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A comparison of biological characteristics of yellowfin tuna (*Thunnus albacares*) in the Western and Central Indian Ocean

Haiyang Liu[1], Liming Song[1,2,3,4],Hao Chen[1], Yuwei Li[1,2,3,4]

(1. *College of Marine Sciences, Shanghai Ocean University, Shanghai* 201306, *China*; 2. *National Distant-water Fishieries Engineering Research Center, Shanghai* 201306, *China* ; 3. *The Key Laboratory of Sustainable Exploitation of Oceanic Fisheries Resources, Ministry of Education, Shanghai* 201306, *China*;4. *Collaborative Innovation Center for National Distant-water Fisheries, Shanghai 201306, China*)

Abstract: Based on the yellowfin tuna (*Thunnus albacares*) biological data collected from two surveys conducted on board two Chinese tuna longliners in the Western and Central Indian Ocean from Sep. 2008 to Jan. 2009 (the 1st survey) and from Oct. 2013 to Apr. 2014 (the 2nd survey) respectively, this paper analyzed the biological characteristics of yellowfin tuna by statistic methods. The goal of this study is to determine if there was an impact of piracy activity on the yellowfin tuna resource in the Western and Central Indian Ocean. Our results indicated: (1) There was significant difference (p = 0.0404<0.05) between the yellowfin tuna fork length distribution of the above two surveys. The average fork length was 136.7±1.43cm , with dominant fork length of 125～145cm from the samples collected in the 1st survey and was 140.2±1.37 cm, with dominant fork length of 115～165cm from the samples collected in the 2nd survey. (2) There was significant difference between the gilled and gutted weight of two surveys (p=0.0414<0.05). (3) The sex ratio (male: female) of the yellowfin tuna sampled between two surveys was significant difference (p = 0.00927 < 0.05), the sex ratio was 2.14:1 in the 1st survey significantly and was higher than that (1:1) of the 2nd survey. (4) Gonad maturity of the sampled yellowfin tuna in the 1st survey was dominated by grade IV(40%) and V(41.1%) and that of the 2nd survey was dominated by grade III (31.2%) and IV(23.9%). There was significant difference (p= $1.186*10^{-12}$ < 0.05) in gonad maturity stages between two surveys. (5) There were significant differences in somatic index (SI) (p = 2.2*10-16 < 0.05) and gonadosomatic index (GSI) (p = 0.0108 < 0.05) between two surveys. (6) The relationship between fork length (L) and somatic wet weight (W_G) of yellowfin tuna was expressed by W_{G1S} $=1.9807\times10^{-5}L^{2.9292}$ for the 1st survey and $W_{G2S}=1.2825\times10^{-5}L^{2.9792}$ for the 2nd survey. There was no significant difference between them (p=0.9915>0.5) .This study suggested that the piracy activity might be good to the recovery of yellewfin tuna resource in the Indian Ocean.

Key words: *Thunnus albacares*; Biological characteristics; the Western and Central Indian Ocean; Resources

1. Introduction

Yellowfin tuna (*Thunnus albacares*) is a main catch species of the tuna fisheries in the world oceans (Meng et al. 2007; Feng et al. 2010). Many scholars conducted studies on yellowfin tuna in the Indian Ocean, involving biological characteristics (Zhu et al. 2006), growth and mortality (Wang et al. 2009), reproductive biology (Zudaire et al. 2014), feeding (Zhu et al. 2006), distribution (Meng et al. 2007; Pillai et al. 2012) and stock assessment (Zhang et al. 2013) and so on.

Due to the piracy activity in the Indian Ocean, fishing effort of purse seine and longline fisheries was reduced. Purse seiners of European Union, longliners of Japan, Mainland China and Taiwan Province of China have evacuated Indian Ocean one after another since 2009. For example, Mainland China had 41, 28 and 9 longliners operating in the Indian Ocean in 2008, 2009 and 2011, respectively. There were 81 purse seiners in 2009 and declined to 57 in 2011, then recovered to 68 in 2012. Indian Ocean Tuna Commission claimed that the impact of piracy activity on the major tuna resources should be assessed.

In this study, the yellowfin tuna biological data of the Western and Central Indian Ocean from Sep. 2008 to Jan. 2009 (the 1st survey) and from Oct. 2013 to Apr. 2014 (the 2nd survey) were collected based on the specification for oceanographic survey of China (State oceanic administration People's Republic of China, 2007). Yellowfin tuna biological characteristics of two surveys were compared to understand the differences of yellowfin tuna biological characteristics of two surveys, and the impact of piracy activity in the Western and Central Indian Ocean on the yellowfin tuna resource. This study will provide a reference to the study of yellowfin tuna biological characteristics and resource status in the Western and Central Indian Ocean.

2. Materials and Methods

2.1 Survey vessel, area and duration

The particulars of two survey vessels, survey durations and areas of two surveys were shown in Table 1, and the survey sites were shown in Fig.1.

Table. 1 Survey vessel particulars, survey durations and areas of two surveys

Items	Survey vessel	Length over all（m）	Molded breadth (m)	Moulded depth (m)	Engine power (kW)	Survey duration	Survey area
1st survey	XinshijiNo. 86	56.40	8.70	3.75	882.0	Sep. 2008~Jan. 2009	2° N～11° S，61° E～69° E
2nd survey	Xinshiji No.76	56.50	8.50	3.65	735.0	Oct. 2013~Apr. 2014	6° N～9° S，88° E～44° E

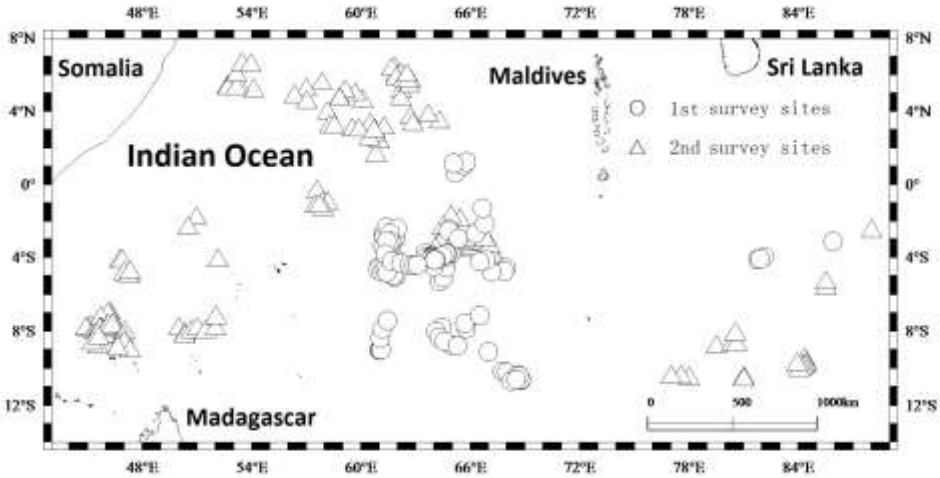

Fig. 1 Survey areas and sites in two surveys

2.2 Survey Item

The fork length, somatic wet weight (gilled and gutted weight)(W_G), sex ratio and maturity stages of the gonad of yellowfin tuna were collected in the Indian Ocean for two surveys based on specification for oceanographic survey of China. The maturity stage of the gonad was divided into six classes, from Ⅰ to Ⅵ; Feeding intensity was divided into five classes, from 0 to 4 (State oceanic administration People's Republic of China 2007). The individuals that were used to analyze different biological parameters were different and shown in Table 2.

Table.2 The individuals that were used to analyze different biological parameters

Item	Fork length	Somatic weight	Sex ratio	Maturity stage of the gonad	SI*	GSI*
1st survey	105	90	90	90	105	90
2nd survey	238	238	138	138	238	138

*: SI is somatic index (Encina et al. 1997); GSI is gonadosomatic index (IOTC 2008; Zhu et al. 2008).

2.3 Data analysis methods

T test was carried out on the yellowfin tuna fork length distribution to test if there was significant difference between two surveys.

Somatic index (SI) (Encina et al. 1997) and gonadosomatic index (GSI) (IOTC 2008; Zhu et al. 2008) were calculated by formula (1) and (2). T test was used to analyze the yellowfin tuna SI and GSI to test if there were significant differences between two surveys.

Somatic index： $$SI = \frac{W_G}{L^3} \times 100 \quad (1)$$

Gonadosomatic index： $$GSI = \frac{G_W}{W_G} \times 100 \quad (2)$$

Where L was the fork length (cm), W_G was the somatic wet weight of the fish (g), G_w was the gonad wet weight (g).

Chisquare test or Fisher's exact test was used to analyze the yellowfin tuna sex ratio and maturity stage of the gonad to test if there were significant differences between two surveys. Fisher's exact test was used to test the null of independence of rows and columns in a contingency table with fixed marginal (R Documentation 2013).

Test analysis of covariance (ANCOVA) was used to test the fork length and the sex if there were significant effects on the somatic weight.

Two methods were used to study the relationship between the fork length and the somatic weight: (1) The relationship between each individual's fork length and the corresponding somatic weight; (2) the relationship between the average value of each fork length group (5cm interval each) and the corresponding somatic weight. We carried out power regression for them, respectively.

$$W_G = a \times L^b \quad (3)$$

The squared value of the correlation coefficient (R^2) obtained from two power regression method mentioned above were compared. The equation with larger R^2 value was defined as the equation that could be used to describe the relationship between the fork length and the round weight (Song and Hui 2012).

Oneway ANOVA was used to test the differences between two survey's power function regression equations and the results of other scholars.

All statistical analyses were conducted by the R software (Xue and Chen 2007; Kabacoff 2011).

3. Results

3.1 Fork length distribution

The yellowfin tuna fork length statistic results of two surveys were shown in Table 3. Results of T test showed that there were significant differences in the fork length distribution of all fish (($t = 1.753$, $p = 0.04035<0.05$, Fig.2) and male ($t = -3.8415$, $p = 9.617\times10^{-5}<0.05$, Fig.3) between two surveys. But, there was no significant difference in the fork length distribution of female between two surveys ($t = -0.5772$, $p = 0.2827 > 0.05$, Fig.4).

Table.3 Yellowfin tuna fork length statistic results of two surveys

Items	Sex	Individuals	Minimum fork length (cm)	Max fork length (cm)	Average fork length (cm)	Dominant fork length (cm)	Proportion of dominant fork length (%)
1st survey	All	105	87	177	136.7±1.43	125～145	69.52%
2nd survey	All	238	86	190	140.2±1.37	115～165	70.17%
1st survey	F	45	87	167	136.2±2.21	130～145	73.33%
2nd survey	F	44	113	178	144.3±3.23	135～165	72.72%
1st survey	M	45	111	177	137.9±2.07	125～145	67.39%
2nd survey	M	94	86	190	149.7±2.18	135～175	72.34%

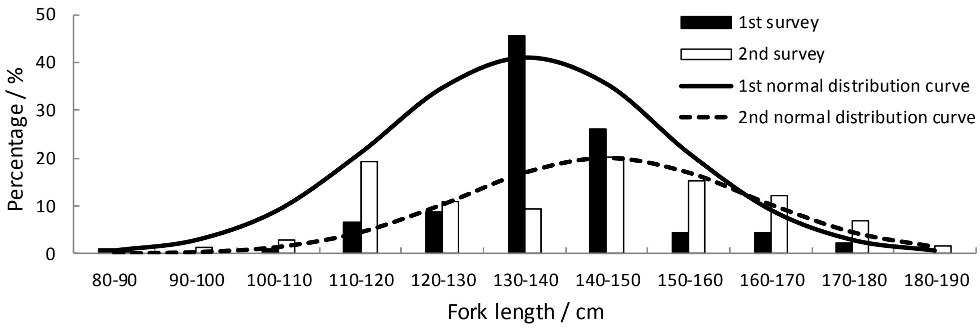

Fig. 2 Yellowfin tuna fork length distribution of two surveys

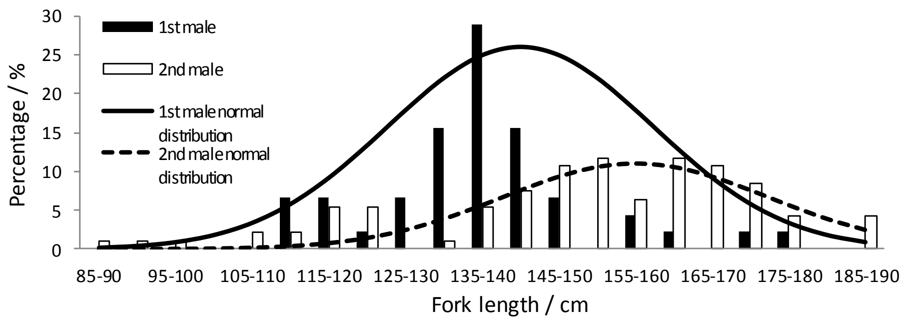

Fig.3 Male yellowfin tuna fork length distribution of two surveys

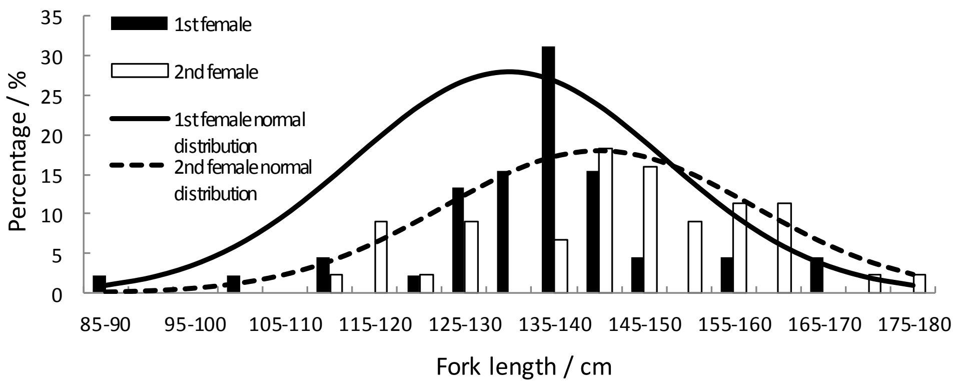

Fig.4 Female yellowfin tuna fork length distribution of two surveys

3.2 Somatic weight

Yellowfin tuna somatic weight statistic results of two surveys were shown in Table 4. The results of T test showed that there were significant differences in the somatic weight of all fish (t = 1.741, p = 0.04035<0.05, Table 4) and male (t = 1.6561, p = 0.00766). There were no significant differences in the somatic weight of female (t = 1.66277, p = 0.06544).

Table.4 Yellowfin tuna somatic weight statistic results of two surveys

Items	Sex	Individuals	Minimum fork length (cm)	Max fork length (cm)	Average somatic weight (cm)	Dominant fork length (cm)	Proportion of dominant fork length (%)
1st survey	All	105	14	89	37.10+1.16	30-45	67.62%
2nd survey	All	238	7.3	83	34.28+1.13	15-45	57.98%
1st survey	F	45	14	66	37.67+1.79	30-45	77.78%
2nd survey	F	44	20	68	34.35+2.62	25-45	72.72%
1st survey	M	45	15	85	37.2+1.75	30-45	73.33%
2nd survey	M	94	9	83	44.38+1.13	30-70	76.59%

3.3 Somatic index

Yellowfin tuna somatic index of two surveys were shown in Table.5. T test showed that there was significant differences in the somatic index of two surveys (t = 9.186, $p < 2.2\times10^{-16} < 0.05$). T test was used to test the yellowfin tuna somatic indices of 20 cm fork length groups of two surveys, and the results were shown in Table.6. Results showed that there were significant differences in fork length groups of 80～160cm of two surveys. The value of somatic index of the first survey was lower than that of the second survey. There were no significant differences in fork length groups of 160～190cm of two surveys.

Table.5 Yellowfin tuna somatic index of two surveys

Items	Sex	Individuals	Minimum value (g/100cm^3)	Max value (g/100cm^3)	Average value (g/100cm^3)
1st survey	All	105	0.896	3.300	1.429±0.028
2nd survey	All	238	0.546	1.903	1.137±0.016
1st survey	F	45	1.082	3.300	1.500r0.042
2nd survey	F	44	0.575	1.537	1.127ey.037
1st survey	M	45	0.896	1.794	1.388r0.042
2nd survey	M	94	0.695	1.903	1.251e0.026

Table.6 Results of T test on somatic indices of different fork length groups

Fork length (cm)	80～100	100～120	120～140	140～160	160～190
1st survey/ind	1	10	57	30	7
2nd survey/ind	4	53	48	84	49
t	/	4.302	7.360	4.041	1.004
p	/	$3.104*10^{-5}$	$2.883*10^{-11}$	$9.677*10^{-5}$	0.340

3.4 Sex ratio

Sex ratio (male:female), the individuals of male, female and those whose sex had not been identified were shown in Table.7. Sex composition was shown in Fig.5. Chisquare test showed that there were significant differences in the sex ratio of two surveys (X-squared = 6.770, p = 0.00927 < 0.05). Yellowfin tuna sex ratio of the 1st survey (2.14:1) was significantly higher than that of the 2nd survey (1:1).

Table.7 Sex ratio (male:female), the individuals of male, female and yellowfin tuna whose sex had not been identified

Items	Male	Female	Sex ratio	Sex had not been identified	Total
1st survey/ind	45	45	1:1	15	105
1st survey/%	42.86	42.86	/	14.29	100
2nd survey/ind	94	44	2.14:1	142	280
2nd survey /%	33.57	15.71	/	50.71	100

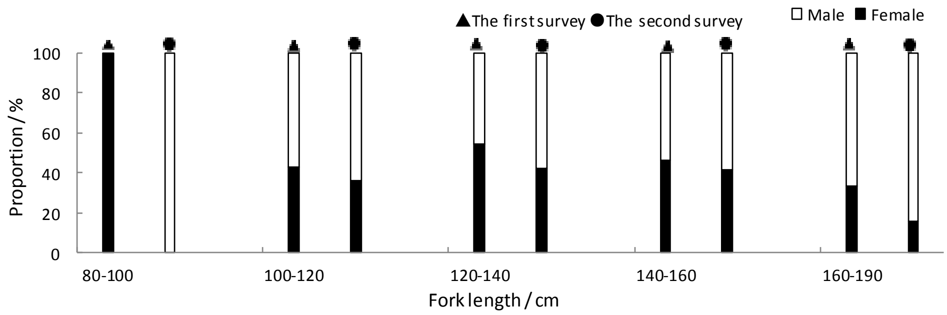

Fig.5 Yellowfin tuna sex composition of two surveys

Results of Fisher exact test on sex ratio of different fork length groups of two surveys were shown in Table.8. Results showed that there were no significant differences in all the groups of two surveys. Compared the sex ratio of different fork length groups of two surveys, the second survey were higher than that of the first survey.

Table.8 Results of Fisher exact test on somatic index of different fork length groups

Fork length	80～100	100～120	120～140	140～160	160～180
1st survey/ind	1	7	48	28	6
2nd survey/ ind	3	14	19	58	43
p	0.25	1	0.4251	0.8165	0.2926

3.5 Maturity stages of the gonad

Fisher's exact test showed that there was significant difference in the maturity stage of the gonad of two surveys ($p < 1.186\times10^{-12} < 0.05$). The maturity stages of the gonad of the first survey were dominant in the phase of Ⅳ and Ⅴ, and the proportion was 40.0% and 41.1%, respectively.The maturity stages of the gonad of the second survey were dominant in the phase of Ⅲ and Ⅳ, and the proportion was 31.2% and 23.9 %, respectively (Fig.6). Dominant gonad maturity stages and fishing areas monthly of two surveys were shown in Table. 9.

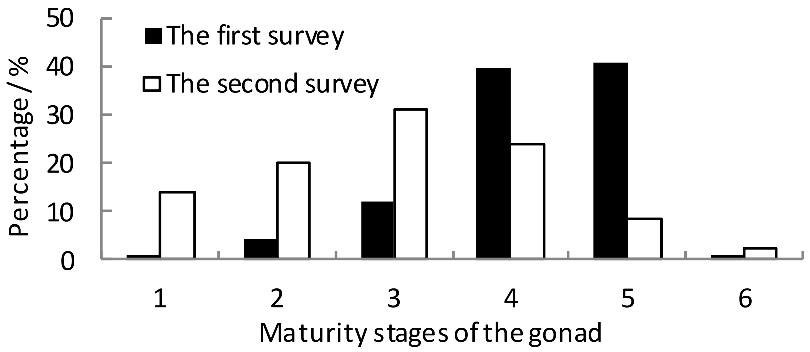

Fig.6 Maturity stages of the gonad of two surveys

Table.9 Dominant gonad maturity and fishing areas monthly of two surveys

Months		September	October	November	December	January	February	March	April
1st survey	Area	3°-9° S 61°-85° E	2°-9° S 61°-64° E	2°-5° S 61°-64° E	3°-10° S 61°-68° E	7° S-1° N 64°-66° E	/	/	/
	Dominant maturity	3,4	4,5	4,5	4,5	4,5	/	/	/
2nd survey	Area	/	2°-10° S 77°-88° E	1°-8° S 64°-80° E	1°-8° S 46°-67° E	6°-9° S 44°-47° E	8° S-6° N 50°-64° E	2°-6° N 48°-60° E	6° N-1° S 56°-62° E
	Dominant maturity	/	3,4	2,3	2,3	4,5	2,3	1,2	3,4

3.6 Gonadosomatic index

Yellowfin tuna gonadosomatic indices of two surveys were shown in Table.10. The gonadosomatic index statistics by month were shown in Fig.7. T test showed that there were significant differences in the gonadosomatic index of all fish, female, male of two surveys (t = 2.3326, p = 0.0108 < 0.05; t = 1.83, p = 0.048 < 0.05; t = 1.81, p = 0.013 < 0.05).

Table.10 Yellowfin tuna gonadosomatic index of two surveys

Items	Individuals	Minimum value (g/100g)	Max value (g/100g)	Average value (g/100g)

1st survey	90	0.09615	8.7222	1.4505±0.1313
2nd survey	138	0.4545	2.4444	1.1345±0.0333

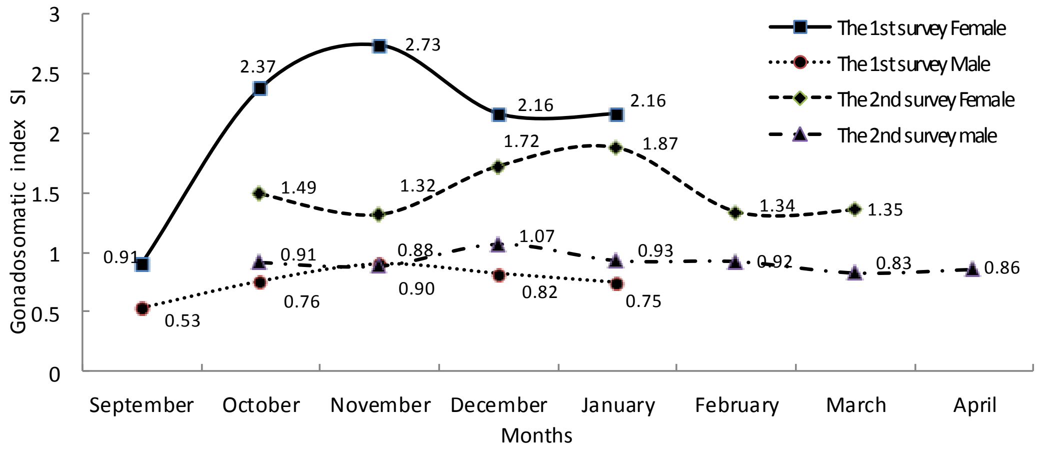

Fig.7 Two surveys'yellowfin tuna Gonadosomatic Index(SI) in different months

3.7 The relationship between somatic weight and fork length

In the 1st survey, there were 105 individuals whose somatic weight (W_G, kg) and the fork length (L, cm) data were collected, including 45 males and 45 females. The fork length ranged from 87 cm to 177 cm, and the somatic weight ranged from 14 kg to 89 kg. Test analysis of covariance (ANCOVA) was used to test if the somatic weight was effected by the fork length and the sex. The results showed that the fork length had a significant effect on the somatic weight (F = 2936.014, $p < 1.251\times10^{-124} < 0.05$), but the sex had no effect on the somatic weight (F = 0.043, p = 0.836 > 0.05). The power regression equations that described the relationship between the fork length and the somatic weight by two methods were developed and shown as follows:

Ungrouped: $W_{G1C}=1.3623\times10^{-4}L^{2.5379}$, ($R^2$ = 0.7494, n=105) (4)

Grouped: $W_{G1S}=1.9807\times10^{-5}L^{2.9292}$, ($R^2$ = 0.9852, n=105) (5)

In the 2nd survey, the somatic weight (W_G, kg) and the fork length (L, cm) data of 238 individuals were measured, including 44 males, 94 females and 100 yellowfin tuna whose sex had not been identified. The fork length ranged from 86 cm to 190 cm, and the somatic weight ranged from 7.3 kg to 83 kg. The results of test analysis of covariance (ANCOVA) showed that the fork length (F = 3573.578, $p < 6.997\times10^{-223} < 0.05$) and sex ($F$ = 11.791, $p = 7.89*10^{-4} < 0.05$) had a significant effect on the somatic weight. The relationship between the fork length and the somatic weight was studied for different sex. Two kinds of power regression equations were as follows:

Ungrouped: $W_{G2C}=8.5670\times 10^{-7}L^{3.5192}$, ($R^2$ = 0.8663, n=238) (6)

Grouped: $W_{G2S} = 1.2825\times 10^{-5}L^{2.9792}$, ($R^2$ = 0.9629, n=238) (7)

Ungrouped: female $W_{G2CF}= 3.1739\times 10^{-4}L^{2.3252}$, ($R^2$ = 0.7351, n=44) (8)

male $W_{G2CM}=8.7583\times 10^{-6} L^{3.0671}$, ($R^2$ = 0.8511, n=94) (9)

Grouped: female $W_{G2SF}=1.1815\times 10^{-4}L^{2.5317}$, ($R^2$ = 0.9204, n=44) (10)

male $W_{G2SM}=1.4033\times 10^{-5}L^{2.9713}$, ($R^2$ = 0.9608, n=94) (11)

The power regression equations with larger squared value of the correlation coefficient were (5) and (7). They were tested by Oneway ANOVA. Results showed that there were no significant differences between them and the results of other scholars, as shown in Fig.8 and Table.11.

Table.11 Length - somatic weight relationship of yellowfin tuna

Source	Somatic weight - Fork length relationship	R^2	Size range (cm)	F	P	Individuals	Area
1st survey	$W_G= 1.9807\times 10^{-5}L^{2.9292}$	0.9852	87～177	0.000143	0.9915	105	Western and Central Indian Ocean
2nd survey	$W_G= 1.2825\times 10^{-5}L^{2.9792}$	0.9629	86～190	0.000143	0.9915	238	Western and Central Indian Ocean
Morita, 1973	$W=1.8000\times 10^{-5}L^{2.9841}$	/	84～174	0.000105	0.9999	/	Eastern Indian Ocean
John et al., 1993	$W=3.9528\times 10^{-5}L^{2.8318}$	/	59～155	0.000661	0.9993	/	India EEZ
Adam et al., 1996	$W=2.8630\times 10^{-5} L^{2.8970}$	/	25～145	0.000199	0.9998	/	Maldives
Stequert et al., 1996	$W_G= 1.5850\times 10^{-5}L^{3.0449}$	/	64～NA	0.000378	0.9996	/	Western Indian Ocean
Ye et al., 2001	$W_G= 1.5270\times 10^{-5}L^{3}$	/	80～150	0.00015	0.9999	241	Eastern Indian Ocean
Zhu et al., 2006	$W_G= 2.8190\times 10^{-5}L^{2.9269}$	0.9973	70～180	0.0001	0.9999	745	Western and Central Indian Ocean
Shih, 2014	$W_G= 3.8000\times 10^{-6}L^{3.2760}$	0.9400	66～165	0.00374	0.9963	1047	Western Indian Ocean

Notes: R^2 is the correlation coefficient.

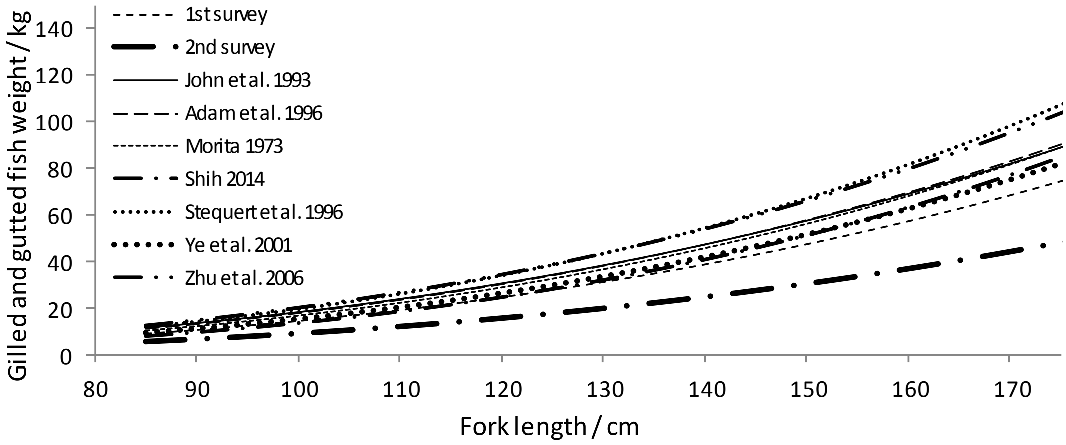

Fig.8 Comparison results of the relationships between W_G and L

4. Discussions

4.1 Fork length

The status of yellowfin tuna resource of the second survey in the Indian Ocean might be better than that of the first survey because of the piracy activity. The number of purse seiners had declined since 2008, thus the fishing mortality of juvenile yellowfin tuna was reduced. The growth equation that was used in the stock assessment of yellowfin tuna in the Indian Ocean by Shih et al. (2014) was as follows:

L_t=166.9(1-exp(-0.209(t+2.663))), (R=0.99, n=386) (12)

Where L_t was the fork length (cm) at age t (year), 166.9 was the theoretical asymptotical fork length, 0.209 was the growth coefficient (per year) and -2.663 was the theoretical age (years) at zero length.

According to the growth equation, the body length of age 6 yellowfin tuna was 139.6 cm. The proportion of yellowfin tuna which fork length was larger than 139.6 cm was 35.24% and 55.88% in two surveys. Therefore, the larger fish of the 2nd survey was more than that of the 1st survey. The fishing effort of longliners had decreased since 2008, and resulted in the average fork length and dominant fork length of the 2nd survey were larger than that of the 1st survey. Therefore, there were significant differences in the fork length of gender-neutral and male between two surveys.

There was no significant difference in the female fork length between two surveys. The spawning activity of the female consumed its large amounts of energy, so the ability of female to escape predators and resist disease was decreased and the natural mortality was increased (Pillai and Satheeshkumar 2012). It caused that the proportion of female yellowfin tuna with large fork length (L_t>165cm) decreased significantly in the 2nd survey, dominant fork length was maintained at 135 cm～165 cm (Fig.3).Therefore, there were no significant difference in the female fork length between two surveys.

4.2 Somatic index

Somatic indices of the male and female yellowfin tuna in the 1st survey were greater than that of the 2nd survey. There were significant differences in different fork length groups of two surveys except the fork length ranges of 160～190cm. The average fork length of male and female in the 2nd survey were greater than that of the 1st survey. The average somatic weight of male in the 2nd survey was greater than that of the 1st survey. The average somatic weight of female in the 2nd survey was less than that of the 1st survey. The 2nd survey was conducted from Oct. to Apr. of the next year. This duration was almost the mature female yellowfin tuna spawning season. In this duration, somatic index of female yellowfin tuna was reduced because of the high metabolic activity in the 2nd survey (Pillai and Satheeshkumar 2012).The other reason might be that the yellowfin tuna abundance was increased, the bait abundance was decreased relatively. At last, these reasons resulted that the total yellowfin tuna somatic index in the 2nd survey was lower than that of the 1st survey.

4.3 Sex ratio

There was significant difference in the sex ratio between two surveys. The yellowfin tuna's sex ratio of the 2nd survey (2.14:1) was significantly higher than that of the 1st survey (1:1). This proved that the female yellowfin tuna natural mortality of the 2nd survey was significantly higher than that of the male. Many scholars found that natural mortality of female was increased with the growth and higher than that of male (Schaefer et al. 1996, Fonteneau et al. 2002, Pillai et al. 2012). The greater of fork length, the greater proportion of males when the fork length of yellowfin tuna were larger than 135cm, which indicated that females' natural mortality was higher than that of the male (Fig.5). This coincided with the phenomenon that the fork length of female' first spawning was 135 cm (Pillai and Satheeshkumar 2012), and well confirmed the views of several scholars. Yellowfin tuna fishing mortality from purse seine fisheries was declined because the purse seine fishing effort had reduced since 2008 (Pillai and Satheeshkumar 2012). This lead to the proportion of hooked male increased (Shih et al 2014) in the 2nd survey when fork length was larger than 100 cm (3～4 years old) (Shih et al 2014). The proportion of male catches reduced when fork length was larger than 100 cm (3～4 years old fish) (Shih et al 2014) because the longline fishing effort had been reduced since 2008. Fishing mortality of the older males decreased, resulting in the proportion of the older male catches declined in 2013. This phenomenon also explained that the yellowfin tuna resources were recovered in 2013.

4.4 Maturity stages of the gonad

There were significant differences in maturity stages of the gonad between two surveys. The maturity stages of the gonad were dominant in the phases of Ⅳ and Ⅴ in the 1st survey, but in the phases of Ⅲ and Ⅳ in the 2nd survey. This might be caused by different sampling positions in two years. The 2nd survey position was westing, and the western area of the Indian Ocean was the area where the larval yellowfin tuna relatively concentrated and was a spawning area (Meng, 2007; Pillai and Satheeshkumar, 2012).

As shown in Table.9, the maturity stages of the gonad were dominant in the phases of Ⅳ and Ⅴ from Nov., 2009 to Jan., 2009 in the 1st survey, and was dominant in the phases of Ⅳ in Oct., 2013, Jan., 2014, and Apr. 2014 in the 2nd survey. From Nov., 2013 through Dec., the maturity stage of the gonad was dominant in the phase of Ⅲ. The longitude range of fishing was E77^{o} ～ E88^{o} in Oct., 2013. This area was in the Central of the Indian Ocean, and the maturing yellowfin tuna migrated to this area from the Western Indian Ocean. From Nov., 2013 through Dec., 2013, the fishing longitude range was E45^{o} ～ E80^{o}, the maturity stages of the gonad was on the rise with the fishing area shifting from the Eastern Central to the Western Central. But the fishing area was mainly in the Central Indian Ocean and had not fished in the Western spawning area, so the maturity stage was also not too high. In Jan., 2014, the longitude range of fishing was E44^{o} ～ E47^{o}, where was the spawning area, so the maturity stage of the catch was higher. From Feb. 2014 through Mar., 2014, the longitude range was E50^{o} ～ E64^{o}, where was the Western and Central Indian Ocean, and was in the yellowfin tuna post spawning season. Therefore, maturity stage of the catch was not high. The maturity stage of the catch was higher in Apr., 2014. This might result from the sampling bias.

Therefore, it was concluded that the spawning season of yellowfin tuna was mainly around the beginning of the year, which was consistent with the results of Zudaire (2013). Zudaire (2013) found that the spawning season of yellowfin tuna was from Sep. to Mar. in the Western Indian Ocean; the spawning grounds was in the Western Indian Ocean; the feeding migration of yellowfin tuna was from West to East; and after maturing, the spawning migration of yellowfin tuna was from East to West.

4.5 Gonadosomatic index

There was significant difference in the gonadosomatic index between two surveys. The average gonadosomatic index in the 1st survey was higher than that of the 2nd survey. This coincided with the result obtained by the analysis of gonad maturity. Female gonad index were higher than that of the male in two surveys. The gonadosomatic index of the male in the 2nd survey was slightly higher than that of the 1st survey. But the gonadosomatic index of female in the 2nd survey was lower than that of the 1st survey. Since the mortality of matured female in the 2nd survey was higher than in the 1st survey, the number of matured female individuals hooked in the 2nd survey were less than in the 1st survey. As shown in Fig.7, the highest GSI in the 1st survey occurred in Nov., while the 2nd survey occurred in Jan.. The main reasons were that the Western Indian Ocean was the spawning ground and the Eastern Indian Ocean was the feeding area; The fishing area of the 1st survey was in the Western Indian Ocean and was in Nov.; The second survey was in the Western Indian Ocean and was in Jan. (Fig. 9).

4.6 The relationship between fork length and somatic weight

The fork length had a significant effect on the somatic weight, but sex didn’t in the 1st survey. Both fork length and sex had a significant effect on the somatic weight in the 2nd survey. The reasons might be that the proportion of matured female hooked in the 2nd survey was less than that of the 1st survey, and the male was dominant. There was significant difference in the gonad weight between male and female, leading to different somatic weight in the same fork length for different sex.

There were no significant differences in Fork length - Somatic weight relationship between this study and the other scholars (Morita, John, Adam, Stequert, Ye, Shih etc.) Yellowfin tuna growth pattern was almost consistent.

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References

Adam MS, Anderson RC (1996) Yellowfin tuna (*Thunnus albacores*) in the Maldives. The Maldivian Tuna Fishery: A collection of Tuna Resource Research Papers, Maldives Marine Research Bulletin 2:23-39.

Dortel E, Sardenne F, Bousquet N, et al. (2014) An integrated Bayesian modeling approach for the growth of Indian Ocean yellowfin tuna. Fisheries Research, 16:0165-7836.

Encina L, Granado LC (1997) Seasonal changes in condition, nutrition, gonad maturation and energy content in barbel, Barbussclateri, inhabiting a fluctuating river. Environmental Biology of Fishes, 50:75–84.

Feng B, Chen XJ, Nishida T (2010) Stock assessment of *Thunnus albacares* in the Indian Ocean using age structured production mode (in Chinese with English abstract). Acta Ecologica Sinica, 13: 3375-3384.

Fonteneau A (2002) Estimated sex ratio of large yellowfin taken by purse seiners in the indian ocean; comparison with other oceans. IOTC Proceedings, 5:279-281.

IOTC secretaria (2008) Estimation of catch-at-size, catch-at-age and total catch per area. Indian Ocean Tuna Commission, IOTC–2013–SC16–INF04.

John ME, Sudarsan D (1993) Fishery and biology of yellowfin tuna occurring in oceanic fishery in Indian seas. In: SudarsanD, John ME (eds) Tuna Research in India. Fishery Survey of India, Bombay, pp 39-62.

Kabacoff R. I (2011) R in Action: Data Analysis and Graphics with R. NJ: Manning Publications.

Morita Y (1973). Conversion factors for estimating live weight from gilled-and-gutted weight of bigeye and yellowfin tunas. Bulletin Far Seas Fish Research Laboratory, **9**:109-122

Meng XM, Ye ZJ, Wang YJ (2007) Review on fishery and biology of yellofin tuna (*Thunnus albacares*) (in Chinese with English abstract). South China Fisheries Science, 4: 74-80.

Moreno G, Herrera M (2013) Estimation of fishing capacity by tuna fishing fleets in the Indian Ocean. Report presented at the 16th Session of the Scientific Committee of the Indian Ocean Tuna Commission. Busan, Republic of Korea, 2–6 December 2013.

IOTC–2013–SC16–INF04.

Pillai NG, Satheeshkumar P (2012) Biology, fishery, conservation and management of Indian Ocean tuna fisheries. Ocean Science Journal, 47(4):411-433.

R Documentation (2013) http://127.0.0.1:16669/library/stats/html/fisher.test.html.

Stequert B, Panfili J, Dean JM (1996) Age and growth of yellowfin tuna,*Thunnus albacares*, from the western Indian Ocean, based on otolith microstructure. Fishery bulletin, 94(1): 124 - 134.

State oceanic administration People's Republic of China (2007) GB/T12763.6 — 2007 Specification for oceanographic survey. Beijing: Standard Press of China.

Song LM, Hui MM (2012) A comparison of the biological characteristics of yellowfin tuna (*Thunnusalbacares*) between Marshall Islands waters and Gilbert Islands waters(in Chinese with English abstract). Marine Fishery, 34(2):145-153.

Shih CL, Hsu CC, Chen CY (2014) First attempt to age yellowfin tuna, *Thunnus albacares*, in the Indian Ocean, based on sectioned otoliths, Fisheries Research, 149:19-23.

Wang D, Su YQ, Mao Y, et al. (2009) Genetic Diversity of *Thunnus thynnus* and *Thunnus albacares* Stocks by AFLP (in Chinese with English abstract). Journal of Xiamen University (Natural Science), 6: 890-894.

Xue Y, Chen LP (2007) Statistical modeling and R software. Beijing: Tsinghua University Press, 232-234.

Ye ZJ, Liang ZL, Xing ZL, et al. (2001) The fishery biology of *Thunnus albacares* in the East of Indian Ocean (in Chinese with English abstract). Marine Fisheries Research, 3:37-41.

Zhu GP, Chen XJ, Xu LX (2006) Preliminary study on the fishery biology of yellowfin tuna,*Thunnus albacares*, in the western central Indian Ocean (in Chinese with English abstract). Marine Fishery, 1:25-29.

Zhu GP, Xu LX, Zhou YQ, Song LM (2008) Feeding habits and its seasonal variations of *Thunnus albacares* in the west-central Indian Ocean (in Chinese with English abstract). Journal of Fishery of China, 5:725-732.

Zhu GP, Xu LX, ZhouYQ, Song LM (2008) Reproductive Biology of Yellowfin Tuna T. albacaresin the West-Central Indian Ocean. Journal of Ocean University of China, 7(3):327-332.

Zhang YY, Chen Y, Zhu JF, et al. (2013) Evaluating harvest control rules for bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) fisheries in the Indian Ocean. Fisheries

Research, 137:1-8.

Zudaire I, MuruaH, Grande M, et al. (2013) Grande Fecundity regulation strategy of the yellowfin tuna (*Thunnus albacares*) in the Western Indian Ocean. Fisheries Research, 138:80-88.

Zudaire I, Murua H, Grande M, et al. (2014) Accumulation and mobilization of lipids in relation to reproduction of yellowfin tuna (*Thunnus albacares*) in the Western Indian Ocean. Fisheries Research, 160:50-59.