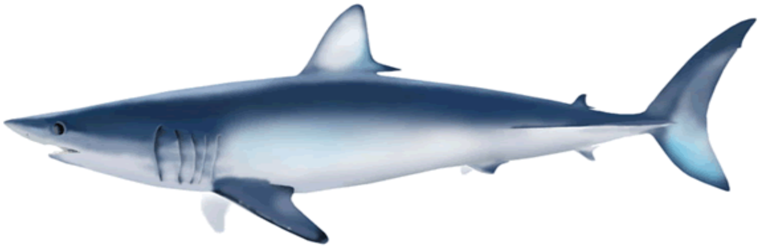
ISC/22/SHARKWG-3/3

Review of biological parameter of shortfin mako (*Isurus oxyrinchus*) in the North Pacific used for the stock assessment in 2018[1]

Yasuko Semba
.

[2] Affiliation: Japan Fisheries Research and Education Agency, Fisheries Resources Institute, Fisheries Stock Assessment Center, Highly Migratory Resources Division
Email: semba_yasuko25@fra.go.jp



---

[1] Working document submitted to the ISC Shark Working Group Workshop, 8-12 December 2022 (JST), Hybrid-meeting. **Document not to be cited without author's permission.**

Summary

The biological parameter of North Pacific shortfin mako used in the previous stock assessment in 2018 was summarized focusing on its growth and reproduction (i.e., maturity size and fecundity). Background behind the parameter agreed in the previous discussion and issue included in each topic were also briefly introduced. For the biological parameters on these topics for the North Pacific population, new information which can be used as alternative parameter has not been published or shared since 2018.

1. Introduction

Shortfin mako (*Isurus oxyrinchus*) is commonly caught as bycatch in the fishery targeting for tuna and billfish species globally. Contrary to blue shark (*Prionace glauca*) similarly caught in the tuna and billfish fisheries, uncertainty in its biology and fishery statistic is large due to relatively small catch amount compared to blue shark and its unique biological feature. Main characteristic of this species is prominent sexual dimorphism (e.g., body size, life history parameter, distribution) and segregation in relation to ontogenetic stage and size (Semba 2018). It is suggested that effort is necessary to treat such uncertainty for the stock assessment and thus, review of previous discussion and understanding of current information may work to discuss the approach and future work to conduct the second stock assessment of this population. In this document, biological parameter used in the previous stock assessment and background information were summarized.

2. Review of biological parameter

2-1. Growth

As described in previous documents (Semba *et al* 2014, Semba 2017a, ISC shark working group 2018a,d), there has been large uncertainty in growth of this population (Figure 1) due to the combination of different band pair periodicity between the west and the east (i.e., biannual up to five years and annual for adults in the eastern (Wells *et al*. 2013, Kinney *et al*. 2016, Madrigal *et al*. 2017) and annual throughout life span in the western (Semba *et al*. 2009)), methodology of band count (e.g., shadowing method, observation of section by X-ray or transmitting light), approach of analysis (e.g., band count vs size data analysis) and so on.

As these factors make it difficult to evaluate the regional difference in growth and select best growth curve to be used for the stock assessment, ISC shark working group launched several studies including collaborative cross-reading (e.g., ISC shark working group 2018a, Madrigal *et al*. 2017), element analysis (Semba 2017b), and size data analysis (Semba in progress). Two trials of cross reading (US-Japan-Mexico work and Japan-Mexico work) were conducted with the same sample via sharing of centrum or image of section, applying different methodology. The results indicated that different band count was obtained depending on the methodology and the band count was same or similar if the same methodology was used. Specifically, the number of band count based on X-ray enhancement method tends to be larger than that of shadowing method. Study between Japan and Mexico (Madrigal *et al*. 2017) reported that age estimation for eastern sample with the assumption of biannual to annual periodicity (X-ray count) closely matched with previous studies including western estimates with annual periodicity (shadowing method; Semba *et al*. 2009). However, discrepancy of growth estimates between band count approach and size frequency analysis has not been resolved.

Against this background, von Bertalanffy growth parameter estimated by meta-analysis based on seven data sets of length at age (5 from vertebrae observation and 2 from length frequency analysis; Takahashi *et al*. 2017) was used in the 2018 stock assessment. Estimated parameter by sex was indicated in Table 1.

2-2. Longevity (maximum age)

Maximum age was set at 31 years based on estimates of Atlantic population based on bomb-radiocarbon aging (Ardizzone *et al*. 2006). In general, maximum age estimated from band count was believed to underestimate the actual maximum age in terms of sampling bias and technique. Sex-specific longevity was not assumed in the stock assessment. In the data preparatory meeting in 2017, WG commented that maximum age may vary across fisheries, and questioned how best to determine the maximum age, and was informed that the bomb-radiocarbon study was the best estimate of maximum age (ISC shark working group 2018b).

2-3. Maturity

In the stock assessment, logistic maturity schedule based on the maturity length at 50% maturity for female shortfin mako was used. Maturity ogive was estimated using the integrated data (i.e., binary data with size and maturity status) of maturity from Japan and Taiwan (Semba *et al* 2017).

As the background, the existing knowledge on the maturity size of North Pacific shortfin mako was different between Japanese estimate (mainly temperate area in the western and central Pacific for study area; Semba *et al*. 2011) and Taiwanese estimate (eastern and northeastern Taiwan for study area; Joung and Hsu 2005). Given that it is unlikely that the sharks in each sampling area are genetically differentiated (at least between Japanese and Taiwanese sampling area) and that the criteria of maturity in each study were similar, synthesis of Japanese and Taiwanese data and re-estimation of 50 % maturity size were requested in the Aging Workshop convened by ISC Shark working group in October 2017 (ISC shark working group 2018a).

The maturity ogive was fitted to binary data for 622 males and 1,100 females. The estimated

50% maturity size was 166 cm in precaudal length (PCL) for males and 233 cm in PCL for females (Semba *et al* 2017). Given that there may be sampling bias due to ontogenetic spatial segregation (i.e., smaller shark in high latitude and larger shark in low latitude) and sampling strategy in each study, estimates based on integrated data from two studies was assumed to be appropriate for the use in the stock assessment of this population (ISC shark working group 2018b).

2-4. Fecundity

Average litter size of 12 was used as fecundity in the stock assessment based on combined Japanese and Taiwanese dataset (ISC shark working group 2018b, d).

As background, the relationship between maternal size and litter size was found in Japanese study (Semba *et al*. 2011) but not supported in Taiwanese study (Joung and Hsu 2005). As both data had very small sample sizes for litter size, samples from both Japan and Taiwan were combined, and a new linear relationship was fitted to the data (ISC shark working group 2018 b). Based on this calculation, WG agreed to use an average litter size of 12, while applying a logarithmic relationship was suggested as a future work (ISC shark working group 2018b).

2-5. Reproductive cycle

Reproductive cycle consists of gestation period and resting period. As base case, reproductive cycle was set as two years (i.e., 6 pups per year) and three-year cycle was used in the sensitivity analysis (ISC shark working group 2018d).

Globally, there are little knowledge on the reproductive biology (especially for the gestation period and resting period) on this species, because of rare occurrence of adult and pregnant female in the fishery (Mollet *et al*. 2000[1], Joung and Hsu 2005, Semba *et al*. 2011). Regarding the gestation period, estimates by Mollet *et al*. (2000) and Joung and Hsu (2005) range from 15 to 18 months and from 23 to 25 months, respectively while Semba *et al*. (2011) estimated the gestation period ranges from 9 to 13 months. They used different approach to estimate the gestation period (i.e., period between the fertilization and birth). Former two studies applied linear regression (monthly growth of embryo) to length at month of embryo, while the latter study fitted nonlinear growth (von Bertalanffy model and modified Gompertz model) to the length at month data of embryo. Regarding the resting period, the existence of resting in this species has been supported based on the observations of adult (postpartum) females with spent ovary and contracting uterus without embryo and pregnant females out of synchronization in terms of development of embryo and ova (Mollet *et al*. 2000 and Semba *et al*. 2011). However, there is not enough data to estimate the resting period quantitatively. Mollet *et al*. (2000) plotted the uterus width index (UWI) of

---

[1] Materials was collected from the western North Atlantic, the eastern Australia (southwestern Pacific), and Kwa-Zulu-Natal, South Africa (southwestern Indian Ocean).

pregnant and postpartum females seasonally and suggested that 3-year cycle matched better with the estimated pupping season (late winter to mid-spring) under the assumption that gestation period is between 15 and 18 months. In their calculation, resting period ranged from 9 (2-year) to 18 (3-year) months depending on the reproductive cycle. Semba *et al*. (2011) did not estimate the resting period but suggest that reproductive cycle may be shorter than previously thought (i.e., 3 years). If 3-year cycle is assumed, resting period may be 23-27 months (if mating and pupping occurs seasonally), which has been rarely reported in sharks and it is suggested that other lamnid sharks has no or shorter resting period (Conrath 2005, Castro 2009). Consequently, two-year reproductive cycle seems to be plausible in the North Pacific population, but periodic (at least monthly) sampling and observation of ova and embryo is necessary to estimate both gestation and resting period accurately.

2-6. Natural mortality rates (M)

Natural mortality was fixed at 0.128/year for both sex and all ages, based on the estimates by Hoenig (1983) with 31 years of a_{max} as maximum age estimated by Ardizzone *et al*. (2006).

As background, Kai and Yokoi (2017) estimated sex-and age- specific M for North Pacific shortfin mako, with the same method applied for North Pacific blue shark (Walter's method; Semba and Yokoi 2016, Walter *et al*. 2016). Regarding the estimated Ms, it was pointed out that the M at age-0 for males was too high for some of the sensitively runs[2], which might cause problems since it did not match the analysis for females (despite both sexes being nearly the same size at age-0, and unlikely to have different M). This issue (i.e., high Ms for all ages) was further investigated in the modelling workshop in 2018 (ISC shark working group 2018c) and three scenarios of M (original (Kai and Yokoi 2017), constant M (based on the estimator by Hoenig (1983)) and estimates in the North Atlantic (Cortés 2017)). Evaluation of Ms following the review by Maunder *et al*. (2023) would be beneficial for discussion to improve the uncertainty included in this parameter.

References

Ardizzone, D., Cailliet, G.M., Natanson, L.J., Andrews, A.H., Kerr, L.A., Brown, T.A. 2006. Application of bomb radiocarbon chronologies to shortfin mako (*Isurus oxyrinchus*) age validation. Environ. Biol. Fish. 77, 355–366.

Castro, J. I. 2009. Observation on the reproductive cycles of some viviparous North American sharks. Aqua 15; 205-222.

---

[2] Sensitivity runs was conducted to check the effect by fluctuation of maximum age on the robustness of the estimate of M (especially for age-0 M).

Conrath, C.C. 2005. Chapter 7. Reproductive biology. In: Musick, J.A., Bonfil, R. (eds) Management techniques for elasmobranch fisheries. FAO FISHERIES TECHNICAL PAPER 474. FAO, Rome.

Cortés. 2017. Estimates of maximum population growth rate and steepness for shortfin mako in the North and South Atlantic Ocean. SCRS/2017/126.

Hoenig, J.M. 1983. EMPIRICAL USE OF LONGEVITY DATA TO ESTIMATE MORTALITY RATES. Fish. Bull. 82(1), 898-903.

ISC Shark Working Group 2018a. REPORT OF THE THIRD SHARK AGE AND GROWTH WORKSHOP SPONSORED BY THE INTERNATIONAL SCIENTIFIC COMMITTEE FOR TUNA AND TUNA-LIKE SPECIES IN THE NORTH PACIFIC. 19pp. https://isc.fra.go.jp/pdf/ISC18/ISC_18_ANNEX_05_Report_of_the_Third_Shark_Age_Workshop_(October_2017)_FINAL.pdf.

ISC Shark Working Group 2018b. REPORT OF THE SHARK WORKING GROUP WORKSHOP 28 November– 4 December 2017. 33pp. https://isc.fra.go.jp/pdf/ISC18/ISC_18_ANNEX_06_Report_of_the_Shark_Working_Group_Workshop_(November-December_2017)_FINAL.pdf.

ISC Shark Working Group 2018c. Report of The Shark Working Group Workshop. https://isc.fra.go.jp/pdf/ISC18/ISC_18_ANNEX_11_Report_of_the_Shark_Working_Group_(April_2018)_FINAL.pdf.

ISC Shark Working Group 2018d. Stock assessment of shortfin mako shark in the North Pacific Ocean through 2016. ISC/18/ANNEX/15 117pp. https://isc.fra.go.jp/pdf/ISC18/ISC_18_ANNEX_15_Shortfin_Mako_Shark_Stock_Assessment_FINAL.pdf.

Joung, S. J., and Hsu, H. H. 2005. Reproduction and embryonic development of the shortfin mako, *Isurus oxyrinchus* Rafinesque, 1810, in the Northwestern Pacific. Zoological Studies 44, 487–496.

Kai, M., and Yokoi, H. 2017. Natural mortality rates for shortfin mako, *Isurus oxyrinchus*, in North Pacific. ISC/17/SHARKWG-3/14.

https://isc.fra.go.jp/pdf/SHARK/ISC17_SHARK_3/ISC_2017_SHARKWG-3-14_kai.pdf

Kinney, M.J., Wells, R.J.D., Kohin, S. 2016. Oxytetracycline age validation of adult shortfin mako shark *Isurus oxyrinchus* after 6 years at liberty. J. Fish Biol. 89, 1828-1833.

Madrigal, J. A. R., Semba, Y., and Ávila, J. A. 2017. Standardization of Mako Shark Ageing Through Different Vertebrae Enhancement Methods and Comparison of Growth Estimations from Eastern and Western North Pacific Ocean. ISC/17/SHARKWG-1/16.

Maunder, M. N., Hamel, O. S., Lee, H. H., Piner, K. R., Cope, J. M., Punt, A. E., Ianelli, J. N., Castillo-Jordán, C., Kapur, M. S., and Methot, R. D. 2023. A review of estimation methods for natural mortality and their performance in the context of fishery stock assessment. Fish. Res., Volume 257,106489. https://doi.org/10.1016/j.fishres.2022.106489.

Mollet, H. F., Cliff, G., Pratt Jr, H. L., and Stevens, J. D. 2000. Reproductive biology of the female shortfin mako, *Isurus oxyrinchus* Rafinesque, 1810, with comments on the embryonic development of lamnoids. Fish. Bull. 98: 299-318.

Semba, Y., Nakano, H., and Aoki, I. 2009. Age and growth analysis of the shortfin mako, *Isurus oxyrinchus*, in the western and central North Pacific Ocean. Environ. Biol. Fishes, 84, 377-391.

Semba, Y., Aoki, I., and Yokawa, K. 2011. Size at maturity and reproductive traits of shortfin mako, *Isurus oxyrinchus*, in the western and central North Pacific. Mar. Freshw. Res., 62, 20-29.

Semba Y, Oshimo S, and Kai M. 2014. Progress report on the re-examination of growth of juvenile shortfin mako (*Isurus oxyrinchus*) in the western and central North Pacific Ocean. Document submitted to 2nd Aging Workshop.

Semba, Y. and Yokoi, H. 2016. Update of Age and sex specific Natural mortality of the blue shark (*Prionace glauca*) in the North Pacific Ocean. ISC/16/SHARKWG-1/06 https://isc.fra.go.jp/pdf/SHARK/ISC16_SHARK_1/ISC2016-SHARKWG-1-06-Semba_BSH_natural_mortality.pdf

Semba, Y. 2017a. Update of growth of juvenile shortfin mako (*Isurus oxyrinchus*) in the western and central North Pacific Ocean. ISC/17/SHARKWG-1/18.

Semba, Y. 2017b. Application of EPMA to juvenile shortfin mako collected in the western and central north Pacific Ocean. ISC/17/SHARKWG-1/17.

Semba, Y., Liu, K.M., and Su, S. H. 2017. Revised integrated analysis of maturity size of shortfin mako (*Isurus oxyrinchus*) in the North Pacific. ISC/17/SHARKWG-1/22.

Semba, Y. 2018. Significance of sex-specific ecological and life history traits on the sustainable exploitation of sharks. In: Aoki, I., Yamakawa, T., Takasuka, A. (eds) Fish Population Dynamics, Monitoring, and Management. Fisheries Science Series. Springer, Tokyo. https://doi.org/10.1007/978-4-431-56621-2_5

Takahashi, N., Kai, M., Semba, Y., Kanaiwa, M., Liu, K.M., Rodríguez-Madrigal, J.A., Ávila, J.T., Kinney, M.J., Taylor, J.N. 2017. Meta-analysis of growth curve for shortfin mako shark in the North Pacific. ISC/17/SHARKWG-3/05.

Walter, J., Sharma, R., Cass-Calay, S., Ortiz, M., Brown, C. 2016. Scaling natural mortality rate as a function of length or weight with an application to yellowfin tuna. SCRS/2016/116.

Wells, R.J., Smith, S.E., Kohin, S., Freund, E., Spear, N., Ramon, D.A. 2013. Age validation of juvenile shortfin mako (*Isurus oxyrinchus*) tagged and marked with oxytetracycline off southern California. Fish. Bull. 111(2), 147-160.

Table 1. Summary of biological parameters of North Pacific shortfin mako (*Isurus oxyrinchus*) used in the previous stock assessment in 2018, focusing on growth, reproduction, and natural mortality.

	Growth parameter		Longevity	Maturity size	Fecundity	Reproductive cycle	Natural Mortality
Reference	Takahashi *et al*. (2017)		Ardizzone *et al*. (2006)	Semba *et al*. (2017)	ISC shark WG (2017b)	ISC shark WG (2017d)	Hoenig (1983)
	L∞ (PCL:cm)	K	bomb-radiocarbon	PCL (cm)			
Male	232 (CI: 224.6-257.3)	0.174 (CI: 0.116-0.238)	-	166	-	-	-
Female	293.1 (CI: 255.2-335.9)	0.128 (CI: 0.080-0.186)	-	233	-	2 years	-
Sex-combined			31		12		0.128/year
Note						3 years in sensitivity analysis	a_{max}: 31 years

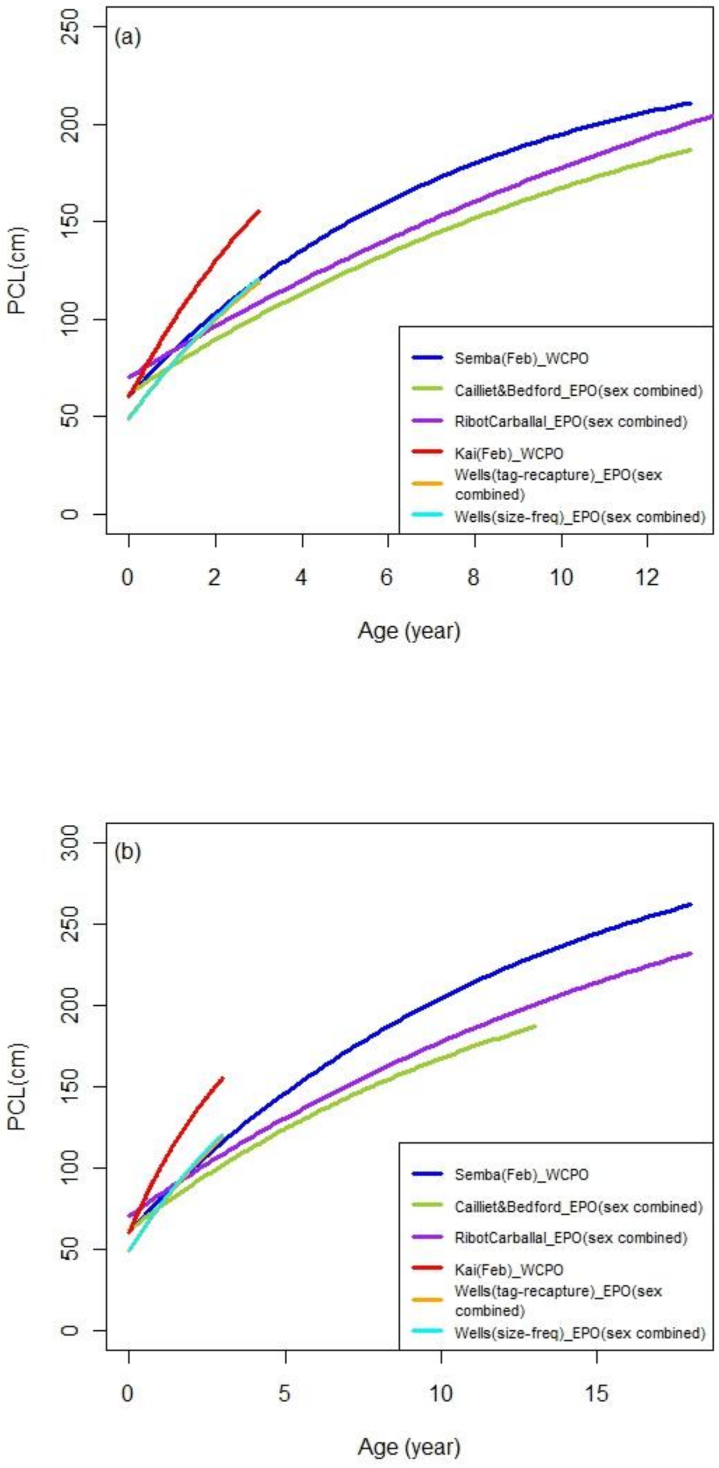


Figure 1. Growth curve estimated for (a) male and (b) female shortfin mako in the North Pacific Ocean (cited from Semba 2017).