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Age and Sex Specific Natural Mortality of the Blue Shark (*Prionace glauca*) in the Indian Ocean.

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Introduction

Biological parameters such as growth and natural mortality form the basis for the inputs for stock assessment models (Siegfried and Sanso 2013) and can be used to assess the vulnerability of the stock to fishing (Hilborn and Walters 1992). Some attempts have been made to combine gross estimates of biological change such as length or age over time, with catch data to get a rough estimate of trends in stock status (e.g. Clarke 2011). In the absence of good biological data, estimates derived from closely related populations or species can be used. However, these estimates may differ from reality and in order to encapsulate the uncertainty appropriately for use in a stock assessment, additional work is required (Cortes 2002).

This work was motivated by a desire for age and sex specific natural mortality estimates for a length based integrated stock assessment model. The IOTC Working Party on Ecosystems and Bycatch requested that age and sex-specific natural mortality estimates be developed for blue shark (*Prionace glauca*) in Indian Ocean based on published literature. This paper documents the methods and results of calculating sex specific natural mortality-at-age for Indian Ocean blue shark are estimated based on length-at-age from Arande et al 2019.

Materials and Methods

Age and growth parameters from the ageing studies (Arande et al 2019) for blue sharks in the Indian Ocean using vertebral counts were used to provide the length-at-age estimates. Natural mortality-at-age was estimated using the Peterson and Wroblewski (1984) who estimated M-at age using:

$$M_t = 1.92 {W_t}^{-0.25}$$

where W_t is weight (g)-at-age (or time).

The average mortality over life of fish was estimated using 3 different methods:

1) Hoenig (1983) who determined that M could be estimated as follows:

$$\text{Ln}(M)=1.46-1.01*\ln(t_{\max})$$

where t_{max} is the maximum age of the fish, and if approximately 5% of the population is still alive at the maximum age. Simpfendorfer et al. (2005) recommend to use the teleost relationship for estimating the t_{max} for sharks. This equation has been updated by Then et al. (2015), based on multiple direct estimates of M .

$$\text{Ln}(M)=1.717-1.01*\ln(t_{\max})$$

2) Hewett and Hoenig (2005) who determined that M could be estimated as follows:

$$M \approx \frac{4.22}{t_{max}}$$

t_{max} is the maximum age observed in the stock (Hewett and Hoenig 2005).

3) Jensen (1996) who estimated M using the von Bertalanffy parameter K:

$$M = 1.5K$$

For $t_{\max}$ in Hoenig (1983) and Hewett and Hoenig (2005), the age of 25 was used, estimate of the theoritcal max age ar available .

Results

The growth curves of from Andrade et al. (2019) showed that male and female growth differed but the sex-specific growth curves from these two studies were broadly similar (Figure 1). Due to the similarity in sex specific growth the resultant age-specific mortality estimates were broadly similar (Figure 2).

M-at-age estimated using Peterson and Wroblewski (1984) sex specific M-at-age was almost identical blue shark based on the growth parameters from Andrade et al. (2019). The estimated natural mortality datasets declined rapidly from a high of 0.288 and 0.277 for females and males, respectively, at age 1 to approximately 0.15 for both sexes by age 5, thereafter M declined slowly over the lifetime of the fish to approximate 0.1 for fish aged 18 and below 0.1 for blue shark older than 18 years of age.

Theoretical maximum age of blue shark was estimated as 23.1 for males and 26.7 for females, calculated via the equation t_{max} = 5(ln2)/k (Cailliet et al., 1992), (Table 2). These values differs slightly from the maximum observed age of 25 (of a male shark) and 20 (for a female). by Andrade et al. (2019).

The average M over life of fish estimated using the three methods are presented in Table 3. The sex-specific values estimated using Hoenig (1983) and Hewett and Hoenig (2005) were similar within sexes and slightly higher for females than for males. For these two methods the average M over life of fish ranged from 0.18 to 0.24 for males and 0.18 to 0.21 for females. Estimates of M were higher for males than for females

Discussion

A new source of length-at-age data (Andrade et al. 2029) for Indian Ocean blue shark were used in this study. The methods derived by Peterson and Wroblewski (1984) provided realistic values of M-at-age where mortality was relatively high for young fish but stabilized at around 0.1 from about age 18. This result was considered to be biologically plausible, and is the best available estimate at present, but further study is necessary for the estimation of accurate age-specific M.

The average M over the lifetime of the fish was assessed using three different methods (Table 3). The Jensen (1996) estimate was the highest of these three methods, and higher than the average of the estimates derived by the Peterson and Wroblewski (1984) method over the sex and study specific maximum ages (Table 1). The remaining two methods (Hoenig (1983) and Hewett and Hoenig (2005)) provided similar results and are likewise considered plausible.

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Table 1. Age and sex specific natural mortality estimates (from Peterson and Wroblewski 1984).

Age	Female	Male
0	0.453	0.453
1	0.288	0.277
2	0.222	0.212
3	0.187	0.179
4	0.165	0.158
5	0.15	0.144
6	0.139	0.134
7	0.131	0.126
8	0.124	0.121
9	0.119	0.116
10	0.115	0.113
11	0.112	0.11
12	0.109	0.107
13	0.107	0.105
14	0.105	0.104
15	0.103	0.102
16	0.102	0.101
17	0.101	0.1
18	0.1	0.1
19	0.099	0.099
20	0.098	0.098
21	0.098	0.098
22	0.097	0.097
23	0.097	0.097
24	0.096	0.097
25	0.096	0.097
26	0.095	0.096
27	0.095	0.096
28	0.095	0.096
29	0.095	0.096
30	0.095	0.096

Table 2: Maximum age of blue shark (*Prionace glauca*) in the Indian Ocean estimated from $t_{max} = 5(\ln 2)/k$ (Cailliet et al., 1992), using the growth coefficient from Andrade et al (2019).

	Andrade et al. 2019
Male	23.10
Female	26.66

Table 3: Sex-specific population mortality estimates of blue shark (*Prionace glauca*) in the Indian Ocean based on the biological parameters presented in Andrade et al. 2019), calculated using three different methods Hoening's 1983 method updated by Then (2015), Hewett and Hoening (2005) and Jensen (1996).

	Male	Female
Hoenig (1983)	0.234	0.202
Hewitt and Hoenig (2005)	0.183	0.183
Jensen (1996)	0.24	0.208

Figures

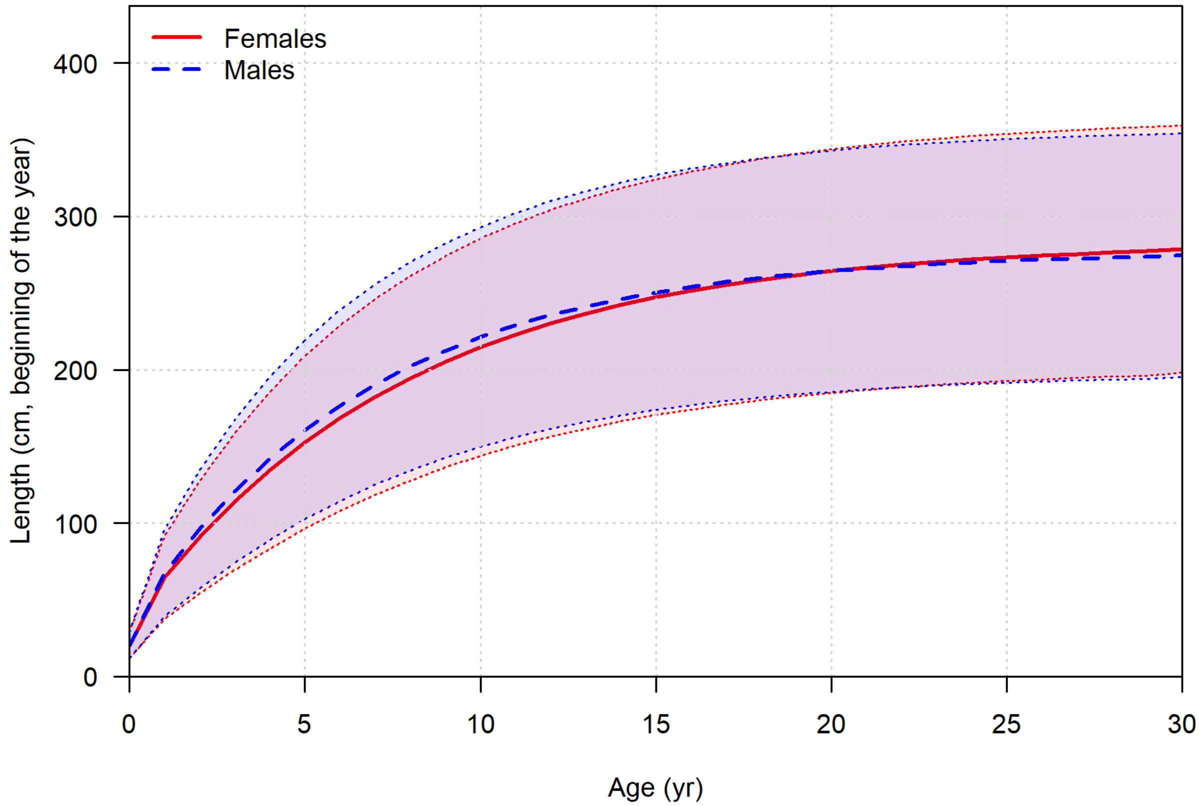

Figure 1: Sex specific length-at-age for Indian Ocean blue shark (*Prionace glauca*) from Andrade et al 2019, with a 95% confidence interval. .

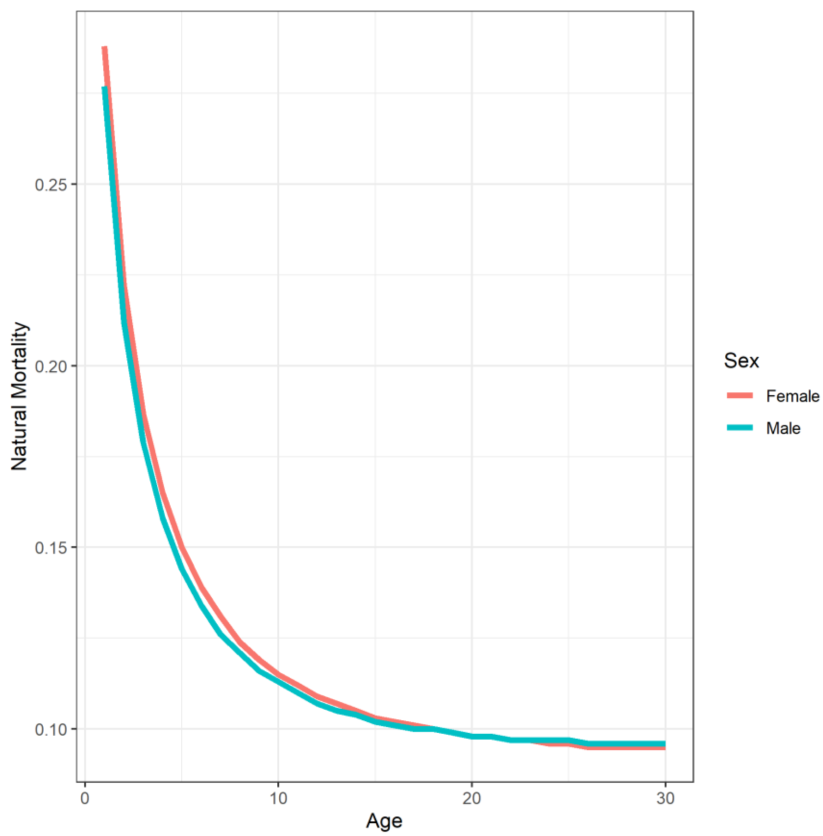

Figure 2: Age specific mortality estimates for Indian Ocean blue shark (*Prionace glauca*) derived from length-at-age estimates Andrade et al 2019, calculated using Peterson and Wroblewski (1984).