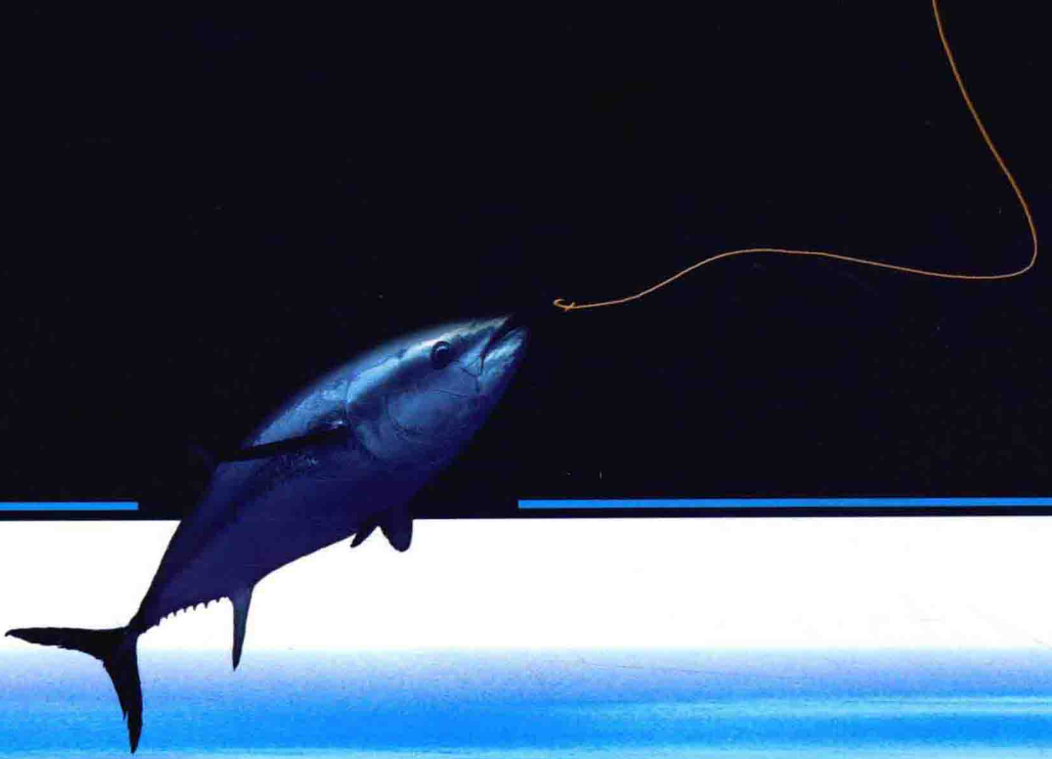

ENVIRONMENTAL BIOLOGY OF FISHES AND GEAR PERFORMANCE
IN THE
PELAGIC TUNA LONGLINE FISHERY

Liming Song

SCIENCE PRESS

Environmental Biology of Fishes and Gear Performance in the Pelagic Tuna Longline Fishery

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Preface

In recent decades, the offshore fishery resources over the world have been depleted due to climate change, environmental pollution, overfishing and other factors, while there are still increasing demands on the marine living resources. Therefore, the international society has attached great importance to the issue as how to achieve equilibrium between the development of fishery economy and the conservation of fishery resources. After the entry into force of the 1982 UN Convention on the Law of the Sea, the coastal countries have further improved the capability of management and protection of fishery resources within their jurisdiction and strengthened the management of fishing operation from foreign countries in their Exclusive Economic Zones. Subsequently, more than 10 regional fisheries management organizations have been established in the world to manage the high value species on the high seas of the three oceans and in the Antarctic Ocean.

Tuna and tuna like species are the large pelagic fish and belong to the highly migratory species. Although most of the tuna resources have been in full exploitation at the end of the last century, the tuna resources are still the key fishery resources exploited by distant water fishing nations or entities due to its high economic value (the fishing industry called the tuna fisheries as "golden fisheries").

The biological characteristics, the habitat of tunas and the longline fishing gear performance are a part of the hot topics of the regional tuna fishery management organizations of the world. This book illustrates the age and growth of bigeye tuna, the biological characteristics of tunas, the integrated habitat index of yellowfin tuna, catch rate calculation methods, and effects of environmental factors and fishing gear on catch performance. It provides references for the reduction of uncertainties in the tuna resource assessment, the standardization of the tuna abundance index (CPUE), the improvement of stock assessment accuracy, the study of the habitat selection, the bycatch mitigation of sharks, turtles and seabirds, protection to marine ecological environment, the improvement of the catch rate of target species, and the study of the biological characteristics, habitat of tunas and longline fishing gear performance.

This book is intended as a reference for fishery researchers, students, managers, conservation enthusiasts, and fisheries industrials. It can also be used as a textbook for fisheries science and technology at undergraduate and graduate levels.

Shanghai Ocean University has been engaged in the research of the fishery biology, fishery oceanography, and fishing technology for a long time. During the past decade, studies have been conducted on the environment biology of tunas and longline fishing gear performance, which have been funded by the National High Technology Research and Development Program of China (2012AA092302), Specialized Research Fund for the Doctoral Program of Higher Education (20113104110004), the Shanghai Municipal Education Commission Innovation Project (12ZZ168), the Ministry of Agriculture of the P.R of China under Project of Distant Water Fishery Exploration from 2005 to 2013, the First-class Discipline Construction Project of Shanghai Higher Education, the Construction of Key Disciplines Project of Shanghai Municipal (S30702), the 2013 Shanghai Municipal Professional Graduate Education Reform Pilot Project. There were more than 20 graduate students (Kaikai Lv, Zhenxin Hu, Yaping Wu, Mingming Hui, Jialiang Yang, Weiyun Xu, Jie Li, Dongjing Li, Haiyang Liu, Hao Chen, et al.) having participated in this research field. During the survey, Chinese Overseas Fisheries Association, Guangyuang Fishery Group Ltd of Guangdong province, Liancheng Overseas Fishery (Shenzhen) Co. Ltd., Zhejiang Ocean Family Co. Ltd., and China Southern Fishery (Shenzhen) Co. Ltd. have also offered strong support. Thanks go to them for their effort and support. I sincerely thank professors Yong Chen at University of Maine, Pingguo He of the University of Massachusetts, and Senior scientist Keith Bigelow of the Pacific Islands Fisheries Science Center, NOAA Fisheries, et al. for their extraordinary efforts in reviewing some of the parts, as well as to those experts who have evaluated our manuscripts and page proofs and provided valuable comments and suggestions!

I am grateful to my wife, Jie Wang, and Son, Haobo Song, for their strong support. It would not have been possible without their support and understanding.

This book is one of the stage achievements of the author in the tuna longline fisheries research, and is only a portion of China's pelagic tuna longline fisheries research. Finally, the critical feedback for improving our work is always welcome!

Liming Song
Shanghai Ocean University
July 2015

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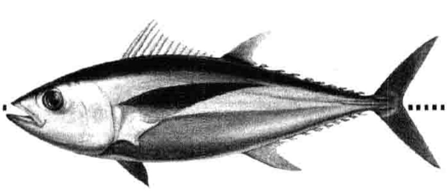
Chapter 1



Age and growth of bigeye tuna

1.1 Age and growth of bigeye tuna, using fin spines

Abstract In order to quantitatively study the morphological characteristics, the phenomena of vascularized core of bigeye tuna (*Thunnus obesus*) fin spines, and the age and growth of bigeye tuna, a total of 1304 bigeye tuna were sampled in the waters near Marshall Islands from November 2009 to January 2010 and their fork length were measured. About 436 dorsal spines have been randomly sampled. We also measured the total length (L) and the width (C) at the base of the fin spines. In the laboratory, the cross sections of the spines were obtained in the position above the condyle base in the distance of half C with an Isomet Low Speed Saw. The cross sections ranging from 400-500 μm thickness were examined with a dissecting microscope with transmitted light. Images of the sections were captured and analysed by the software Image-Pro plus version 3.1. In this study, the following parameters were measured for each spine: the total surface area of the cross section (S, mm^2), the surface area of the vascularized core (S_0, mm^2), and the annual ring surface areas of one to three years old fish including the translucent rings (S_1, S_2, S_3, mm^2). The results showed that: ①The relationships between the L, C and the fork length were the power function; ②We could identify the age of one to three years old fish because of the vascularized core; ③The relationships between S and fork length, S_0 and fork length were the power function and the ratio of S_0 to S was about 0.4; ④From the frequency analysis of the translucent ring surface area, the fork length of bigeye tuna from one to three years old fish was 48 cm, 71 cm, and 90 cm.

Keywords *Thunnus obesus*, fin spine, age, growth, Marshall Islands

1.1.1 Introduction

The age structure is an important parameter to the growth rate, mortality, productivity of fish stocks, and the stock assessment (Ragonese and Reale, 1992; Campana and Thorrold, 2001). There are many methods to identify the age of fish, such as tagging and releasing, length frequency and the hard tissue, scales (Yukinawa and Yabuta, 1963), vertebra (Alves *et al.*, 2002), otolith (Farley *et al.*, 2006), fin spine (Gaikov *et al.*, 1980; Antoine *et al.*, 1983; Sun *et al.*, 2001; Stéquert and Conand, 2003).

Lehodey and Leroy (1999) used the tag releasing and otolith to study the age of bigeye tuna (*Thunnus obesus*) in the Western and Central Pacific. Cayre and Diauf (1984) tagged and released 139 bigeye tuna and recapture them in the eastern Atlantic to study its growth. Hallier *et al.* (2005) studied the age and growth of bigeye tuna by tagging and releasing 625 bigeye tuna in the eastern Atlantic.

The structure of rings of fin spine is comprised of euphotic zone and opaque zone. There were many studies about the age and growth of the fish by reading the number of rings of the fin spine cross-section (Gaikov *et al.*, 1980; Antoine *et al.*, 1983; Alves *et al.*, 1998; Sun *et al.*, 2001; Stéquert and Conand, 2003). Alves *et al.* (1998) used the first dorsal fin spine to study the age and growth of bigeye tuna in the Madeira Archipelago waters and found that the age and growth of different gender bigeye tuna were basically the same and estimated the fork length of the one to eight years old fish. Stéquert and Conand (2003) suggested that the method of using sliced spine was not suitable to study the age because the cross-section of the sliced spines was not clear, each ring could not be accurately identified, and the incorrect number of rings would cause the bias. Gaikov *et al.* (1980) and Draganik and Pelczarski (1984) used spines to identify the age of bigeye tuna in the Atlantic. Sun *et al.* (2001) found that the growth ring of dorsal fin spines of bigeye tuna in the Western and Central Pacific was comprised of euphotic zone and opaque zone. They suggested that the bigeye tuna dorsal fin spines were convenient to be collected and conserved, the structure of rings were clear, and could be used to identify the age. But they also found that the area of the vascularized core continued to expand with the fish growth. In order to quantitatively study the morphological characteristics, the phenomenon of the vascularized core of bigeye tuna fin spines, and accurately identify the age of bigeye tuna, the bigeye tuna dorsal fin spines were collected in the waters near Marshall Islands, and the relationship between fork length and morphology size of fin spine were analyzed.

1.1.2 Materials and methods

Sampling duration and area

The sampling duration was from November, 2009 to January, 2010. The samples were from the longliners of Liancheng Overseas Fishery (Shenzhen) Corporation fishing in waters near Marshall Islands. The sampling area was defined as 3°30′N-5°00′N, 166°48′E-169°48′E (Fig. 1-1-1).

Data collection

We used caliper to measure the fork length of bigeye tuna in Majuro tuna processing factory of Liancheng Overseas Fishery (Shenzhen) Corporation. The measurement accuracy was 0.5 cm.

The fork length of 1304 bigeye tuna was measured, and randomly sampled 436 spines of bigeye tuna. In this study, the fin spine was sampled from the first ray of the first dorsal fin.

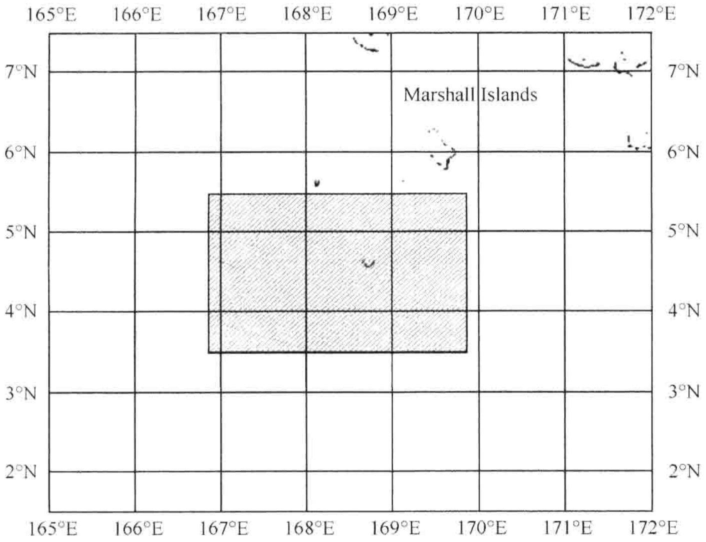


Fig. 1-1-1 Sampling area of bigeye tuna in waters near Marshall Islands

Spine processing

Spine processing procedures were as follows:

(1) Removing the muscle at the base of the fin spine with a knife.

(2) Immersing the spine quickly into the boiling water (the duration depends on the spine size), taking it out and cooling it in the cold water.

(3) Removing the remaining connective tissue and black epidermis of fin spine.

(4) Putting it into 4% KOH solution to immerse 5 hours.

(5) Rinsing with water.

(6) Measuring the total length (L, mm) and the width at the base of the fin spines (C, mm) after drying, L and C were shown in Fig. 1-1-2.

We assumed that the growth of hard part was proportional to the fish growth. The power regression was used to fit the relationship between the fin spine length L, width at the base C and the fish fork length FL.

Spine cross section was obtained in the position above the condyle base in the distance of half C (Fig. 1-1-2) with an Isomet Low Speed Saw (Buehler, Isomet low-speed saw). The thickness of spine cross section was about 2 mm. It was polished to about 1 mm by the 600 and 2000 grist waterproof and sandpaper. Lastly, we used 0.3 μm thickness alumina flannel to polish it to show the clear rings. The cross sections ranging from 400-500 μm thickness were examined with a dissecting microscope (Nikon ZOOM645S) with transmitted light.

We took the picture of spine cross section and input it to the computer for the data measurements.

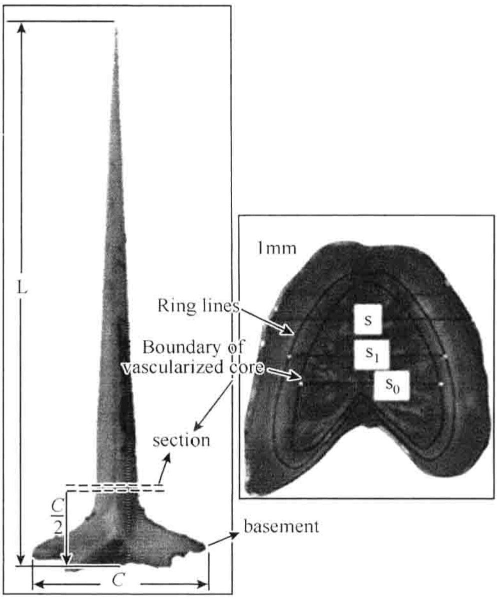


Fig. 1-1-2 Schema of the dorsal spine and the section of the dorsal spine

Ring structure interpretation and measurement

Spine cross section under a microscope showed the translucent zone and the opaque zone alternately. We could not estimate the ring formation time because the sampling duration was only two and a half month. Based on the conclusions of other scholars [the translucent zone formed in March (Nose *et al.*, 1967)], we identify the ring and age of bigeye tuna.

By observing the cross section of fin spines (Fig. 1-1-2), we found the opaque zone with translucent zone formed the annual ring. It was impossible to read each ring accurately because the spine sliced cross-section was not clear or vascularized. The incorrect numbers of ring would influence the accuracy of the result. In this study, we used the ring area method proposed by Stéquert and Conand (2003) to study the ring area of fin spine and the age of bigeye tuna. Analysing the spine cross-section photograph by the software Image-Pro plus version 3.1, the ring area of each annual ring (S_1, S_2, S_3, mm^2), the slice surface area (S, mm^2) and vascular area (S_0, mm^2) (Fig. 1-1-2) were measured. The boundary line between the out edge of the translucent zone and opaque zone was the measuring baseline. The data of the clear ring were only measured. The unclear or incomplete rings were discarded. Comparing the frequency distribution for all measured ring area, the ring area might be the ring area of growth ring if the frequency of ring area was relatively high.

1.1.3 Results

Relationships between spine size and fork length

The first dorsal fin spine length L and the base width C were measured for 389 bigeye tuna

(Fig. 1-1-2), and we collected 375 spine length *L* and 180 complete spine width *C*. The relationships between the fin spine length *L*, base width *C* and fork length *FL* were shown in equations 1-1-1 and 1-1-2 (Fig. 1-1-3 and Fig. 1-1-4).

$$L = 1.758FL^{0.937}, R^2 = 0.900 \tag{1-1-1}$$

$$C = 0.278FL^{0.983}, R^2 = 0.884 \tag{1-1-2}$$

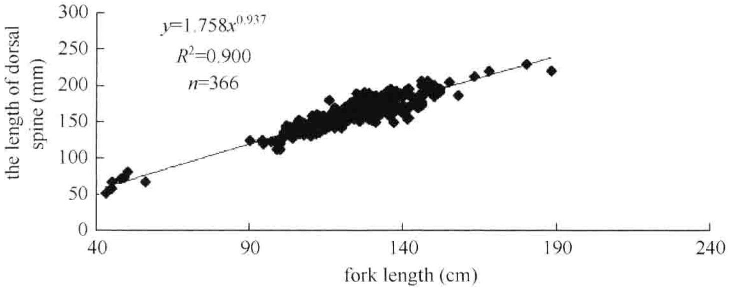


Fig. 1-1-3 The relationship between fork length and the length of dorsal fin spine

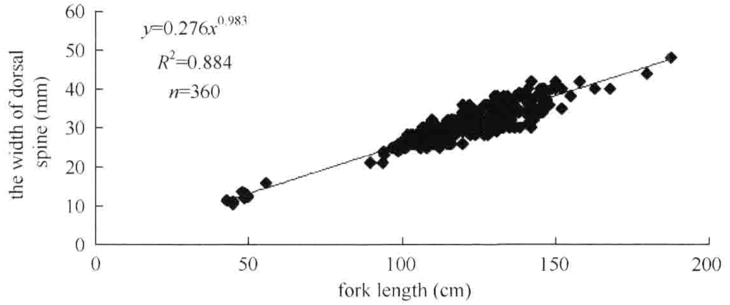


Fig. 1-1-4 The relationship between fork length and the width of dorsal fin spine

The relationship between fin spine area and fork length

The spine cross section surface area *S* (mm^2) of 179 fish was measured. The relationship between fork length *FL* (cm) and the spine cross section surface area was shown in equation 1-1-3 (Fig. 1-1-5). We found that the greater the cross section of spine was, the greater the area of vascularized core S_0 (mm^2) was. So, in this study, the area of vascularized core S_0 of the fin spine cross section was measured. The relationship between fork length *FL* and the area of vascularized core S_0 was indicated in equation 1-1-4 (Fig. 1-1-6).

$$S = 6.220 \times 10^{-4} FL^{2.438}, R^2 = 0.955 \tag{1-1-3}$$

$$S_0 = 2.607 \times 10^{-4} FL^{2.497}, R^2 = 0.900 \tag{1-1-4}$$

Based on equation 1-1-3 and equation 1-1-4, the ratio between the surface area of the vascularized core and the area of the dorsal fin spine was 0.41-0.45 while the fork length of bigeye tuna was 45.0-170.0 cm (Fig. 1-1-7). The area of vascularized core expanded with the fork length increasing.

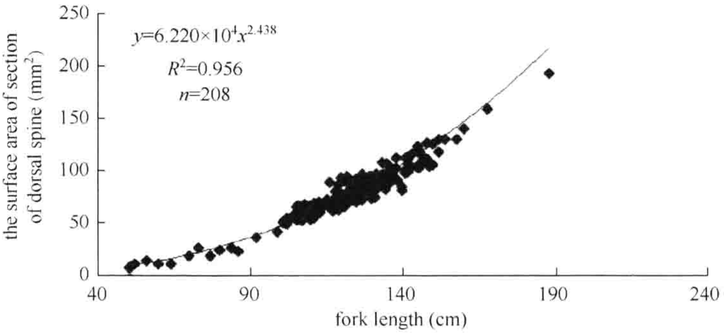


Fig. 1-1-5 The relationship between fork length and the surface area of section of dorsal fin spine

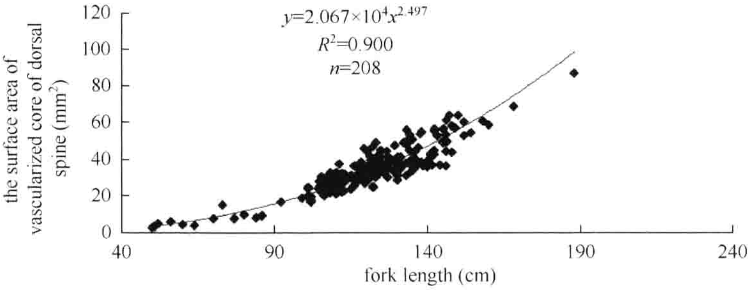


Fig. 1-1-6 The relationship between fork length and the surface area of vascularized core of dorsal fin spine

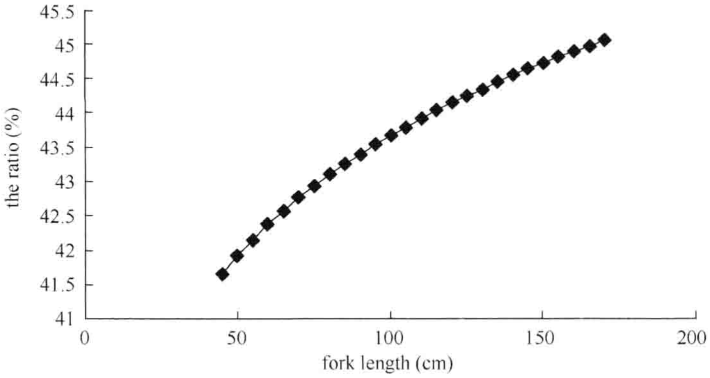


Fig. 1-1-7 The ratio between the surface area of vascularized core and the area of dorsal fin spine

The average growth rate of the dorsal fin spine

The ratio between the surface area of the vascularized core and the area of the dorsal fin spine was 0.41-0.45. The ring in the first round would be into the area of vascularized core when the fork length was greater than 45 cm, but the ring in the first round has been seen. However, as the fork length was greater than 90 cm, the first round of the spine became very illegibility. When the fork length was greater than 100 cm, the ring in the first round would disappear, and it was only to be estimated by the experience. Therefore, this study only identified the rings of fin spine when the fork length was less than 100 cm for age determination. The frequency distribution of the area of fin spine cross section was indicated in Fig. 1-1-8. The optimal area of fin spine cross section was

8 mm^2, 20 mm^2, 36 mm^2, 54 mm^2, 70 mm^2, and 82 mm^2, for the one to six years old fish, and their corresponding fork length was 48 cm, 71 cm, 90 cm, 106 cm, 118 cm, and 126 cm, respectively. We only used the fork length data of one to three years old fish to estimate the growth rate of fish because the fin spine was only suitable to identify the age of bigeye tuna which fork length was below 100 cm. The fork length of one to three years old fish was 48 cm, 71 cm, and 90 cm. Their average growth rate was 48 cm/yr, 23 cm/yr, and 19 cm/yr, respectively.

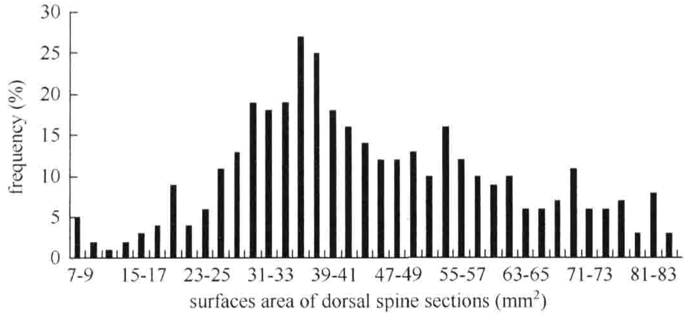


Fig. 1-1-8 Frequency distribution of surface area of the dorsal fin spine cross section

1.1.4 Discussions

This study suggested that the fin spine was only suitable to identify the age of bigeye tuna whose age was smaller than three years old. If the fish was older than three years, the vascularized core would affect the accuracy of the annual ring data. The numbers of annual ring were only identified by the subjective judgments, and the results would be in bias. For the serious vascularized core of the fin spine section, it was impossible to accurately read each ring of the cross section, especially the first and second ring. In this study, by measuring the area of vascularized core of dorsal fin spine, we found that the area of vascularized core of the dorsal fin spine was about 0.4 of the total area of the fin spine. We calculated the area of vascularized core of the dorsal spine of two years old fish and found that the location of the first ring was near the edge of the vascularized core. When the fish was three years old, the first ring was in the inner of the area of vascularized core, but it could be identified. When the fish was four years old, the first ring was completely disappear.

This study suggested that the relationships between the fin spine length and base width of bigeye tuna and fork length was a power function (equation 1-1-1 and equation 1-1-2), and the fin spine was the suitable material to identify the fish age smaller than three years old. Sun *et al.* (2001) studied the age of bigeye tuna in Western and Central Pacific (*FL*=70-189 cm) by spine, and found the relationship between the length of fin spine and fork length was a linear function. This was generally consistent with our results. Li (2010) studied the relationship between the base width of fin spine and the fork length of bigeye tuna in the Indian Ocean, and suggested there was no corelation. This might be caused by the small samples of the base width of fin spine.

The ring area method proposed by Stéquert and Conand (2003) avoided the shortcomings of reader's subjectivity for judgment, and the precision was high. Stéquert and Conand (2003) used the method to infer the fork length of one to three years old bigeye tuna, and pointed out that this method wasn't suitable when the samples were over three years old. They did not give specific reasons. In this study, we measured the area of vascularized core of the dorsal spine, and found the first ring was disappeared in the inner area of vascularized core while the age was over three years old. That was the reason why the fin spine was only suitable to identify the age of fish which was three years old or small. The fork length of one to three years old fish in this study was similar to the results obtained by Cayré and Diouf (1984) and Alves *et al.* (2002). There were some differences from the other studies (Shomura and Keala, 1963; Yukinawa and Yabuta, 1963; Kume and Joseph, 1966; Gaikov *et al.*, 1980; Lehodey *et al.*, 1999; Li, 2010) (Tab. 1-1-1). That might be resulted from the different methods and study areas.

Tab. 1-1-1 The bigeye tuna fork length of ages one to three in various studies

Author	Time	Area	1	2	3
This study	2011	Marshall Islands	48	71	90
Shomura & Keala	1963	Pacific	67	101	125
Yukinawa & Yabuta	1963	Pacific	41	73	100
Kume & Joseph	1966	the eastern Pacific	31	80	114
Gaikov *et al.*	1980	Atlantic	46	79	107
Cayré & Diauf	1984	Atlantic	44	69	92
Lehodey	1999	Western and Central Pacific	63	96	123
Alves	2002	Madeira Archipelago	48	73	94
Li	2010	Indian Ocean	58	79	97

In this study, we did not consider the impact of gender on various parameters. We could not use the method of marginal increment to analysis and verify the formation time of annual ring. The samples were from longliners, and the individuals whose fork length smaller than 85 cm or higher than 160 cm were less. That might cause the samples smaller than one to two years old fish and higher than seven years old fish less.

In the future study, the sampling area, time and rang of individual size should be increased. We should use more suitable methods to identify the age structure by vertebrae, otolith, scale, and tagging, and compare the results to achieve an optimal method to identify the age of bigeye tuna. Combining with the biological data of gonad of bigeye tuna, we can study the growth of bigeye tuna in different life span (such as maturity and ovulation).

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