Review of Indian Ocean albacore biological parameters for stock assessments

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Abstract

We reviewed the stock structure and seven biological parameters of ALB (albacore) for IOTC stock assessments by Stock Synthesis (SS3), Statistical-Catch-At-Size (SCAS) etc. to be conducted in July 2019 during WPTmT07 in Japan. Seven types of biological parameters are (1) sex ratio, (2) LW relation, (3) growth equation, (4) life span, (5) natural mortality, (6) fecundity and (7) maturity-at-age. In this review, we referred to parameters used in ISC and three RFMOs (ICCAT, WCPFC and IOTC) in the past. New biological information in the western Indian Ocean derived by Dhurmeea et al (2016) (Sex ratio, LW relation and Maturity-at-age) and Farley et al (2019) (growth equation) is included for reviews and discussions. During this data preparatory meeting for WPTmT07 in January 2019 in Kuala Lumpur, Malaysia, we will evaluate and select the most feasible parameters for IOTC ALB stock assessments used as a base case and a sensitivity in stock assessments. We provided our suggestion, but the final decision will be made during this data preparatory meeting.

Contents

1. Introduction

IOTC will conduct stock assessments for ALB (albacore) in the WPTmP07 on July 22-25, 2019 (Japan) for the first time in three years since the last assessments in 2016. Before the July meeting, IOTC will have a "data preparatory meeting" for WPTmT07 in January 2019 in Kuala Lumpur, Malaysia as the first attempt in the IOTC history and plan to discuss biological input data for stock assessments. For this opportunity, we reviewed the stock structure and seven types of biological parameters for stock assessments. Seven types of biological parameters are (1) sex ratio, (2) LW relation, (3) growth equation, (4) life span, (5) natural mortality, (6) fecundity and (7) maturity-at-age. In the review, we referred to parameters used in ISC and three RFMOs (ICCAT, WCPFC and IOTC) in the past. New biological information in the western Indian Ocean studied by Dhurmeea et al (2016) (sex ratio, LW relation and Maturity-at-age) and Farley et al (2019) (Growth equation) is included for discussion. During this data preparatory meeting, we will evaluate and select the most feasible parameters for ALB stock assessments as a base case and a sensitivity.

2. Reviews

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 stock in its eastern and western end respectively. Nevertheless, we suggest the single stock hypothesis for the 2019 stock assessment as in the past.

2.2 Biological parameters

(1) Sex ratio

It has been reported that sex ratio of immature ALB is approximately 1:1, while for mature, the male ratio is higher than female by ISC (2017), ICCAT (2014), WCPFC (2018) and Dhurmeea *et al* (2016) (western Indian Ocean) (Figs. 1 and 2). In ISC, WCPFC and ICCAT, due to sampling problems, 1:1 sex ratio had been used for stock assessments. IOTC also used 1:1 in the past. But we have new information from Dhurmeea et al (2016) and we need to evaluate if we can use the heterogenous sex ratios.

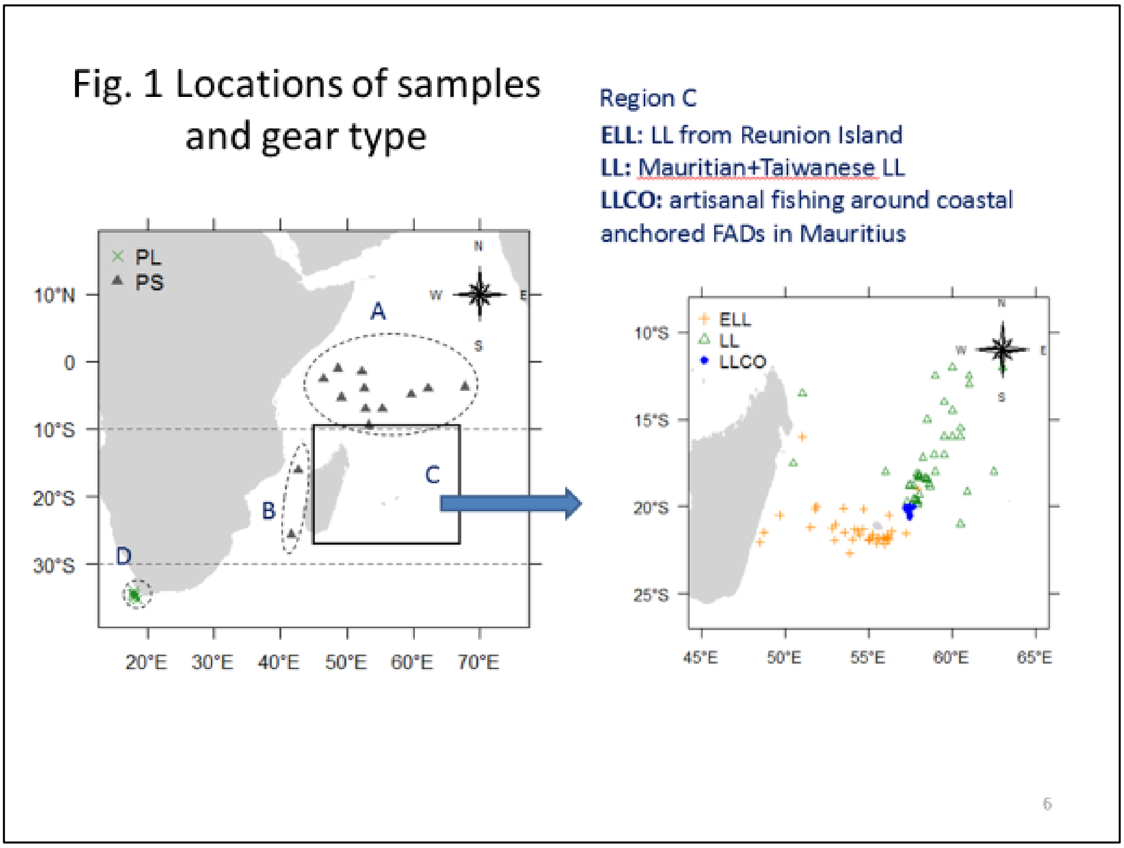


Fig. 1 Locations of samples and gear type
Region C
ELL: LL from Reunion Island
LL: Mauritian+Taiwanese LL
LLCO: artisanal fishing around coastal anchored FADs in Mauritius
PL
PS
A
B
C
D
10°N
0
10°S
20°S
30°S
20°E 30°E 40°E 50°E 60°E 70°E
ELL
LL
LLCO
10°S
15°S
20°S
25°S
45°E 50°E 55°E 60°E 65°E
6

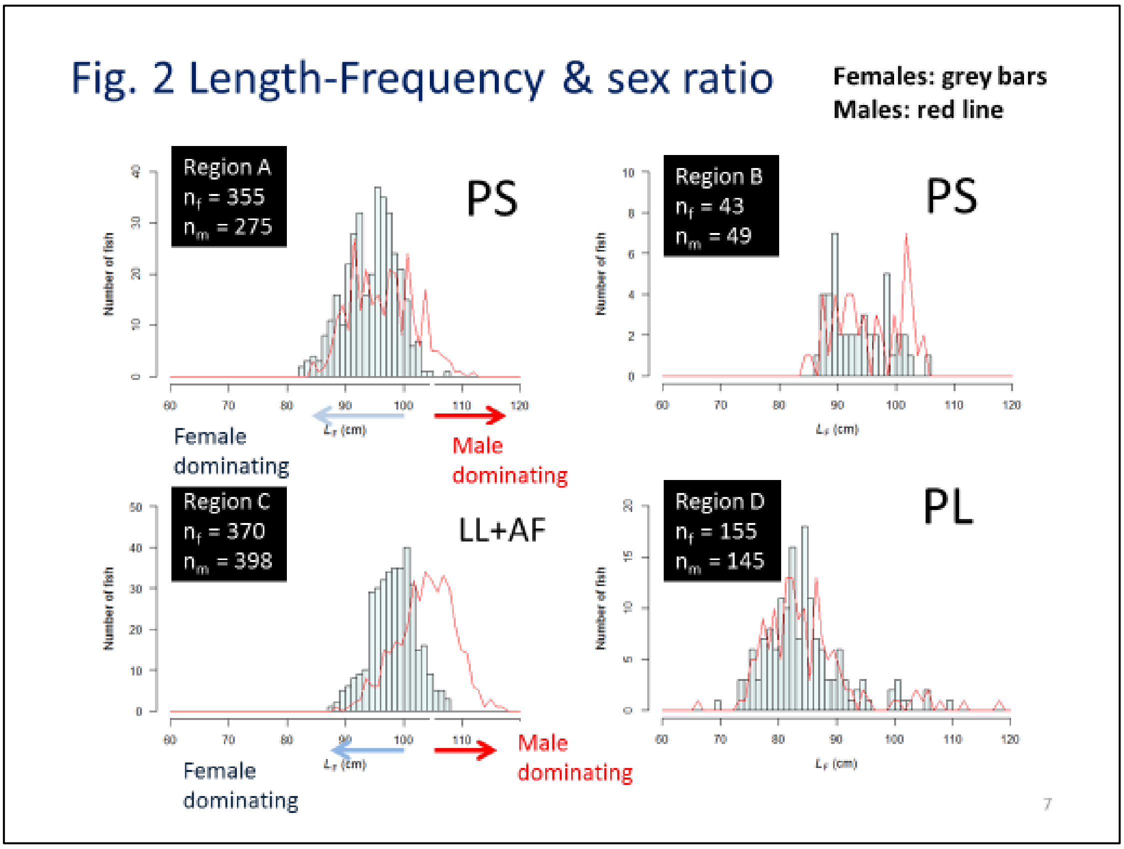


Fig. 2 Length-Frequency & sex ratio
Females: grey bars
Males: red line
Region A
n_f = 355
n_m = 275
PS
Region B
n_f = 43
n_m = 49
PS
Female dominating
Male dominating
Region C
n_f = 370
n_m = 398
LL+AF
Region D
n_f = 155
n_m = 145
PL
Female dominating
Male dominating
Number of fish
L_F (cm)
7

(2) LW relation

Table 1 and Fig. 3 show the LW relations by Ocean and fisheries. In the Indian Ocean, the LW relation in the South Atlantic Ocean was applied in the last stock assessment in 2016. This is because the LW relations in the Indian Ocean was based on the data from gillnet only, with the limited size ranges, thus they were not applied in the past stock assessments.

Hence the LW relation from South Atlantic Ocean adjacent to the Indian Ocean (possible intermingling in the bordering waters) is considered to be plausible. The new LW relation by sex was reported by Dhurmeea et al (2016) using samples collected in the western Indian Ocean which are similar to the one in the eastern Indian Ocean by Setyadi et al (2012). However, as shown in Table 2, size ranges in the Indian Ocean are limited especially for the lower bound which may produce biases in LW equations, while those for N and S Atlantic are fully covered thus they are considered to be less biased. Therefore, we suggest using the one from S Atlantic again.

Table 1 Summary of LW relation by Ocean (tuna RFMO) and fisheries

Ocean	Equations W: Round weight (kg) L: Fork length (cm)	Authors (year)	Type of gear, ranges and n (sample size)	Assessment year (RFMO) and models **Red: most recent one**
Indian	$W = (5.6907 \times 10^{-5}) * L^{2.75140}$	Hsu (1999)	Gillnet (n=2,499) (46-112 cm)	2012 (IOTC) SS3+ASPM
	$W = (8.0000 \times 10^{-5}) * L^{2.27271}$	Setyadi et al (2012)	Eastern LL (n=497) (83-106cm)	
	[♂] $W = (4.3378 \times 10^{-6}) * L^{3.3551}$	Dhurmeea et al (2016) (Western IO)	All (n= 702) (67-118cm)	
	[♀] $W = (1.7551 \times 10^{-6}) * L^{3.5625}$		All (n= 814) (70-110cm)	
	[♂+♀] $W = (3.2537 \times 10^{-6}) * L^{3.4240}$		All (1,516) (67-118cm)	
N. Atlantic	$W = (1.3390 \times 10^{-5}) * L^{3.1066}$	Santiago (1993)	All (n=714) (42-117cm)	2013・**2016 (ICCAT) SS3 MFCL and VPA+2BOX**
S. Atlantic	$W = (1.3718 \times 10^{-5}) * L^{3.0973}$	Penney (1994)	All (n=1,008) (46-118cm)	**2016 (IOTC) SS3＋SCAA**
N. Pacific	$W = (8.7000 \times 10^{-5}) * L^{2.6700}$	Watanabe *et al.* (2006)	All (Japan + USA + Taiwan) (1989-2004)	2011・**2017 (ISC) SS3 + VPA-2BOX**
S. Pacific	$W = (0.69587 \times 10^{-5}) * L^{3.2351}$	Hampton (2002)	All	2012 ・**2018 (WCPFC) MFCL**

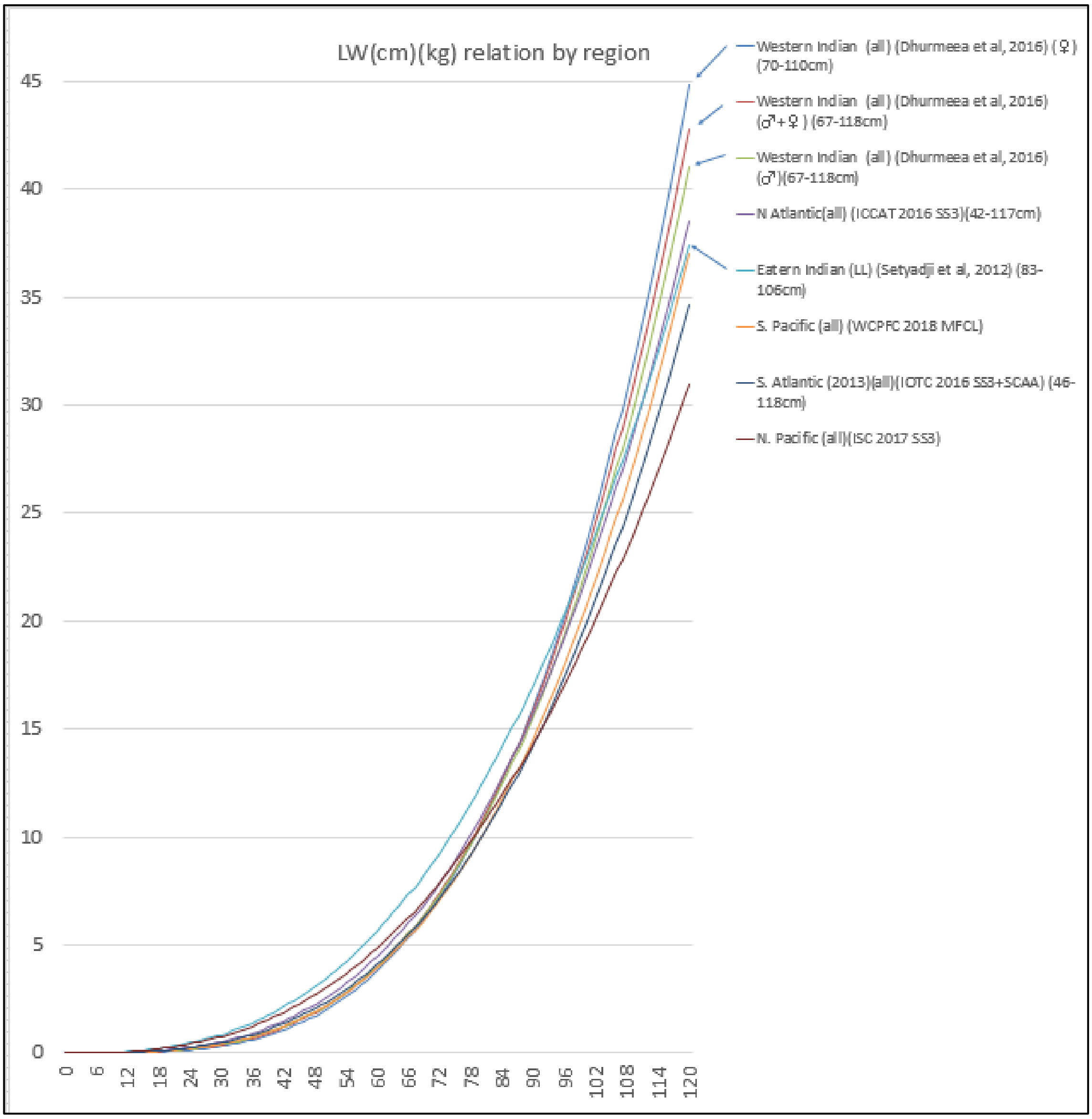


Fig. 3 LW relation by region

Table 2 Size ranges used for LW relation by region

cm	Western Indian (all) (Dhurmeea et al, 2016) (♂)(67-118cm)	Western Indian (all) (Dhurmeea et al, 2016) (♀) (70-110cm)	Eatern Indian (LL) (Setyadji et al, 2012) (83-106cm)	N Atlantic(all) (ICCAT 2016 SS3)(42-117cm)	S. Atlantic (2013)(all)(IOTC 2016 SS3+SCAA) (46-118cm)
0					
2					
4					
6					
8					
10					
12					
14					
16					
18					
20					
22					
24					
26					
28					
30					
32					
34					
36					
38					
40					
42					
44					
46					
48					
50					
52					
54					
56					
58					
60					
62					
64					
66					
68					
70					
72					
74					
76					
78					
80					
82					
84					
86					
88					
90					
92					
94					
96					
98					
100					
102					
104					
106					
108					
110					
112					
114					
116					
118					
120					
122					
124					
126					

(3) Growth equation

Table 3 lists equations by Ocean and Fig. 4 compares the growth curves used in the most recent stock assessments among different tuna RFMOs. There are a few studies on growth equations in the Indian Ocean (Table 3) in the past. But they are based on scales, spines and size frequency. As growth equations based on otolith are preferable, in the last IOTC stock assessment in 2016, the growth equation based on otolith from North Pacific Ocean by sex (Xu *et al* 2014) was used for SS3 and the sex-combined one by Well *et al* (2013) for SCAA. There is the new study by Farley et al (2019) based on otolith collected in the western Indian Ocean (Seychelles, South Africa, Reunion and Mauritius). Although the results are promising, it was suggested that sample of smaller size (< 75cm) are needed to estimate more plausible growth equation. Thus, we suggest not to apply this equation for this time and wait until the plausible one developed using size (< 75cm). Therefore, we suggest using the growth equation (based on otolith) by Xu et al (2014), same one as in the previous stock assessment (2016).

Table 3 Summary of growth equations by Ocean (tuna RFMO), range, n and method

<table>
<tr><td>Ocean</td><td>Equations
L: fork length(cm) t: year</td><td>Range(cm)
Sample size
(n)</td><td>Authors
(year)</td><td>Estimation
method</td><td>Assessment year
(RFMO) models
Red: most recent one</td></tr>
<tr><td rowspan="6">Indian</td><td>$L(t)=128.13\ [1-e^{-0.1620\ (t+0.8970)}]$</td><td>65-106
(n=227)</td><td>Huang et al.
(1990)</td><td>Scale patterns</td><td rowspan="3"></td></tr>
<tr><td>$L(t)=163.70\ [1-e^{-0.1019\ (t+2.0668)}]$</td><td></td><td>Lee + Liu (1992)</td><td>Vertebrate rings</td></tr>
<tr><td>$L(t)=136.00\ [1-e^{-0.1590\ (t+1.6849)}]$</td><td></td><td>Hsu (1991)</td><td>Size frequency</td></tr>
<tr><td>$L(t)=147.50\ [1-e^{-0.1260\ (t+1.8900)}]$</td><td>51-131
(n=469)</td><td>Lee and Yeh
(2007)</td><td>Spine and
Vertebra</td><td>2012 (IOTC)
SS3+ASPM</td></tr>
<tr><td>$L(t)=113.7\ [1-e^{-0.194\ (t+8.39)}]$</td><td>97-120
(n=106)</td><td>Cheng et al
(2012)</td><td>Dorsal
spine</td><td></td></tr>
<tr><td colspan="2">
<table>
<tr><th>MODEL</th><th>SEX</th><th>n</th><th>L_∞</th><th>k</th><th>b</th><th>t_0</th></tr>
<tr><td>VB</td><td>F</td><td>251</td><td>103.8
(0.77)</td><td>0.38
(0.03)</td><td>-</td><td>-0.86
(0.33)</td></tr>
<tr><td>Richards</td><td>F</td><td>334</td><td>103.4
(0.71)</td><td>0.43
(0.04)</td><td>3784.4
(NA)</td><td>-0.16
(0.27)</td></tr>
<tr><td>VB</td><td>M</td><td>251</td><td>110.6
(0.81)</td><td>0.34
(0.02)</td><td></td><td>-0.87
(0.25)</td></tr>
<tr><td>Richards</td><td>M</td><td>334</td><td>110.0
(0.73)</td><td>0.39
(0.03)</td><td>1494.1
(339.7)</td><td>0.02
(0.19)</td></tr>
</table>
</td><td>Farley et al
(2019)</td><td>Otolith</td><td></td></tr>
<tr><td rowspan="2">N
Pacific</td><td>$L(t)=124.10\ [1-e^{-0.164\ (t+2.2390)}]$</td><td>52-128</td><td>Well et al
(2013)</td><td>Otolith</td><td>2014 (ISC) SS3
2016 (IOTC) SCAA</td></tr>
<tr><td>[♂]
$Lt = 119.15 + (47.563 – 119.15)\ e^{(-0.20769*(t-1))}$
[♀]
$L(t) = 106.57 + (43.504 – 106.57)\ e^{(-0.29763*(t-1))}$
[♂+♀]
$L(t) = 112.379 + (45.628 – 112.38)\ e^{(-0.2483*(t-1))}$</td><td></td><td>Xu et al (2014)
(base on
Chen- Wells
equations)</td><td>Otolith</td><td>Equation by sex
(1) 2017 (WCPFC)
N Pacific: SS3
(2) 2018 (WCPFC)
S Pacific: MFCL
(3) 2016(IOTC) SS3</td></tr>
<tr><td rowspan="2">S
Pacific</td><td>$L(t)=121.00\ [1-e^{-0.1340\ (t+1.9220)}]$</td><td>44-110</td><td>Labelle et al.
(1993)</td><td>Vertebrate rings</td><td>2011 (WCPFC)
MFCL</td></tr>
<tr><td colspan="3">Growth equation estimated by MFCL
with L1 parameter (length at which individuals first enter the fishery) of 34.2 cm
and sex-combined growth equation by Williams et al. (2012)</td><td></td><td>2018(WCPFC)
MFCL</td></tr>
<tr><td rowspan="2">N
Atlantic</td><td>$L(t)=124.74\ [1-e^{-0.2300\ (t+0.9892)}]$</td><td>46-113</td><td>Bard (1981)</td><td>Spine (n=352)</td><td>2016 (ICCAT)
SS3+ MFCL</td></tr>
<tr><td>$L(t)=127.10\ [1-e^{-0.2300\ (t+0.9892)}]$</td><td>40-119</td><td>Santiago et al
(2005)</td><td>Spine</td><td></td></tr>
<tr><td>S
Atlantic</td><td>$L(t)=147.50\ [1-e^{-0.1260\ (t+1.8900)}]$</td><td>51-131
(n=469)</td><td>Lee and Yeh
(2007)</td><td>Spine and
Vertebra</td><td>not used as production
models were applied</td></tr>
</table>

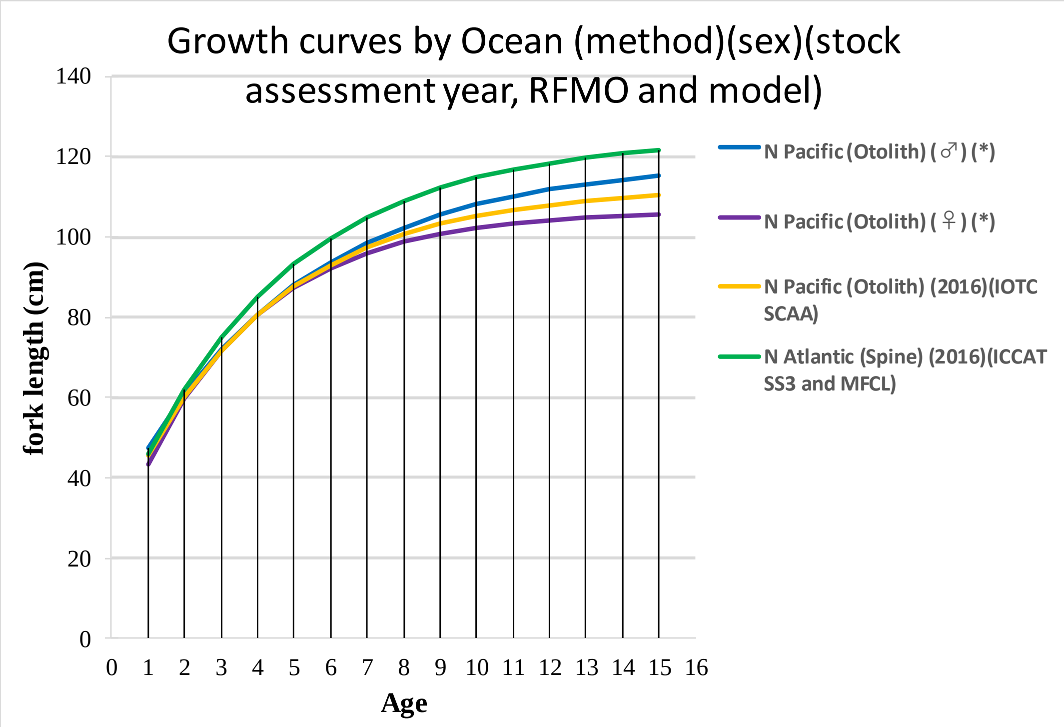


Fig.4 Growth equation by Ocean and RFMO

(RFMO used for stock assessment in the most recent years and the model names)

(4) Life span

Table 4 shows the life span and + group age and Fig. 5 depicts the life span by Ocean (tuna RFMO). There are large discrepancies in life spans among Oceans (tuna RFMOs). According to the tag recovery information, Age 16 is recorded as the maximum one (Table 4), thus age 8 (N Atlantic) may be too short. Therefore, Age 14+ and 15+ (IOTC and N. Pacific) are likely most plausible.

Table 4 Summary of life spans and + group age by Ocean (tuna RFMO)

Ocean	Life span (years old)	Authors (year)	Method	Assessment year (RFMO) Stock assessment models **(red: most recent assessments)**
Indian	8	Huang *et al.* (1990)	Scale	Not used in assessment
	10	IOTC (2012)		2012 (IOTC) SS3+ASPM
	14	IOTC (2016)		**2016 (IOTC) SS3**
	15			**2016 (IOTC) SCAA**
N. Atlantic	8	ICCAT (2013)		2013+**2016 (ICCAT) MFCL, VPA+2BOX and SS3**
S. Atlantic				Not used in assessment
N. Pacific	16	Anon (2013)	Tagging (based on the long-term recovery)	Not used in assessment
	14			2011 +**2017 (ISC) SS3 + VPA-2BOX**
S. Pacific	11		Tagging (based recovery data)	Not used in assessment
	12			2012+**2018 (WCPFC) MFCL**
	14		Otolith	Not used in assessment

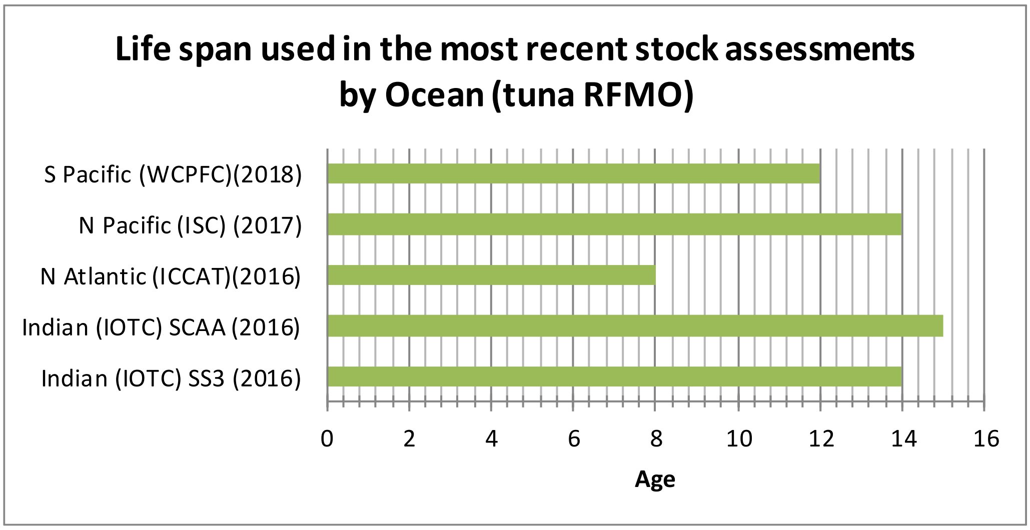


Fig.5 Life span used in the most recent stock assessments by Ocean (tuna RFMOs)

(5) Natural mortality

Table 5 and Fig. 6 show natural mortality (M) by age, sex and RFMO used in the most recent stock assessments. Fig. 7 shows M used in IOTC stock assessments (2016) indicating both base case and two sensitivities. As explained in the note (Table 5), M=0.3 is unlikely plausible. As M=0.3 was used in the last assessment in IOTC (2016), we may need to explore another M.

Table 5 M by age, sex and RFMO used in past stock assessments.

Ocean	Parameters ( ) selectivity	Authors (year)	Estimation method	Assessment year (RFMO) Stock assessment models **(red: most recent assessments)**
Indian (IOTC)	0.2207 (0.4)	Lee and Liu (1992)	Estimated by Z=q*F+M using LL data	2012(IOTC) SS3 and ASPM
	0.2060	Lee *et al.* (1990)	Pauly (1980) method (using temperature)	
	0.3 (0.2207 and hybrid)	(N Atlantic and N Pacific)		**2016 (IOTC) SS3+SCAA**
N. Atlantic (ICCAT)	0.3 (age 0-14) (0.63; 0.46; 0.38; 0.34; 0.31; 0.29; 0.31; 0.34; 0.38; 0.44; 0.55; 0.55; 0.55; 0.55; 0.55)	Santiago (2004)	M is from SPC (2003) and M by age is estimated by Chen and Watanabe (1988) using the Bard's method	2013 + **2017 (ICCAT) SS3,** MFCL, SS3 and VPA+2BOX
	Age 0-2 Male age 3+; 0.39 Female 3+: 0.48			
N. Pacific (ISC)	0.3	Watanabe et al (2006)		2011 (ISC) SS3 + VPA-2BOX 2014 (ISC) SS3
	Female Male Age 0: 1.36 1.36 Age 1: 0.56 0.56 Age 2: 0.45 0.45 Age-3+: 0.48 0.39	Teo (2017a)	(*) (see note below)	**2017(ISC) (SS3)**
S. Pacific (WCPFC)	0.4 (0.3 and 0.5)	Hoyle et al (2012)		2012 (WCPFC) MFCL
	0.3 (0.2, 0.4 and 0.5)	Tremblay-Boyer et al (2018)		**2018 (WCPFC) MFCL**

(*) (note) (quoted from ISC, 2017)

In previous assessments, M was assumed to be 0.3 y-1 for both sexes at all ages but this assumption was not well supported (Kinney and Teo 2016). For this assessment, the ALB-WG (ISC) incorporated results from studies that used meta-analytical methods on a range of empirical relationships between M and life history parameters, which identified an M of 0.38 and 0.49 y-1 for adult male and female albacore tuna, respectively. These results corresponded well to an independent study of tagging data, which estimated a non-sex-specific M of 0.45 – 0.5 y-1 for north Pacific albacore. Based on these results, the ALB-WG assumed that the M of juvenile north Pacific albacore tuna followed a Lorenzen (1996) relationship between size and M for age-0 to age-2, with no difference between the sexes until age-3+. Upon reaching age-3, the M for male albacore is assumed to be 0.38 y-1 and the M for female albacore is assumed to be higher, reaching 0.49 y-1, which may reflect the cost of reproduction.

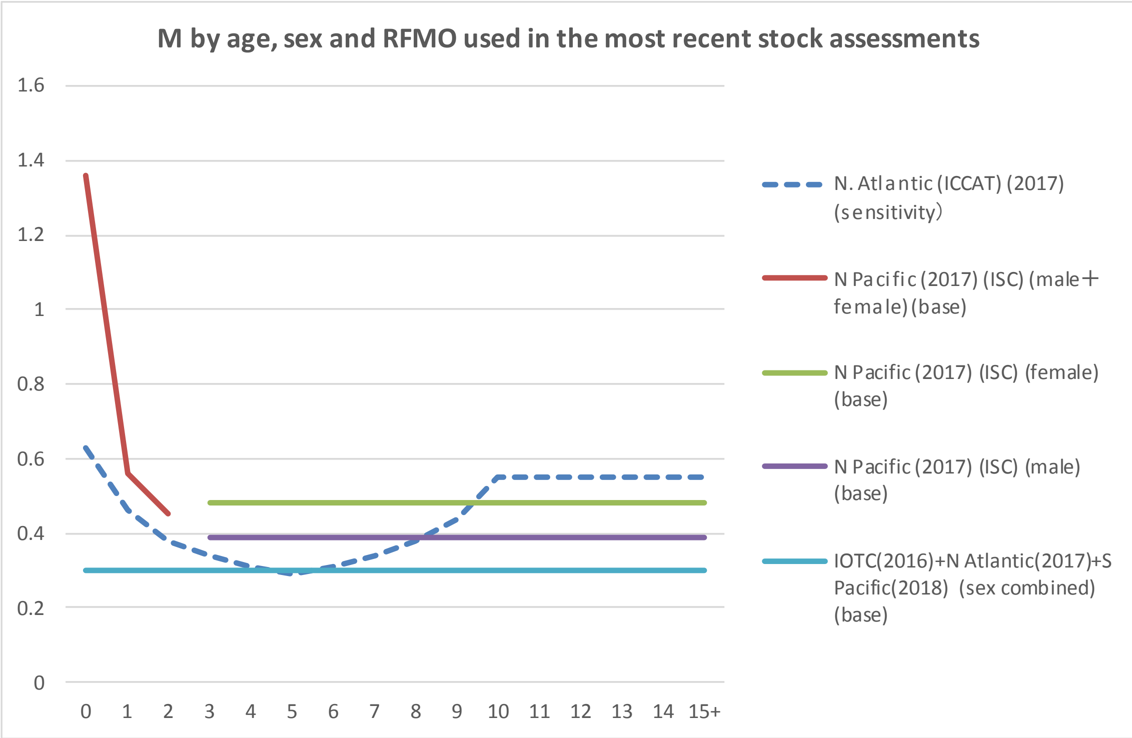


Fig. 6 M by age, sex and RFMO used in the most recent stock assessments

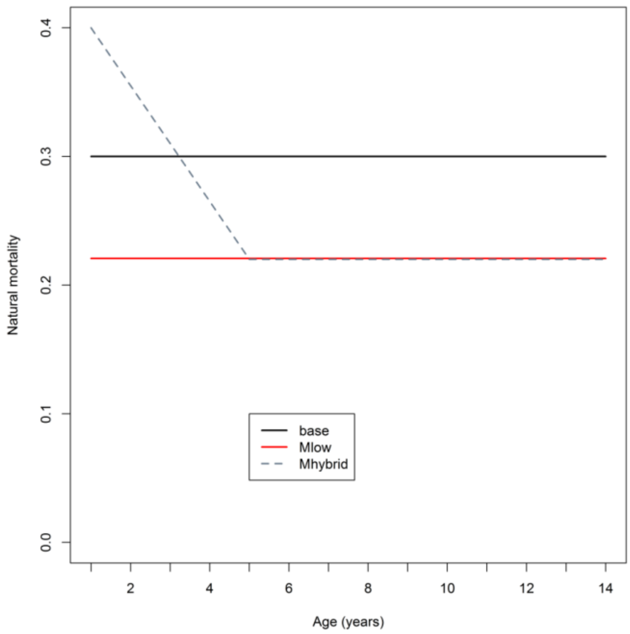


Fig. 7 M used in the last stock assessments (SS3 and SCAA) in IOTC (2016)
Base case M=0.3 and two sensitivities (0.2207 and hybrid between 0.4 and 0.227)

(6) Fecundity-at-age

It is assumed that fecundity is proportional to female weight at age.

(7) Maturity-At-Age

Table 6 and Fig. 8 show the summary of Maturity-At-Age information by Ocean (tuna RFMO). In the most recent stock assessments, two types of maturity-at-age were used i.e., (a) 0 (age <=4), 0.5 (age=5) and 1.0 (age =>6) by Bard (1981) (N. Atlantic) were used in MFCL and SS3 (ICCAT) and (b) Age specific maturity-at-age developed by Farley et al (2012) (S. Pacific) covering large samples in S Pacific, were used in SS3 (WCPFC, 2018) and in SS3 and SCAA (IOTC, 2016).

There is new maturity-at-size by Dhurmeea et al (2016) (Fig. 9), which was presented in the last WPTmT06. The WPTmT report was noted that length at maturity (L50), appears to be smaller than the one in other oceans, although additional samples are needed for a longer time-period to confirm the findings of the study, as well as the extent of temporal variation in the data. However, results of the growth analyses for WIO by Farley et al (2019) suggests that growth differences between males and females arise as from around 85 cm FL which actually corresponds to their length-at-maturity. So, it is very highly likely that 85 cm FL is the appropriate L50 for the WIO ALB. Farley et al (2019) also made a preliminary estimate of age-at-maturity. However, due to the lack of small fish for the analysis, we suggest re-using the one by Farley et al (2012) as a base case and the one by Dhurmeea et al (2016) and Farley et al (2019) as a sensitivity.

Table 6 Summary Maturity-at-age by Ocean (tuna RFMO)

Ocean	Parameters	Authors (year)	Assessment year (RFMO) Stock assessment models **(red: most recent assessments)**
Indian	0 (age <=3), 0.25 (age=4), 0,5 (age=5), 0.75 (age 6) and 1 (age =>7)	Anon (2012)	2012 (IOTC) SS3+ASPM
	0.5 (85cm) age 3.2 if the growth eq. by Farley et al (2019) is applied.	Dhurmeea et al (2016); Farley et al (2019) Western Indian Ocean	
N. Atlantic	0 (age <=4), 0.5 (age=5) and 1.0 (age =>6)	Bard (1981)	2013+**2016 (ICCAT) MFCL and SS3**
N. Pacific			2011・**2017 (ISC) SS3**
S. Pacific	0, 0, 0, 0, 0.089, 0.466, 0.746, 0.881, 0.944, 0.973, 0.987, 0.994, 0.997 and 1 for older ages	Biological data by Farley et al (2012) and derived by the method by Hoyle (2008)	2012・**2018 (WCPFC) MFCL** **2016 (IOTC)** **SS3+SCAA**
	0 (age<=4), 0.23 (age 5), 0.57 (age=6), 0.88 (age=7) and 1 (age=> 8)	Anon (2011)	2011 (ISC) SS3

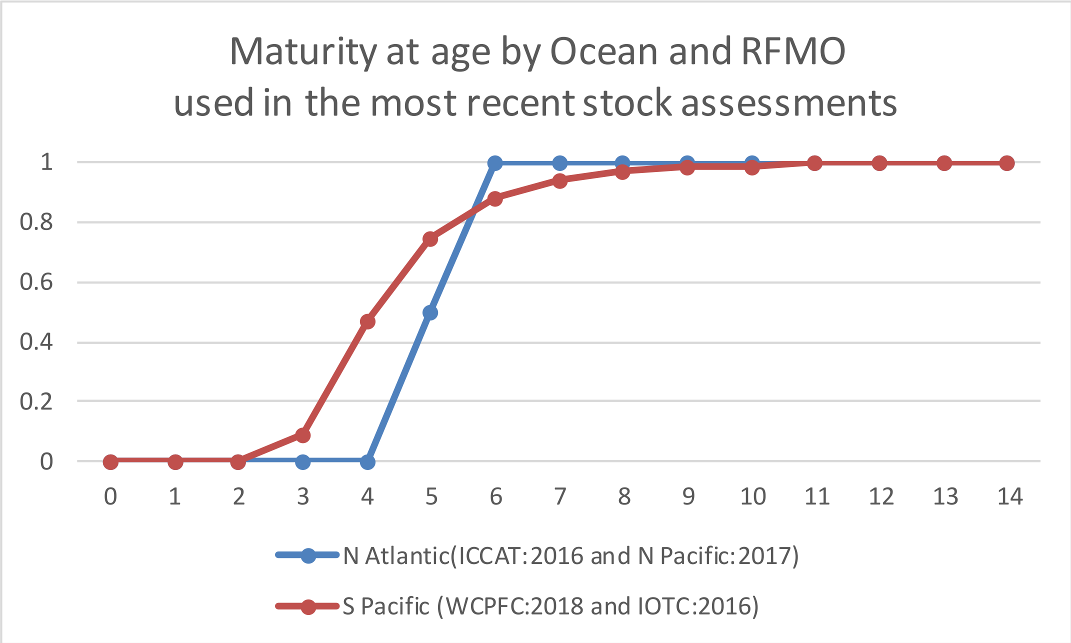


Fig.8 Maturity-at-age by Ocean (tuna RFMO)
S Pacific one used by WCPFC (2018) and IOTC (2016)

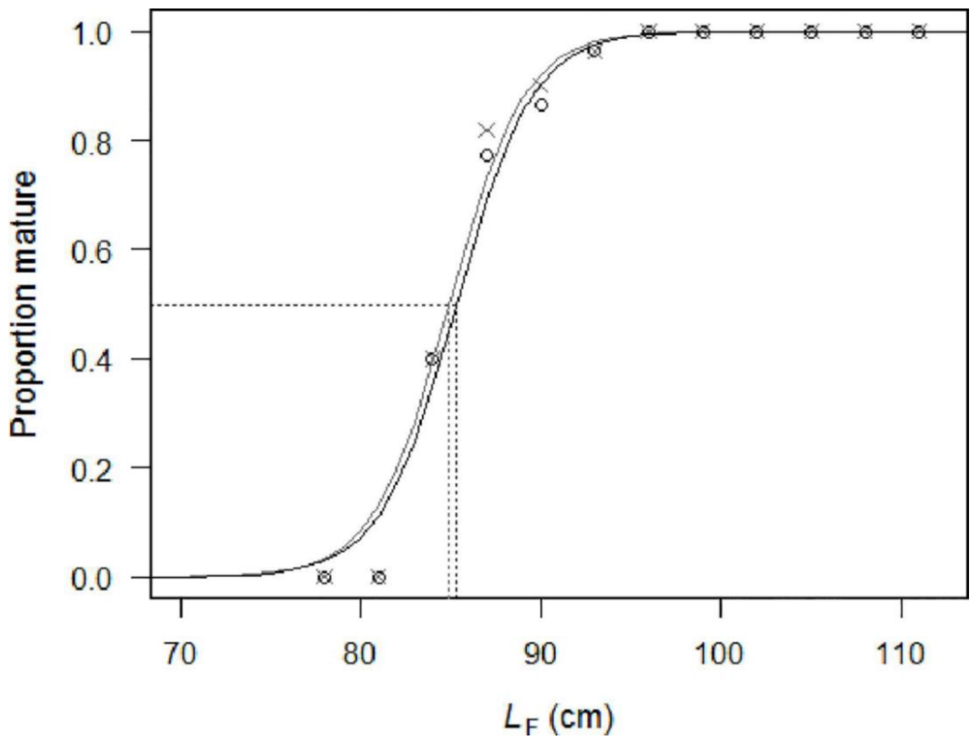
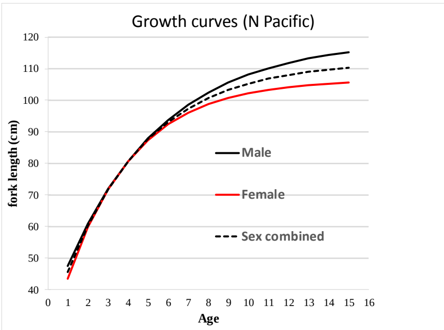
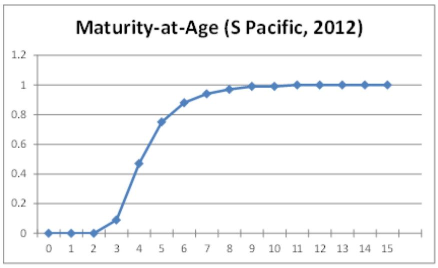


Fig. 9 Maturity-at-size by Dhurmeea et al (2016) using two different maturity thresholds

3. Summary

Table 7 shows our suggestions on biological and ecological parameters to be applied to the 2019 albacore stock assessment in the Indian Ocean in the WPTmT07 (July 22-25, 2019, Shimizu, Shizuoka, Japan).

Table 7 Summary on the suggested parameters for 2019 ALB stock assessments in the Indian Ocean

Parameters	Base case	Sensitivity
2.1 Stock structure	Single	No
2.2 Biological parameters		
(1) Sex ratio	1:1	?
(2) LW relation	Dhurmeea et al (2016) by sex (western Indian Ocean)	?
(3) Growth equation	Xu *et al* (2014) base on Chen- Wells equations) [♂] $Lt = 119.15 + (47.563 – 119.15)\ e^{(-0.20769*(t-1))}$ [♀] $L(t) = 106.57 + (43.504 – 106.57)\ e^{(-0.29763*(t-1))}$ [♂+♀] $L(t) = 112.379 + (45.628 – 112.38)\ e^{(-0.2483*(t-1))}$ 	?
(4) Life span	Age 14+ (SS3) or 15+(SCAS)	?
(5) M by age	To be discussed	
(6) Fecundity	It is assumed that fecundity is proportional to female weight at age.	
(7) Maturity-at-age	Farley et al (2012) (S. Pacific) Age (0-15): 0, 0, 0, 0.09, 0.47, 0.75, 0.88, 0.94, 0.97, 0.99, 0.99, 1, 1, 1 	Dhurmeea et al (2016) (Western IO) Age 3.2 (L50) if the growth eq. by Farley et al (2019) is applied.

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