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Age and growth of North Pacific albacore tuna (Thunnus alalunga) based on sectioned fin ray

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Age and growth of North Pacific albacore tuna (*Thunnus alalunga*) based on sectioned fin ray

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Abstract: The North pacific albacore (*Thunnusal alunga*) is one of the main targeting species of tuna longline fisheries, the conservation and management of this species have been increasingly concerned by tuna regional management organization, such as WCPFC. Information on the age and growth is very important for conducting stock assessment of this species. Based on 258 fin ray samples collected on the Chinese tuna longliner *Tianxiang 16* operated in the North Pacific between October 19, 2013 and April 5, 2014, the age and growth of the North Pacific albacore were studied. Three different cutting positions were involved in the processing of section selection. Three functions, i.e. linear function, exponential function, and exponential function, were used to fit the relationship between the fork length and fin ray radius. The Von Bertalanffy growth function was estimated to be L_t=112.231*[1-e$^{-0.277(t+1.435)}$].

Key words: growth; albacore tuna; fin ray; North Pacific

Introduction

Albacore tuna (*Thunnus alalunga*) is a highly migratory species mainly living in the tropical and subtropical waters. This species living in the North Pacific Ocean generally spawn at the western and central part of the tropics and subtropics of the Pacific Ocean in spring and early summer (Jorge Landa et al., 2015). In the juvenile period, a number of albacores migrate from the North Pacific to the temperate waters of the eastern Pacific (Kogas et al., 1958).The spawners will migrate to the western tropical and subtropical regions of the Pacific to spawn. This set of patterns of movement will be juvenile fish recorded. The migratory characteristics of this species can provide an important basis for its sustainable utilization and management (Yeh et al., 1996).

Age and growth of albacore tuna have been usually conducted by identifying the increments of otoliths (Stequert B et al., 2004), vertebrae (Alves A et al., 2002), and fin ray (Tankevich P et al., 1982). Although otoliths and vertebrae were often utilized for age determination, fin ray is also one of hard parts of tuna which can be used to identify the age. Age determination is one of the important components in the study of fishery population dynamics (Bailey et al., 1986).

Due to the difficulty in the field sampling of hard part, such as fin ray and spine, few study on age determination of the North Pacific albacore tuna has been reported. The aims of the present study are 1) to determine the age of North Pacific albacore tuna based on sectioned fin ray; 2) to provide the alternative option for ageing this species; and 3) further to understand the growth of this species. The results derived from the present study will provide input parameters for building stock assessment model of albacore tuna in the North Pacific Ocean.

1 Materials and methods

1.1 Sample collection

Longliner *Tianxiang 16* is a deep frozen tuna longline fishing vessel of Dalian Ocean Fishing Company Limited, China. The survey was conducted from October 19, 2013 to April 5, 2014, which focused on the area of 30 ~ 42 ° N, 164 ~ 143 ° W in the North Pacific Ocean (Fig.1). The fork length, wet weight were recorded and sex was identified. The first dorsal fin ray was removed and stored, and then returned to the laboratory at the Shanghai Ocean University for later analysis.

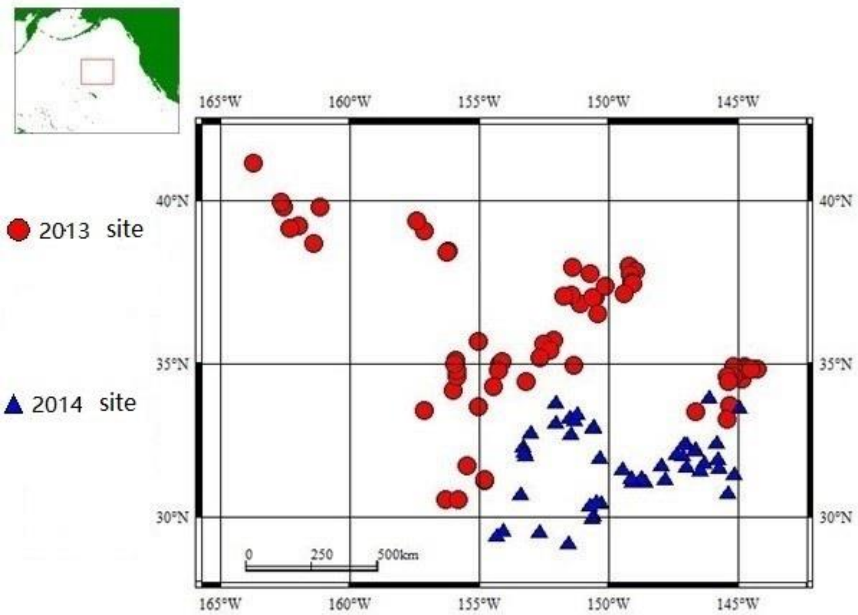

Fig .1 The sampling locations

1.2 Sample processing

In order to explore the impacts of different cutting sections on the age determination, the fin rays were divided into three positions. The first position was measured from the bone protrusion at the beginning of the measurement of the total length for the 10% marker segment (The first group); the second position was from the bone protrusion, the total length for 20% marker segment (The second group); the third position was 10% of the full-length marker segment from the bony prominences (the third group), as shown in Fig. 2. Using a low-speed precision cutting machine (Model Number DTQ-5), the fin ray was cut into a slice about 2 mm in thickness which was marked and stored in a paper sample bag. The two sides of the grinder were polished to near the cutting line at the thickness of 1 mm using the 600 grits of water-resistant abrasive paper installing on the grinder LABOPOL-25. Then, the rest was grinded with 1200 grits and 2000 grits till the increments pattern clearer in the microscope. By the grinding and polishing machine (TegraPol-1) the increments slice will be polished.

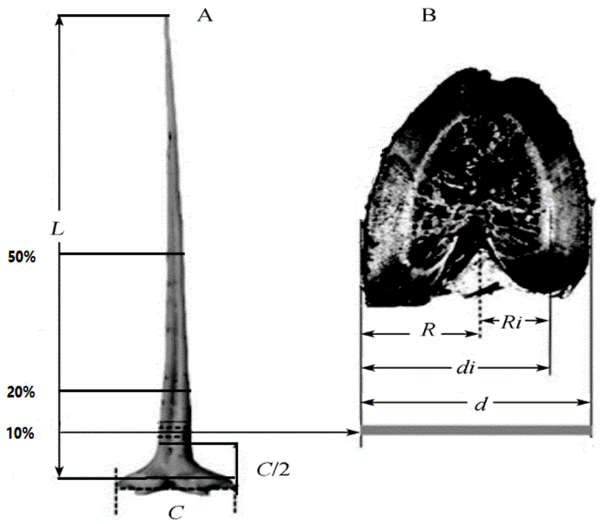

Fig .2 Diagram of cutting position and cross section of the fin ray

Note: A—fin ray and measurement parameters; B—ring number on the cross section of ray slice C-- the width of the base of fin ray; L--the vertical length of the fin ray from the base to the end; 10%, 20%,50% --the central line of the cross section at different heights. R--the cross-section radius of the fin ray; R_i--radius of ring i；d--fin ray cross-section diameter; di--the distance of ring i from one side to the ring line.

1.3 Age determination

The polished fin ray was photographed using an optical microscope (Olympus-SZX-ZB7). The narrow band (transparent band) and wide band (opaque band) were observed under the 0.8-5.6 times objective lens, and a ring was observed according to the adjacent narrow band and a broadband. We determined the age by the numbers of narrow band. If the central region of the fin ray is found to be vasculature, the position of the first few fringes is estimated by comparing using the young fish by the tread radius' mean and confidence intervals. Fin ray ally, we used the electron microscope to take pictures, and the photos was synthesize into one picture by the Photoshop software (Kogas et al., 1958).

1.4 Data analysis and processing

1.4.1 Fork length frequency

The fork length was divided by the group interval of 5cm. The significant sexual difference for the fork length and the fin ray radius (Vertebral Radius, VR) were measured by the analysis of covariance (ANCOVA).

1.4.2 The average percentage error (APE)

In the identification of the albacore fin ray, the identification of the fin ray due to the grinding of the fin ray and the fin ray itself might lead to a certain error in the identification of the age. Therefore, after the completion of the age of identification, we conducted the average percentage error analysis. The average percentage error (APE) is an indicator of age determination between different appraisers (Kogas et al., 1958). When the APE is less than 10%, it indicates that the accuracy of ring-ring identification is acceptable. Otherwise it was needed to re-identify their age. The APE was calculated as follows:

$$APE_j = \frac{1}{N}\sum_{j=1}^{N}\frac{|x_{ij} - x_j|}{x_j} \times 100\% \qquad (1)$$

Where N is the number of times of the j^{th} sample for repeated calculation; X_{ij} is the number of the i^{th} counted for the j^{th} sample; X_j is the mean of the repeated counting for the j^{th} sample.

1.4.3 Relationship between the radius of fin ray and fork length

Besides the ANCOVA which was used to test whether the sexual factor affects the relationship between the fork length and the radius of the fin ray, the exponential equation, linear equation and power function equation were used to fit the relationship between the fork length and the radius of the fin ray (Bernard et al., 1983).

Exponential equation: $FL=a_1e^{b1R}$ （2）

Linear equation: $FL=a_2R+b_2$ （3）

Power function equation: $FL=a_3R^{b3}$ （4）

Where FL was the fork length (cm), R is the radius of the fin ray (mm), a_1, a_2, a_3, b_1 and $b_3$was regression coefficients, $b_2$was the intercept.

The results of three models were tested using the AIC (Bailey et al., 1986) to fin ray d the most suitable model. The model was best when AIC value was smallest. The AIC can be calculated as follows:

$$AIC = n \times ln\left(\frac{RSS}{n}\right) \qquad (5)$$

Where, n was the number of samples; RSS was the sum of squares of residuals [6]; k is the number of model parameters.

1.4.4 Inverse calculation for the fork length

The model with the smallest AIC value was used to calculate the fork length. If the exponential model was most suitable, it can be directly calculated by exponential regression parameters. However, when the linear model or the power function model was best, the fork length calculation needed to use Fraser-Lee's method or Monastyrsky method (NATHANAELCO et al., 2001). The formulas for these two methods were showed as follows:

Fraser-Lee's Act:

$$Ln = \left(\frac{R_n}{R}\right)(FL - b) \qquad (6)$$

Monastyrsky Act:

$$Ln = FL\left(\frac{R_n}{R}\right)^{b_2} \qquad (7)$$

Where, FL was the fork length (mm) measured by the albacore tuna; Ln was the inverse length (mm) when the n-th ring was formed; R was the radius of the fin ray; Rn is the age corresponding to Radius (mm); b1 was the intercept for the fin ray bone radius and fork length linear regression equation; b2 was the regression coefficient for the fin ray radius - the fork length of the power function.

1.4.5 Growth

We used the Von Bertalanffy growth equation to describe the relationship between age and growth. The optimal value of the growth parameters were estimated by the solution function of Excel2013. Von Bertalanffy growth equation is the most important model describing the growth of tuna, many scholars have used this method to describe the growth of tuna. Von Bertalanffy growth equation was as follows:

$$L_t = L_\infty[1 - e^{-K(t-t_0)}] \quad (8)$$

Where Lt was the fork length at t age; L∞ was the limit body length; K was the instantaneous relative growth rate; t was the age; t0 was the theoretical age corresponding to the fork length.We also estimated the inflection point age using the formula as:

$$t_{tp} = \frac{ln3}{k} + t_o \quad (9)$$

2. Results and Analysis

2.1 Fork length frequency

The number of valid samples used in this experiment was 258. The range and mean of the fork length was 57 ~ 109cm and 88.79 ± 4.871cm. The dominant fork length was 81 ~ 100cm, accounting for 76.74% of the total sample numbers. As shown in Figure 3, for male, the range and mean of the fork length was 63 ~ 109 cm and 87.93 ± 4.334 cm. The dominant fork length was 81 ~ 90 cm, accounting for 71.82% of the total female sample numbers. For female, the range and mean of the fork length was 57 ~ 108 cm and 89.65 ± 5.408cm. The dominant fork length was 81 ~ 90cm, accounting for 74.47% of the total male sample numbers.

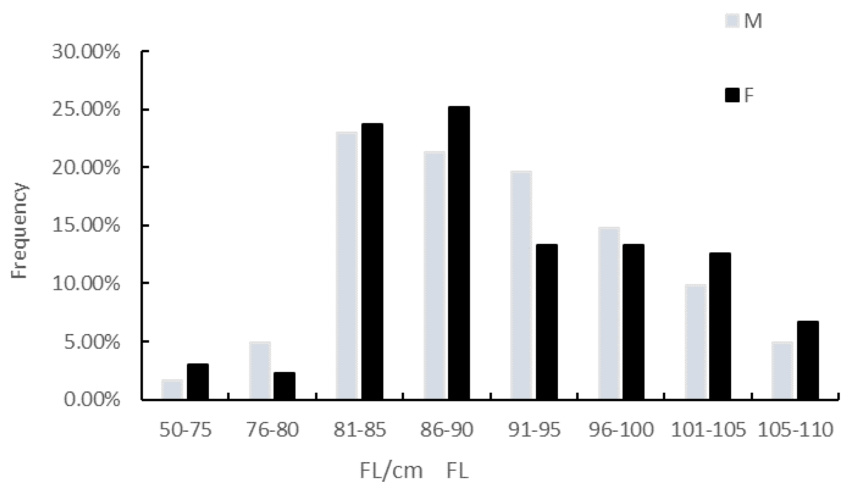

Fig .3 The frequency of fork length（n=258）

2.2 Age Composition and average percentage error (APE)

A total number of 774slices from 258 fin ray samples, which reached the identification requirements of 717. There were 246 samples for first group corresponding to the requirements; 240 samples for the second group and 231 samples for the third group (Table 1). As shown in

Table 2, (APE2 <APE1 <APE3), the second group result was better than the other two groups. the age distribution was shown in Fig.4.

Tab.1 The age composition by cutting position

Age/a \ Group	1	2	3	4	5	6	7	8	9	Total
The first group	6	15	36	54	66	36	21	9	3	246
The second group	6	21	30	45	60	39	24	9	6	240
The third group	3	18	24	45	54	45	30	9	3	231
Total	15	54	90	144	180	120	75	27	12	717

Tab.2 The average percentage error for different cutting position

The experimental group	The average percentage error index
The first group	APE_1=2.343%<10%
The second group	APE_2=1.631%<10%
The third group	APE_3=3.461%<10%

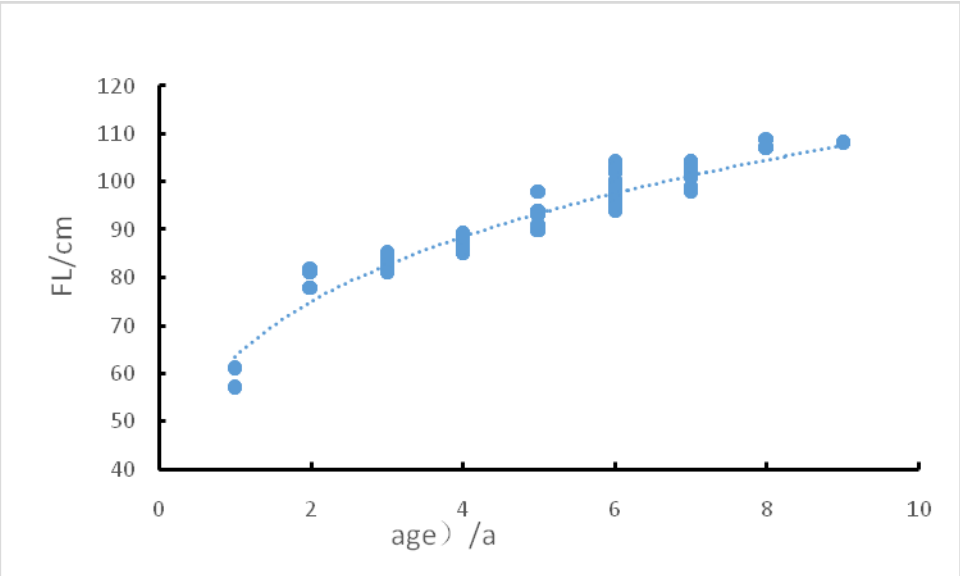

Fig.4 Relationship between fork length and age of albacore tuna based on fin rays

2.3 Age determination

In the identification of the age of albacore tuna, due to the inevitable problems of vascularization, some samples cannot be properly identified their increments. Therefore, the identification process could be based on the average and standard deviation of the rings to predict and determine the location of the lost rings. Vascularization of young fish was more serious. With age growing, vascularization area also increased. The age composition and the mean radii for each age of the albacore was shown in Fig.5

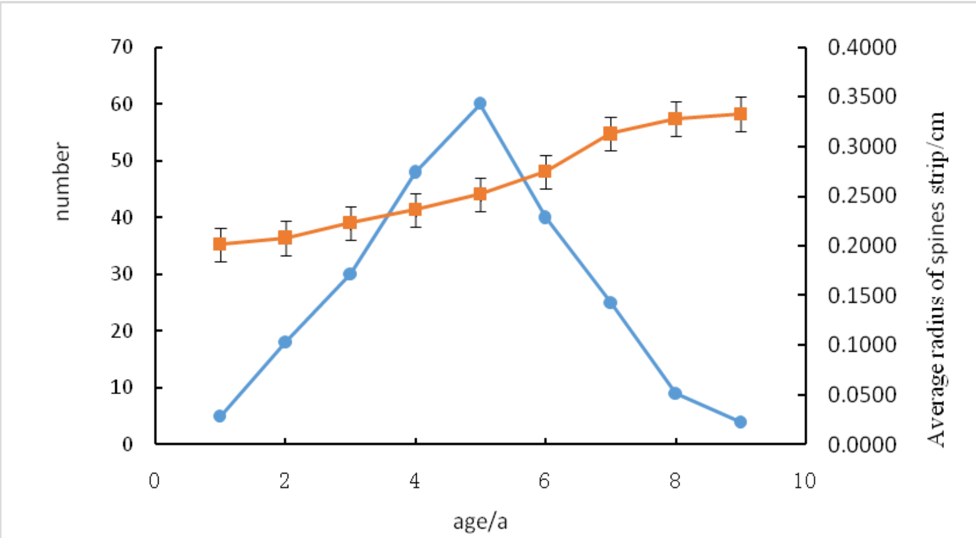

Fig.5 The age composition and the mean radii for each age of the albacore based on fin rays（n=239）

2.4 Relationship between fork length and the radius of the fin ray

By the results of ANCOVA, there was no significant difference (P> 0.05) between male and female on the fork length and fin ray radius of the albacore tuna. Therefore, it could be combined when fitting the relationship between fork length and the radius of the fin ray. The results were showed in table 3 and Fig.6.

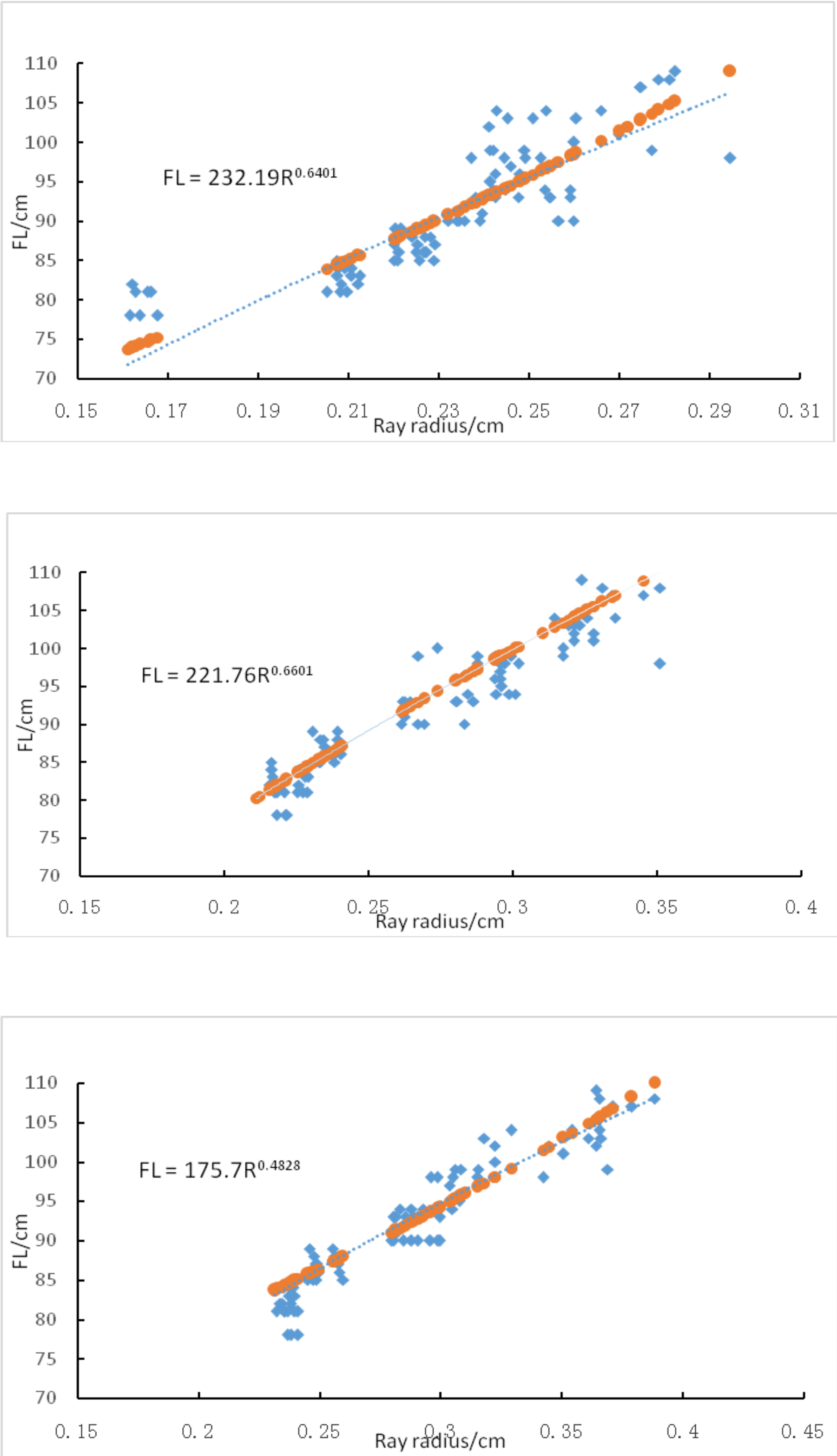

Fig.6 Relationship between fork length and the radius of the fin ray for albacore tuna

Tab.3 The relationship between fork length and the radius of the fin ray by three function models

	Group	The first group	The second group	The third group	Total
	The effective sample /cm	246	240	231	717
	Fork length range /cm	57～108	61～109	61～107	57～109
	Ray radius range /cm	0.1611～0.2946	0.2111～0.3512	0.2311～0.3882	0.1611～0.3882
Fork length and radius of fin ray strip	Exponential model	$FL=45.402e^{2.9769R}$ (AIC=281)	$FL = 48.578e^{2.397R}$ (AIC=298)	$FL = 54.072e^{1.8539R}$ (AIC=313)	$FL = 56.933e^{1.8083R}$ (AIC=986)
	Linear model	$FL = 259R+ 31.011$ (AIC=281)	$FL = 215.45R + 35.099$ (AIC=301)	$FL = 167.97R + 44.359$ (AIC=315)	$FL = 161.45R + 49.644$ (AIC=983)
	Power function model	$FL = 232.19R^{0.6401}$ (AIC=280)	$FL = 221.76R^{0.6601}$ (AIC=292)	$FL = 186.56R^{0.5599}$ (AIC=308)	$FL = 175.7R^{0.4828}$ (AIC=973)

2.5 Inverse calculation for the fork length

After using the three models to fit the relationship between the age of the albacore and the radius of the fin ray, it could be concluded that the AIC values were the smallest for the power function model which meant this model was most reasonable in describing their relationship. Therefore, in the next analysis about the inverse length calculation, we used Monastyrsky method and the formula $FL = 221.76R^{0.6601}$ to calculate the fork length. The results of inverse calculation for the fork length was shown in Table 4.

Tab.4 The inverse calculated fork length corresponding to number of ring

Method		Age	Number	Inverse calculation for the fork length to each age/cm								
				I	II	III	IV	V	VI	VII	VIII	IX
Monastyrsky	Monastyrsky method	1	5	77.25								
		2	18	79.48	77.50							
		3	30	76.95	83.47	82.82						
		4	48	74.38	74.63	76.09	84.58					
		5	60	—	77.28	80.00	87.78	87.80				
		6	40	—	80.00	82.14	84.32	90.33	94.67			
		7	25	—	—	90.28	84.85	90.63	92.94	104.74		
		8	9	—	—	—	86.16	86.12	95.32	105.50	102.97	
		9	4	—	—	—	—	91.12	95.10	98.73	109.39	107.25
Mean /cm				77.03	78.61	82.33	85.54	89.21	94.51	103.01	106.20	107.25

Note: "—"represents no valid data due to the fin ray vascular

2.6 Growth equation

According to the inverse mean fork length from 1-9 ages, combined with Von Bertalanffy growth model, the growth equation was obtained by using the solution function of planning.

$$L_t = 112.231 * [1 - e^{-0.277132*(t+1.43517)}]$$

The age t_{tp} at inflection point was 2.53.

3. Discussion

3.1 The advantages and disadvantages of fin ray and other age determination materials

The age of the albacore is generally determined by the calcification structure of the growth-related tissue, like vertebrae, fin ray and otoliths. The authors have previously identified albacore tuna through the vertebrae. For each material, both advantages and disadvantages exist as shown in Tab 5.

Tab.5 The advantages and disadvantages in age determination based on different materials

material	Advantages	disadvantages
Vertebrae	The chakra is clearly marked, and the increments is complete.	The process of sampling and processing of vertebral vertebrae is cumbersome, especially when it comes to dyeing
Otolith	Otolith has stable structure. The impacts of external factors are smaller to this tissue than other materials. Although growth tends to be stagnancy, otolith continues to be deposited. The deposits are stable after their formation.	Otolith is difficult to extract from the fish and it is also fragile which may be prone to breakage
Fin ray	The samples are easy to collect and do not affect the economical value of tuna	The phenomenon of aged fish vascularization is severe. There is often a blurred pattern of increments lines, which may not be distinguished clearly.

3.2 The rationality of the position of the fin ray cutting

For the cutting position of albacore fin ray polished, the controversy is very large. Choosing different locations to cut for the age determination of discrimination may have different degrees of clarity. In addition, the radius of the fin ray is not the same which, from the base to the top, has a decreasing trend. Therefore, in this study, we used three different cutting positions for the cutting and grinding of the albacore fin ray to select the best cutting position. From Table 3, we can see that the AIC values obtained by cutting the different positions are different. While the second group corresponding to the three functions of the AIC value is the smallest, which means the position from the bone protrusion, the total length for 20% marker segment is the most ideal.

3.3 Three kinds of three-function model selection

The method of three kinds of three-function model selection can better express the relationship between the length and the radius of the fin ray tuna and then effectively guarantee the accuracy of the fin ray al inverse value. From Table 3, we can easily fin ray d, not only for the three experimental data but also for the fin ray al total sample data, power function model can be more accurate to describe the relationship between them. Therefore, the power function and Monastyrsky method were used to express the relationship between the fork length and the radius for the albacore tuna.

3.4 Comparison of growth equations

The growth model is very important as the method of determining fish growth, growth point, growth rate and growth index. Many scholars use the three models of Von Bertalanffy model, Logistic model and Gompertz model to fit the growth of albacore tuna. Through the comparison of the three models, the Von Bertalanffy growth equation, which is common in both past and present fishery studies, has been highly valued and widely used. Therefore, in this study, the Von Bertalanffy growth equation was used for age and growth.

Many experts have studied the growth of albacore. The results showed that the minimum length of long-tailed tuna was 102.9cm and the maximum was 146.5cm. The limit length of different scientists' study was 109.1cm and 112.2cm; the maximum average curvature of the growth curve was 0.4, while the minimum was 0.134. And our study was 0.277. t_0 has a maximum of 1.999 and a minimum of -2.273 for different scientists' study, and our study was -1.435.All of the parameters of this study were within range. There was no significant difference between this study and Labelle in 1993 using the data of albacore vertebrae from South Pacific ($P> 0.05$), and Santiago and Arrizibalaga in 1963 using the data of albacore fin ray ($P> 0.05$). CLEMENS had less samples and small range of fork length which might result a large limit fork length. This means we should put our attention to the sample collection with large length range. The results of this study are similar with BELL in 1962 through the otoliths on the North Pacific albacore which means, to a certain extent, the results of this study is theoretical basis, the results are credible (Chen Y et al.,1992; SUN Cet al.,1992; LABELLE et al.,1991; SANTIAGO Jet al.,2005; NOSE Yetal.,1957; Sarre Get al.,2000).

Tab.6 Results about albacore tuna growth equation from other studies

Source	Method	Size range(cm)	Location	L_∞/cm	k/a^{-1}	t_0/a
This study	fin ray	69-109	North Pacific	112.2	0.277	-1.435
Nose *et al*. (1957)	Scales	65–120	North Pacific	114.4	0.308	0.818
Otsu (1960)	Tagging	60–91	North Pacific	118.8	0.250	1.999
Clemens (1961)	Tagging	54–77	North Pacific	135.6	0.170	-1.870
Bell (1962)	Scales	51–94	North Pacific	108.8	0.225	-2.273
Yabuta and Yukinawa(1963)	Scales	48–95	North Pacific	146.5	0.149	-0.860
Labelle et al.,1993	Vertebrae	44–110	South Pacific	121.0	0.134	-1.922
Santiago and Arrizibalaga(2005)	Fin ray	40–119	North Atlantic	127.1	0.180	-1.620
Farley and Clear (2008)	Otoliths	48–108	South Pacific	102.9	0.321	-1.107
Williams *et al.*(2012)	Otoliths	43–116	South Pacific	104.5	0.400	-0.490
Chen *et al*. (2012)(males)	Otoliths	45–118	North Pacific	114.0	0.253	-1.010
Chen *et al*. (2012)(females)	Otoliths	46–101	North Pacific	103.5	0.340	-0.530

3.5 Prospects and shortcomings

In general, the study on the age and growth of the North Pacific albacore is not enough. In this study, the data of the samples were analyzed by statistical method to give the range of fork length, average fork length and other biological basis of biological information. Then the fin ray age of the albacore tuna was obtained. Fin ray ally, the growth equation of the albacore tuna was obtained.

In this paper, we studied the age and growth of Atlantic albacore tuna from 2013 to 2014, but our results need more samples or other tissues to validate. Since the study for the albacore growth in North Pacific Ocean in recent years are also insufficient, so in next work, we also need to collect more samples to do future studies which could be beneficial for the Pacific albacore tuna utilization and their stock assessment.

References

Alves A, et al. Age and growth studies of bigeye tuna *Thunnus obesus* from Madeira using vertebrae. Fish Res, 2002, 54(3): 389−393.

Bailey K N. A preliminary analysis of the stomach contents of albacore (*Thunnus alalonga*) from the Subtropical Convergence Zone east of New Zealand. The First South Pacific Albacore Research (SPAR) Workshop. Auckland, New Zealand: SPac Comm, 1986: WP/17

Bernard H, et al. Stomach contents of albacore, skipjack, and bonito caught off southern California during summer 1983. Cacofl Rep, 1985, 26: 175-183

Chen Y, et al. A comparison of Von Bertalanffy and polynomial functions in modelling fish growth data. Canadian Journal of Fisheries and Aquatic Sciences, 1992, 49(6): 1128−1235.

Landa J, et al. Growth of bluefin tuna (*Thunnus thynnus*) in the North-easternAtlantic and Mediterranean based on back-calculation ofdorsal fin spine annuli, Fisheries Research,2015,170 (2015) 190–198.

Kogas. On the stomach contents of tuna in the west Indian Ocean. Bull Faculty Fish, Nagasaki Univ, 1958, 6, 85-92

Labelle M, et al. Determination of age and growth of South Pacific albacore (*Thunnus alalunga*) using three methodologies. Fish Bull 91, 649–663.

Overman NC et al. Stable isotope composition of walleye: ^{15}N accumulation with age and area specific differences in ^{13}C. Can J Fish Aquat Sci, 2001, 58: 1 253- 1 260.

Nose Y, et al. Age and Growth of Pacific Tunas by Scale Reading. Tokyo University Press, Japan, pp1957. 701-716.

Santiago J, et al. An integrated growth study for North Atlantic albacore (*Thunnus alalonga* 1788). ICES J Mar Sci 62, 740-749.

Sarre G, et al. Variation in age compositions and growth rates of *Acanthopagrus butcheri* (Sparidae) among estuaries: some possible contributing factors. Fish Bull, 2000, 98(4): 785-799

Stequert B, et al. Age and growth of bigeye tuna (*Thunnus obesus*) in the western Indian Ocean. Cybium, 2004, 28(2): 163−170.

Sun C, et al. Age and growth of the swordfish (*Xiphias gladius* L.) in the waters around Taiwan determined from anal-fin rays. Fish Bull, 2002, 100(4): 822-835.

Tankevich P. Age and growth of the bigeye tuna, *Thunnus obesus* (Scombridae) in the Indian Ocean. J Ichthyol, 1982, 22(4): 26−31.

Yeh, Y M, et al, Stock assessment of the South Pacific albacore by using the generalized production model, 1967-1991. ACTA Oceano Grahica Taiwanica. 1996, 35(2): 125-139.