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The relationships between muscle fat content and biological parameters in *Thunnus albacares* in the high seas of the Indian Ocean

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Abstract：The relationships between muscle fat content fluctuation and biological parameters of the yellowfin tuna (*Thunnus albacares*) were studied to better understand its characteristics of growth, reproduction and the fishing ground. The biological data and muscle fat content of 91 yellowfin tuna were collected from the longline fishery in waters of 6°33'N ~ 10°33'S, 44°54'E ~ 88°0' E, Western Central Indian Ocean from October, 2013 to April, 2014. Histogram count figures were made to show the spatial or temporal distribution of fat content and fat content by gender, dressed weight, and gonad maturity. A generalized additive model (GAM) was used to analyze the relationships between fat content and condition factor (K), somatic index (SI), gonadosomatic index (GSI) and fork length (FL). Results showed that: (1) the fat content of yellowfin tuna was in the range of 0.1~26.7 %, and the average was 6.94 %; (2) the fat content of yellowfin tuna was low from October to December, 2013, increasing after December, 2013. The fat content of the area in 2°N～3°N，59°E～60°E was the highest (15.3%) and that of the area in 7°S ~ 8°S，44°E ~ 45°E was the lowest (1.2%), there was significant differences among them; (3) there were no significant differences among the fat content by gender, gonad weight, gonad maturity stages or fork length; (4) By GAM, the results showed that there were no significant correlations between fat content and K, SI, GSI or FL. Results of this study suggest that: (1) the yellowfin tuna begin to reproduce in March and April; (2) the area of 2°N ~ 3°N，59°E ~ 60°E might be an important spawning ground; (3) there was no significant correlation between female reproductive capability and muscle fat content.

Key words：*Thunnus albacares*; muscle fat content; biological parameters; high seas of the Indian Ocean

1 Introduction

Yellowfin tuna (*Thunnus albacares*) is a highly migratory species. Basic biological characteristics of yellwofin tuna including spatial distribution (Meng et al., 2007; Zhang et al., 2014), population (Appleyard et al., 2001), growth (Shomura et al., 1994;Xu and Zhu, 2006), reproduction (Chen et al., 2014) and feeding (Song et al., 2004) were studied by many scholars of the world. Zhu et al. (2008) studied the feeding habits of yellowfin tuna in western and central Indian Ocean, and found that squid, mackerel and crabs were the main bait food of yellowfin tuna. Fish body fat content is often used as the index of physiological status change. Fat can provide metabolic energy while the fish are in the spawning migration. And for the spawning fish, fat will transfer to the developing eggs (Black and Pickering, 1998). Fat content increases linearly with the fishing season which shows the fish are in the feeding migration (Goni and Arrizabalaga, 2010). Measuring the fat content and combined with age can be used to study physiological status and habitat changes (Encina and Granado-Lorencio, 1997). Gabriel et al. (2001) and Zudaire et al. (2014) studied respectively the fat content of female bluefin tuna (*Thunnus thynnus*) during sexual mature period, and the fat accumulation and transfer of yellowfin tuna during spawning in the Western Indian Ocean. The former concluded that the fat content of ovary of bluefin tuna significantly increased from gonad maturity to spawning. The latter pointed out that the energy required for reproduction was mainly derived from feeding and only a few part of energy was derived from fat accumulated in muscle, so there were no significant correlations between female reproductive capability and fat content of fish muscle. Song et al. (2014) studied the relationship between fat content and fork length of albacore tuna (*Thunnus alalunga*) in waters near Cook Islands and suggested that there were no significant correlations between them. Song et al. (2015) studied the relationship between fat content and age of bigeye tuna in the Western Central Indian Ocean and argued that the change of fat content probably coincided with the metabolic changes of growth, reproduction and aging.

At present, there are few studies on the relationship between fat content and biological parameters of yellowfin tuna in the high seas of the Indian Ocean. This paper studied on fat content by frequency statistics and the generalized additive model (GAM), using the biological data of yellowfin tuna in the high seas of the Indian Ocean. This paper can provide an important reference for further study on migration, growth, reproduction, habitat changes and fishing ground properties of yellowfin tuna.

2 Materials and methods

2.1 Survey information

The survey vessel was the longliner 'Xinshiji 76' with length 56.50 m, width 8.50 m, type deep 3.65 m, main engine power 735.00 kW, maximum speed 15 kn. Fish were randomly sampled from October, 2013 to April, 2014 in the high seas of the Indian Ocean (6°33′N ~ 10°33′S , 44°54′E ~ 68°32′E) (Fig.1). Survey area and sites were decided by the captain based on his experience and knowledge of fishing conditions.

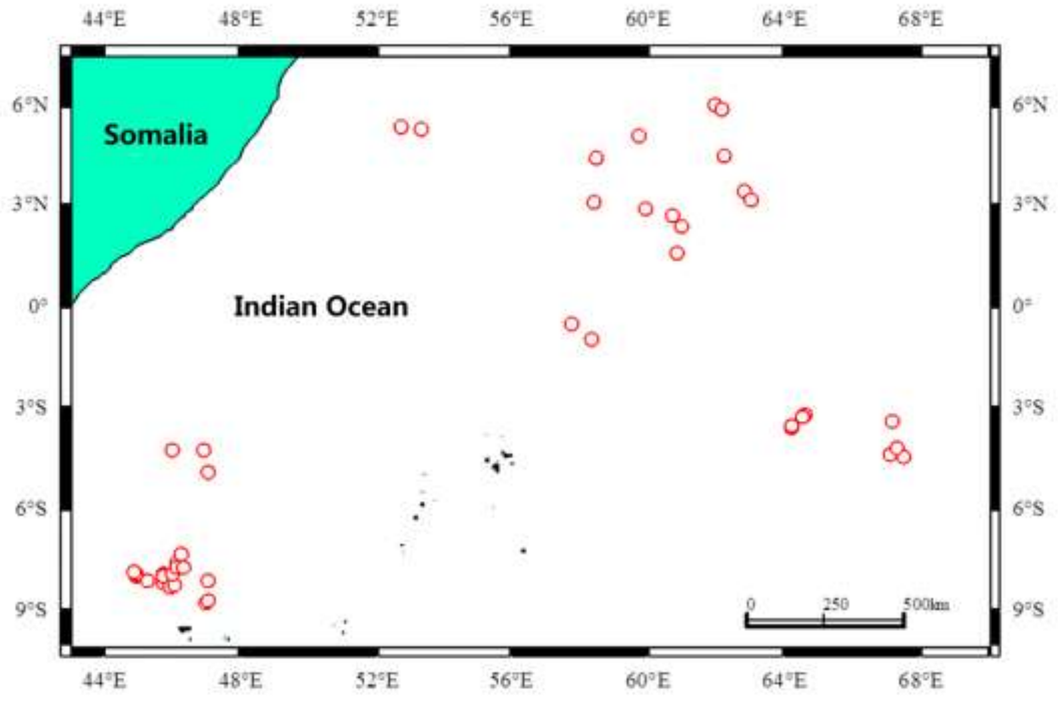


Fig.1 The survey area and sites (○)

2.2 Method

2.2.1 Survey method

The fork length (FL), round weight, somatic weight, gender, gonad weight, gonad maturity stage and fat content of yellowfin tuna were measured or identified from randomly selected samples. The FL of yellowfin tuna was measured with a taut tape (accurate to cm). The round weight and somatic weight were measured with a scale (accurate to kg). And the gonad weight was measured with an electronic scale (accurate to g). A Distell fish fat meter (FFM692, Scotland, UK) was used to measure the fat content. The measurement error of fat content was 0.5% ~ 1.0%. The fat contents in five body locations (Fig.2) were measured and their arithmetic mean was recorded as the fat content for the fish. Gonad maturity stage was based on the specification for oceanographic survey of China (State oceanic administration People's Republic of China, 2007).

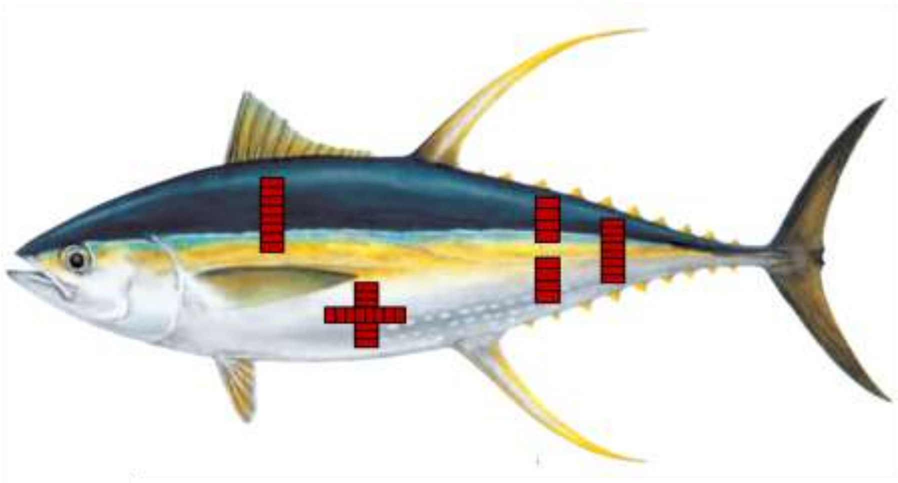


Fig.2 The area for fat content measurement in yellowfin tuna (read areas)

2.2.2 Fishing gears and method

The survey fishing gear is a drifting longline. The float size is 360 mm in diameter. The float line sizes are 4.5 mm in diameter and 35 m in length. The main line size is 6.5 mm in diameter. The first part of branch line is a red polyester rope with 4 mm in diameter and about 2 m in length, the second part is monofilament with 2.5 mm in diameter, the third part is a lead-wrapped rope with 2.5 mm in diameter and 3 m in length, the fourth part is monofilament with 2 mm in diameter and 13 m in length, the fifth part is a lead-wrapped rope with 2.5 mm in diameter and 3 m in length and the sixth part is monofilament with 1.3 mm in diameter and 8 m in length. The automatic hanging buckle connects the first part with a swivel and the sixth part connects the hook directly. The whole length of the drifting longline is about 48 m.

The longline was deployed from 6:00 am to 11:30 am and the duration was about 5.5 hours. Then hoisted rope from 1:00 pm to 4:00 am in the next day, and the duration was about 15 hours. The average speed of vessel was 10.1 kn when deploying the rope. The average speed of line shooter was 6.7 m/s. The average time interval of two hooks was 7.4 s. The number of hooks between two floats was 16.

2.2.3 Data processing method

FL, round weight, gonad maturity stage and fat content distribution were analyzed by making histogram count figures. The arithmetic mean fat content of the daily sampled yellowfin tuna was calculated as the daily fat content. Chi square test was used to check if there were significant differences in the fat content between each group of genders, gonad maturity stage and fork length (Xue and Chen, 2007). The average fat content of each group of fork length was determined to make a fork length frequency and fat content distribution histogram (group interval was 10 cm). And the average fat content of each group of round weight was determined to make a round weight and fat content frequency distribution histogram (group interval was 10 kg). The average fat content of gonad maturity stage Ⅰ to stage Ⅵ was determined to make a gonad maturity frequency and fat content distribution histogram. The average fat content of each group of fat content was determined to make a fat content frequency distribution histogram (group interval was 5%). Condition factor (K), somatic index (SI), and gonadosomatic index (GSI) were calculated using the following Eqs. (1) to (3) (Encina and Granado-Lorencio, 1997). A generalized additive model (GAM) was used to analyze the relationships between fat content and FL, GSI, K, and SI.

Condition factor: $K = \frac{T_W}{FL^3} \times 100$ (1)

Somatic index: $SI = \frac{S_W}{FL^3} \times 100$ (2)

Gonadosomatic index: $GSI = \frac{G_W}{T_W} \times 100$ (3)

where G_W is the gonad weight (kg), T_W is the round weight (kg), L is the fork length (cm), S_W is the somatic weight (kg).

3 Results

3.1 Biological index

3.1.1 Fork length frequency distribution

The FL range of yellowfin tuna was 100～190 cm (Fig.3). The dominant FL of total was 140～150 cm, and 24 individuals were in this range which accounted for 26.4% of total. The dominant FL of female was 140～150 cm, and 11 individuals were in this range which accounted for 34.1% of female. The dominant FL of male was 160～170 cm, and 21 individuals were in this range which accounted for 25.5% of male.

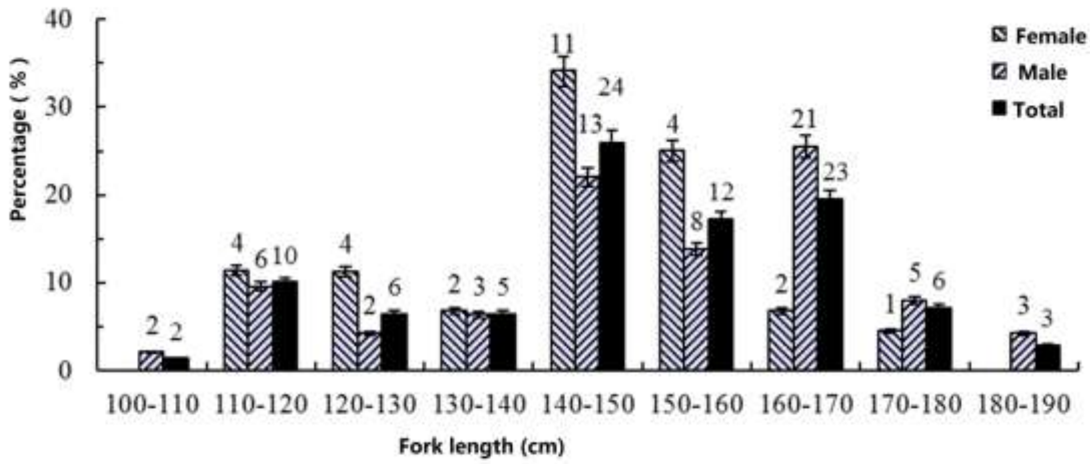


Fig. 3 Fork length frequency distribution of yellowfin tuna

(Note: numbers represent total fish in each category)

3.1.2 Round weight frequency distribution

The round weight range of yellowfin tuna was 9～83 kg (Fig.4). The dominant round weight of total was 30～40 kg, and 24 individuals were in this range which accounted for 26.4% of total. The dominant round weight of female was 30～40 kg, and 12 individuals were in this range which accounted for 42.9% of female. The dominant round weight of male was 50～60 kg, and 16 individuals were in this range which accounted for 25.4% of male.

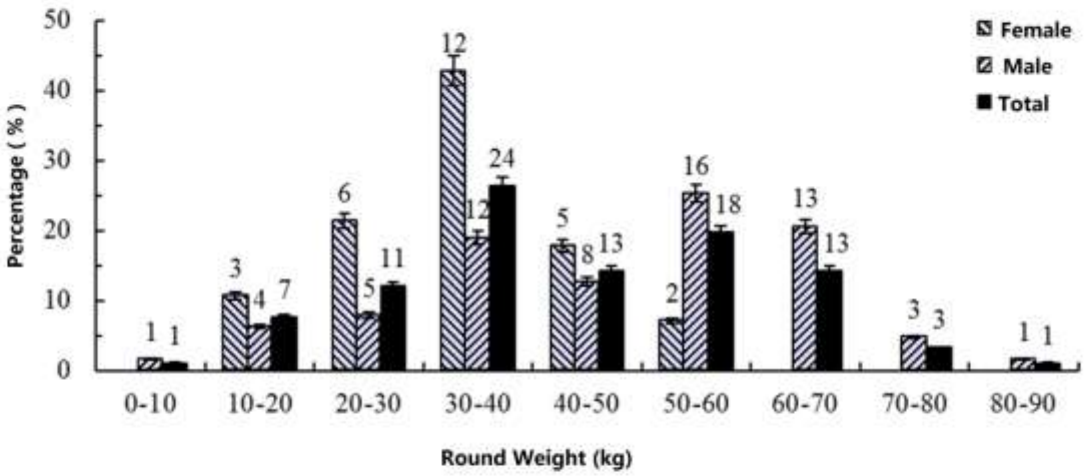


Fig.4 Round weight frequency distribution of yellowfin tuna

(Note: numbers represent total fish in each category)

3.1.3 Gonad maturity frequency distribution

The gonad maturity frequency distribution was shown in Fig. 5. The dominant gonad maturity stages of female were stage Ⅲ and stage Ⅳ which accounted for 60.5% of total. The largest proportion of yellowfin tuna were in a stage Ⅳ condition (30.8%), followed by stage Ⅲ (29.7%). The proportion of male in stages Ⅲ and Ⅳ accounted for 23.8% and 41.3%, respectively. The proportion of female in stages Ⅱ, Ⅲ and Ⅳ accounted for 25%, 42.9% and 7.1%, respectively. The gonad maturity distribution of yellowfin tuna was basically in normal in total fish, presenting an increasing trend from stage Ⅰ to stage Ⅳ and following a decreasing trend.

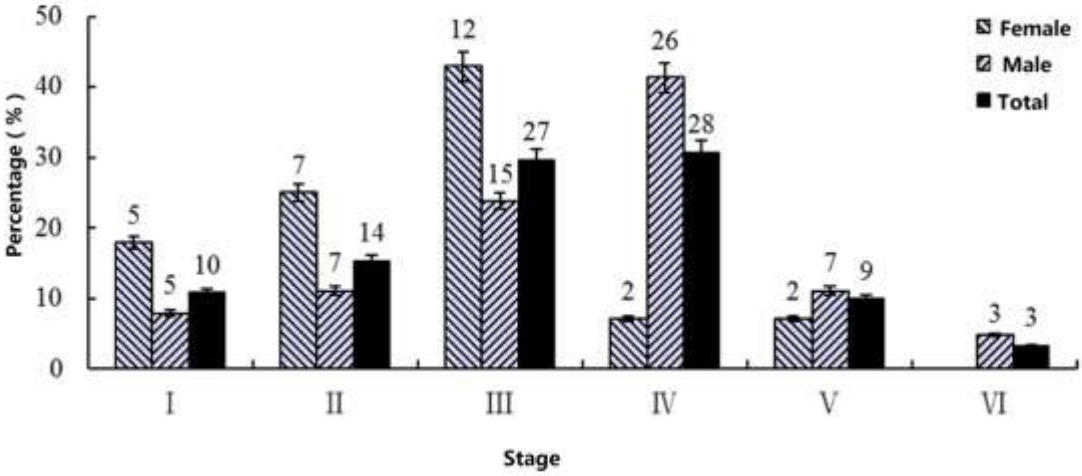


Fig.5 Gonad maturity frequency distribution of yellowfin tuna

(Note: numbers represent total fish in each category)

3.1.4 Fat content frequency distribution

The fat content frequency distribution of yellowfin tuna was shown in Fig. 6. The fat content range was 0.1～26.7%, and the average was 6.94%. The fat content was mainly distributed within the range of 0～10%, which accounted for 75.8% of total. The monthly average fat content value was relatively low from October to December, and presented a minimum value on December which was 4.04%. The monthly average fat content value presenting an increasing trend after December (Fig. 7). The daily average fat content value from October to December was basically lower than the average fat content of total fish while the daily average fat content value from January to April was higher than the average fat content of total fish (Fig. 8), which coincided with the monthly average fat content value. The average fat content was observed by 1° grid. The maximum value of average fat content was 15.3% (2°N～3°N and 59°E～60°E), and the minimum value was 1.2% (7°S～8°S and 44°E～45°E). There were significantly difference between them (chi-square value = 12.0491, p = 0.0005) (Fig. 9).

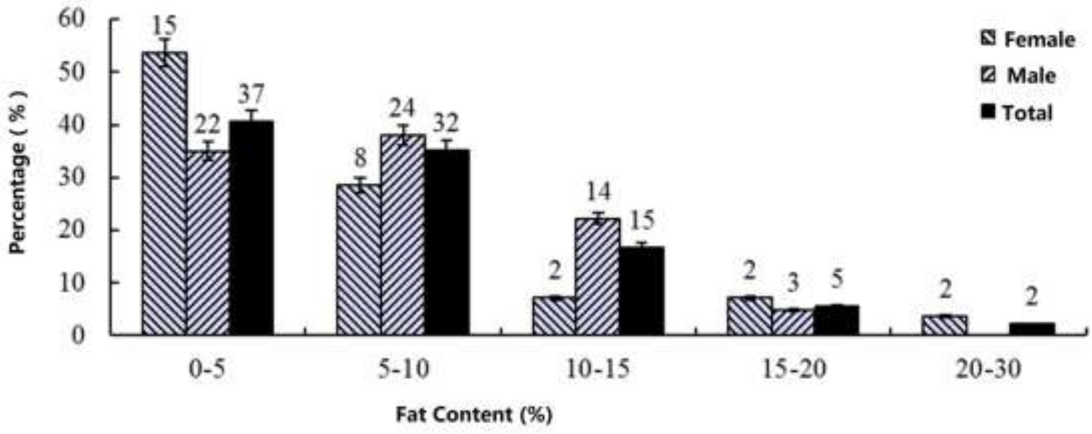


Fig.6 Fat content frequency distribution of yellowfin tuna

(Note: numbers represent total fish in each category)

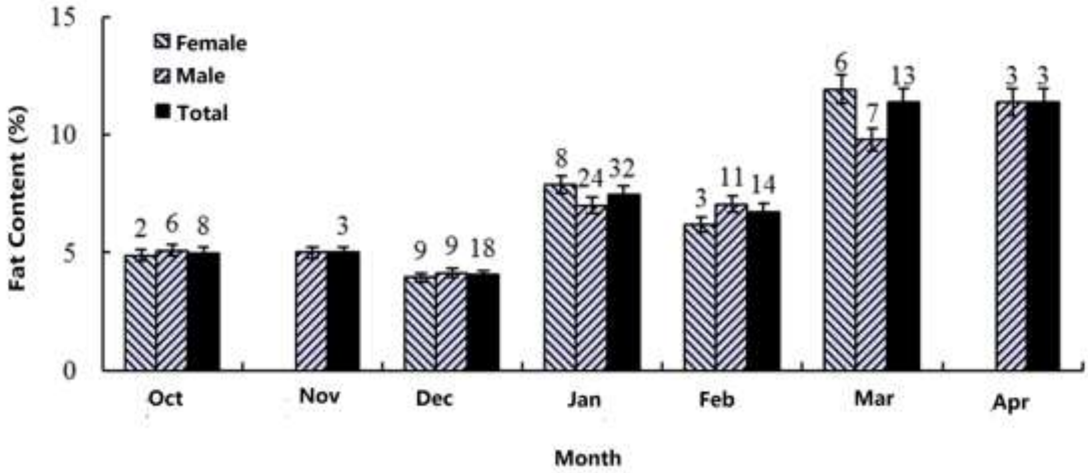


Fig. 7 Fat content distribution of yellowfin tuna from October to April

(Note: numbers represent total fish in each category)

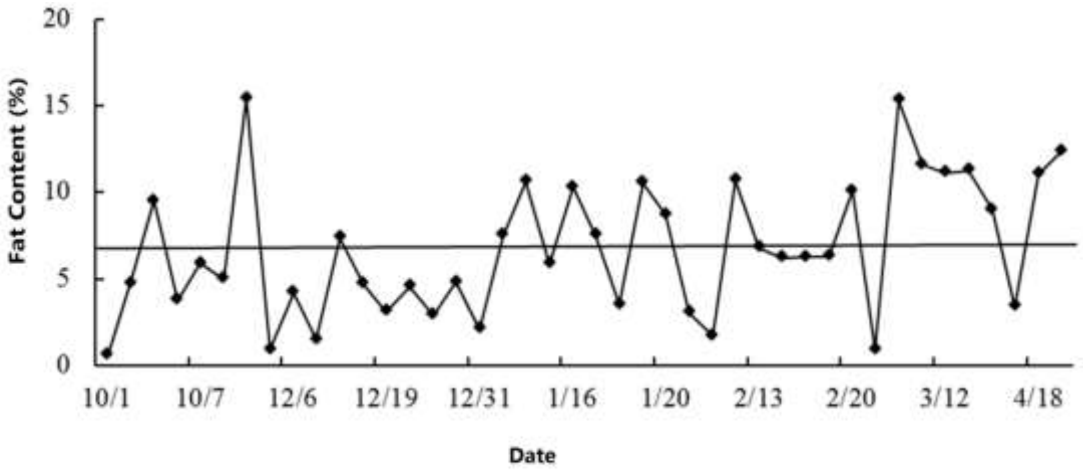


Fig.8 Distribution of daily average fat content of yellowfin tuna

（—：the average of total；♦：the daily average）

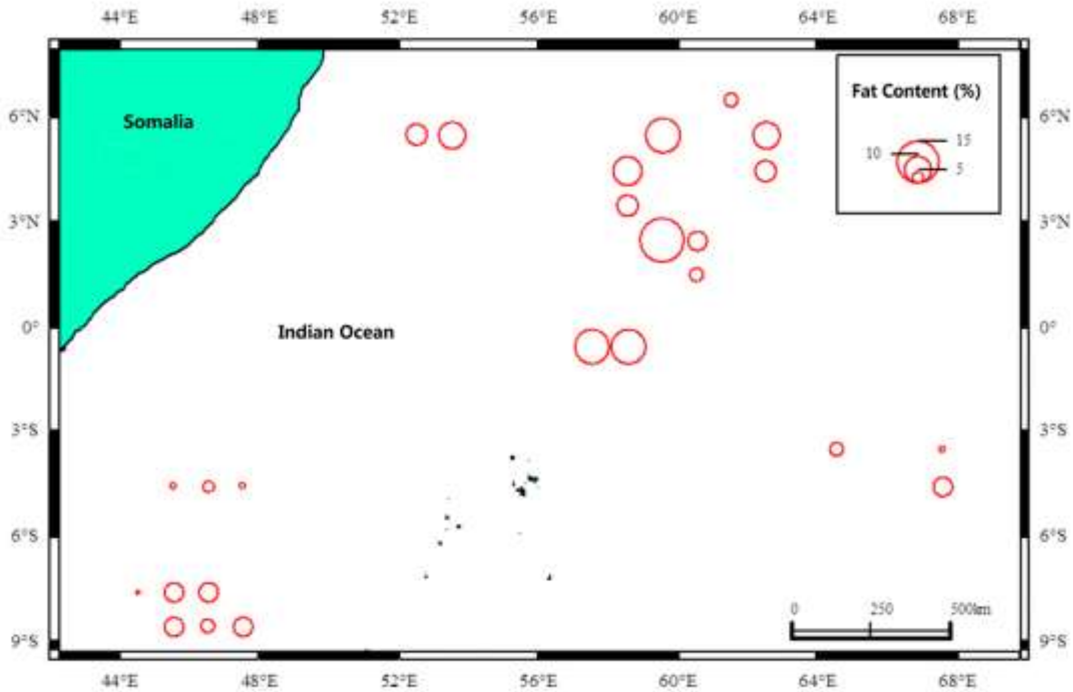
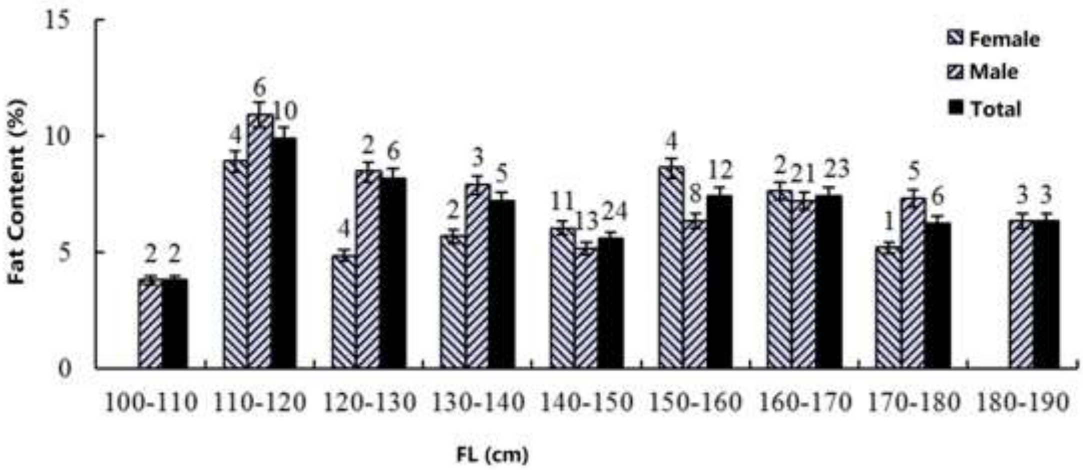


Fig. 9 The fat content spatial distribution of yellowfin tuna

3.2 The Relationships between fat content and biological indicators

3.2.1 The relationship between fat content and FL

The average fat content values of each fork length group were shown in Fig. 10. The average fat content value of the fork length group of 110～120 cm was the maximum, reaching to 9.91%. It presented a decreasing trend after the group of 110～120 cm. The average fat content value increased when the fork length reached to 140～150 cm. The average fat content value decreased after the fork length reached to 150～170 cm. The result of chi-square test showed that there were no significant differences between the average fat content values of each fork length group of the total fish and each fork length group of male, or female (p>0.05), and there were no significant differences among the average fat content values of each fork length group



of the total fish (p>0.05).

Fig.10 The relationship between fat content and fork length of yellowfin tuna

(Note: numbers represent total fish in each category)

3.2.2 The relationship between fat content and genders

The average fat content values was 6.26% for female, 7.24% for male and 6.94% for the total fish. The result of chi-square test showed that there were no significant differences among female, male and the total fish (p>0.05).

3.2.3 The relationship between fat content and weight

The relationship between fat content and weight was shown in Fig. 11. For the total fish, the average fat content value of the weight group of 80～90 kg was the maximum, reaching to 12.1%, while the value of the group of 0～10 kg was the minimum, reaching to 1.1%. For female, the average fat content value of the weight group of 10～20 kg was the maximum, reaching to 9.43%, while the value of the group of 30～40 kg was the minimum, reaching to 3.62%. And for male, the group of 80～90 kg had a maximum value which was 12.1%, while the group of 0～10 kg had a minimum value which was 1.1%. The result of chi-square test showed that there were no significant differences among male, female and the total or among each group.

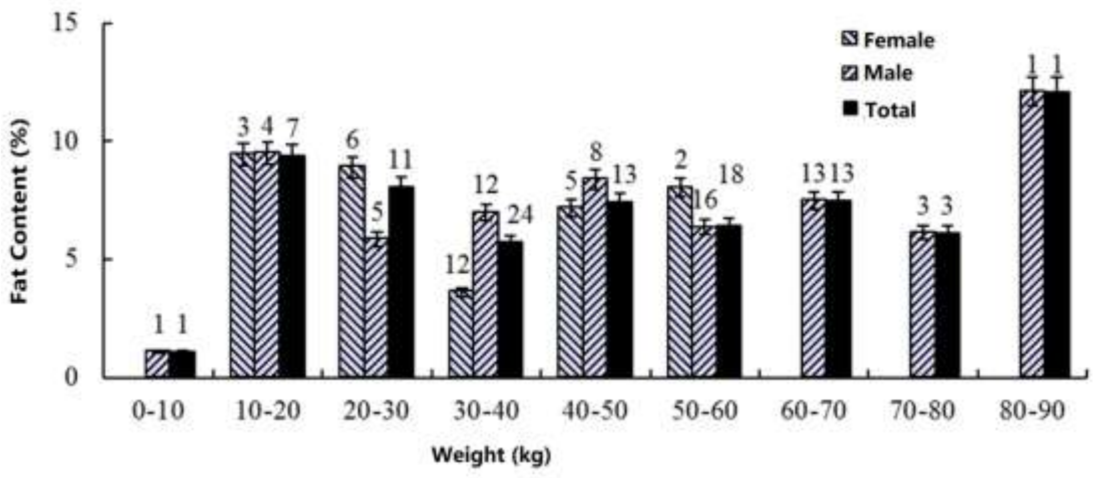


Fig. 11 The relationship between fat content and weight of yellowfin tuna

(Note: numbers represent total fish in each category)

3.2.4 The relationship between fat content and gonad maturity stages

Fat content appeared to fluctuate as fish matured. When the gonad maturity stages of yellowfin tuna were from stage Ⅰ to stage Ⅵ, the average fat content values were 8.52%, 6.76%, 6.17%, 7.14%, 6.56% and 8.09%, respectively. The result of chi-square test showed that there were no significant differences among each stage for male, female and the total fish or among each stage of the total fish.

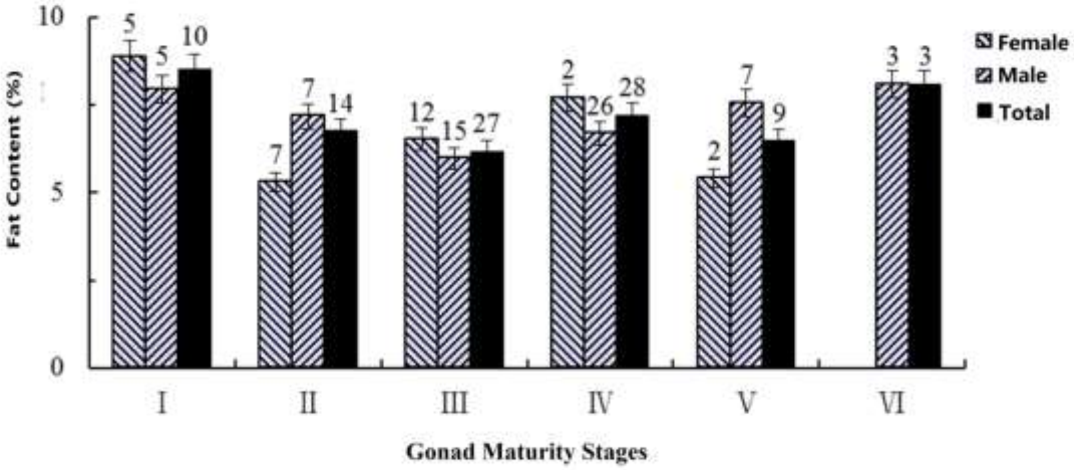


Fig .12 The relationship between the fat content and gonad maturity of yellowfin tuna (Note: numbers represent total fish in each category)

3.3 Analysis result by GAM

By GAM , there was no significant correlation between fat content and K, SI, GSI, or FL (p>0.05, Table. 1 and Fig. 13). The solid lines represent the corresponding impact levels of biological parameters on fat content and trend, and the dot lines represent 95% confidence interval.

Table.1 Analysis results of generalized additive model (GAM)

Items	Degree of freedom	F	p-value
Condition factor (K)	2.303	2.055	0.114
Somatic index (SI)	1.207	0.087	0.842
Gonadosomatic index (GSI)	1.000	1.634	0.205
Fork length (FL)/cm	2.803	1.658	0.173

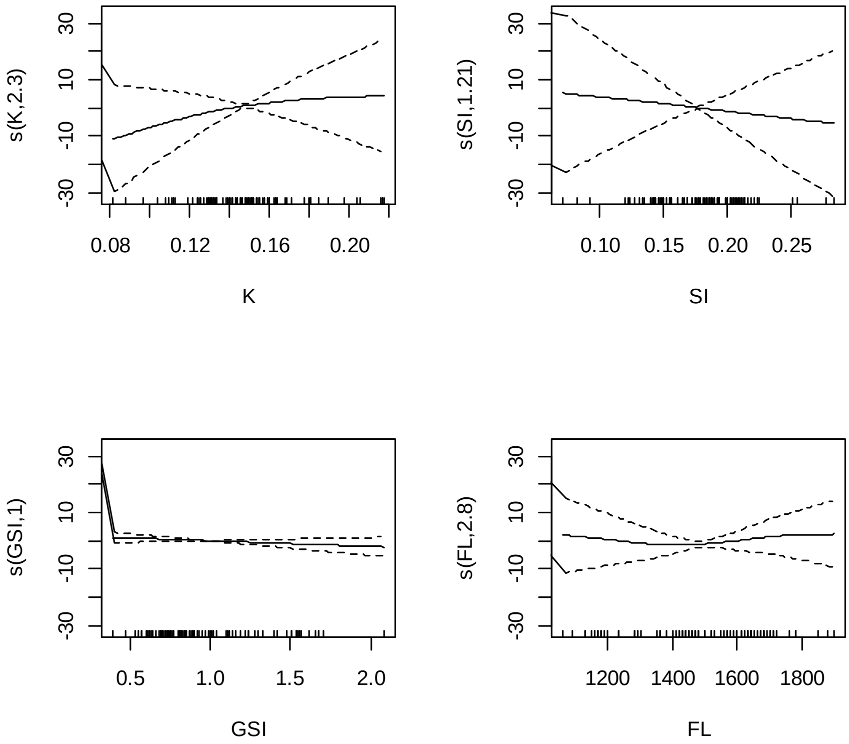


Fig.13 The relationship between fat content and K, SI, GSI, and FL

4 Discussion

4.1 Distribution and change of fat content

The highest frequency of fat content of yellowfin tuna was in the range of 0 to 5%. It is suggested that fat content of yellowfin tuna was relatively low in the survey area. The average fat content from October to December was relatively low in the total. The average fat content presented an increasing trend after December. The reason might be that yellowfin tuna make preparations for spawning starting from January (Black and Pickering, 1998). Spawning season started in March or April, and the fat content reached to the peak at this time. Ye et al. (2001) studied on biological characteristics of yellowfin tuna in the Indian Ocean and found that the spawning season of yellowfin tuna in this area started in March, which was consistent with the results of this study. Spatial distributions of fat content of yellowfin tuna in the survey area were significantly different. This might be related to the marine environmental factors and seasonal differences in the survey. The average fat content in the area of 2°N～3°N，59°E～60°E was the highest, so this area might be an important spawning ground.

4.2 The fat content distribution by gender

Genders of 91 yellowfin tuna were identified during the survey. The frequency of the average fat content value ranging from 0 to 5% was the largest, reaching to 53.6% for female, and the frequency of the average fat content value ranging from 5% to 10% was the largest, reaching to 38.0% for male. Chi-square test was used to test the relationship between fat content and gender and the result showed that there was no significant difference between the fat content of the female and that of the male (p>0.05). The reasons might be that: 1) there was no significant difference in metabolic process of male and female yellowfin tuna in the survey area; 2) growth, reproduction and aging process of male and female yellowfin tuna in the survey area were synchronized.

4.3 The relationship between fat content and weight

The weight of yellowfin tuna was in the range of 9 ~ 83 kg in the survey. Fat content had a maximum value in the weight group of 80~90 kg and a minimum value in the group of 0~10 kg. As the samples in the groups of 0~10 kg and 80~90 kg were very small, the average fat content probably had relatively large error. Chi-square test showed that there was no significant difference in fat content among each group for male, female and the total fish (p>0.05). The reason was the same as 4.2. And there was no significant difference in fat content among each group in total, and the reason might be that the changes of weight were mainly caused by the growth of skeleton and muscle.

4.4 The relationship between fat content and gonad maturity stages

Chi square test was used to test if there was significant differences among the fat content of each gonad maturity stage of the female the male, and the total fish. The results showed that there was no significant difference between female and male (chi-square value = 0.0882, p = 0.9987), between male and the total fish (chi-square value = 0.0069, p = 0.9992) and between female and the total fish (chi-square value = 0.0365, p = 0.9998). This might be due to the monthly changes of gonad maturity stages of female and male were basically the same and stable. Chi square test was used to test if there was significant differences among the fat content of each gonad maturity stage of the total fish. The results showed that there were no significant difference among the fat content of each gonad maturity stage of the total fish ($p>0.05$). This is consistent with the conclusion of Zudaire et al. (2014). They suggested that the energy required for reproduction was mainly derived from feeding, only a few part of energy was derived from fat accumulated in muscle, and there were no significant correlations between female reproductive capability and fat content of fish muscle.

4.5 The relationships between fat content and FL, GSI, K, and SI

By GAM , there was no significant correlation between fat content and FL, GSI, K, or SI ($p>0.05$). Goni and Arrizabalaga (2010) suggested that there was no significant correlation between fat content and condition factor, which was consistent with the result of this study. Growth of muscle and skeleton was the main reason for changes of somatic index (SI), and fat content had relatively small influence on the changes of somatic index (SI); there was no significant correlation between gonadosomatic index (GSI) and fat content. This is consistent with the conclusion of Zudaire et al. (2014). They argued that the energy required for reproduction was mainly derived from feeding, only a few part of energy was derived from fat accumulated in muscle, and there were no significant correlations between female reproductive capability and fat content of fish muscle. This study found that there was no significant correlation between fork length and fat content. The reasons might be that: 1) there was some bias because of the relatively small sample; 2) most samples of yellowfin tuna were not the first sexual maturity but had been matured for twice or more times. Song et al. (2014) studied the relationship between fat content and fork length of albacore tuna in waters near Cook Islands and argued that there were no significant correlation between them. This is consistent with the result of this study.

4.6 Outlook

There might be some bias in our study because the survey duration was short and the samples were limited. Therefore, it is necessary to extend the survey duration, expand the survey area, increase the sample size, change the sampling method to improve the accuracy of the results in the future study.

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