Received: 19 & 20 August, 2012

Age and growth of Albacore Tuna (*Thunnus alalunga*) in the southern and central Indian Ocean based on Chinese observer data

Zhou Cheng[1], Li Fengying[1], Tang Hao[1], Xu Liuxiong[1,2,3] and Tian Siquan[1,2,3]

1. College of Marine Sciences, Shanghai Ocean University,
2. National Engineering Research Center for Oceanic Fisheries, China
3. The Key Laboratory of Sustainable Exploitation of Oceanic Fisheries Resources, Ministry of Education, China

Abstract: The age and growth of fish are essential biological parameters for the assessment of fishery resources. Albacore tuna age and growth was studied by examining growth rings on the cross sections of the first dorsal fin spines based on 106 samples collected by Chinese scientific observers in the southern and central Indian Ocean from September 2008 to April 2009. The fork length (FL) of the Albacore tuna samples ranged from 97 to 120 cm, with the dominant FL class at 103-115 cm. A comparison with Akaike information criterion (AIC) suggested that among power regression, linear regression, and exponential regression, linear regression equation was most suitable for describing the relationship between fork length and spine radius (AIC=754.30). The mean back-calculated *FL* was estimated by Fraser-Lee's method, and von Bertalanffy growth equation was $L_t = 113.7\ [1–e^{-0.194(t + 8.39)}]$.

Key words: age; growth; *Thunnus alalunga*; spine; the southern and central Indian Ocean

1 Introduction

Albacore tuna are widely distributed in temperate and sub-tropical waters of the Pacific Ocean, the Atlantic Ocean and the Indian Ocean. The central and southern Indian Ocean is one of the major fishing grounds, concentrating at 15°S~35°S (Hsu 1990). As one of the most important fishing species of longline fisheries, this species can also be fished by a variety of gears, such as purse seine, trawl and so on (Li 2010).

The accurate and precise estimation of age is essential for the accurate assessment of the albacore stock, which can be determined by counting growth increments on suitable calcified structures including vertebrae (Foreman 1980; Labelle 1993), spines (Gonzalez-Garcés and Farina-Perez 1983; Megalofonou 2000; Santiago and Arrizabalaga 2005; John 2010) and otoliths (Chen 2012).

Estimation based on cross section of spine is relatively easy and reliable (John 2010), however issues still exist about the accuracy of the results caused by such factors as re-absorption of the core, multiple banding within each annulus, cutting position and so on (Compean-Jimenez and Bard 1983; Santiago and Arrizabalaga 2005). Therefore the age needs to be validated further. Mark and recapture experiments (Ortiz de Zárate *et al*. 1996) and daily increment counts in otoliths (Lee and Yeh 2006) have been used.

The aim of this study is to estimate the age and growth parameters using growth rings on cross sections of the first dorsal spines based on samples collected by Chinese scientific observers in the southern and central Indian Ocean from September 2008 to April 2009. It can provide new information on albacore biology in the southern Indian Ocean.

Received: 19 & 20 August, 2012

2 Material and methods

2.1 Sampling

The first dorsal spines of the albacore tunas were collected by Chinese scientific observers on board Chinese deep frozen longlining vessel "Longxing 602" operating in the Southern Indian Ocean which covered 12°10′S~ 32°15′S, 59°10′E ~ 78°50′E (Fig.1) from September 2008 to April 2009. The collected spines were frozen preserved on board the fishing vessel and then were transported to the laboratory.

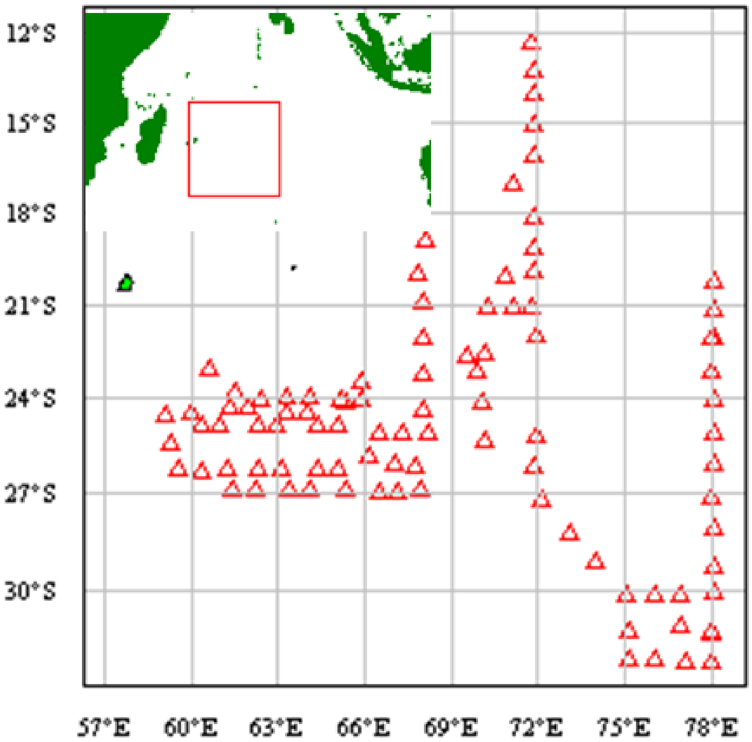

Fig. 1 Sampling locations of *Thunnus alalunga*

2.2 Processing methods

In laboratory, the spines were soaking in hot water (80-90℃) for about 5-6 minutes after unfreezing. The muscles adhering to spines were cleaned after they were flexible. And then the spines were stored after air-dried.

The length from the spine condyle base to the top was defined as the total length of the spine by L, and the width of the spine condyle was expressed by C. One cross section was taken along the length of each spine about the length of C above the condyle base (Fig.2) using a low-speed saw and diamond wafering blades. Sections ranging from 0.8 to 1.0 mm thick were examined using a dissecting microscope (Olympus-SZX-ZB7) with transmitted light at 0.75 X magnification. Images of the dorsal spine sections were captured by using an image analysis software package, a CCD (charged coupled device) camera, and a high resolution computer monitor. Then the morphological parameters of the spine section were measured by professional image analysis software (WT-1000GM). The parameters included: (1) the diameter of the spine (d); (2) distance between annual ring i and the

Received: 19 & 20 August, 2012

distal spine edge beyond ring *i* (d_i); (3) radius of the spine section (R), the radius of annual ring *i* (R_i), $R=d/2$, $R_i=d_i-R$ (Fig.2).

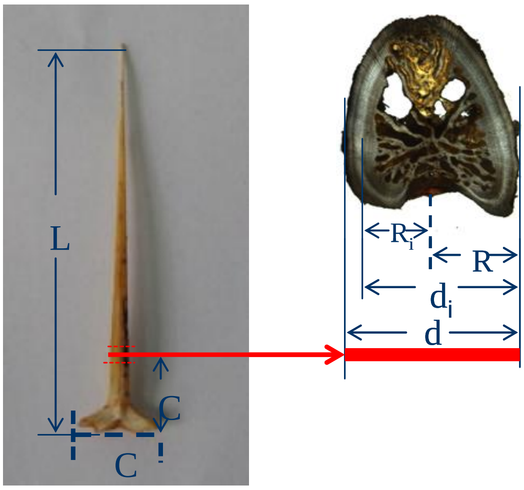

Fig.2 Sketch map of cutting location and measurement parameters of spine cross section

(A): cutting location of spine, *L*: length of spine; *C*: width of condyle base.

(B): measurement parameters of spine cross-section, *R*: radius of spine cross section; *d*: diameter of spine cross section; R_i: radius of ring *i*; d_i: distance between annual ring *i* and the distal spine edge beyond ring *i*.

2.3 Age interpretation

Growth bands were identified based on the presence of a narrow translucent zone (slow winter growth) and a wider opaque zone (rapid summer growth). The age of each fish was estimated by the number of translucent by two readers independently without prior information on *FL* (Cort 1991). When ring counts disagreed, images were read again by both readers simultaneously, and any questionable spines were discarded.

2.4 Data analysis

2.4.1 Fork length frequency analysis

The fork length was grouped by 3cm intervals to describe size frequency distribution of the albacore samples by using Microsoft excel software.

2.4.2 Relationship of spine diameter to fork length

Firstly, Wilcoxon signed ranks test was used by R version 2.9.2 to test the significant differences between the right spine section radius and the left one of each albacore. Then regression analysis was used to establish the strength of correlations between increasing fork lengths and spine diameters using the following three equations:

Linear regression: $FL= a_1R+b_1$ (1)

Power regression: $FL= a_2R^{b_2}$ (2) Exponent

regression: $FL = a_3e^{b_3R}$ (3)

Where *FL* is fork length; a_1, a_2, a_3 , b_2 and, b_3 are regression coefficients; b_1 is slope of fitted line; *R* is radius of the spine section.

The most suitable model was selected by Akaike Information Criterion (AIC) (Akaike 1983) through examining the relationship between fork length and spine section radius and the back-calculated fork length. The simplified equation for calculating AIC is:

$$AIC=n*\ln(RSS/n)+2k \quad (4)$$

Where n is sample number; RSS is residual sum of squares; k is the number of parameters.

The model with relative lower AIC value was considered as the more suitable one.

2.4.3 Back-calculation of the fork length

The regression model of fork length-spine section radius with the lowest AIC value was taken to speculate the back-calculated fork length of various ages. The exponent model can use the exponent regression expression to calculate directly, and the linear model and power model can use Fraser-Lee's method and Monastyrsky method. The following were the expressions:

Fraser-Lee's method: $$L_n=\left(\frac{R_n}{R}\right)(FL-b_1)+b_1 \quad (5)$$

Monastyrsky method: $$L_n=\left(\frac{R_n}{R}\right)^{b_2}-FL \quad (6)$$

Where Ln is the back-calculated fork length at age n; R is the spine section radius; b_1 is intercept of the linear regression of the fork length-spine section radius; b_2 is the regression coefficients of the power function regression.

2.4.4 Growth parameters estimation

Mean FL at different ages was used to estimate the growth parameters of the von Bertalanffy growth function:

$$L_t=L_\infty(1-e^{-k(t-t_0)}) \quad (7)$$

Where, L_t is the FL of fish at time t; L_∞ is the asymptotic FL; k is a constant expressing the rate at which the length reaches L_∞, and t_0 is the theoretical age when FL is 0.

3. Results

3.1 Fork length frequency analysis

A total of 183 individuals of albacore were collected by observers and valid number was 106. Their fork length ranged from 97 to 120 cm, with the dominant FL class at 103-115 cm and accounting for 93.4% of the total number (Fig. 3).

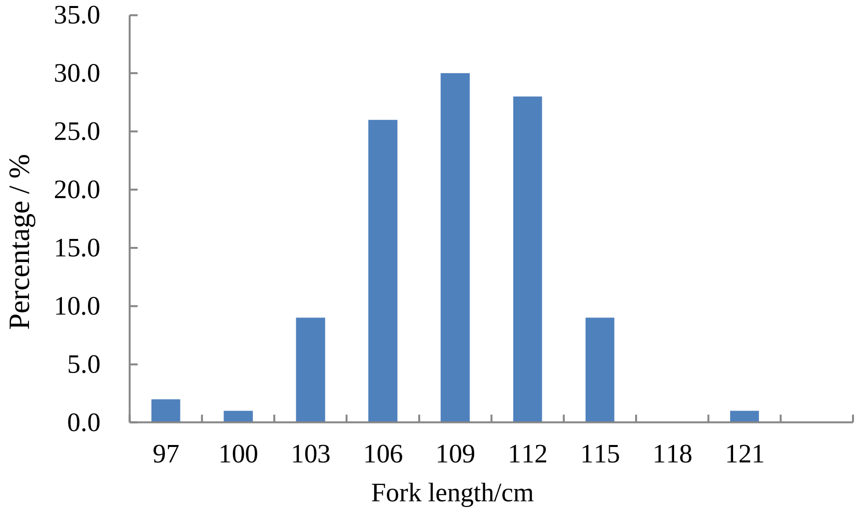

Fig. 3 Frequency distribution of fork length of *Thunnus alalunga*

3.2 Relationship between spine diameter and fork length

30 spine samples were randomly selected and their radiuses were measured under light microscope. Wilcoxon signed ranks test showed that there is no significant difference between the left radius and the right one (P>0.05) which was showed in Table. 1.

Table. 1 Relationship between fork length and radius

valid number	FL range (cm)	radius range (mm)	relationship between fork length and radius		
			linear regression	exponent regression	power regression
106	97~120	2.205~3.145	FL= 100.49R + 804.54 (AIC=754.3018, n=106`)	FL= 836.31$e^{0.093R}$ (AIC=754.4169 , n=106)	FL= 835.87$R^{0.254}$ (AIC=754.3243, n=106)

3.3 Back-calculation of the fork length

The result showed that the linear regression could better describe the relationship between fork length and radius due to the lowest AIC value. The fork length was back-calculated by Fraser-Lee's method. Weighed back-calculated fork length of each age was showed in Table. 2.

Table. 2 Radius corresponding to each annual ring and weighted ring radius

age	number	back-calculated mean FL (mm) by annulus							
		Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ	Ⅵ	Ⅶ	Ⅷ
1	0								
2	1	991	1049						
3	9	973	1013	1046					
4	22	956	994	1026	1051				

5	41	948	978	1005	1028	1052			
6	27	953	982	1010	1034	1056	1073		
7	4	952	975	998	1012	1034	1054	1068	
8	2	935	962	979	1000	1017	1031	1045	1063
total	106								
weighed ring radius		953	985	1014	1034	1052	1068	1060	1063

3.4 Estimation of growth parameters by von Bertalanffy growth function

The solver optimization function in Microsoft excels was used to analyze the back-calculated fork length data for the age from 2 to 8 years to obtain the von Bertalannfy parameters for a minimum sum of squares value. The von Bertalanffy equation for the theoretical growth of albacore in fork length was described Lt = 113.7 [1–e-0.194(t + 8.39)] and its curve could be seen in Figure 4.

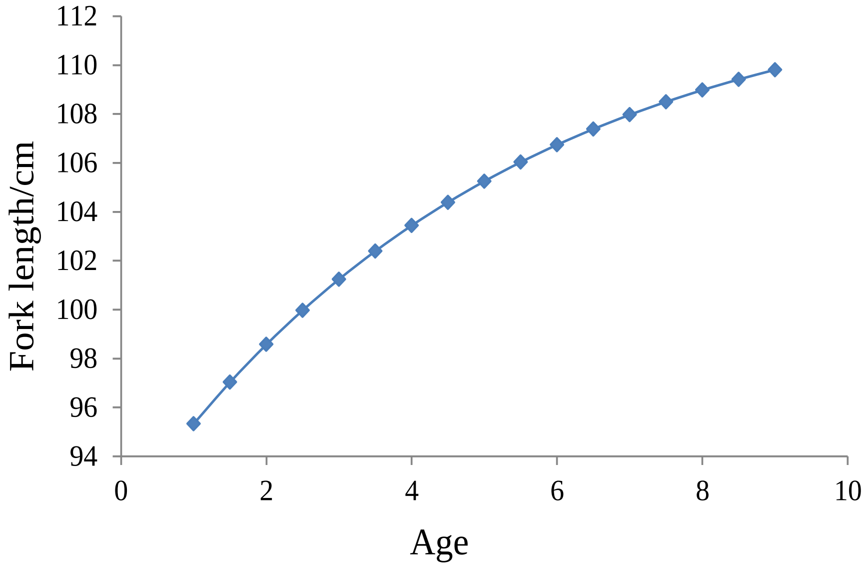

Fig. 4 Von Bertalanffy growth curve of Albacore tuna (*Thunnus alalunga*) in the southern and central Indian Ocean

4 Discussions

4.1 Ageing

The accuracy of the age determination will be affected by many factors. Firstly, with increasing size the progression of opaque and translucent bands became crowd, it should increase the difficulty of distinguishing between opaque and translucent zones and therefore impacted the judgment of these annulus. This difficulty was addressed by recounting until an agreed value was agreed. The evaluation of this method for age determination must await further sampling of older age fish or the collection of hard parts from fish of known age.

Secondly, the cutting position is still disputed for the radius affects the clarity of the annulus, and with the increase of the radius, the vascularization of the core will be more serious. Some studies used the spine condyle as the standard (Lu 2007), and some used the half of the spine condyle (Sun 2001), others even used the protuberance near the base of the spine (Zárate 2007). Although the protuberance near the base of spine has the largest radius, but it is very difficult to be recognized by naked eyes because of their subjectivity. This study tried to select the width of the spine condyle as the cutting standard which was relatively easy and might get better results. But it still needs to be corrected by further studies.

4.2 Von Bertalanffy Growth Parameters

The previous studies related to age and growth of the albacore tuna were summarized in Table 3. Many evidences showed that it should be more uncertain if very small or very large samples were absent in growth parameters estimation. Actually, if the samples consisted of more small size fish, the L_∞ would be relatively small, and vice versa. L_∞ in this study was lower than those in other areas, but was higher than that in the eastern Mediterranean. This result could be explained because there was the lower age composition in the eastern Mediterranean. K estimated in this study which reflects the growth rate at which the length reaches L_∞ was close to those in other areas. But K estimated by Foreman (1980) in the Western North Pacific was significantly higher than others, expressing the vigorous growth. It looks that t0 in this study was underestimated significantly than other studies. The result was probably caused by the following aspects: firstly, there was a smaller range of sizes and the very small size and large size fish were absent; secondly, the fish may grow very slowly in the early life stage due to the wicked environment or lack of food; thirdly, some of the spine sections were polished too thin to recognize the clear annulus, and the results need to be validated by mark-recapture technique and other materials.

Table. 3 Variables of von Bertalanffy growth equation for *Thunnus alalunga*

resource	methods	fork length range (cm)	area	L_∞ (cm)	K (yr^{-1})	t_0 (yr)
Foreman (1980)	V		Western North Pacific	104.8	0.431	1.504
Boyd (2010)	D	47~120	North East Atlantic	127.42	0.190	-1.635
Lee and Chou (1992)	V		Indian Ocean	163.71	0.1019	-2.0668
ICCAT (1996)	L		North Atlantic	122.8	0.217	-
Lee and Yeh (2007)	D		South Atlantic	147.5	0.126	-1.890
Karakulak (2011)	D	55.5~ 101	Eastern Mediterranean	93.198	0.295	-1.213
Present study	D	97~120	Southern Indian ocean	113.7	0.194	-8.39

Where, L: length frequency; V: vertebrae; S: scales; D: dorsal spine.

Acknowledgments

We would like to extend our thanks to Mr. Chen Jintao and Mr. Li Pan for providing the spine samples and fish measurements they collected during observer mission on the board fishing vessel in the southern Indian Ocean, and members in our working group for their assistance with the laboratory work and data processing.

References

Akaike, H. (1983). Information measures and model selection. Bulletin of the International Statistical Institute, 44, 277- 291.

Compeán-Jiminez, Gand Bard, F.X. (1983). Growth increments on the dorsal spines of eastern Atlantic bluefin tuna and their possible relation to migration patterns. NOAA Technical Report NMFS 8,77-86.

Chen, K.S., Shimose, T., Tanabe,T., Chen, C.Y.& Hsu, C.C. (2012). Age and growth of albacore *Thunnus alalunga*in the North Pacific Ocean. Journal of Fish Biology 80(6), 2328-2344.

Cort, J.L. (1991). Age and growth of the bluefin tuna, *Thunnusthynnus* (L.) of the Northeast Atlantic. Collective Volume of Scientific Papers, ICCAT 35, 213-230.

Karakulak, F.S., Özgür, E., Gükoğlu, M., Emecan, Ì.T. & Başkaya, A. (2011). Age and growth of albacore (*Thunnus alalunga* Bonnaterre,1788) from the eastern Mediterranean. Turkish Journal of Zoology 35(6), 801-810.

Foreman, T.J. (1980) Synopsis of biological data on the albacore tuna, *Thunnus alalunga* (Bonnaterre, 1788), in the Pacific Ocean. IATTC Special Report no.2, 17-70.

Gonzalez-Garcéz, A. & Farina-Perez, A.C. (1983). Determining age of young albacore, *Thunnusalalunga*, using dorsal spines. NOAA Technical Report NMFS 8, 117-122.

Hsu, C.C. & Liu, H.C. (1990). A brief updated stock assessment of Indian albacore by production model. FAO IPTP/TWS/90/55, 123-125.

ICCAT. (1996). Report of the final meeting of the ICCAT albacore research program. Collective Volume of Scientific Papers, ICCAT 43, 1-140.

Labelle, M., Hampton, J., Bailey, K., Murray, T., Fournier, D.A. & Sibert, J.R. (1993). Determination of age and growth of South Pacific albacore *(Thunnusalalunga*) using three methodologies. Fishery Bulletin 91(4), 649-663.

Lee, L.K. & Yeh, S.Y. (1998). Studies on the age growth of south Atlantic albacore (*Thunnus alalunga*)specimens collected from Taiwanese longliners. Collective Volume of Scientific Papers, ICCAT 40(2), 354-360.

Lee, Y.C. & Liu, H.C. (1992). Age determination, by vertebra reading, in Indian albacore, *Thunnus alalunga* (Bonnaterre). Journal of the Fisheries Society of Taiwan 19(2), 89-102.

Li, P., Xu L.X., Zhu, G.P. & Chen J.T. (2010). Biological characteristics of albacore *Thunnus alalunga* in the southern and central Indian Ocean. Journal of Dalian Ocean University 25(3), 248-252.

Lu, C., Zárate, V. & Yeh, S. (2007). Morphology of rings on otolith and spine characters from north Atlantic albacore of 40-44 cm fork length. Collective Volume of Scientific Papers, ICCAT 60(2), 437-442.

Boyd, J. (2010). The age and growth of albacore (*Thunnusalalunga*) of the north east Atlantic Ocean as inferred from the Irish pelagic trawl fishery of 2002. Collective Volume of Scientific Papers, ICCAT 65(4), 1268-1281.

Megalofonou, P. (2000). Age and growth of Mediterranean albacore. Journal of Fish Biology 57(3), 700-715.

Ortiz de Zarate, V., Megalofonou, P., De Metrio, G. & Rodriguez-Cabello, C. (1996). Preliminary age validationresults from tagged-recaptured fluorochrome label albacore in the north east Atlantic. Collective Volume of Scientific Papers, ICCAT 43, 331-338.

Santiago, J. & Arrizabalaga, H. (2005). An integrated growth study for North Atlantic albacore (*Thunnusalalunga* Bonn. 1788). ICES Journal of Marine Science 62, 740-749.

Sun, C., Huang, C. & Yeh S. (2001). Age and growth of the bigeye tuna, *Thunnusobesus*, in the western Pacific Ocean. Fishery bulletin, 99(3):502-509.

Zárate, V., Valeiras, J. & Ruiz, M. (2007). Sampling protocol for skeletal structures of north Atlantic albacore (*Thuunusalalunga*) and ageing interpretation. Collective Volume of Scientific Papers, ICCAT 60(2), 492-506.