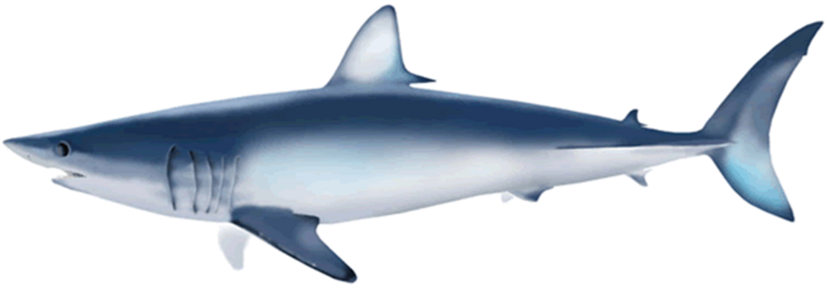
ISC/18/SHARKWG-2/03

Stock-recruitment relationships of shortfin mako, *Isurus oxyrinchus*, in the North Pacific[1]

Mikihiko Kai[2]

.

[2]National Research Institute of Far Seas Fisheries, Japan Fishery Research and Education Agency
5-7-1 Orido, Shimizu-ku, Shizuoka 424-8633, JAPAN
Email: kaim@affrc.go.jp



---

[1] Working document submitted to the ISC Shark Working Group Workshop, 10 - 16 April 2018, SWFSC NOAA LaJolla, CA, USA. **Document not to be cited without author's permission.**

Abstract

This working paper provides estimates of steepness, which represents a fraction of the unfished recruitment when spawning stock biomass is 20% of the unfished spawning stock biomass, for North Pacific shortfin mako (*Isurus oxyrinchus*). I applied an existing age-structured model for the reproductive ecology of elasmobranchs. I conducted numerical simulations to incorporate uncertainties in the natural mortality and produced the variance of steepness. I also examined the impacts of different maximum ages and reproductive cycles on the estimates. The mean values and those standard deviation for steepness with the Beverton-Holt model and default maximum age 31 years were 0.316 (standard deviation = 0.054) and 0.252 (standard deviation = 0.039) for the reproductive cycle of 2 years and 3 years, respectively. The results suggested that the stock-recruitment relationship in North Pacific shortfin mako remains little density-dependent and that its productivity is lower than that of other elasmobranchs.

Introduction

Stock assessment of shortfin mako (*Isurus oxyrinchus*) in the North Pacific is scheduled to conduct in spring 2018 using a stock synthesis (SS) (Method and Wetzel, 2013). However, it is unknown about the stock-recruitment relationships of the North Pacific shortfin mako. Therefore, it is urgent to provide the stock-recruitment relationships of this species. The main objective of this working paper is to estimate the steepness (Mace and Doonan, 1988), which represents a fraction of the unfished recruitment when spawning stock biomass is 20% of the unfished spawning stock biomass, for North Pacific shortfin mako. I modified an existing age-structured model for a compensatory stock recruitment relationship (Beverton-Holt model) of elasmobranchs such as blue sharks (Kai and Fujinami, 2018) and applied the model to the North Pacific shortfin mako.

Materials and Methods

I applied an existing age-structured model for the reproductive ecology of elasmobranchs developed by Kai and Fujinami (2018) to the North Pacific shortfin mako. Kai and Fujinami (2018) developed a model that accounts for the pre-recruit survival of requiem sharks such as a blue shark, while accounting for differences in the survival rate at four life history stages before recruitment, i.e. fertilized eggs (stage 0), embryos inside the body of female fish (stage 1), neonates immediately after pupping (stage 2), and pre-recruit juveniles (stage 3). A product of the survival rates at each stage has been used:

$$S_{pre} = S_0 S_1 S_2 S_3 \quad , \tag{1}$$

where S_{pre} is a pre-recruit survival rate and $S_0 S_1 S_2 S_3$ is a product of the survival rate at each stage from 0 to 3. Unlike the requiem sharks, shortfin mako is lamniform sharks of families that exhibit different reproductive strategy and the embryos feed on the unfertilized yolked ova (oophagy) that the pregnant female continues to produce during gestation (Snelson et al., 2008). It makes the modeling of survival rates for embryos inside the body of female fish difficult (stage 1). In addition, there is no information about the survival rates of fertilized eggs (stage 0) and neonates immediately after pupping (stage 2). Therefore, the survival rates of stages 0-2 were not modeled explicitly and I considered the survival rates of juveniles at stage 3. I assumed that the observed litter size of neonates is the same as the number of neonates immediately after pupping.

It is supposed that the natural mortality is a constant for different size and sex because the birth size for male and female is almost similar (i.e. 60 cm PCL) and the size is enough for maintaining high survival rate thereafter. In addition, it was difficult to apply Method II (Walter et al., 2016) used in Kai and Fujinami (2018) to this species due to a high natural mortality rate at age 0 (0.369 year^{-1}) based on the Target-M = 0.127 from Hoenig's equation with maximum age is 31 that causes a steep depletion of the neonates and makes the population of low fecundity difficult to maintain.

The parameters of the stock-recruitment model for shortfin mako in the North Pacific were estimated from biological data collected across the North Pacific (e.g., Semba et al., 2009, 2010; Joung and Hsu, 2005; Chang and Liu, 2009). The value of $S_{pre} = S_3$ and the natural mortality after recruitment for females was estimated from an empirical equation for cetaceans (Hoenig 1983):

$$M = \exp(0.941) {a_{max}}^{-0.873} \tag{1}$$

The reasons why we used the Hoenig's equation is that this equation is commonly used for the study of pelagic sharks due to not only the rationale of the use of maximum ages but also an application to cetaceans (Hoenig, 1983). The value of sex ratio (r) was assumed to be 1-1 (Semba et al., 2011). The average period from parturition to recruitment was estimated from the growth curves given birth size and the mean size at recruitment (Kai et al., 2015). The value of body weight (W) for females was estimated using the equations of length at ages (Takahashi et al., 2017) and body weight at length (Su et al., 2017). The value of the maturity ogive for females ($p_{f,m}$) was estimated using the equation of the maturity rate at length (Semba and Liu, 2017). The value of reproductive year (y) was determined from the studies on the reproductive cycle (Semba et al., 2011; Joung and Hsu, 2005). The value of litter size (ψ) was fixed to 12 (Semba et al. 2011; Joung and Hsu, 2005). A value of 31 was used as the longevity of the shortfin mako (Ardizzone et al., 2006). The default values of all parameters are shown in Table 1.

I conducted the same numerical simulations as used for the North Pacific blue shark (kai and Fujinami, 2018) to incorporate uncertainties in the natural mortality and produced the variance of steepness. I also examined the impacts of different maximum ages (i.e. 28 and 34) and reproductive cycles (2 years and 3 years) on the estimates.

The computation of the numerical simulation was implemented using a code based on the R package (R Development Core Team, 2016).

Results and Discussion

The mean values and those standard deviation for steepness with the Beverton-Holt model and default maximum age 31 years were 0.316 (standard deviation = 0.054) and 0.252 (standard deviation = 0.039) for the reproductive cycle of 2 years and 3 years, respectively (Table 2 and Figure 1). The sensitivity analysis of steepness to the different maximum ages showed that the impacts of the maximum ages were very small on the estimates of steepness (Table 2). The results suggested that the stock-recruitment relationship in North Pacific shortfin mako remains little density-dependent and that its productivity is quite lower than that of other viviparous elasmobranchs.

Steepness of shortfin mako in the North and South Atlantic were computed based on the biological information using a dual life table/Leslie matrix approach (Cortés, 2017). The estimated steepness ranged from 0.34 to 0.52 for the North Atlantic and from 0.44 to 0.72 for the South Atlantic. These higher values in the Atlantic were largely different from the lower estimates of steepness in the North Pacific because the natural mortality schedules of Atlantic shortfin mako were quite lower (constant values of 0.081 for immature female and lower than the value for the mature female) than that (0.127) of North Pacific shortfin mako in addition to the different biological parameters such as growth curves for North Atlantic shortfin mako (e.g. L_∞=350.6 and k=0.064). It would be required to reduce the uncertainties in the biological parameters to improve the accuracy of the estimates of steepness in future work.

The parameters (zfrac and β) of low fecundity stock recruitment relationships (LFSR; Taylor et al., 2013) were not estimated in this study because it does not make sense without estimating the unfished biomass and recruitment in SS and without fixing the shape of the stock recruitment relationships. The shape of the stock recruitment relationships could be selected from the likelihood in the process of the fitting to the SS model.

References

Ardizzone, D., Cailliet, G.M., Natanson, L.J., Andrews, A.H., Kerr, L.A. and Brown, T.A. (2006)

Application of bomb radiocarbon chronologies to shortfin mako (*Isurus oxyrinchus*) age validation. Environ. Biol. Fish. 77, 355–366. DOI: 10.1007/s10641-006-9106-4

Chang, J.H. and Liu, K.M. (2009). Stock assessment of the shortfin mako (*Isurus oxyrinchus*) in the Northwest Pacific Ocean using per recruit and virtual population analyses. Fish. Res. 98, 92–101. doi: 10.1016/J.FISHRES.2009.04.005

Cortés, E. (2017). Estimate of maximum population growth rate and steepness for shortfin makos in the North and South Atlantic Ocean. SCRS/2017/126.

Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bul. 82:898–903.

Joung, S.J., and Hsu, H.H. (2005). Reproduction and embryonic development of the Shortfin Mako, *Isurus oxyrinchus* Rafinesque, 1810, in the northwestern Pacific. Zool. Stud. 44, 487–496.

Kai, M. and Fujinami, Y. (in press). Stock-recruitment relationships in elasmobranchs: Application to the North Pacific blue shark. Fish. Res.

Kai, M., Shiozaki, K., Semba, Y. and Yokawa, K. (2015) Estimation of growth curve from length composition of juvenile shortfin mako, *Isurus oxyrinchus*, in the western and central north Pacific Ocean. Mar. Freshwater Res. 66, 1176-1190. http://dx.doi.org/10.1071/MF14316

Kai, M. and Yokoi, H. (2017) Natural mortality rates for shortfin mako, *Isurus oxyrinchus*, in the North Pacific. ISC/17/SHARKWG-1/14.

Mace, P.M., Doonan, I.J., 1988. A Generalised Bioeconomic Simulation Model for Fish Population Dynamics. New Zealand Fishery Assessment Research Document 88/4. Fisheries Research Centre, MAFFish, POB 297, Wellington, NZ.

Methot, R.D. and Wetzel, C.R. (2013) Stock synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fish. Res. 142, 86–99.

R Development Core Team, 2016. R: a Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: http://www.R-project.org. (Accessed 27 December 2017).

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 Ocean. Mar. Freshwater Res. 62, 20–29. doi:10.1071/MF10123

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

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.

Snelson Jr., F.F., Burgess, G.H., Roman, B.L., 2008. The reproductive biology of pelagic elasmobranchs. In: Camhi, M.D., Pikitch, E.K., Babcock, E.A. (Eds.), Sharks of the

Open Ocean: Biology, Fisheries and Conservation. Blackwell Publishing Ltd., Oxford, pp. 24–53.

Su, S.H., Kohin, S., Taylor, J., Semba, Y., Tsai, W.P. and Liu, K.M. 2017. Relation between weight and length of shortfin mako sharks in the North Pacific Ocean. ISC/17/SHARKWG-1/13.

Takahashi, N., Kai, M., and Semba, Y. 2017. Meta-analysis of growth curve for shortfin mako shark in the North Pacific. ISC/17/SHARKWG-1/05.

Taylor, I.G., Gertseva, V., Methot, R.D. and Maunder, M.N. (2013) A stock- recruitment relationship based on pre-recruit survival, illustrated with application to spiny dogfish shark. Fish. Res. 142, 15–21.

Walter, J., Sharma, R., Cass-Calay, S., Ortiz, M. and Brown, C., (2016) Scaling Natural Mortality Rate as a Function of Length or Weight with an Application to Yellowfin Tuna. SCRS/2016/116.

Table 1. Default parameters on biological data of female shortfin mako and other sources. The symbol follows the Kai and Fujinami (2018).

No.	Function name	Parameter name	Symbol	Unit	Value	Reference
1	von-Bertalanffy growth curve	Asymptotic size	L_∞	cm in PCI	293.1	Takahashi (2017)
		Growth rate	k	year^{-1}	0.128	
		Length at age0	L_0	year	60	
2	Weight-length relationship		c_1		3.4	Su et al. (2017)
			c_2		2.84	
3	Length-based maturity ogives		c_3		34.23	Semba et al. (2017)
			c_4		-0.146	
4	Littersize				12	Semba and Liu (2017)
5	Natural mortality					
	Theoretical equation	Natural mortality at ages	M	year^{-1}	0.128	Kai and Yokoi (2017)
	Gamma distribution		v		9.7	Mangel et al. (2010)
			λ		71.9	
6		Maximum age	$a_{\max}$	year	31	Ardizzone et al. (2006)
7		Sex ratio	r		0.5	Semba (2011)
8	Pre-recruit survival					
		Survival at stage 0-2	$S_{0\text{-}2}$	year^{-1}	1	
	Theoretical equation	Survival at stage 3	S_3	year^{-1}	0.880	Kai and Yokoi (2017)
9	Reproductive cycle					
	No function	Reproductive period	y		2 and 3	Semba et al. (2011); Joung and Hsu (2005)
		Days to recruit from partrition	d	day^{-1}	180	Kai et al. (2015)

Table 2. Estimates of steepness parameters for different reproductive cycles: 2 and 3 years and maximum ages: 28, 31, and 34 years.

SR-models	Parameter	2 year reproductive cycle			3 year reproductive cycle		
		Maxage-28	Maxage-31	Maxage-34	Maxage-28	Maxage-31	Maxage-34
Beverton-Holt	Mean value of steepness	0.307	0.316	0.323	0.246	0.252	0.256
	SD of steepness	0.055	0.057	0.058	0.036	0.039	0.041

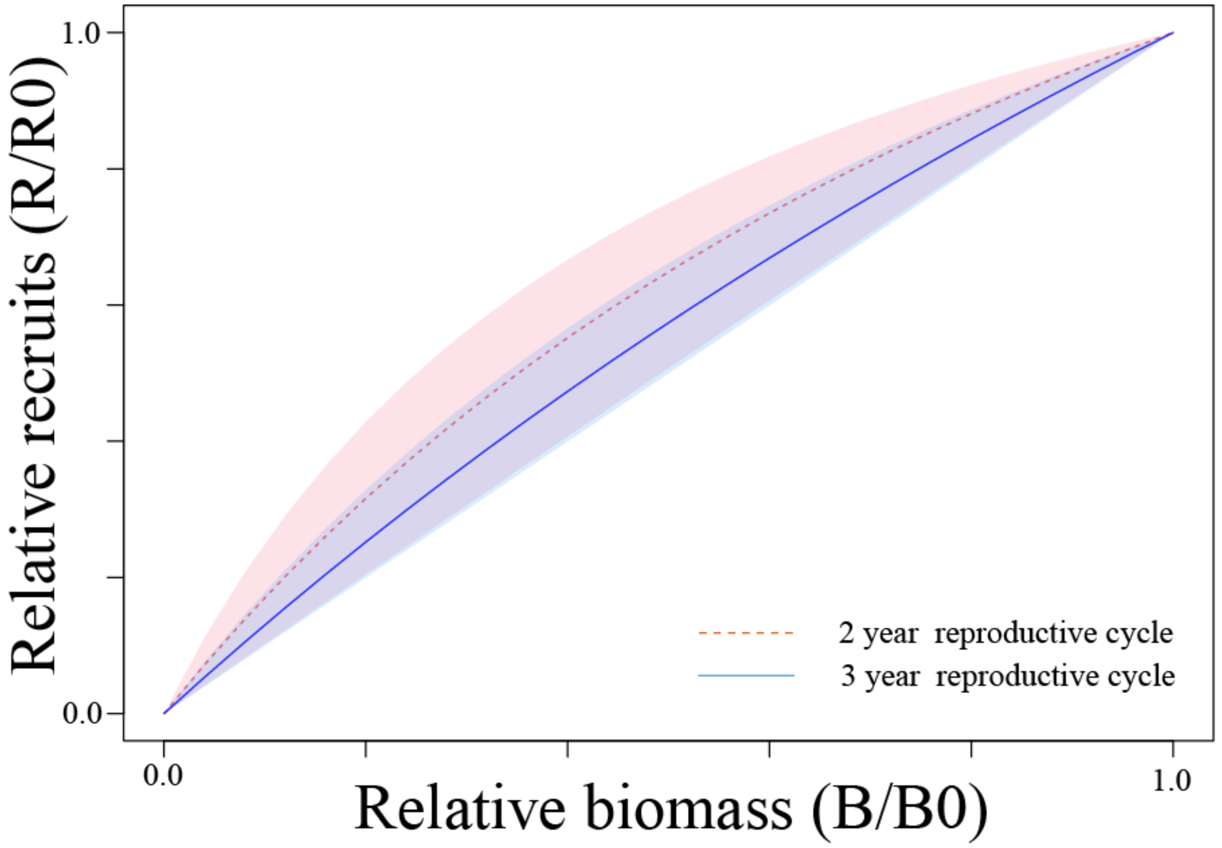


Figure 1. Estimates of the North Pacific shortfin mako stock-recruitment relationship for Beverton-Holt model for different reproductive cycles: 2 and 3 years. Shaded blue and red areas denote 95% confidence intervals. Relative recruits indicate recruitment (R)/unfished recruitment (R0), and relative biomass indicates biomass (B)/unfished biomass (B0).