Candidate biological parameters for the Western and Central Northern Pacific Ocean striped marlin stock assessment

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Abstract

This working paper summarized the biological information required for assessing Western Central North Pacific Ocean (WCNPO) striped marlin stock, including growth curves and natural mortality rate. The growth curves were obtained from several studies in the Pacific Ocean, and these parameters were converted to the parameter in Stock Synthesis 3. Specifically, the lower jaw-fork length was converted to eye-fork length, and the L1 and L2 parameters were associated with age 0.5 and 15, respectively. The natural mortality was estimated by the same meta-analysis method as the previous study using the growth curve reported in the South Pacific Ocean. Furthermore, multiple population assessment model settings were proposed due to the relationship between natural mortality and growth curves.

Introduction

The growth curve is the most important biological information in the stock assessment because it determines age at maturity and natural mortality parameters that are the most sensitive for the population growth rate (Yokoi et al. 2017, Ijima et al. 2019). The growth curve of striped marlin in the Pacific Ocean has been reported in different waters (Melo-Barrera et al. 2003, Sun et al. 2011, Kopf et al. 2011, Shimose and Yokawa 2019). These growth significantly differed among waters, and these differences were thought to be due to differences in growth among the area (Kopf et al. 2011). However, recent detailed studies using otoliths have indicated that the growth of juvenile striped marlin in the Eastern Pacific Ocean (EPO) and South West Pacific Ocean (SWPO) is similar (Shimose and Yokawa 2019). The ISC Billfish Working Group (ISC BILLWG) has been concerned about the significant differences in growth curves among the different waters. Although joint research has been initiated, sampling has just begun, and there is no agreement on which growth curve is the most appropriate for Western Central North Pacific Ocean (WCNPO) striped marlin stock.

When uncertainties are recognized in the stock assessment assumptions and there are multiple candidates, an ensemble approach that combines these elements is increasingly being used in recent stock assessments (Ducharme-Barth et al. 2019). The BILLWG needs to prepare candidate biological assumptions for the following stock assessment. For example, for the EPO and the WCNPO, natural mortality rates have been estimated by meta-analysis (Piner and Lee 2011a, Piner and Lee 2011b). However, for SWPO, natural mortality has not been estimated. These three growth curves need to be adapted to Eye Fork Length (EFL) based length composition data because they were fit to Lower Jaw Fork Length (LJFL) data. These three models need to converted to growth curve model for SS3 because of difference of parameters.

This working paper summarized these candidate growth curves and provided the parameters to be used in the Stock Synthesis 3 (SS3) model. It was also estimated the natural mortality associated with the growth curve in the South Pacific using the same method as for the other growth curves.

Material and Methods

- Striped marlin growth

Before the data preparation meeting of the WCNPO striped marlin stock assessment, the BILLWG decided that the growth curve to be used for SS3 would be Sun et al. (2011), Kopf et al. (2011), and Melo-Barrera et al. (2003). Sun et al. 2011 combined two back-calculating methods (Fraser-Lee's and Monastyrsky) and two growth curves (standard von Bertalanffy and Richards growth model) and selected the best model using the AIC. The combination with the lowest AIC was the Richards model with the monaskyrsky method. However, the BILLWG selected the standard von Bertalanffy with the monaskyrsky method for comparison with other growth curves. Kopf et al. 2011 also estimated the parameters in various ways. In this paper, I used the parameters fitted directly to the observed values. In addition, Kopf et al. 2011 has found significant differences in the growth curves for males and females. However, this study calculates the mean values of males and females to compare with other growth curves. Melo-Barrera (2003) estimated the standard standard von Bertalanffy growth curve parameters.

The LJFL estimated these three growth curve parameters. However, length composition data in the SS3 model is summarized by the EFL. Thus, the LJFL needs to convert to the EFL to fit the length composition data for the SS3. The conversion function of Sun et al. (2011) and Kopf et al. (2011) as follows;

$$LJFL = 1.12EFL + 7.33,$$

$$EFL = 0.834LJFL + 36.61 \quad \text{(Both gender)}.$$

Melo-Barrera (2003) did not describe the conversion equation. Thus, the two conversion equations were used and checked the difference.

The growth curves of von Bertalanffy for the SS3 require three parameters $L1$, $L2$, and K, and $L1$ and $L2$ parameters were set EFL at ages 0.5 and 15, respectively. Parameter K has used the estimated values without modification.

- Natural mortality

The age-specific natural mortality corresponding to Sun et al. 2011 and Melo-Barrera (2003) have already been estimated (Piner and Lee 2011a, Piner and Lee 2011b). This working paper estimates the natural mortality corresponding to Kopf et al. (2011) using the same method as Piner and Lee 2011a, b. The natural mortality for ages 5+ was estimated by meta-analysis. It was used the meta-analysis results to rescale the mortality rate for ages 0-4 estimated using the Lorenzen 1996 method as

Scaling rate = M_5(meta-analysis)/M_5(Lorenzen 1996).

The combination of natural mortality estimators used in the meta-analysis was the same as Piner and Lee 2011a (Table. 1). The biological parameters used to estimate natural mortality were compiled from those reported in SWPO (Table. 2). The total variance of each method (V_i) can be explained variance in method (v_i) and random effect (τ^2), and its total weight (W_i) is

$V_i = v_i + \tau^2,\ W_i = \frac{1}{V_i}$ (1).

τ^2 was based on heterogeneity statistic (Q), number of natural mortality estimators j ($df = j - 1$) and scaling factor (C) as

$\tau^2 = \begin{cases} \frac{Q-df}{C} & if\ Q > df \\ 0 & if\ Q \le df \end{cases}$ (2).

The heterogeneity statistic (Q) and scaling factor (C) can calculate as

$Q = \sum_{i=1}^{j} w_i (X_i - \bar{X})^2$ and $C = \sum_{i=1}^{j} w_i - \frac{\sum_{i=1}^{j} w_i^2}{\sum_{i=1}^{j} w_i}$ (3),

where w_i is the weight of each estimator that is inverse variance in method (v_i), X_i is the each estimator mean and $\bar{X}$ is the weighted mean $\bar{X} = \frac{\sum_{i=1}^{j} w_i X_i}{\sum_{i=1}^{j} w_i}$ (4).

Using total weight and each estimator mean, weighted natural mortality (M) and that variance (V_M) are given by

$M = \frac{\sum_{i=1}^{j} W_i X_i}{\sum_{i=1}^{j} W_i}$ and $V_M = \frac{1}{\sum_{i=1}^{j} W_i}$ (5).

Result and Discussion

- Growth curve of striped marlin

The three growth curves were converted from LJFL to EFL and compared to the growth curve used in the 2019 stock assessment (Table. 3, Figure. 1). Melo-Barrera (2003) growth curves did not change significantly with the different conversion factors (Figure 1 EPO A, EPO B). Therefore, it is not expected to make a significant difference in which parameter is used for SS3. However, it might be better to use the conversion equation of Kopf et al. (2011) (EPO B) because Shimose and Yokawa (2019) showed similarity in growth between EPO and SWPO.

There were differences between the 2019 assessment growth curve and the present study result (Figure.1 WCNPO 2019, WCNPO rev). In particular, the parameter K was significantly different from that described in Sun et al. 2011, and the value of L2 could not be reproduced. In order to ensure transparency and reproducibility of the stock assessment, it is proposed that the parameters of the WCNPO converted in this study will be used in the next stock assessment.

The striped marlin length of age 0 fish, except for WCNPO 2019, depends on the t0 parameter (Figure 1). The SS3 model requires the length of age 0 fish to match the minimum length bin size. The 2019 stock assessment was set to 50cm however, the SS3 warning indicated that "Minimum size bin is:_50; which is >10cm, which is large for use as size-at-age 0.0 recruitment". Thus, both bin size and age 0 fish length need to be set to 10cm.

- Natural mortality

Several methods were used to estimate natural mortality for South Pacific striped marlin, but Hoening's estimator was excluded from calculating weighted means because estimated natural mortality is larger than the total mortality ($M>Z$) (Table. 4). The inverse weight means of natural mortality for males and females combined was 0.632 (variance = 0.0005) (Table 4). When the meta-analysis results were fixed to the natural mortality over five years old fish and the natural mortality under four years fish was rescaled, the natural mortality corresponding to Kopf et al. 2011 was the largest compared to the other growth curves (Table 5). It is primarily due to the estimation methodology. Specifically, most natural mortality estimators used K and maturity age (t_m) values. Using such estimators, the larger natural mortality value will estimate when the faster growth curve is applied(Figure 2A, C). On the other hand, the faster growth becomes the smaller natural mortality when the Lorenzen estimator was used (Figure 2A, B). Despite faster growth in the present study, natural mortality was higher because the final rescaling was based on the meta-analysis results (Table 4). Striped marlin grows significantly faster and larger than other fish (Kopf et al., 2011). It may not be appropriate for the striped marlin to assume that K or t_m dependent natural mortality. For example, the method of Then2015, which also takes L_∞ into account, may need to be considered (Figure 2 D). However, even using such estimators, natural mortality remains large. If the BILLWG assumes that the natural mortality rate of juvenile fish becomes smaller with faster growth, it may not be appropriate to use the meta-analysis results for rescaling.

Suggestions for natural mortality configuration on SS3 model

As mentioned above, the author questions the method of rescaling for natural mortality. However, there is no clear evidence to support the best natural mortality estimates. Thus, the following options are proposed to the BILLWG members.

- Option 1

The BILLWG will use the natural mortality values from the meta-analysis associated with each growth curve (Table 5). It is problematic that the faster the growth has high natural mortality, and Piner and Lee 2011b might have used a smaller *K* value for Sun et al. 2011 than the actual value.

- Option 2

The BILLWG will make the SS3 model calculate natural mortality internally (Methot et al. 2021). When growth and maturity parameters are set in SS3 model, SS3 model can calculate the corresponding natural mortality rate as follows;

1. SS3 model applies the Lorenzen 1996 estimator up to the maturity age and the Then et al. 2015 estimator after maturity.
2. The transformation points will be smoothed.

If the BILLWG choose option 2, the model building process will be efficient because it saves the time of external calculations. However, the natural mortality of SWPO is still higher than other areas.

- Option 3

The BILLWG will set the natural mortality for age 5+ at 0.38, the same value as Piner and Lee 2011, and rescale natural mortality rates for younger fish. The faster the growth curve has, the lower the natural mortality, which is more in line with the general assumption. Since there is no basis for unifying at 0.38, it might be necessary to consider several values in the South Pacific stock assessment (Ducharme-Barth et al. 2019).

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Table 1. List of natural mortality (M) estimators.

Method	Reference	Type	Equation
Maximum age sample size	Derived from Hoenig (1983)	Maximum age theory	$Z \cong \ln(2n+1)/(t_{max} - t_c)$
Jensen K	Jensen (1996)	Life history theory	$M = 1.5K$
Jensen t_m	Jensen (1996)	Life history theory	$M = 1.65/t_m$
Roff	Roff's (1984)	Life history theory	$M = 3K/(\exp(t_m K) - 1)$
Revised Alverson and Carney	Zhang and Megrey (2006)	Life history theory	$M = \beta K/\left(\exp\left(K(0.302t_{max} - t_0)\right) - 1\right)$
Pauly	Pauly (1980)	Empirical	$\ln(M) = -0.0066 - 0.279\ln(L_\infty) + 0.6543\ln(K) + 0.4634\ln(T)$
Empirical K	Jensen (1996)	Empirical	$M = 1.60K$
Empirical t_m	Charnov and Berrigan (1990)	Empirical	$M = 2/t_m$
Hoenig*	Hoenig (1983)	Empirical	$\ln(Z) = 1.46 - 1.01\ln(t_{max})$
Lorenzen	Lorenzen (1996)	Empirical	$M = 3W^{-0.288}$

Z: Total annual mortality.
n: Sample size.
t_{max}: Maximum observed age.
t_c: Youngest age represented catch.
K: Growth coefficient of von Bertalanffy growth curve.
t_m: Maturity at age.
α: Parameter of length-weight relationship.
β: Parameter of length-weight relationship.
t_0: Age at hypothetical zero length.
L_∞: Asymptotic length.
T: Temperature.
W: Weight at age.
*This study did not include Hoenig 1983 method because total annual mortality (Z) was lower than the fishing mortality estimated by 2019 stock assessment.

Table 2. List of the biological and environmental information for natural mortality (M) estimators.

Parameter	Range	Source
K	Female; 0.46 to 0.60	Kopf et al. (2011)
	Male; 0.44 to 0.68	
L_∞	Female; 256.5 to 262.8cm (LJFL)	Kopf et al. (2011)
	Male; 243.8 to 261.5cm (LJFL)	
t_0	Female; –0.59 to –0.92	Kopf et al. (2011)
	Male; –0.68 to –1.00	
n	Female; 206	Kopf et al. (2011)
	Male; 211	
t_m	Female; 2.0, 2.5 ,3.0 (210cm)	Kopf et al. (2011)
	Male; 1.0, 1.5 (166.8cm)	Kopf et al. (2012)
α	Female; 4.171e–11	Kopf et al. (2011)
	Male; 1.902e–9	
β	Female; 3.55	Kopf et al. (2011)
	Male; 3.67	
T	20 to 28 °C	Piner and Lee 2011a
t_{max}	Female; 8.5	Kopf et al. (2011)
	Male; 7	
	*Both; 6 to 12	
t_c	1 to 2 yr	Ducharme-Barth et al. (2019)
F	0.5 to 0.7^{-yr} (Adult 2006-2009)	Ducharme-Barth et al. (2019)

Z: Total annual mortality.
n: Sample size.
t_{max}: Maximum observed age.
t_c: Youngest age represented catch.
K: Growth coefficient of von Bertalanffy growth curve.
t_m: Maturity at age.
α: Parameter of length-weight relationship.
β: Parameter of length-weight relationship.
t_0: Age at hypothetical zero length.
L_∞: Asymptotic length.
T: Temperature.
W: Weight at age.
*Summarized previous study.

Table 3. Growth curve parameters for the Stock Synthesis 3. EPO MLS A was converted by Sun et al. 2011 equation. EPO MLS B was converted by Kopf et al. 2011 equation.

Parameter	EPO MLS A	EPO MLS B	WCNPO MLS Revised	SWPO Both	WCNPO MLS 2019
L1 (age 0.5)	69	74	110	115	104*
L2 (age 15)	186	184	203	212	214
K	0.23	0.23	0.34	0.64	0.24

*Eye-fork length at age 0.3.

Table 4. Estimated natural mortality by different method.

Method	Gender	Mean	Variance
Maximum age sample size	Female	0.265	0.013
	Male	0.509	0.020
	Both	0.387	0.031
Jensen K	Female	0.769	0.009
	Male	0.795	0.024
	Both	0.782	0.014
Jensen t_m	Female	0.678	0.019
	Male	1.375	0.151
	Both	0.957	0.193
Roff	Female	0.626	0.038
	Male	1.794	0.278
	Both	1.093	0.470
Revised Alverson and Carney	Female	0.429	0.003
	Male	0.463	0.007
	Both	0.446	0.005
Pauly	Female	0.592	0.003
	Male	0.608	0.006
	Both	0.600	0.004
Empirical K	Female	0.820	0.010
	Male	0.848	0.028
	Both	0.834	0.016
Empirical t_m	Female	0.822	0.028
	Male	1.667	0.222
	Both	1.160	0.284
Hoenig*	Female	-	-
	Male	-	-
	Both	-	-
Inverse weight mean	Female	0.611	0.005
	Male	0.744	0.010
	Both	0.632	0.005

*This study did not include Hoenig 1983 method because total annual mortality (Z) was lower than the fishing mortality estimated by 2019 stock assessment.

Table 5. Age specific natural mortality using Lorenzen method. Natural mortality of young striped marlin was rescaled by meta-analysis result (adult values).

Age	Piner and Lee. (2011a) (Weighted) Melo-Barerra (2003)	Piner and Lee. (2011b) (Weighted) Sun et al. (2011)	This study (Both genders, weighted) Kopf et al. (2011)
0	0.87	0.54	1.15
1	0.61	0.47	0.82
2	0.50	0.43	0.71
3	0.44	0.40	0.67
4	0.40	0.38	0.64
5+	0.38	0.38	0.63

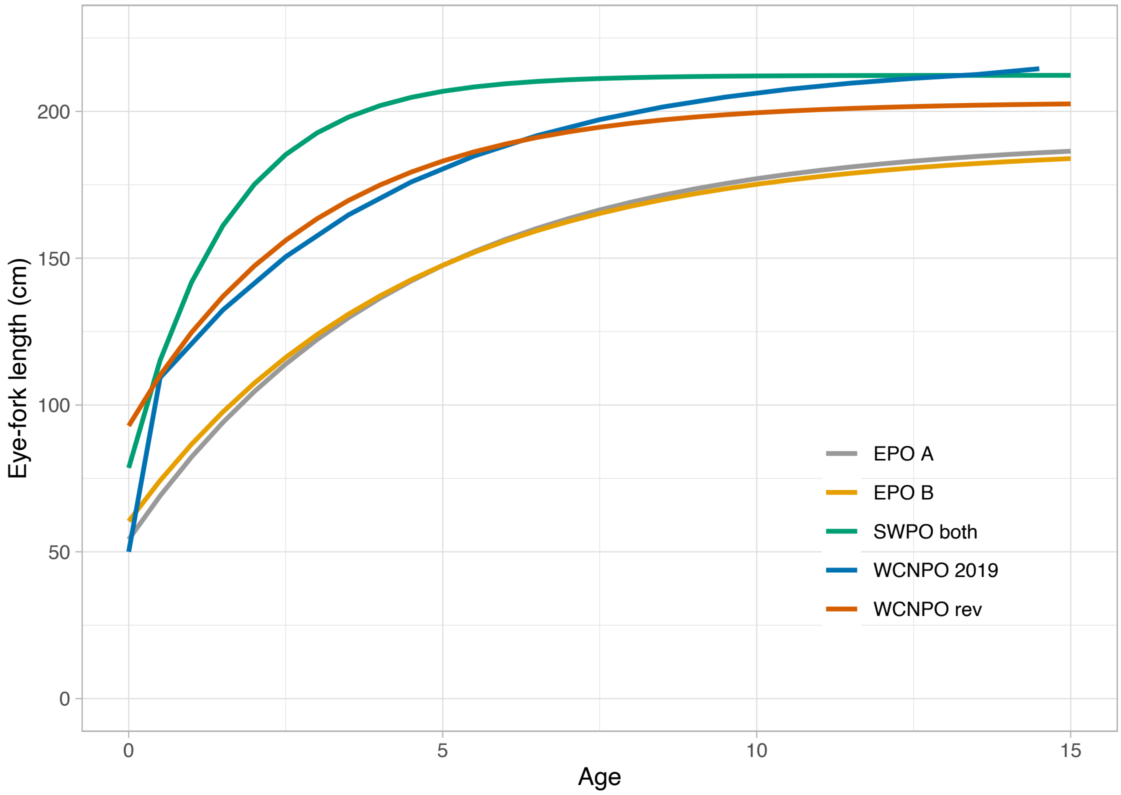

Figure 1. Comparison different growth curve that was converted from Lower Jaw Fork length (LJFL) to Eye Fork Length (EFL).

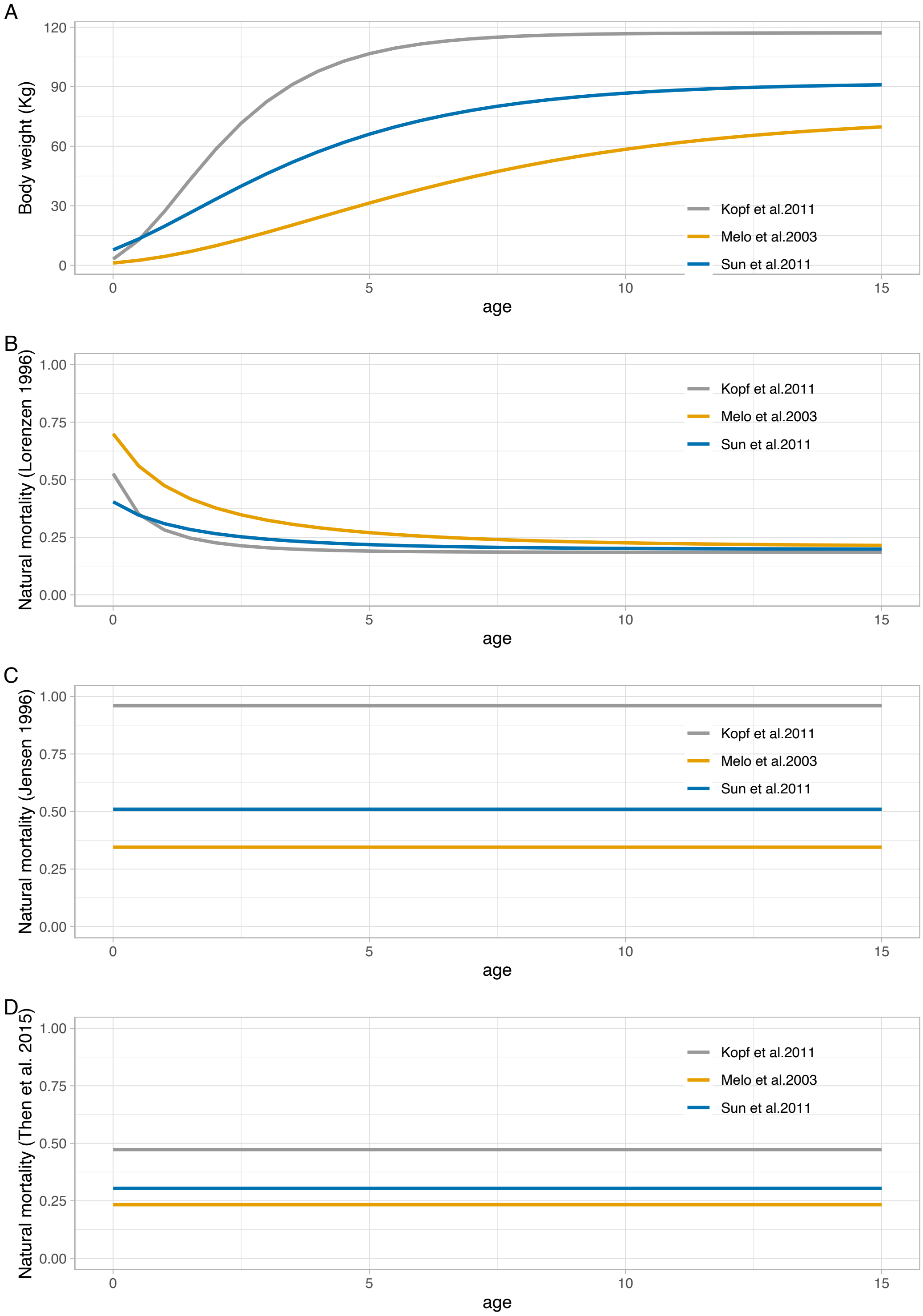

Figure 2. Comparison of different natural mortality estimators that depends on life-history parameters. A: Weight at age by different studies. B: Natural mortality that was given by weight at age. C: Natural mortality associated with growth parameter K. D: Natural mortality associated with growth parameter K and L_{∞}.