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## **A trial calculation of natural mortality estimators for Pacific saury**

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### **ABSTRACT**

The Small Scientific Committee on Pacific Saury (SSC PS) is now moving toward an application of age-structured models to the Pacific saury stock assessment. Natural mortality coefficient is one of the key parameters in the age-structured models. Several natural mortality estimators were calculated for Pacific saury on trial. The calculated estimators distributed relatively high range, between 1.71 and 2.75. We also discussed several issues that have to be considered before we incorporate these estimates into age-structured models.

### **INTRODUCTION**

Pacific saury (*Cololabis saira*) is a commercially important species and has been subject to the stock assessment by North Pacific Fisheries Commission (NPFC). The Technical Working Group on Pacific Saury Stock Assessment (TWG PSSA) of the NPFC obtained

an agreed result of the stock assessment using a surplus production model in 2019 (4<sup>th</sup> Meeting of the TWG PSSA, 2019), and is now moving toward the next stage, an application of age-structured models. Natural mortality coefficient, denoted by  $M$ , is one of the key parameters in the age-structured models. Since  $M$  is difficult to estimate inside the age-structured models, it is generally fixed at plausible levels that are estimated outside the model. For this purpose, many  $M$  estimators, which are able to be calculated from easily observable traits, are developed [reviewed in Kenchington et al. (2014)]. We picked up several estimators according to the suggestion of Kenchington (2014) and Then et al. (2015) and the arguments in the NPFC chub mackerel technical working group (Takahashi et al., 2019, Table 1). In this document, we report the results of the trial calculation of the  $M$  estimators for Pacific saury and discuss the usage of the  $M$  estimators in the age structured models.

## **THE $M$ ESTIMATORS**

### *Growth parameter-based estimators*

Some of the  $M$  estimators we picked up are based on the life history of the target fish. “Pauly” estimator (Pauly, 1980), which is calculated from the von Bertalanffy growth parameter ( $K$ ), asymptotic fish length in centimeters ( $L_\infty$ ), and mean environmental temperature in Celsius ( $T$ ). It has been broadly used over the past three decades and is known to work well for archetypal teleosts with reliable  $K$  (Kenchington 2014). Then et al. (2015) re-analyzed and updated “Pauly” (“Pauly update”). They excluded the parameter  $T$  based on an analysis with over 200 direct estimates of  $M$ . “Jensen” estimator

(Jensen, 1996) takes a simple form that is dependent only on  $K$ . This estimator was derived not from regression, but from a theory that optimizes a trade-off between survival and fecundity. “Gislason 1” (Gislason et al., 2010) and “Gislason 2” (Charnov et al., 2013) estimators, calculated from  $K$  and  $L_\infty$ , are unique that  $M$  is given by a function of fish body length ( $L$ ). “Gislason 1” was developed by a regression with 168 intra- and inter-species data, then Charnov et al. (2013) re-analyzed the data and reduced “Gislason 1” into the form of “Gislason 2”.

#### *Longevity-based estimators*

“Hoenig” (Hoenig, 1983) and “Hoenig update” (Then et al., 2015) estimators are based on only the observed maximum age of the target species in year ( $A_{max}$ ), and have been widely used due to their easy-to-use feature. Note that, although “Hoenig” estimator was originally (Hoenig, 1983) developed as an estimator of  $Z$ , sum of natural mortality coefficient and fishing mortality coefficient, Hewitt and Hoenig (2005) treated it as an estimator of  $M$ , because the data used in Hoenig’s regression (Hoenig, 1983) came from lightly exploited populations.

#### *Estimates from FishLife*

FishLife (Thorson et al., 2017) is an R package that predicts life-history parameters for over 30,000 fish species. This package predicts natural mortality using life-history correlations as well as other life-history based estimators, but also includes information of related species as random effects. The potential inputs for  $M$  estimation are  $L_\infty$ ,  $K$ ,  $A_{max}$ ,

$T$ , asymptotic fish weight in grams ( $W_\infty$ ), age at mature ( $A_{mature}$ ), and length at mature ( $L_{mature}$ ).

## METHOD

We estimated  $K$  by fitting von Bertalanffy growth curve to 357 daily age versus length data of Pacific saury caught by Japanese stick held dip net fishery, collected through 2002–2006. Maximum likelihood method under an assumption of log-normal residual distribution was used for the fitting (Fig. 1). The estimated  $K$  was 1.55 and with standard error of 0.0195.  $L_\infty$  was estimated in a same way as the estimation of  $K$ , but with Gompertz growth curve (Fig. 1) because it showed a better fit than von Bertalanffy growth curve ( $\Delta AIC = 55.5$ ). The estimated  $L_\infty$  was 30.8 with standard error of 0.165. Because the standard errors were small relative to the estimates, hereafter we ignored the uncertainty derived from the input parameters estimation. Considering the fact that the body weight of Pacific saury decreases during spawning and then recovers (Suyama, 2002, Fig. 2), we gave up fitting existing growth curves and set  $W_\infty = 150$  by an expert decision.

To calculate each estimator,  $K$ ,  $L_\infty$ ,  $A_{max}$ ,  $W_\infty$  were fixed at the obtained values, 1.55, 30.8, 2, and 150, respectively (Table 2). Because  $A_{mature}$  and  $L_{mature}$  were not clear for Pacific saury, we predicted  $M$  by FishLife with likely minimum and maximum values, 0.67–1.00 years and 25–27cm, respectively.  $T$  was also not clear due to the large migration of Pacific saury, therefore we fixed it at a plausible value of 14°C by an expert judgement.

## RESULT and DISCUSSION

The estimators, except for “Gislason1” and “Gislason2”, ranged from 1.71 of “Pauly” to 2.75 of FishLife with  $A_{mature} = 0.67$  and  $L_{mature} = 27$  (Table 2).  $A_{mature}$  negatively affected the estimations by FishLife, whereas  $L_{mature}$  had little effect. “Gislason1” and “Gislason2” showed similar concave curves that declined from approximately 3.0 to 1.5, as the body length increased from 20cm (the minimum length subject to fishery) to 30cm (Fig. 3), which corresponds the age of 0.5–2.0 years according to the Gompertz growth curve (Fig. 3).

Before using these  $M$  estimators in age-structured models, we should carefully consider whether their derivation processes are consistent with the physiology of Pacific saury. An otolith analysis (Suyama et al., 2006) showed that there are certain proportions of age 0 and 1 fish, but almost no age 2 or older ones. This result indicates that Pacific saury population declines not gradually, but suddenly, perhaps after spawning in age of 1. Because these  $M$  estimators have no such determinate lifetime in mind, the values calculated here might be overestimated. Also, it might be better to set different  $M$  values for age 0 and 1 fish. If we apply year-based models, this kind of assumption are likely to affect the output of the model, since Pacific saury has only two age classes. In this case, “Gislason1” and “Gislason2” are reasonable, because they are length- or age-dependent.

Regardless of which estimator we use, we should also keep in mind that these  $M$  estimators generally have large uncertainty. The assumption of  $M$  is critical for the calculation of reference point and following setting of total allowable catch. When we select one age-structured model for the stock assessment of Pacific saury, we need to

focus on how the candidate models react against the variety of  $M$  assumption, as well as other performances.

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Table 1. The list of the  $M$  estimators.

Estimator	Formula	Reference
Pauly	$M = 0.985L_{\infty}^{-0.279}K^{0.654}T^{0.463}$	Pauly (1980)
Pauly_update	$M = 4.12L_{\infty}^{-0.33}K^{0.73}$	Then et al. (2015)
Jensen	$M = 1.5K$	Jensen (1996)
Hoening	$M = 4.30/A_{max}$	Hoening (1983)
Hoening_update	$M = 4.90/A_{max}^{-0.916}$	Then et al. (2015)
Gislason1 (mean)	$M = 1.73L^{-1.61}L_{\infty}^{1.44}K$	Gislason et al. (2010)
Gislason2 (mean)	$M = K(L/L_{\infty})^{-1.50}$	Charnov et al. (2013)

$L_{\infty}$ : asymptotic fish length (in cm)

$K$ : Body growth rate parameter of the von Bertalanffy curve

$T$ : mean environmental temperature (in degree Celsius)

$A_{max}$ : longevity (in year)



Table 2. The parameters and calculated values of the estimators

Estimator	$M$	$L_{\infty}$	$K$	$T$	$A_{max}$	$W_{\infty}$	$A_{mature}$	$L_{mature}$
Pauly	1.71	30.8	1.55	14	-	-	-	-
Pauly_update	1.82	30.8	1.55	-	-	-	-	-
Jensen	2.32		1.55	-	-	-	-	-
Hoening	2.15		-	-	2	-	-	-
Hoening_update	2.60		-	-	2	-	-	-
Fishlife	2.75 (SD = 0.515)	30.8	1.55	14	2	150	0.67	25
	1.75 (SD = 0.327)	30.8	1.55	14	2	150	1	25
	2.74 (SD = 0.513)	30.8	1.55	14	2	150	0.67	27
	1.74 (SD = 0.326)	30.8	1.55	14	2	150	1	27

$L_{\infty}$ : asymptotic fish length (in cm)

$K$ : Body growth rate parameter of the von Bertalanffy curve

$T$ : mean environmental temperature (in degree Celsius)

$A_{max}$ : longevity (in year)

$W_{\infty}$ : asymptotic fish wet weight (in gram)

$A_{mature}$ : age of maturation

$L_{mature}$ : fish length of maturation

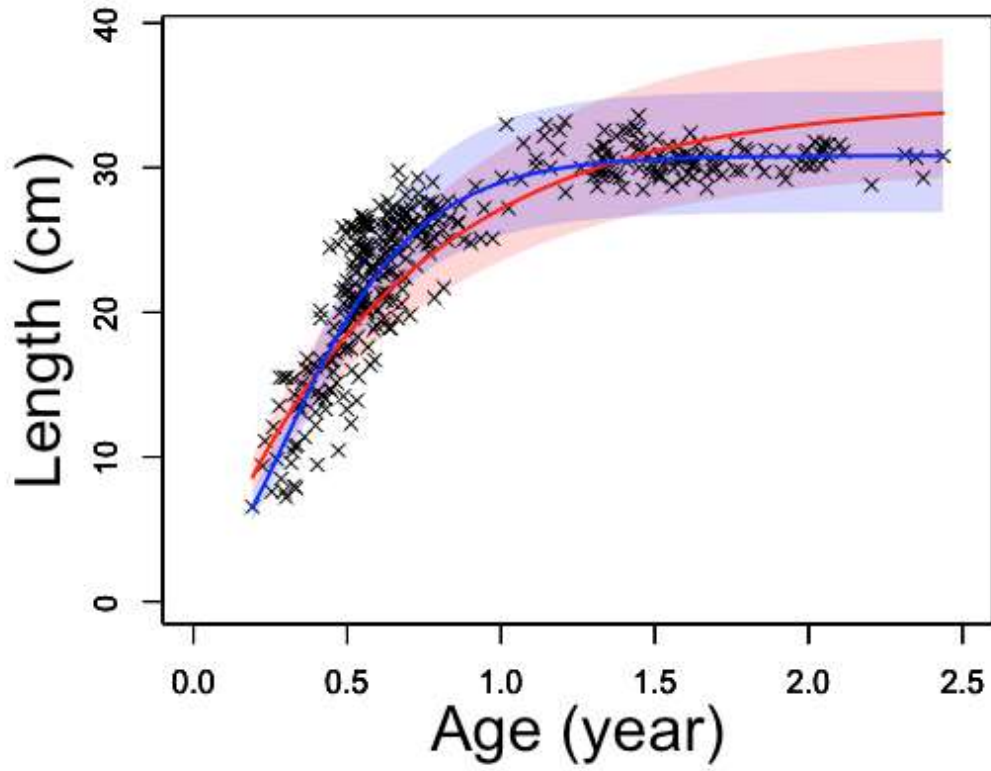


Fig. 1. von Bertalanffy (red) and Gompertz (blue) growth curve fitting to the length versus age data. Shadows around the curves are standard deviations.

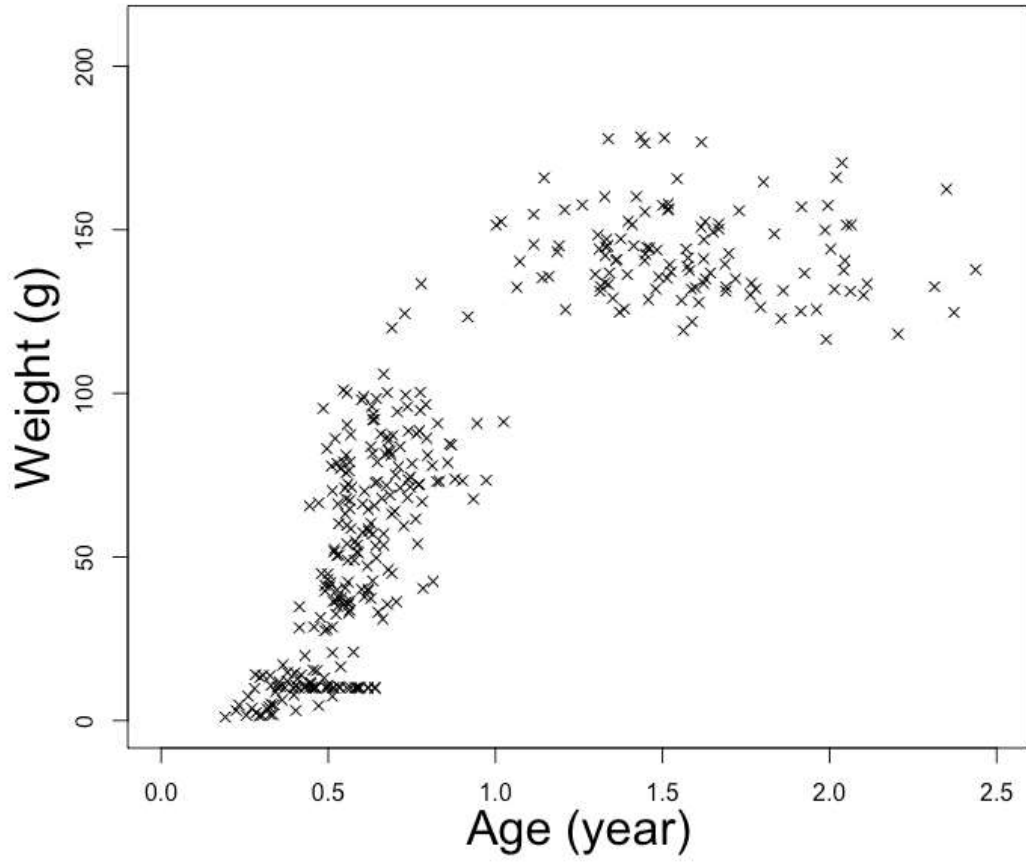


Fig. 2. Weight versus age data used to determine  $W_{\infty}$ .

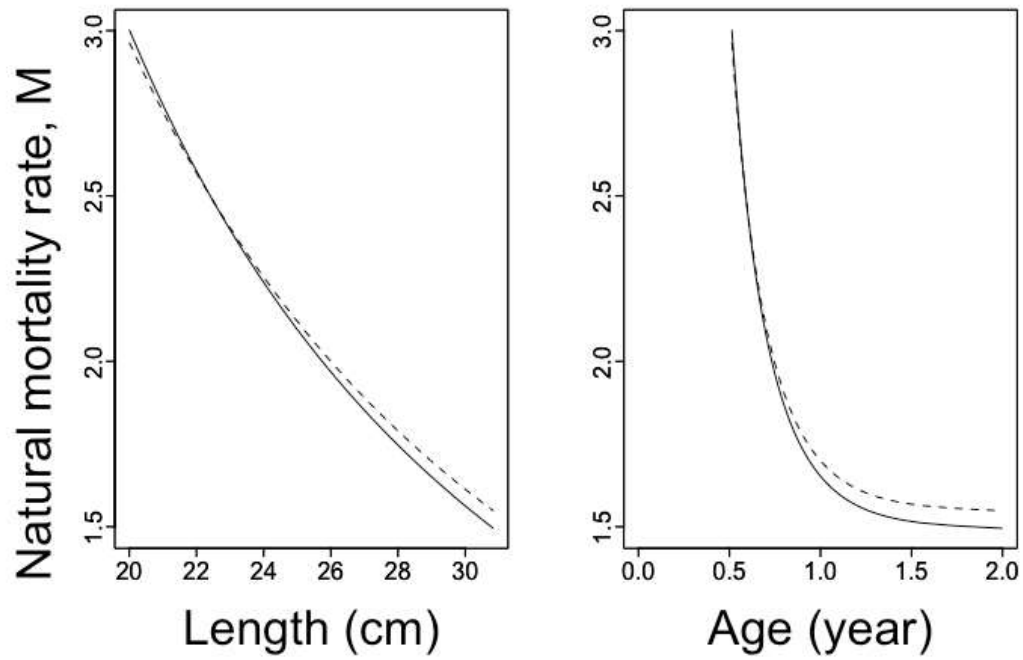


Fig. 3. Length (left) and age (right) dependence of “Gislason 1” (solid line) and “Gislason 2” (dashed line) estimators.