Estimation of confidence intervals for the von Bertalanffy growth function parameters using the bootstrap method with a data set of direct age estimates from otoliths

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1. Abstract

To evaluate the uncertainty in the growth of the Pacific bluefin tuna, we estimated 95% confidence intervals (CI) for each parameter of the von Bertalanffy growth function and the estimated body length at 3 years of age by the bootstrap method, using length-at-age data based on otolith observations. Three different procedures for two sets of samples, a total of six cases were tested in the bootstrap method, including stratification of the data set and trimming of infrequent data. The results showed that the 95% CI for the asymptotic length and the fork length at 3 years of age within ± 2 cm for all cases. These indicated that the length-at-age data used for the estimation of growth of Pacific Bluefin tuna have a consistent information regarding the growth rate and asymptotic length and the procedure of the sampling (resampling) does not affect critically to the growth parameter estimation. These results may contribute to an assessment of appropriate uncertainty range in the growth of this stock when using the von Bertalanffy growth function.

2. Introduction

The ISC is requested to develop Management strategy evaluation (MSE) for the management of Pacific bluefin tuna (PBF) stock, and there are many candidates for Harvest Control Rules (HCR) currently under consideration. For the selection of HCR, it is important to evaluate the robustness of HCR to the possible uncertainty in the ecological process as well as the sampling process. Uncertainties about the ecological information of PBF are largely considered in terms of reproduction, natural mortality, and growth. For PBF, data obtained by direct observation of otoliths can be used, which should provide a realistic range of growth uncertainty. In this document, uncertainty (95% confidence intervals [CI]) for each parameter of the growth function and the estimated body length at 3 years of age, which is used for the current stock assessment of this species, were estimated by the bootstrap method using the length-at-age data estimated from otolith daily rings and annual rings.

3. Materials and Methods

3-1. Length-at-age data

The length-at-age data used for the bootstrap method in the present study was identical with those used by Fukuda et al. (2015) to estimate growth function (Fig. 1). The fork length (FL), age and birthyear distribution of the whole data set and the length distribution of the age from 2.8–3.2 years were shown in Fig. 2. In the length composition, the most abundant FL was 240–250 cm (Fig. 2a). The age composition was dominated by the age from 0–1 year, followed by the age from 8–9 years (Fig. 2b). In individuals whose age was estimated from annual rings, birth years estimated from age and catch dates ranged from 1980 to 2013 (Fig. 2c). The mean FL of individuals estimated to be 2.8–3.2 years of age was 119.8 cm (Fig. 2d).

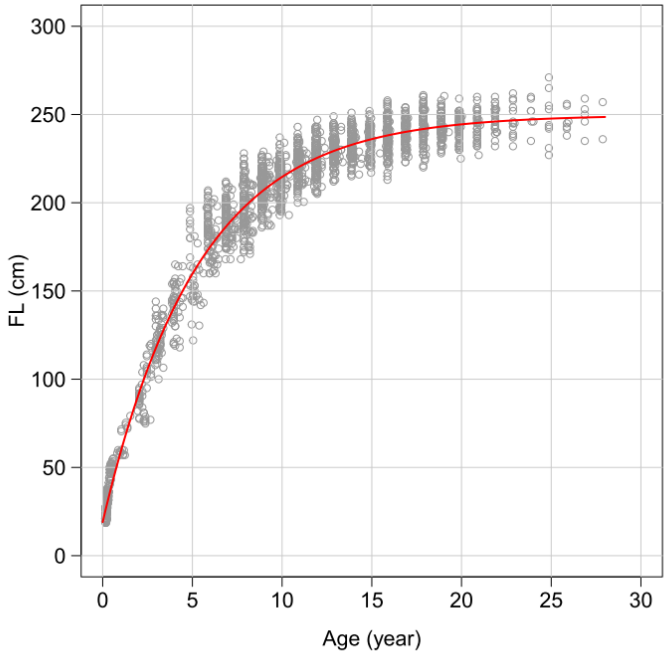

Fig. 1: Age-length data (circles) and estimated von Bertalanffy growth curves (solid red) used in Fukuda et al., 2015. FL: Fork length.

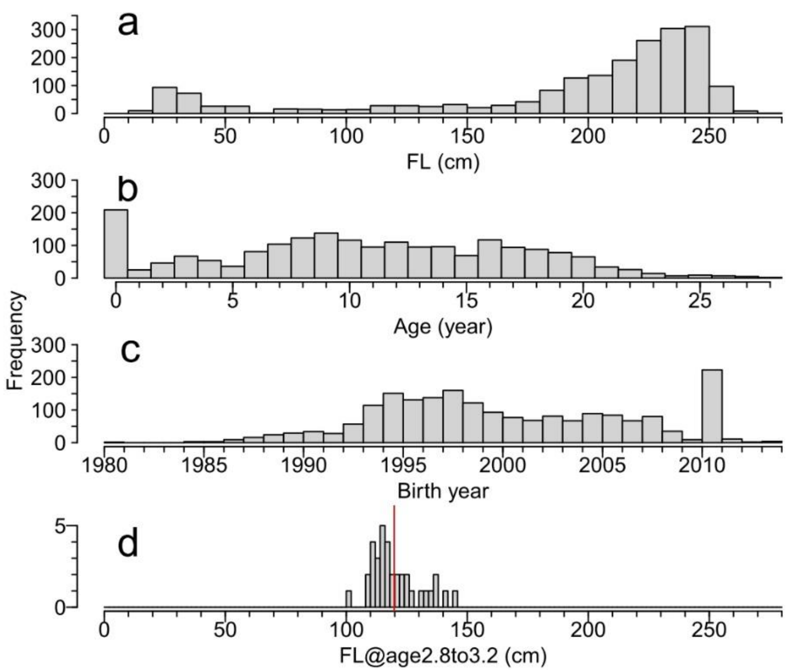

Fig. 2: Length distribution (a), age distribution (b), birth year distribution and length distribution at age between 2.8 and 3.2 years (d) in the entire original data set. Red line: mean, FL: fork length.

Otolith annual ring count data: A total of 1,782 PBF otoliths with corresponding FL data (70.5-271 cm) were collected from fish landed in Japan (N = 978) and Taiwan (N = 1,032) between 1992 and 2014. Those samples from Japan and Taiwan came from fish caught by several fishing gears such as troll, purse seine, set-net, hand line, and longline fisheries (Fukuda et al. 2015). Those samples covered the whole possible length range of this species. The procedures for sampling and age estimation of individuals from which these data were obtained follow the Age Estimation Manual (Shimose and Ishihara, 2015). Matched age estimates from two or more researchers were selected for the data set. The age estimation results according to this manual have also been validated by the post-bomb radiocarbon dating method (Ishihara et al., 2017). Ages of individual fish were assigned as monthly based on the relationship between the catch month of individual fish and assumed birthday, which they hatched in the 1st day of July.

Otolith daily ring count data: Otolith of 228 PBF (18.6–60.1 cm FL) caught at 2010-2013 were sampled from fish landed mainly west part of Japan. The fishing grounds of these samples were distributed both in the Sea of Japan and Pacific Ocean, and those samples were caught mainly by troll and set-net and partly by the purse seine (Fukuda et al. 2015). For otolith ring counting procedures, see Fukuda et al. 2015. Ages of individual fish were assigned as days after hatching based on the relationship between the catch day and estimated birthday of each individual.

3-2. Bootstrap resampling

In total, 2000 replicates of bootstrap samples were obtained by bootstrap resampling. Each bootstrap data set was obtained by resampling the same number of data from the original data set, allowing for duplicates.

The following two types of sample data sets were prepared. Whole: the entire original data set was used as sample dataset. Trimmed: data set excludes large individuals (≥260 cm FL) and older individuals (>22 years old) for which data are scarce ($n \leq 20$).

The following three procedures were applied to the two sample data sets; 1) no stratification of the data set, 2) stratify the data set by 10 cm FL, 3) stratify the data set by age.

3-3. von Bertalanffy growth function

The parameters were estimated by fitting the von Bertalanffy growth function (VBGF) to bootstrap resampled data sets obtained with three different bootstrap procedures for each of Whole and Trimmed data set.

von Bertalanffy growth function:

$$L_t = L_{inf}(1 - e^{-k(t-t_0)})$$

where L_t is the length at age t, L_{inf} is the asymptotic length, k is the growth coefficient, and t_0 is the theoretical age at L = 0. The log-normal error distribution was assumed for the estimation.

Median values and 95% confidence intervals (CI) from bootstrap resampled data sets were estimated using the percentile method for the estimated parameters and the estimated FL at 3 years of age (FL@age3) calculated from the VBGF.

4. Results and Discussion

The median of estimated FL@age3 by each case ranged from 118.57–118.82 cm FL (Table 1, Fig. 3). The median of estimated each parameter of the VBGF by each case ranged from 249.57–249.80 cm FL for L_{inf}, from 0.188–0.190 for k, and from 0.395–0.406 for t_0 (Table 1, Fig. 4). The median of L_{inf} and t_0 were estimated to be slightly smaller and FL@age3 slightly larger when "Trimmed" was used, rather than "Whole" was used. However, the variation of each estimated parameter of the VBGF and FL@age3 was very small in all cases (range of Coefficient of Variation: L_{inf} [0.0018–0.0024], k [0.0091–0.0115], t_0 [0.0193–0.0260], FL@age3 [0.0038–0.0070]).

The effect of resampling procedure varied depending on the sampled data set. In the "Whole" sample data set, the median of estimated L_{inf} was slightly smaller and the median of estimated FL@age3 was slightly larger in the stratified resampling (for both FL and age) than those in the no stratification. In the "Trimmed" sample data set, the stratified resampling showed slightly smaller estimates in median of estimated L_{inf} and median of estimated FL@age3 than those in the no stratification. In both sample data sets, the 95% CI were narrower when stratified by length for L_{inf} and FL@age3, and wider when stratified by age (Fig. 3 and 4).

The results of the bootstrap resampling estimations indicated that the 95% CI for each parameter were narrow, and the variation was estimated to be small when the data were fitted to the VBGF. The 95% CI for the estimated L_{inf} and FL@age3 were generally within ± 2 cm. These indicated that the length-at-age data set used for the estimation of growth of Pacific Bluefin tuna have a consistent information regarding the growth rate and asymptotic length and the procedure of the sampling (resampling) does not affect critically to the growth parameter estimation. This information may contribute to the evaluation of appropriate uncertainty ranged the growth of this stock for the operating model of the PBF MSE.

Table. 1: Median (Med.) and 95% confidence interval (*Lower*, *Upper*) of each parameter (L_{inf}: asymptotic length, *k*: growth coefficient, *t0*: theoretical age at which body length = 0) of the von Bertalanffy growth function and the estimated body length at 3 years of age (FL@age3) estimated by the bootstrap resampling.

		L_inf			*k*			*t0*			FL@age3		
Dataset	Stratify	Med.	*Lower*	*Upper*	Med.	*Lower*	*Upper*	Med.	*Lower*	*Upper*	Med.	*Lower*	*Upper*
Original	-	249.78	-	-	0.188	-	-	0.422	-	-	118.57	-	-
Whole	No stratified	249.80	248.60	250.93	0.188	0.184	0.192	0.422	0.400	0.444	118.57	117.54	119.65
Whole	FL	249.77	248.85	250.67	0.188	0.185	0.192	0.422	0.406	0.437	118.58	117.66	119.48
Whole	Age	249.75	248.58	250.92	0.188	0.184	0.192	0.422	0.404	0.441	118.58	116.92	120.14
Trimmed	No stratified	248.65	247.44	249.83	0.190	0.186	0.195	0.416	0.395	0.439	118.82	117.76	119.91
Trimmed	FL	249.59	248.61	250.56	0.189	0.185	0.192	0.421	0.405	0.437	118.62	117.69	119.51
Trimmed	Age	249.57	248.37	250.78	0.188	0.184	0.193	0.421	0.403	0.440	118.63	116.96	120.19

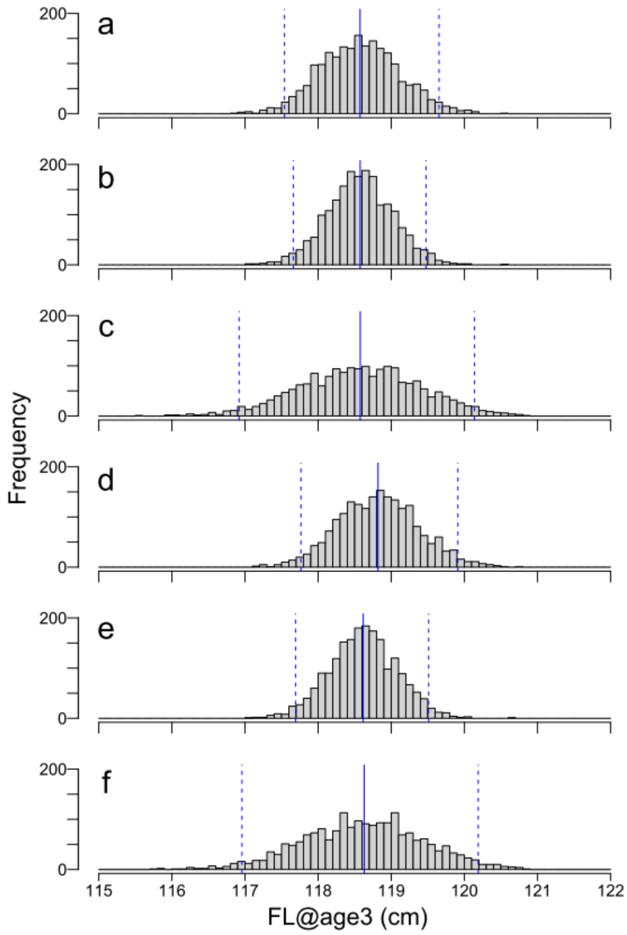

Fig. 3: Frequency distribution of body length at 3 years of age (FL@age3) estimated from the von Bertalanffy growth function estimated from bootstrap resampling in each case. Resampling from each "Whole" and "Trimmed" data set without stratification (a, d), stratified by fork length (b, e), and stratified by age (c, f). Blue solid line: median, blue dashed line: 95% confidence interval.

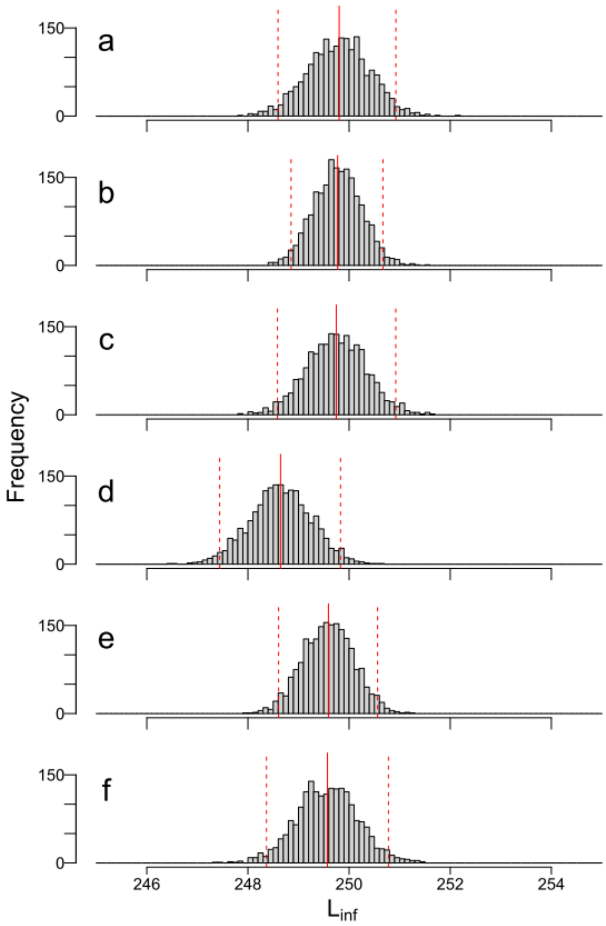

Fig. 4: Frequency distribution of the asymptotic length (L_{inf}) estimated from the von Bertalanffy growth function estimated from bootstrap resampling in each case. Resampling from each "Whole" and "Trimmed" data set without stratification (a, d), stratified by fork length (b, e), and stratified by age (c, f). Red solid line: median, red dashed line: 95% confidence interval.

Reference

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