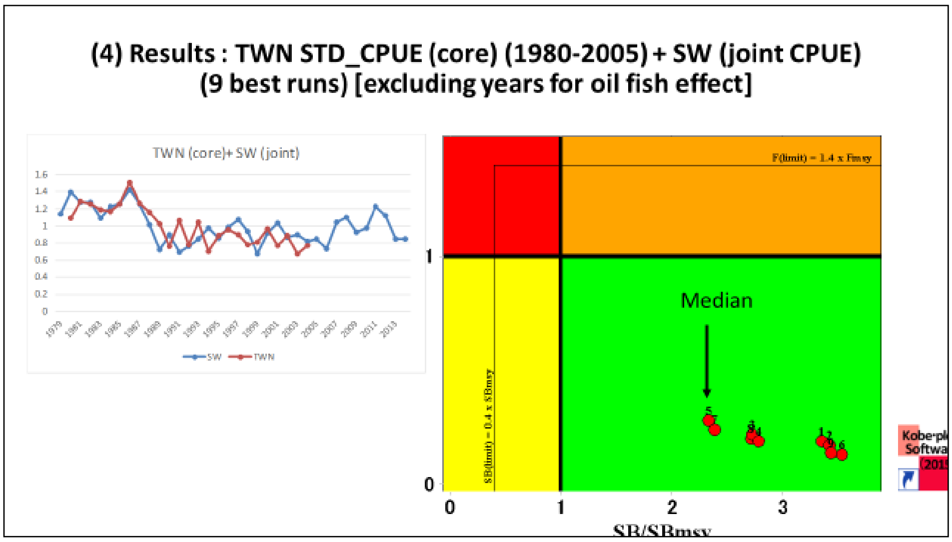


Results : (2) Joint CPUE (SW+SE) (9 best runs)

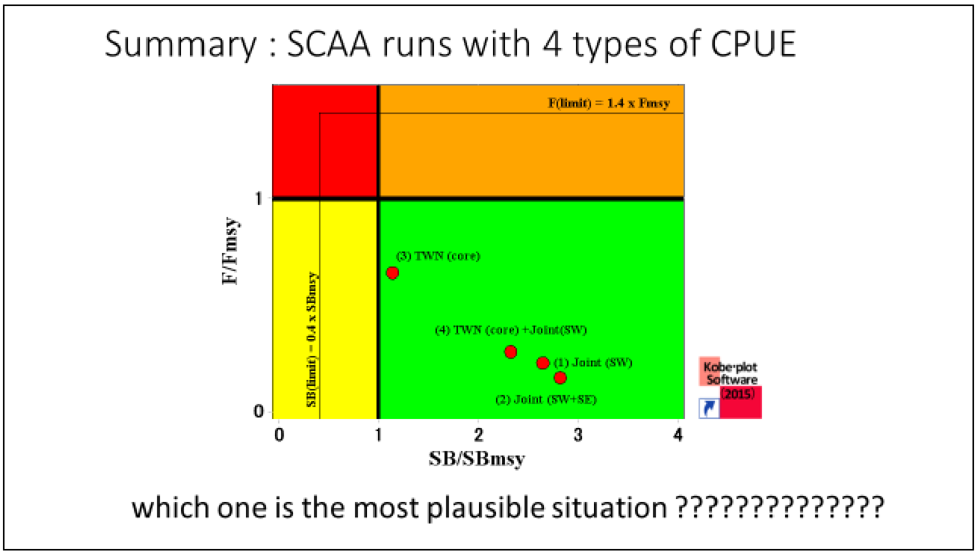


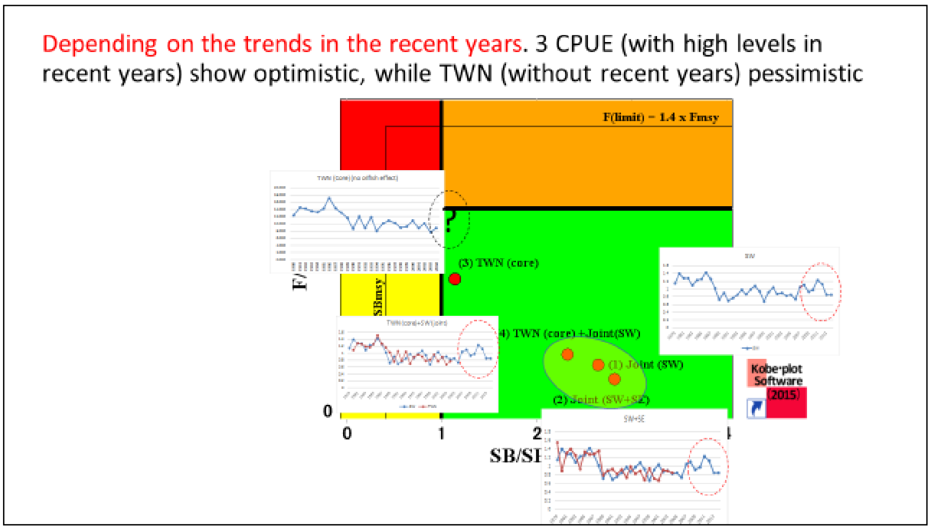
(3) Results : TWN STD_CPUE (core) (1980-2005) (9 best runs) [excluding years for oil fish effects]

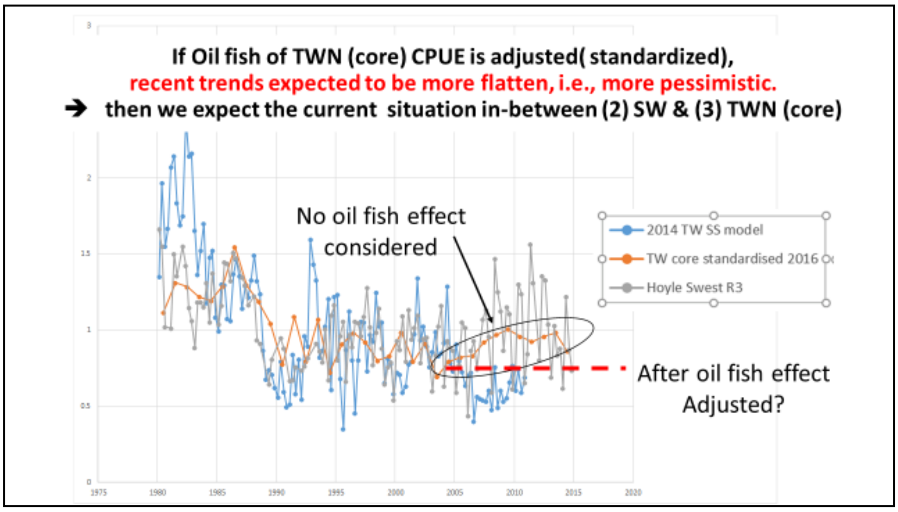


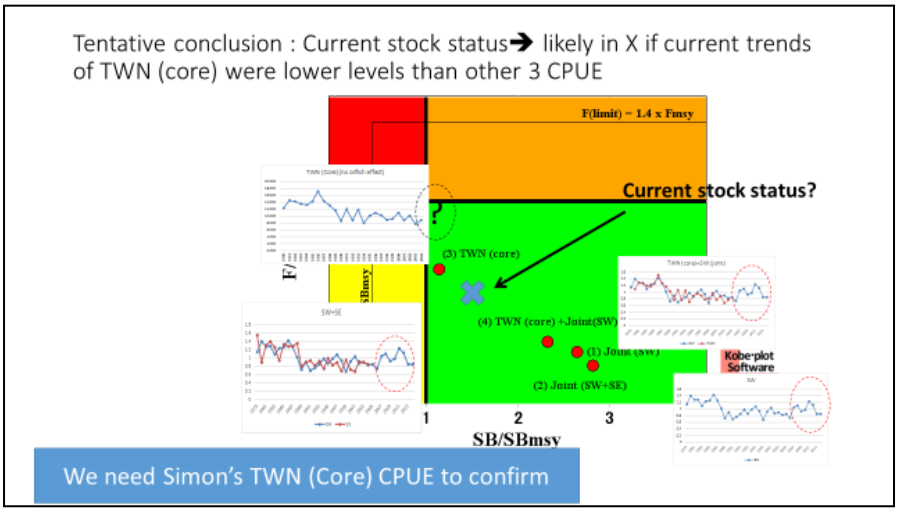


3.4 Summary and discussion







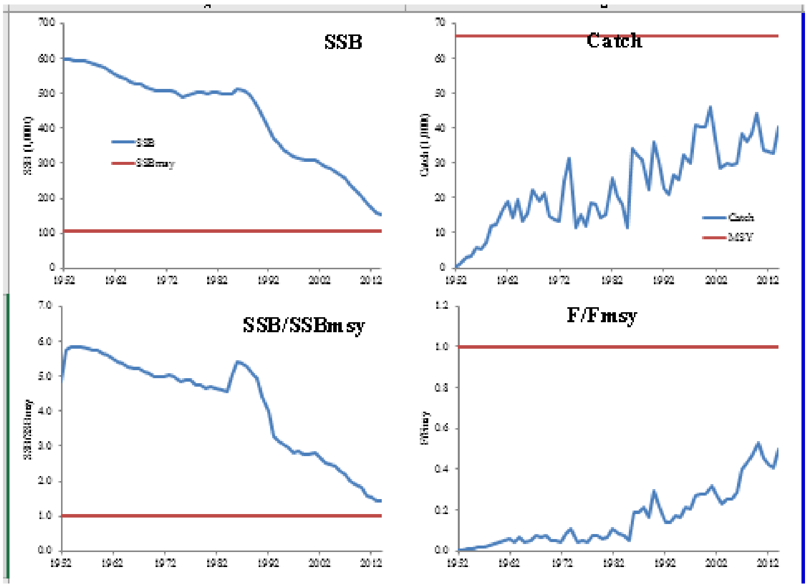


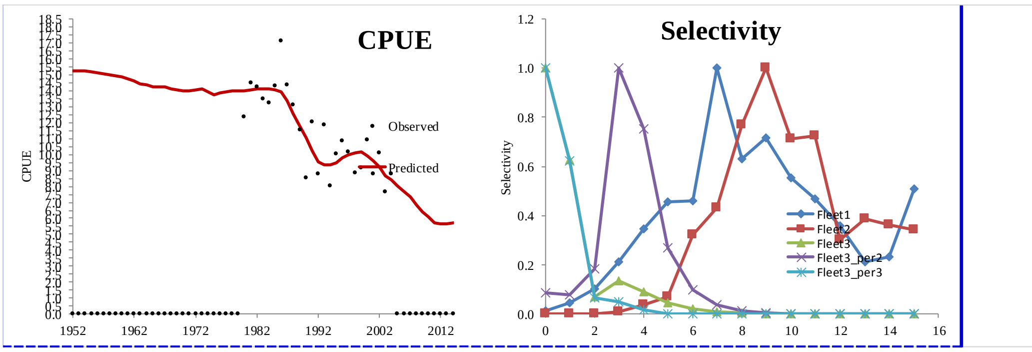
3.4 Results of final SCAA run

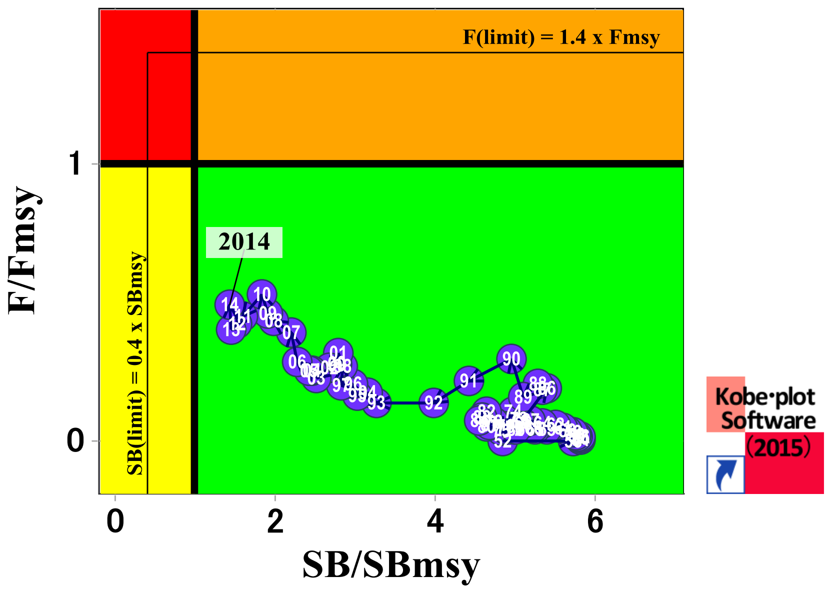
Table 6. Key management quantities from the SCAA assessment (scenario 3)

Management Quantity	Indian Ocean
2014 catch estimate	40,233
Mean catch from 2010–2014	36,855
MSY (1000 t) (80% CI)	59.0 (n.a.)
Data period used in assessment	1952–2014
F_{MSY} (80% CI)	0.65 (n.a.)
B_{MSY} (1000 t) (80% CI)	106 (n.a.)
F_{2014}/F_{MSY} (80% CI)	0.65 (n.a.)
B_{2014}/B_{MSY} (80% CI)	(n.a.)
SB_{2014}/SB_{MSY}	0.68
B_{2014}/B_{1950} (80% CI)	1.14 (n.a.)
SB_{2014}/SB_{1952}	0.26
$B_{2014}/B_{1952, F=0}$	n.a.
$SB_{2014}/SB_{1952, F=0}$	n.a.

Box 4 Results of the final SCAA run (Scenario 3)







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We sincerely thank to James Geehan and Fabio Fiorellato, Data section (IOTC) for providing nominal catch and Catch-At-Age (CAA) of albacore tuna in the Indian Ocean. We also appreciate Alain Fonteneau (Emeritus scientist, IRD and UMR MARBEC, France) and Rebecca Rademeyer (University of Cape Town, South Africa) provide useful technical suggestions.

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