INTER-AMERICAN TROPICAL TUNA COMMISSION

2nd REVIEW OF THE STOCK ASSESSMENT OF BIGEYE TUNA IN THE EASTERN PACIFIC OCEAN

La Jolla, California (USA)
11-15 March 2019

DOCUMENT WSBET-02-05

GROWTH USED IN THE EPO BIGEYE TUNA ASSESSMENT

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1. SUMMARY

As with many tuna species, specifying growth in the bigeye stock assessment for the EPO presents some challenges. Age-at-length data derived from readings of daily increments on otoliths are available for fish up to four years of age only and few samples of tag recaptures from larger fish have been available from the longline fisheries. Estimates of management quantities are highly dependent on the growth curve, particularly to the length of the oldest individuals. There is little information to estimate the mean length at age for large bigeye tuna in the EPO. The estimates of parameters for the growth curves can be influenced by the preponderance of data for younger individuals resulting in biased estimates of mean length at age for the old individuals. The parameters for the Richards growth curve used in the stock assessment model should be based on appropriately weighting the data to reduce bias in the estimates of the mean length at age for the old individuals.

2. INTRODUCTION

As with many tuna species, specifying growth in the bigeye stock assessment for the EPO presents some challenges. Age-at-length data derived from readings of daily increments on otoliths are available for fish up to four years of age only (Schaefer and Fuller 2006), a narrow spectrum of ages for a species that is estimated from tagging studies to have a lifespan of at least 15-16 years (Langley et al. 2008). Otolith readings for large (older) fish are very difficult to interpret and annual aging is questionable. Acquiring tag-recapture information for the older fish has been problematic since it is difficult to capture large bigeye for tagging, and few samples of tag recaptures from larger fish have been available from the longline fisheries.

Much of the information presented here is taken directly from other IATTC documents. Kolody et al. (2016) reviews modelling of growth in tuna stock assessments.

3. MEAN LENGTH AT AGE

Following the recommendations of the previous external review of the bigeye tuna stock assessment, held in May 2010, a transition was made from the traditional von Bertalanffy model to a more flexible Richards growth model. Subsequently, progress has been made in reducing the uncertainty regarding bigeye growth, in particular the average size of the older fish (L2 in Stock Synthesis). A Richards growth model was developed to fit simultaneously to the age-at-length (otolith readings) and tag-recapture data (Aires da Silva et al 2015), following the Laslett-Eveson-Polacheck statistical framework (Laslett et al. 2002; Eveson et al. 2004). The age-at-length data consisted of age estimates from counts of daily increments on otoliths, and the lengths of 254 fish caught in 2002 in the floating-object fisheries (Schaefer and Fuller 2006). As noted above, these otolith readings are mostly from bigeye less than 4 years old and less than 150 cm in length. The available tag-recapture data are also dominated by young bigeye of less than 150 cm. However, some tag-recapture observations from larger (older) bigeye are also available, thanks to the recent recaptures of bigeye of up 190 cm after times at liberty up to almost 8 years. Fits to the data are shown in Figure 1.

The parameterization of the Richards growth curve in Stock Synthesis was fit to the quarterly estimates of mean length at age from the growth curve estimated by Aires da Silva et al. (2015) to estimate the parameters to use in the stock assessment (Table 1).

Aires da Silva et al (2015) updated the growth curve using the Francis (2015) method, to include three additional tag recovery records for bigeye, all with times at liberty greater than 10 years (Figure 2). This analysis reduced the estimated asymptotic length. The mean length at age 40 quarters reduced from 196 cm to 193 cm.

Maunder et al. (2018) developed the Growth Cessation Model and found that it fits better to the data than the Richard's curve (Figure 3). In particular, it fits better to the few large tag recoveries (Figure 3). However, Stock Synthesis does not have the Growth Cessation Model as an option. Maunder et al. (2018) found that down weighting the age-length data allowed the Richards to be more similar to the Growth Cessation Model and this might be a useful approximation to use in the stock assessment.

Length composition data can also provide information of growth rates. The mean length at age from the otolith data is consistent with the modal progression in the length composition data from the floating object fisheries (Figures 4 and 5). Historic length composition data from the Japanese longline fishery in the 1950s when it expanded into the EPO might provide information on near virgin conditions. The Growth cessation model with the parameters describing growth for young individuals fixed at those estimated when fitting to both the otolith and tagging data was fit to the length composition for large individuals (Figure 6). The estimates of asymptotic length were lower than currently used in the assessment model and were highly dependent on the assumed value for the variation of length at age (Figure 7). Very few individuals are observed in the Japanese longline length composition data used in the assessment model at the size of the large fish represented by the growth curve used in the assessment (Figure 8).

Zhu et al. (2016) found using simulation analysis that the L1 (mean length of young fish) and L2 (mean length of old fish) parameters of the Stock Synthesis von Bertalanffy growth equation and the standard deviation of length at age for young fish can be reliably estimated in the EPO bigeye tuna stock assessment, but estimates of the growth rate and the standard deviation of length at age for old fish were less reliable.

The little information there is on the mean length at age of large bigeye does not show evidence of differences in growth between females and males (Figure 9).

4. VARIATION OF LENGTH AT AGE

Another important component of growth used in age-structured statistical catch-at-length models is the variation in length-at-age, which can also be influential on results. Information on the variability of length-at-age can be obtained from age-at-length data, which is available for bigeye tuna (Schaefer and Fuller 2006). Unfortunately, the bigeye otolith samples were not collected randomly, but rather to cover a range of sizes to provide information on mean length-at-age. Therefore, these data do not provide a good measure of variation of length-at-age. In a previous assessment using A-SCALA (Maunder and Hoyle 2007), conditional probability was used to apply an appropriate likelihood to the data and estimate variation of length-at-age. The values used in the current assessment are taken from Airies da Silva et al. (2015). The previous external review (Sibert et al. 2012), recommended the variance of the length-at-age be estimated and the age-at-length data derived from otolith readings from fish caught in the floating-object fisheries (Schaefer and Fuller 2006) integrated into the stock assessment model to provide information on variation in length at age.

5. WEIGHT-LENGTH

The following weight-length relationship, from Nakamura and Uchiyama (1966), was used to convert lengths to weights in the current stock assessment:

$$w = 3.661 \times 10^{-5} \cdot l^{2.90182}$$

where w = weight in kilograms and l = length in centimeters.

6. SENSITIVITY OF MANAGEMENT QUANTITIES TO THE GROWTH CURVE

Previous sensitivity analyses have shown that the bigeye assessment results are highly sensitive to the assumed value for L2 (Hampton and Maunder 2005; Aires-da-Silva and Maunder 2007; Aires da Silva and Maunder 2010; Zhu et al. 2016). Aires-da-Silva (2018) conducted sensitivity analyses assuming two lower values (193 and 183 cm) for the average size of the oldest fish (L2) under two different weighting factors for the length composition data (base case λ = 0.05 and λ = 1). In terms of the spawning biomass, assuming a lower value of L2 results in more optimistic SBR levels regardless of the weighting factor. This is to be expected, given that the lower L2 implies that the model expects to find smaller proportions of the larger fish in the data, hence a less depleted stock.

7. DISCUSSION

Estimates of management quantities are highly dependent on the growth curve, particularly to the length of the oldest individuals. There is little information to estimate the mean length at age for large bigeye tuna in the EPO. The estimates of parameters for the growth curves can be influenced by the preponderance of data for younger individuals resulting in biased estimates of mean length at age for the old individuals. The parameters for the Richards growth curve used in the stock assessment model should be based on appropriately weighting the data to reduce bias in the estimates of the mean length at age for the old individuals.

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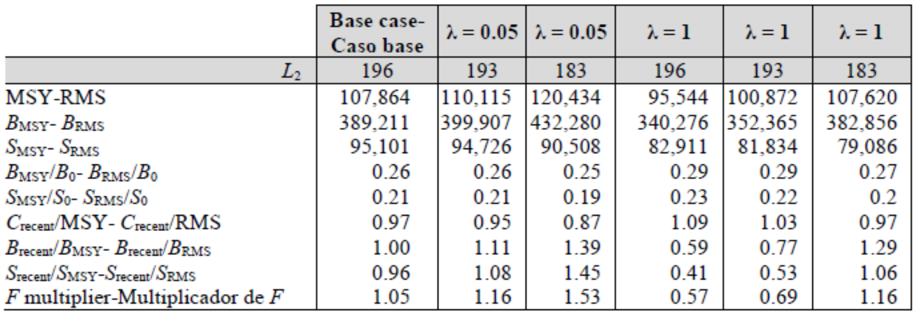
TABLE 1. Growth parameters used in the stock assessment model. (K is quarterly)

L_1	29.22706
L_40	196.3405
K	0.108753
Shape	0.234367
sd_1	1.834114
sd_40	8.877998

TABLE 2. Estimates of management-related quantities for bigeye tuna for the base case and the sensitivity analysis to the average size of the oldest fish (L2). Unlike in the base case and the first two analyses of sensitivity to lower values of L2 (193 and 183 cm), in which the size-composition data of all fisheries are down-weighted (λ = 0.05), in the last three sensitivity analyses they are all up-weighted to their original sample sizes (λ = 1). From Aires da Silva et al. (2018).



	Base case-Caso base	**λ = 0.05**	**λ = 0.05**	**λ = 1**	**λ = 1**	**λ = 1**
L_2	196	193	183	196	193	183
MSY-RMS	107,864	110,115	120,434	95,544	100,872	107,620
B_{MSY}- B_{RMS}	389,211	399,907	432,280	340,276	352,365	382,856
S_{MSY}- S_{RMS}	95,101	94,726	90,508	82,911	81,834	79,086
B_{MSY}/B_0- B_{RMS}/B_0	0.26	0.26	0.25	0.29	0.29	0.27
S_{MSY}/S_0- S_{RMS}/S_0	0.21	0.21	0.19	0.23	0.22	0.2
C_{recent}/MSY- C_{recent}/RMS	0.97	0.95	0.87	1.09	1.03	0.97
B_{recent}/B_{MSY}- B_{recent}/B_{RMS}	1.00	1.11	1.39	0.59	0.77	1.29
S_{recent}/S_{MSY}-S_{recent}/S_{RMS}	0.96	1.08	1.45	0.41	0.53	1.06
F multiplier-Multiplicador de F	1.05	1.16	1.53	0.57	0.69	1.16

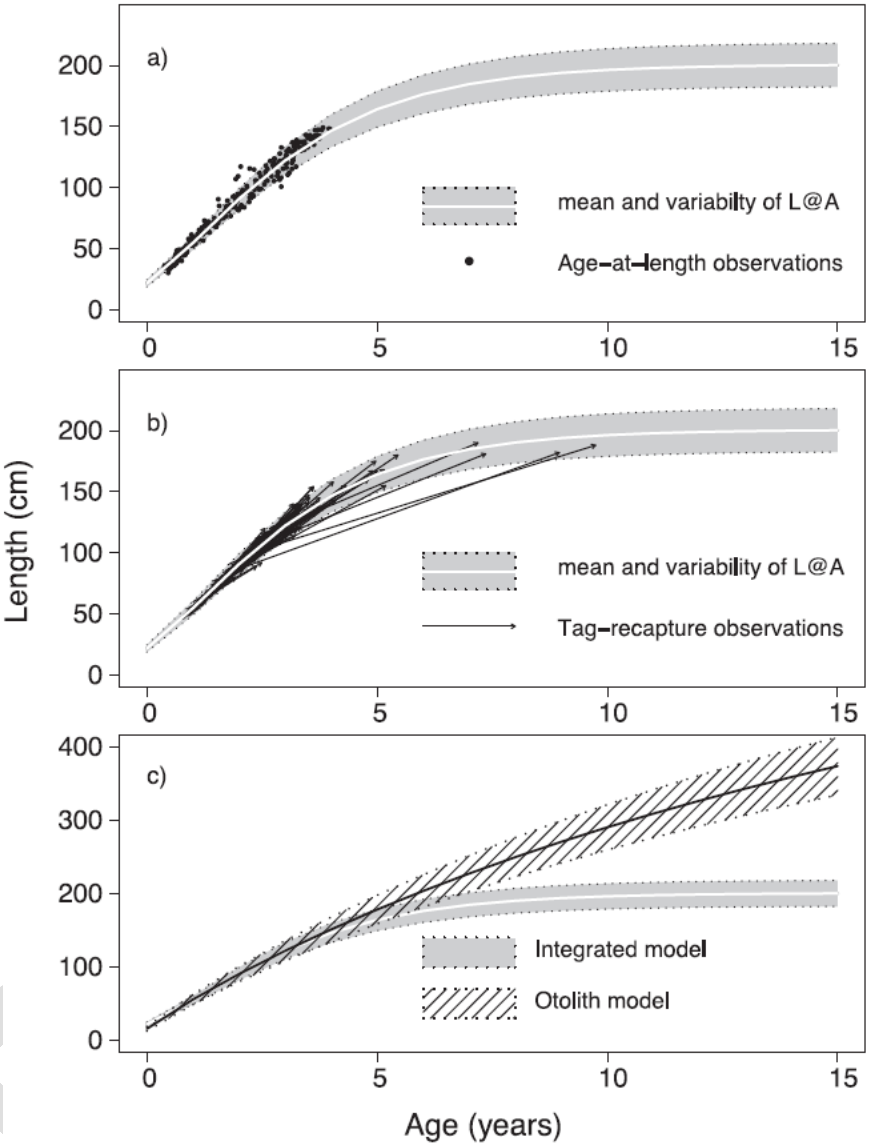


FIGURE 1. Integrated growth model fit to the two data components available for bigeye:(a) age-at-length observations from otolith readings, (b) lengths at tag–release (l1)and tag–recapture (l2), represented by a vector. A comparison between the growthestimates obtained from the integrated model and the model fit exclusively to theotolith data (otolith model) is also shown at the bottom of (c). In each panel, thevariability of the length-at-age is expressed as the 2.5 and the 97.5 percentiles ofthe distribution of the length-at-age. From Aires da Silva et al. (2015).

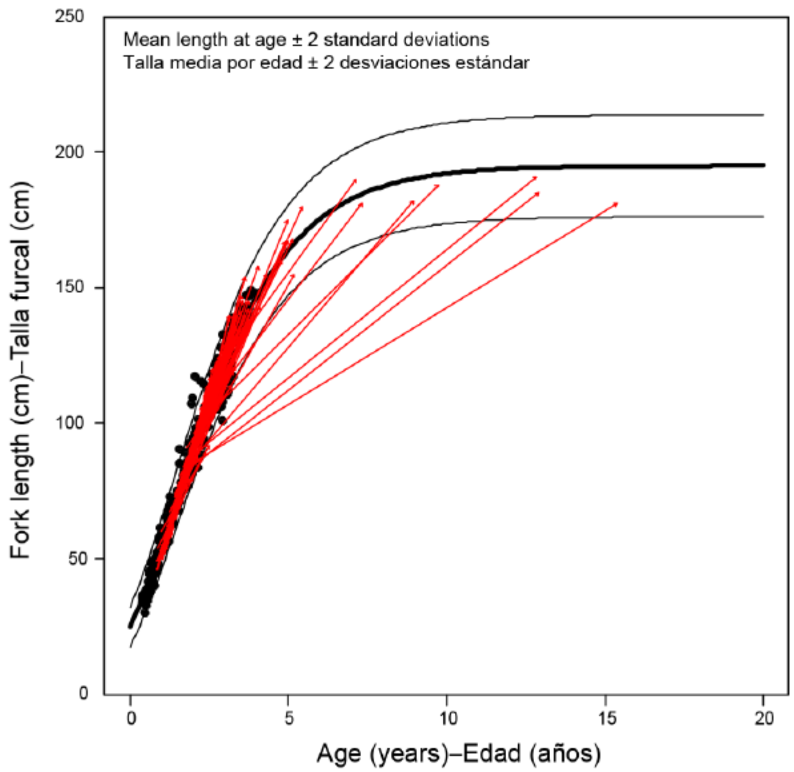


FIGURE 2. Integrated growth model fitted to the two data components available for bigeye: black dots are age-at-length observations from otolith readings; red vectors link lengths at tag-release and tag-recapture. The growth curve is an update of Aires-da-Silva et al. (2015) to include three new observations, all with lengths at liberty above 10 years. From Aires da Silva et al. (2018).

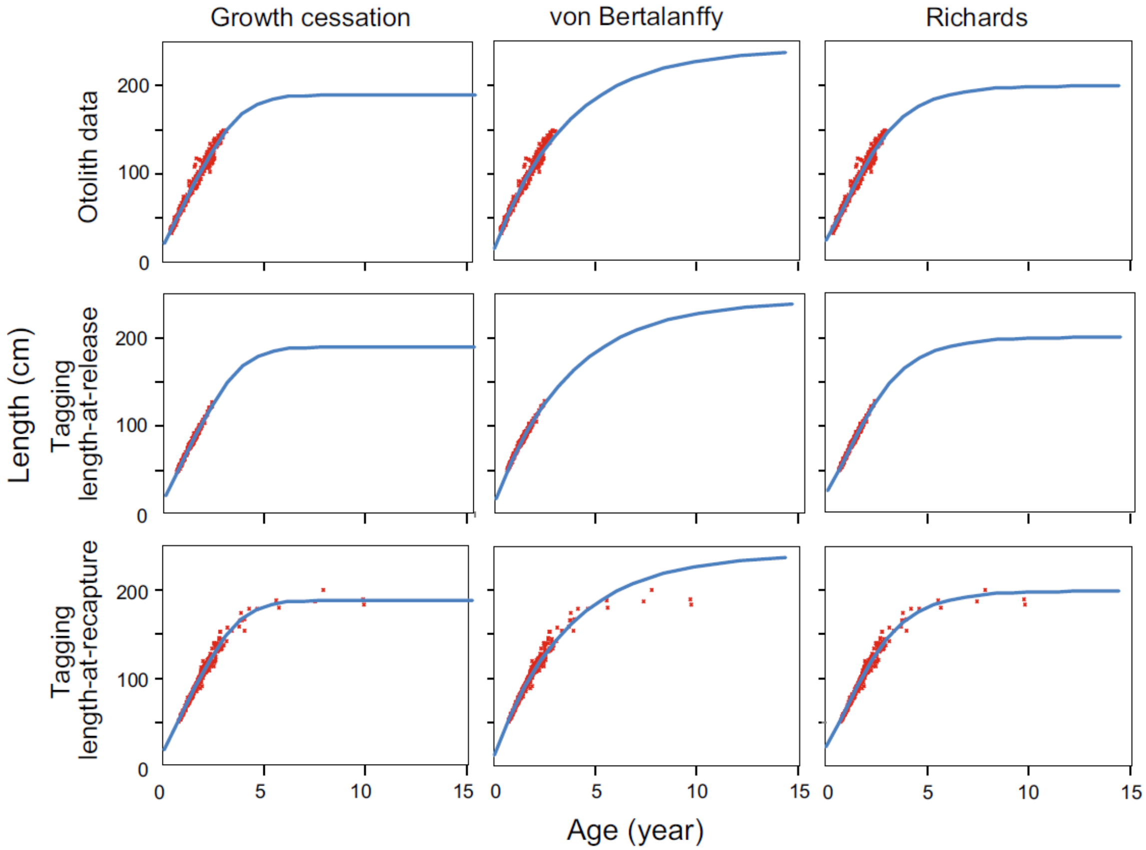


FIGURE 3. Fit of the growth-cessation model (left panels) to the otolith age–length data (top), tagging length at release (middle), and tagging length at recapture (bottom) for bigeye tuna in the eastern Pacific Ocean compared to the von Bertalanffy (middle panels) and Richards (right panels) models. From Maunder et al. (2018).

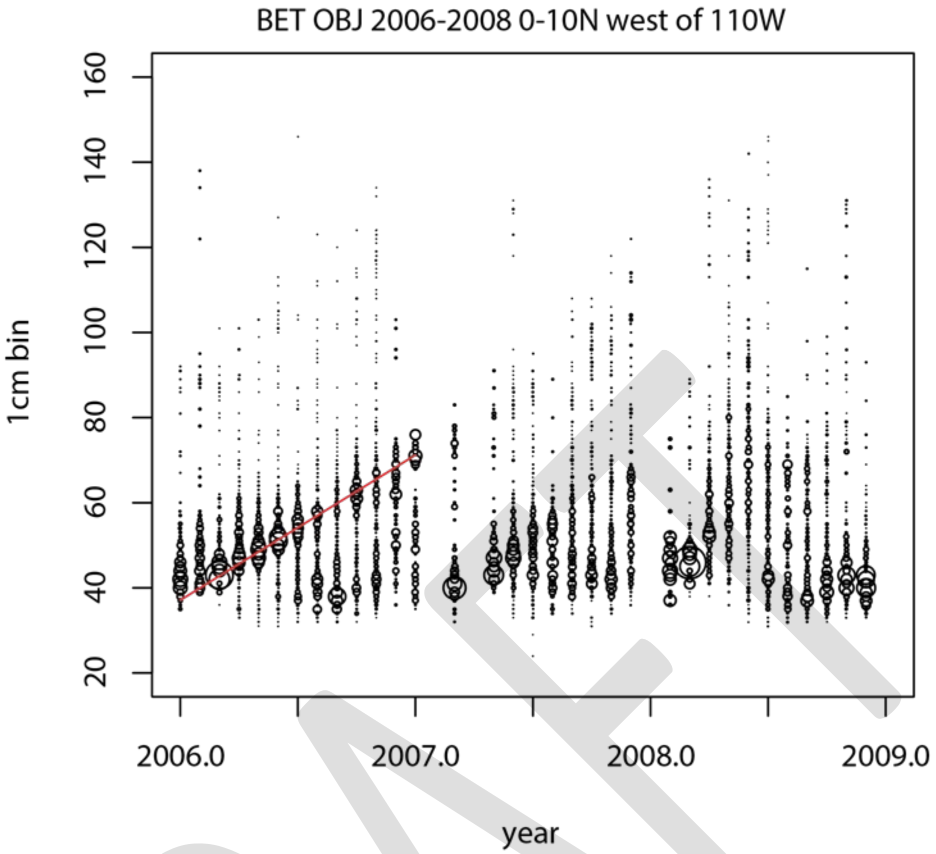


FIGURE 4. Comparison of the mean length at age from the growth model with the modal progression in the length composition data.

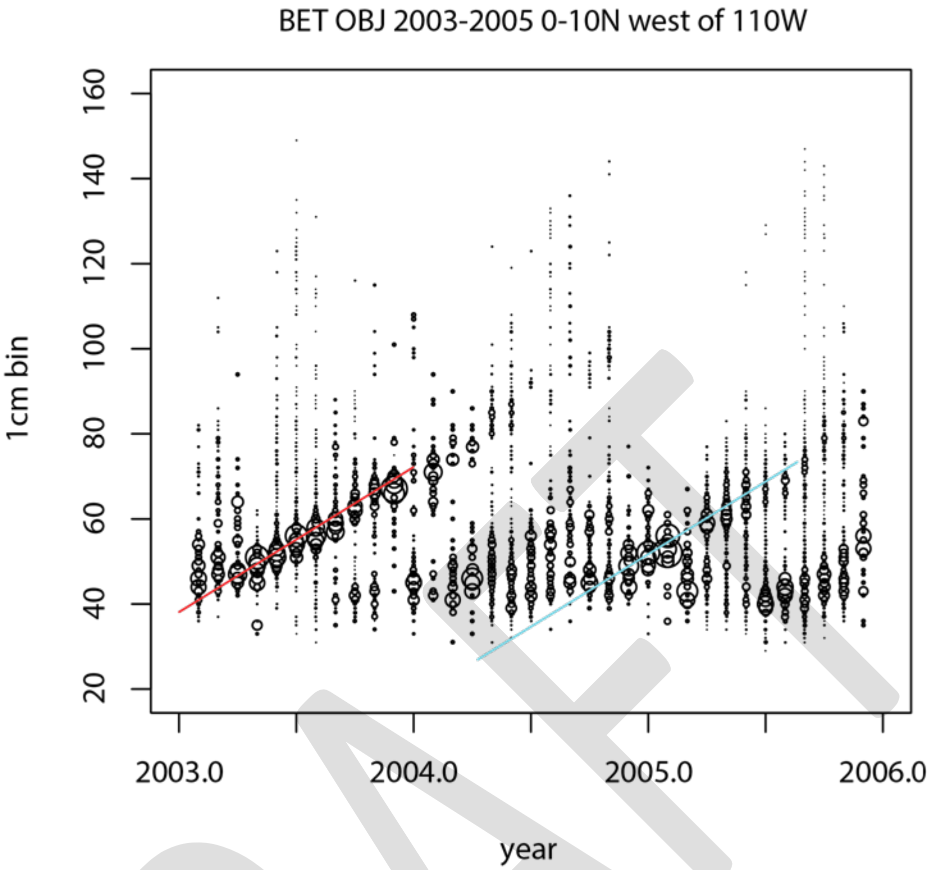


FIGURE 5. Comparison of the mean length at age from the growth model with the modal progression in the length composition data.

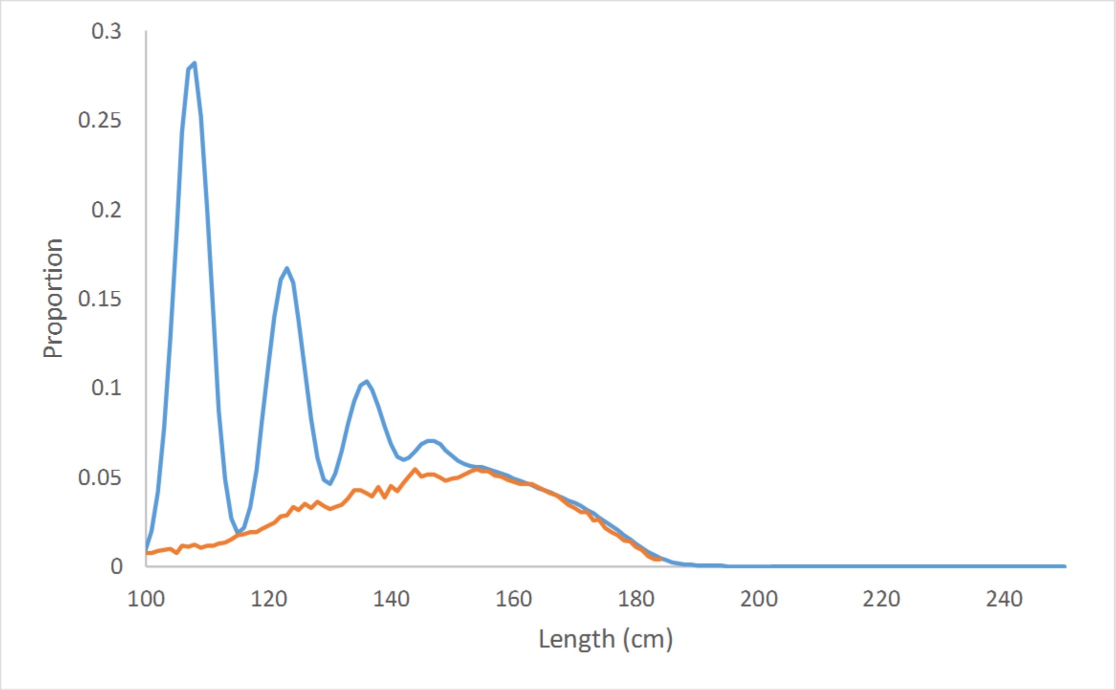


FIGURE 6. Fit of the Growth Cessation model to the large individuals in 1950s Japanese longline length composition data.

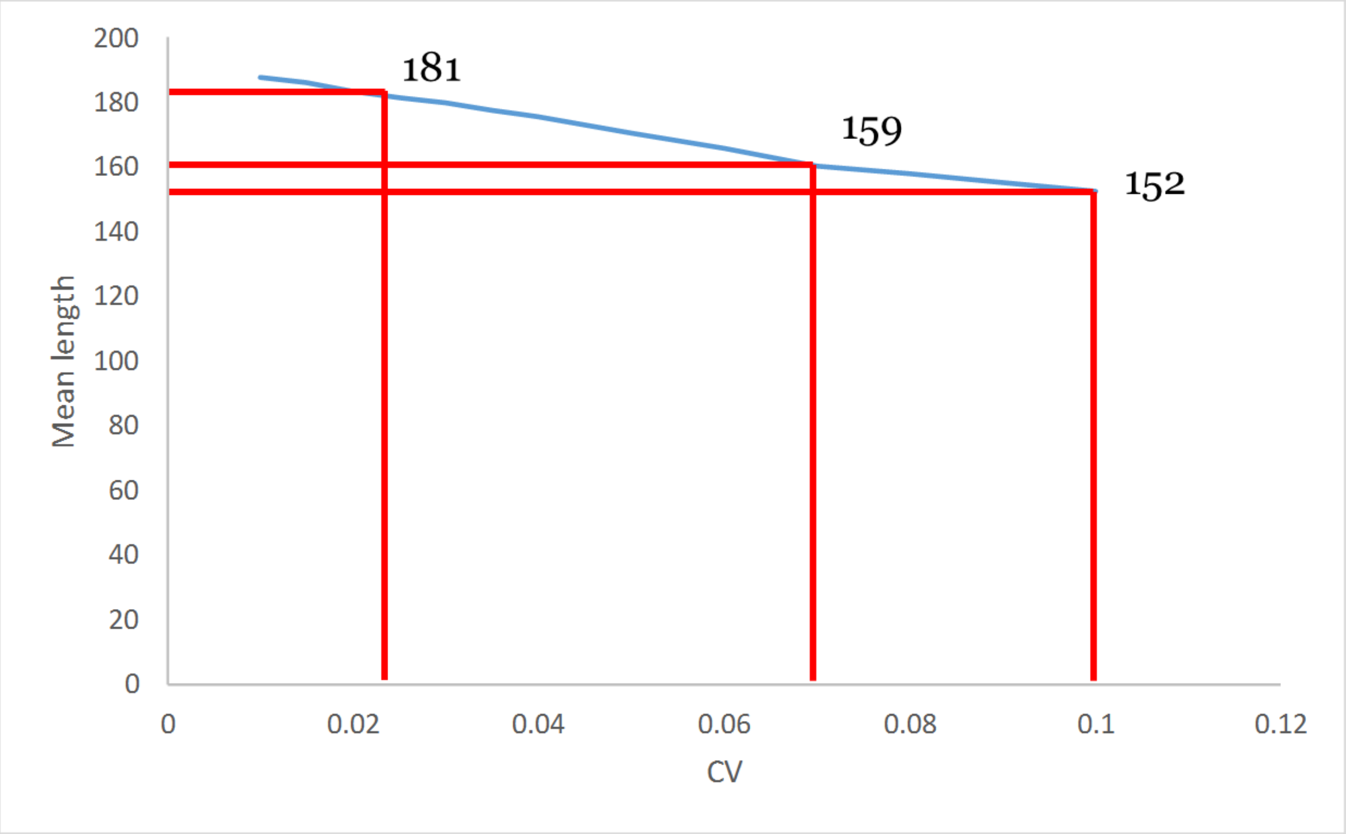


FIGURE 7. Estimates of asymptotic length (mean length) when fitting the growth cessation model to the large individuals in 1950s Japanese longline length composition data for different values of the variation of length at age. For reference, the asymptotic length from the growth cessation model fit to otolith and tagging data was 189 cm.

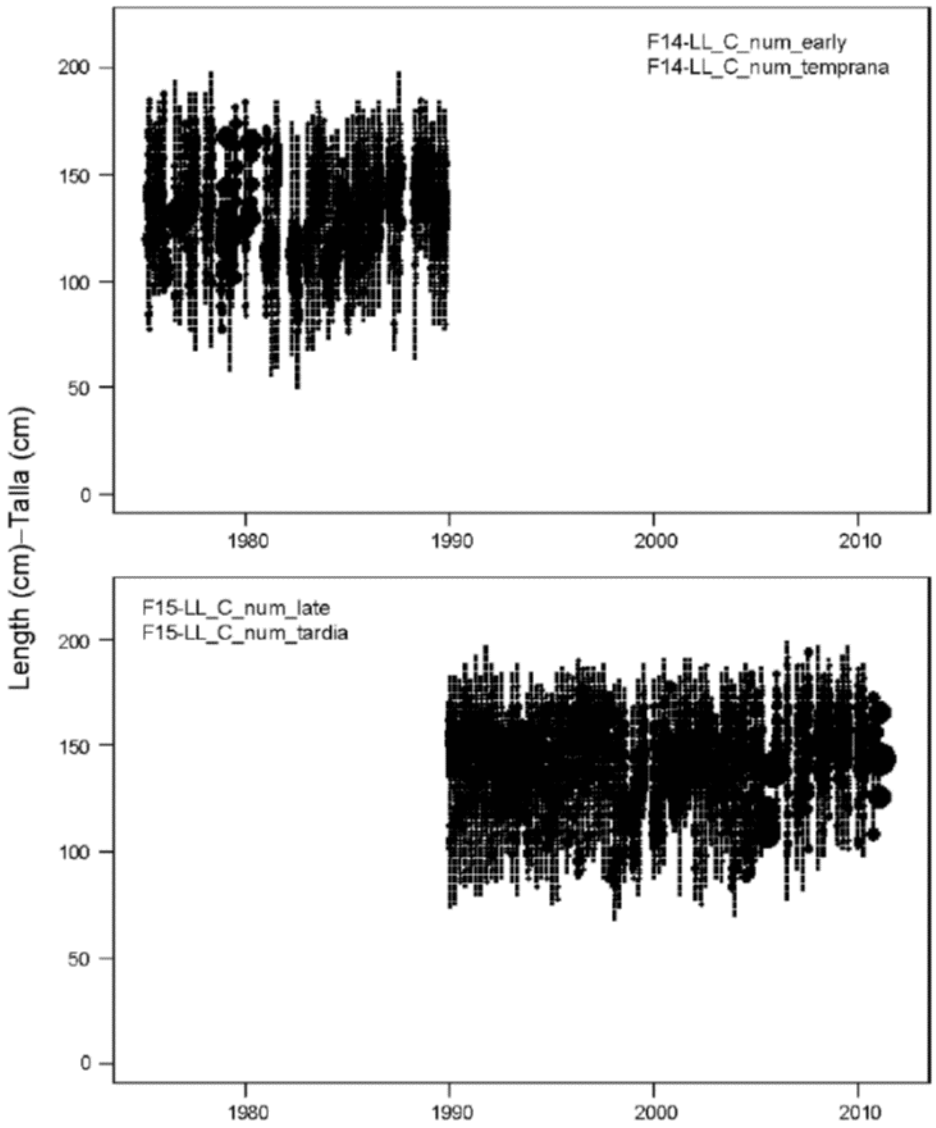


FIGURE 8. Observed length composition of the Japanese longline fisheries used in the assessment.

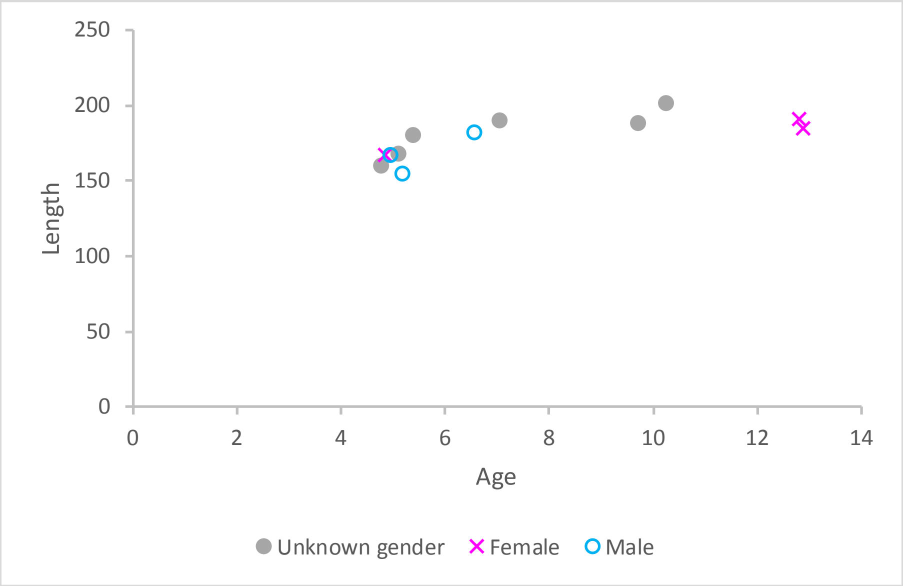


FIGURE 9. Length at age by gender for the long time at liberty tag recoveries.