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Natural mortality rates for shortfin mako, *Isurus oxyrinchus*, in North Pacific[1]

Mikihiko Kai[2] and Hiroki Yokoi[2]

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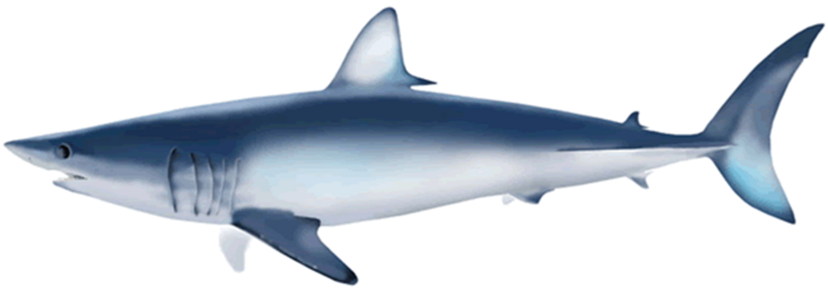
[2] National Research Institute of Far Seas Fisheries, Japan Fishery Research and Education Agency
5-7-1 Orido, Shimizu-ku, Shizuoka 424-8633, JAPAN
Email: kaim@affrc.go.jp



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Abstract

This working paper presents sex-and age- specific natural mortality rates (M) for shortfin mako in the North Pacific. We applied a same method used in the estimation of the M for blue shark in the North Pacific. A constant value of target-M is estimated using an empirical equation, and then the M is allocated to age using a theoretical equations developed for yellowfin tuna in the North Atlantic. The estimated target-M was 0.16 and 0.13 for male and female respectively. The estimated M at age-0 was 0.39 and 0.37 for male and female respectively. The Ms gradually decreased and reached at 0.12 and 0.094 for the maximum age of male and female respectively. These results are likely to be reasonable because (i) the natural mortality rate at age-0 is almost same between male and female, (ii) the natural mortality rate at maximum age of male was higher than those of female, and (iii) the estimates of natural mortality are possible ranges in comparisons with the values of blue shark.

Introduction

Natural mortality rates (M) is a key biological parameter in the stock assessment. However, an accurate estimation of the M is very difficult because it typically requires substantial amounts of data (Simpfendorfer et al., 2005). In common, indirect methods such as empirical equations and direct methods such as a tagging study had been explored to estimate M; however, indirect methods are commonly applied to the population assessments of sharks and other organisms due to the limitation of the data for the use of direct methods (Simpfendorfer et al., 2005). The majority of these indirect methods assumes that mortality is independent of age (e.g., Pauly, 1980; Gunderson, 1980; Brander, 1981; Hoenig, 1983; Gunderson and Dygert, 1988; Jensen, 1996), whereas several methods give age-dependent values (e.g. Peterson and Wrobloski, 1984; Chen and Watanabe, 1989).

Shortfin mako (*Issurus oxyrinchus*) is a pelagic sharks and frequently caught by longline fishery as a bycatch (Kai et al., 2017). The M of shortfin mako in the North Pacific has not been developed. However, the estimates of key parameter is required to conduct a full stock assessment of shortfin mako in the North Pacific. The objective of this document paper is to estimate the sex-and age-specific natural mortality rates for shortfin mako in the North Pacific. The contents of this document paper are mostly referred from the discussions with regards to the natural mortality for blue shark in the North Pacific (Kai and Fujinami, in press).

Materials and Methods

Although many estimators of M were developed as described above, a theoretical equation (Walter et al., 2016) was used to allocation M to age, because pelagic sharks may be prey when young and predators when older, a situation that leads to changes in M during growth. In addition, there is no evidence that M for pelagic sharks in the older age classes increases due to senescence.

It is supposed that the M at age is size and sex dependent, and the values are estimated using a modified equation (referred to below as Method II) proposed in the stock assessment of Atlantic yellowfin tuna (*Thunnus albacares*) in 2016 (Walter et al., 2016). This is because several empirical equations were not suitable for sharks (see Appendix A of Kai and Fujinami, in press). In addition, the equations were not always estimated for sharks and there are several serious issues with those equations. Method II was therefore developed to allocate a constant M into each age class, and it is defined as

$$M(a) = \frac{M_T(a_{max}-a_c)}{ln\left(\frac{L_c}{L_c+L_\infty(\exp(k(a_{max}-a_c))-1)}\right)} ln\left(\frac{L(a)}{L(a)+L_\infty(\exp(k)-1)}\right), \qquad (1)$$

where M_T is a Target-M defined as a mean natural mortality per year from the age at first full recruitment (a_c) to the maximum age (a_{max}), L_c is the body length at a_c, L_a is the body length at age (a), L_∞ is the theoretical asymptotic size, and k is the growth coefficient. The concept of this method is two-step approach. In first step, M at length is calculated based on M_T. In second step, age-specific M is estimated based on the length at age using Von-bertaranffy growth curve. The Target-M is estimated from an empirical equation for cetaceans (Hoenig 1983):

$$M = \exp(0.941){a_{max}}^{-0.873} \qquad (2)$$

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 sex-specific biological parameters used for the calculation are summarized in **Table 1**. The value of a_c is assumed to be 0 because longline fishery frequently catch age-0 shortfin mako in the North Pacific (Kai et al. 2017).

Results and Discussions

The estimated target-M was 0.16 and 0.13 for male and female respectively. The estimated M at age-0 was 0.39 and 0.37 for male and female respectively (**Table 2** and **Figure 1**). The Ms gradually decreased and reached at 0.12 and 0.094 for the maximum ages of male and female respectively. These results are likely to be reasonable because (i) the natural mortality rate at age-0 is almost similar between male and female, (ii) the natural mortality rate at maximum age of male was higher than those of female, and (iii) the estimates of natural mortality are possible ranges in comparisons with the values of blue shark. Since the birth sizes of male and female are almost same around 60 cm PCL (Semba et al. 2011), the M of neonates is considered to be same between male and female. The longevity of female is longer than that of male (Takahashi et al. 2017). In addition, the maximum size of female is larger than that of male (Takahashi et al. 2017). These results suggest that the M of adult female is lower than that of male. The M of blue shark for female was estimated using the Method II (Kai and Fujinami, in press). The estimates of M for age-0 and maximum age at 20 was 0.79 and 0.14 respectively. These values are larger than those of shortfin mako because the birth size of blue shark is around 33.4 cm PCL (Fujinami et al. 2017) which value is much smaller than that of shortfin mako, and the maximum size of female's shortfin mako is larger than that of blue shark (Semba et al. 2011).

Then et al. (2015) evaluated the predictive performance of age-independent empirical estimators of the natural mortality rate using information on over 200 fish species and concluded that an a_{max}-based estimator performed the best among all estimators evaluated. The conclusion supports to use the empirical equation of Hoenig (1983) when we calculate the target-M.

For the stock assessment of shortfin mako in the North Atlantic, the natural mortality schedules for male and female were estimated using the empirical equations (Cortés, 2017). However, the values had a problem because there was a large difference of M for age-0 between male and female. Therefore, the estimation method and the estimates of M in this study is more reasonable than those in the study for North Atlantic shortfin mako.

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Table 1. Summary of biological parameters used for the calculation of the natural mortality schedules for male and females.

Parameter	Female	Male	Refference
age-max	31	24	Ardizzone, (2006) for F; ISC (2017) for M*
Target-M	0.1279	0.1599	Hoening (1983)
Linf	293.1	232	Takahashi et al. (2017)
para-k	0.128	0.174	Takahashi et al. (2017)
age-0	-1.789	-1.72	Takahashi et al. (2017)

* maximum age of male was reffered from the observed maximum length at age from Taiwanese data

Table 2. Estimates of sex-and- age specific natural mortality rates.

Age	Female	Male
0	0.369	0.387
1	0.271	0.287
2	0.220	0.236
3	0.188	0.205
4	0.167	0.185
5	0.152	0.171
6	0.141	0.161
7	0.133	0.153
8	0.126	0.147
9	0.121	0.142
10	0.117	0.139
11	0.113	0.136
12	0.110	0.133
13	0.108	0.132
14	0.106	0.130
15	0.104	0.129
16	0.102	0.128
17	0.101	0.127
18	0.100	0.126
19	0.099	0.125
20	0.098	0.125
21	0.097	0.124
22	0.097	0.124
23	0.096	0.124
24	0.096	0.123
25	0.095	
26	0.095	
27	0.095	
28	0.094	
29	0.094	
30	0.094	
31	0.094	

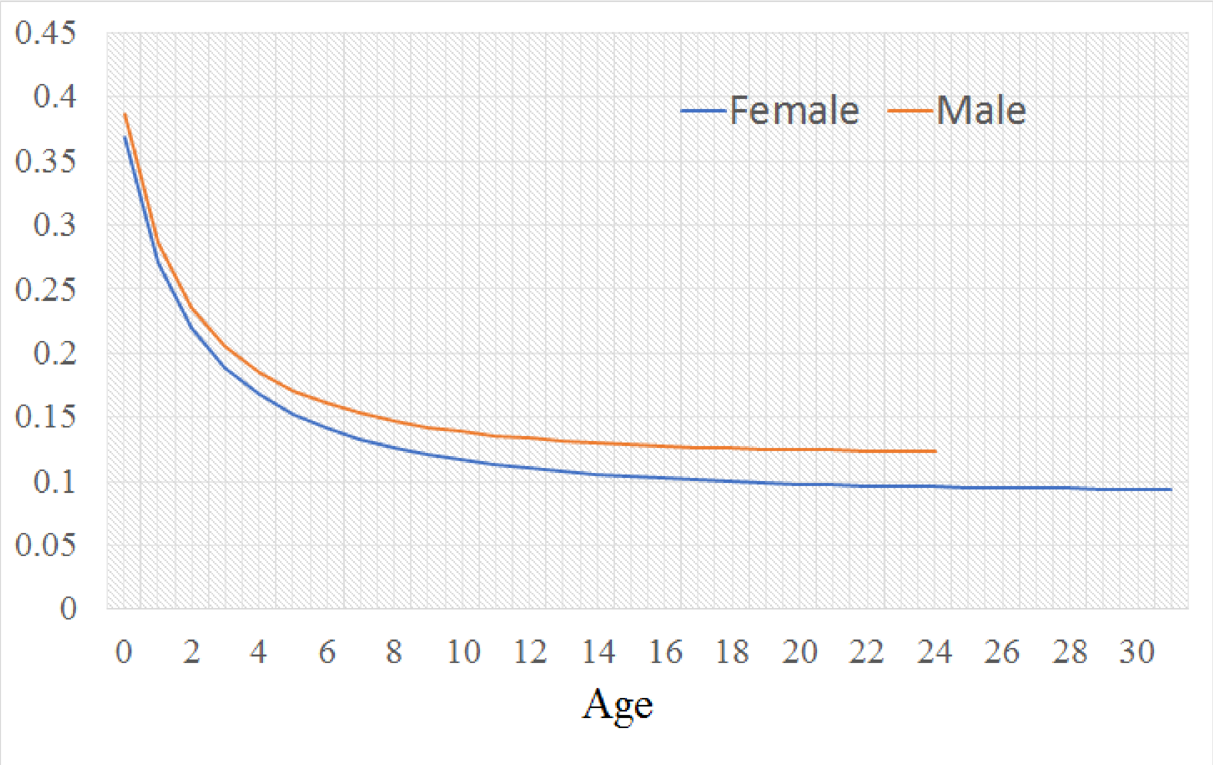

Figure 1. Sex and age specific natural mortality schedules.