ISC/17/SHARKWG-3/18

Update of growth of juvenile shortfin mako (*Isurus oxyrinchus*) in the western and central North Pacific Ocean.

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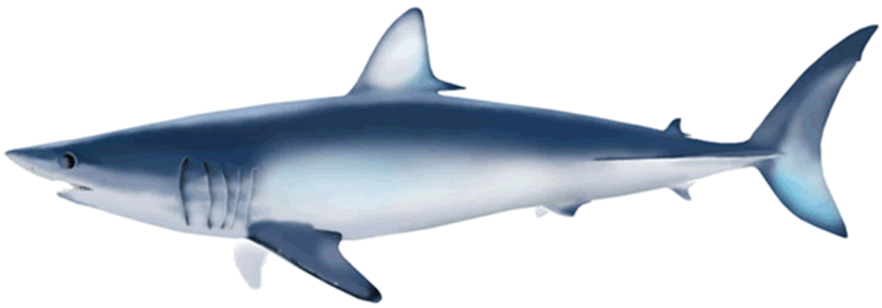

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Summary

The growth of shortfin mako (*Isurus oxyrinchus*) is variable depending on study not only within the North Pacific and among Oceans. In the Western and Central north Pacific Ocean (WCPO), the growth rate based on size data of juveniles approximately smaller than 150 cm precaudal length (PCL) was faster than that based on vertebrae. Between WCPO and Eastern North Pacific Ocean (EPO), different hypothesis of periodicity of band pair deposition has been proposed. The disagreement of growth within WCPO was investigated based on analysis for band pair for small juveniles (≤100 cm PCL) which was scarce in the past study. The results support annual band pair periodicity for small juveniles and suggest that difference in growth rate between study could be explained partly by the aging for additional samples with size range between 70 and 100 cm PCL. Filling the gap of size range and application of several approach other than band count (e.g., size frequency data analysis, tag-recapture data, and chemical analysis of centrum) will improve the accuracy of growth parameter for this population.

Introduction

It is urgent to obtain reliable growth curve of shortfin mako (*Isurus oxyrinchus*) representative in the North Pacific population and to apply it to the stock assessment. However, the growth of this species is variable depending on study not only within the North Pacific (Figure 1) and among Oceans. Regarding the publicly-available study on the age and growth of shortfin mako in the North Pacific, four studies are known from the EPO (off California: Cailliet and Bedford. 1983, Wells *et al*. 2013, Kinney *et al*. 2016, off the Mexican coast: Ribot-Carballal *et al*. 2005) and two studies from WCPO (Semba *et al*. 2009, Kai *et al*. 2013). There are many differences such as sample size and size range, material of analysis, enhancement method, and hypothesis of band pair deposition (Table1).

Regarding the difference within WCPO, Semba *et al*. (2014) investigated the effect of difference of birth month and periodicity of band pair deposition. It was suggested that the effect of difference in the birth month would not be major factor to explain the difference in growth between studies. The assumption of periodicity of band pair deposition would be more influential and the difference smaller got smaller if growth based on biannual deposition was applied. However, centrum edge analysis for juveniles (≤ 150 cm PCL) and those between 100 and 150 cm PCL supported annual deposition with uncertainty left for individuals ≤ 100 cm PCL. Moreover, the sample of juvenile (≤100 cm PCL) in Semba *et al*. 2009 was scarce and thus further investigation was left to be done. In this context, the collection of juvenile vertebrae in each month has been launched since autumn in 2013 with high priority.

In this document, I focused on the growth band pair periodicity for juveniles (≤100 cm PCL) and update of growth curve based on band counts.

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Materials and Methods

In this work, vertebrae from juvenile (≤150 cm PCL) were newly added and processed following the procedure described in Semba *et al*. (2009). Most of the samples were collected from individuals smaller than 100 cm PCL throughout year since 2013. For the analysis described below, data from Semba *et al*. (2009) and newly collected sample were combined.

In this document, the comparison of growth curves among other study was conducted after converting each body length (i.e., FL and TL) into PCL using the conversion equation in Semba *et al*. (2009).

Centrum edge analysis

For the periodicity of growth band pair deposition, the most peripheral structure on each centrum was classified as either concave or convex structure. The ratio of convex structure was calculated by month after year was aggregated. Same calculation was conducted for individuals smaller than 100 cm PCL to compare the pattern of periodicity for smaller juveniles. The periodicity of growth band pair deposition was evaluated using the methods by Okamura and Semba (2009). Individual before the birth band is completed was removed from the analysis.

Estimation of growth curve

Based on the results of centrum edge analysis (described below) and the assumption of month at which growth band is formed in Semba *et al*. (2009), decimal age was assigned for each individual, following the procedure described in Semba *et al*. (2009).

After estimation of decimal age, a modified form of the von Bertalanffy growth equation was fitted to the length-at-age data independently foe males and females to ensure that the curve passed through the known size at age at birth (Simpfendorfer *et al*.2002, Chidlow *et al*. 2007).

$$L_t = L_0 + (L_\infty - L_0)[1 - \exp\{(-K)t\}]$$

where Lt= PCL at time t (cm); L_0= size at birth (cm) (74 cm TL) given by Joung and Hsu (2005); L_∞ = asymptotic length (cm); and k= brody growth constant (year^{-1}).

The nonlinear least-squares method was used to estimate this modified von Bertalanffy growth equation for each sex (Haddon 2001).

Growth curves were compared to that of Kai *et al*. (2015) after converting the values for body length (i.e., TL or FL) into PCL.

All statistical analyses were conducted using the R statistical software (R 3.2.2: R Development core Team 2009).

Results

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In this analysis, 116 samples (≦100 cm PCL) were newly added through the sampling program between 2013 and 2015. The analysis was conducted after combining corresponding data from Semba *et al*. (2009).

Centrum edge analysis

For the centrum edge analysis, a total of 135 individuals was available. The occurrence pattern of convex structure was shown in Figure 2. The ratio of convex structure was above 0.5 between October and December and then ranged between 0.3 and 0.5 between January and March. It was less than 0.2 between April and September. The model with annual periodicity was selected with the lowest AIC among three models (model with no trend: 167.8, annual: 141.3, and biannual periodicity: 168.3).

Estimation of growth curve

The estimated growth equations are as follows;

Males $L_t = 60 + 230.6\{1 - \exp(-0.16t)\}$ (n=181),

Females $L_t = 60 + 279.6\{1 - \exp(-0.11t)\}$ (n=209),

where t is age (years). The estimated S.E. (standard error) of L_∞ for females was larger than that for males, while S. E. of K for males was larger than for females (Table 2).

The growth rate in the updated equation was slower than that estimated based on size frequency data in Kai *et al*. (2015) as observed in the past analysis, however, the observation (i.e., individual length-at-age data) based on juveniles (≦100 cm PCL) was much closer to the growth by Kai *et al*. (2015) as shown in Figure 3. Compared to estimates by Semba et al. (2009), the parameters for male was almost same between past and current estimates, however, L_∞ and K got smaller and larger than past estimates for females.

Discussion

Based on current and past document (Semba *et al*. 2014), the periodicity of band pair deposition for small and large juveniles in WCPO was suggested to be annual. Although this has not been investigated for adults yet, I applied annual growth band periodicity for estimation of decimal age for individuals from WCPO. In EPO, different periodicity hypothesis was proposed based on validation for juveniles (Wells *et al*. 2013) and adult (Kinney *et al*. 2016). In order to investigate for the mismatch between areas, cross-reading has been conducted among different enhancement methods.

Regarding the difference in growth rate within WCPO (i.e., Semba *et al*. (2009) and Kai *et al*. (2015)), estimated growth was still different, however, length-at-age (i.e., decimal age) for newly

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added samples were closer to growth by Kai *et al*. (2015). In this context, the revised growth parameter, *K* for females was slightly higher than past estimate. This result is suggested to be caused partly due to the improvement of size range especially between 70 and 100 cm PCL, which was scarce in Semba *et al*. (2009).

In case of Japan, direct validation of band pair deposition using injection of chemical agent such as OTC is difficult due to regulation food safety issue and appropriate sample for bomb radiocarbon is not available. In this situation, NRIFSF launched research program to validate the growth estimated based on band pair counts. Except for collection of vertebrae from young juvenile (outcome of the present document), the program consists of 1) size data collection for juvenile (≦100 cm PCL) between 2014 and 2015, 2) tag-recapture research for juveniles since 2014 with PR activity to fisherman, 3) application of EPMA to survey its effectiveness as tool for validation.

In summary, this work reports the result of indirect validation of band pair periodicity of small juveniles and re-estimated the growth curve based on annual periodicity of band pair deposition. The results indicate that difference between past work in WCPO might be explained by the paucity of observation of band counts for particular size of animals (70-100 cm PCL) rather than hypothesis of band pair periodicity. As reflected in the modified growth parameters, additional analysis for missing size admit of improvement (change) of growth curve for WCPO individuals. Further work which incorporates several approrch indicated above will progress the estimation of reliable growth of shortfin mako in WCPO.

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Table1. Summary of age and growth study reported in the North Pacific Ocean.

Author	Area covered	sample size	Material	range of samples	enhancement method	band pair validation
Cailliet& Bedford 1983	NE Pacific (off southern California)	44	Vertebrae	90cm-321cm TL	wholecentra: x-radiography	modal frequency analysis
Ribot-Carballal et al. 2005	NE Pacific (W coast off Baja California)	109	Vertebrae	77cm-290cm TL	whole centra stained w/ silver nitrate	edge analysis
Semba et al. 2009	NWC Pacific (10-40N,140E-140W)	275	Vertebrae	53 cm-300 cm PCL	half-cut centra w/ shadowing method	edge analysis
Wells et al. 2013	NE Pacific (off southern California)	14,720 for size analysis 62 for tag-recapture analysis	Size data tag-recapture data		na	OTC, modal frequency, and tag-recapture data
Kai et al. 2013	NWC Pacific(west of 160W)	138,604	Size data	57-300cm PCL	na	na

Table 2. Updated von Bertalanffy growth parameter estimates and standard errors (S.E.) for male and female shortfin mako in WCPO. The figures in parentheses denote estimates in Semba *et al*. (2009).

	Sample size		L_∞ (cm)	K (year^{-1})	L_0 (cm)
Males	181	Estimate	231.0 (231.0)	0.16 (0.16)	60.0
		S.E.	9.9 (15.5)	0.02 (0.02)	–
Females	209	Estimate	279.6 (308.3)	0.11 (0.09)	60.0
		S.E.	12.0 (21.7)	0.01 (0.01)	–

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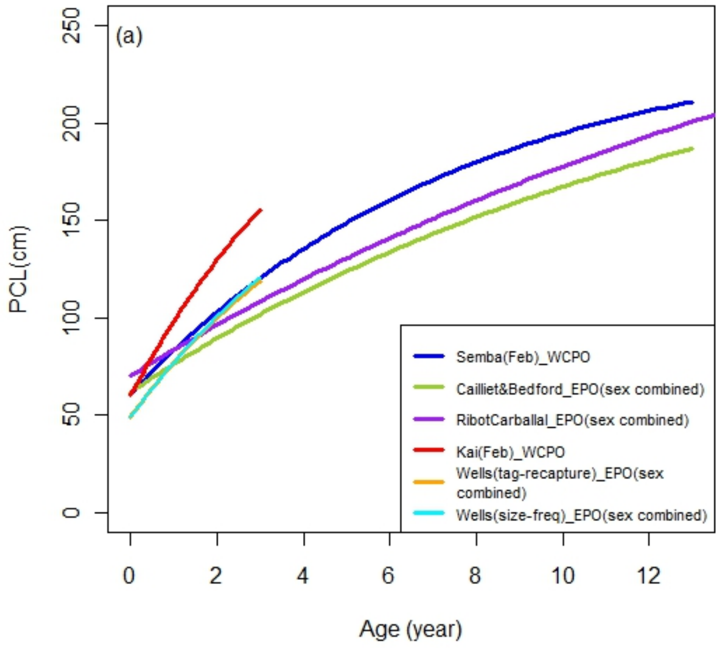

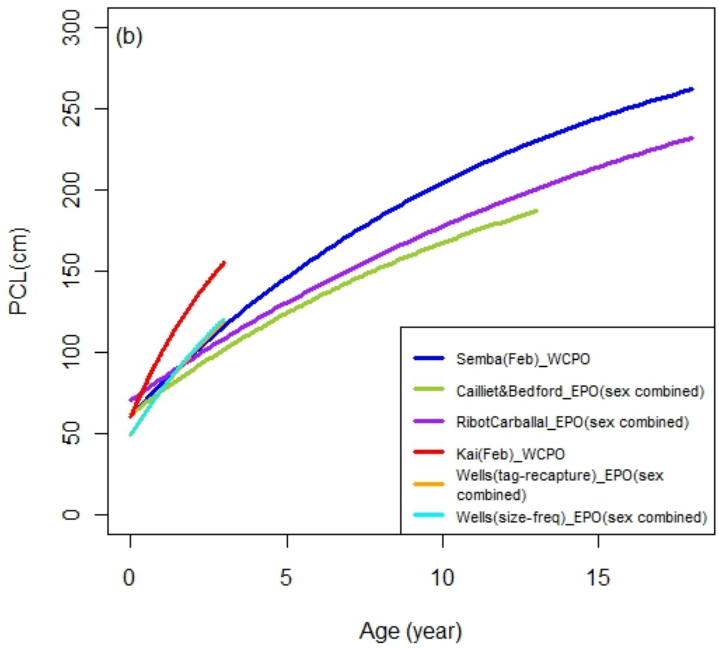

Figure 1. Growth curve estimated for (a) male and (b) female shortfin mako in the North Pacific

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Ocean.

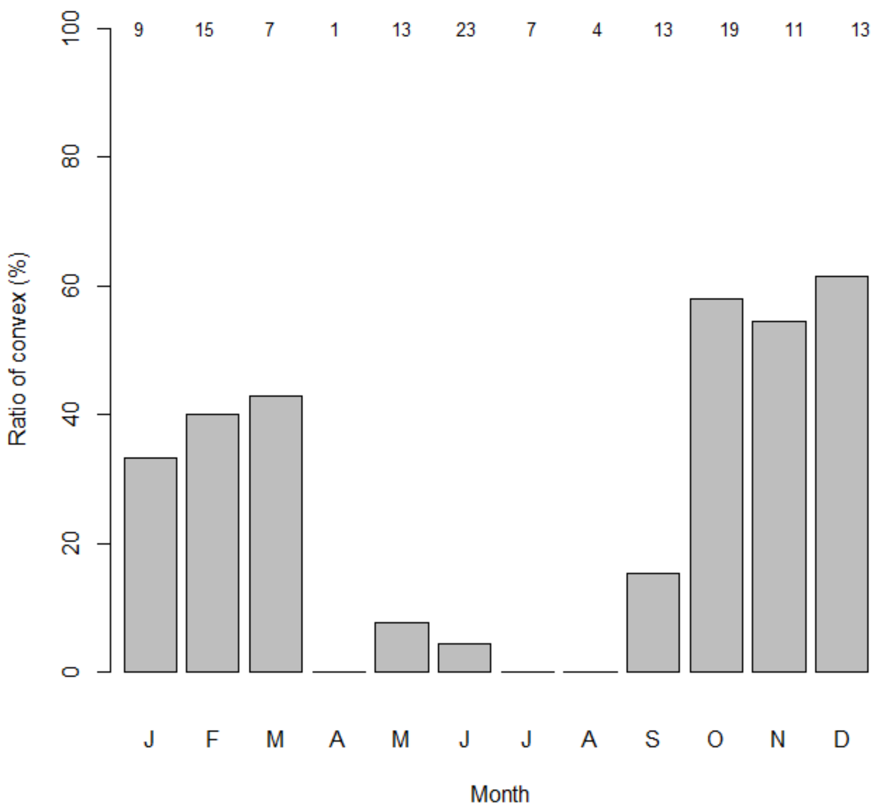

Figure 2. Monthly occurrence pattern of convex structure observed on the periphery of the centrum for juvenile shortfin mako (≦ 100 cm PCL) collected in WCPO. Sample size in each month was indicated on the top of the bar.

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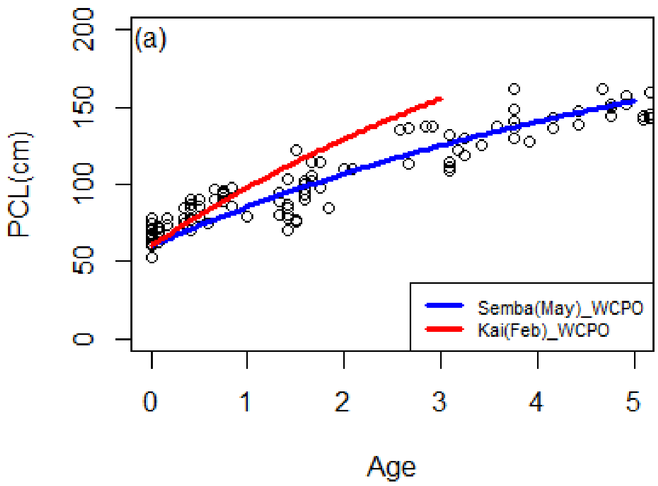

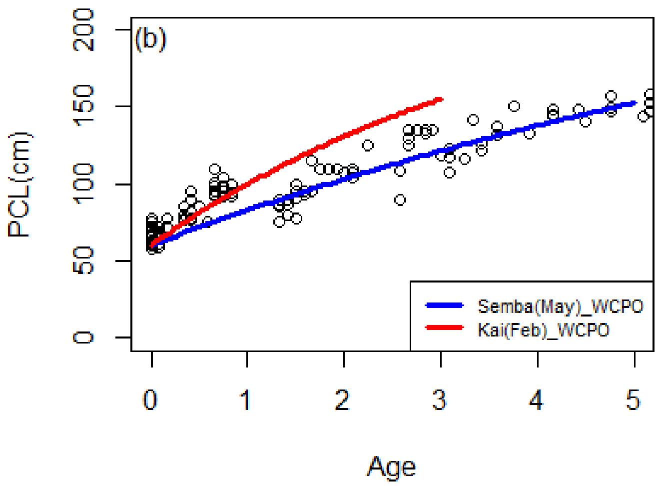

Figure 3. Comparison of revised growth curve and growth by Kai et al. (2015) with observation of length at age (circle) from 181 males (a) and 209 females (b).

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