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SENSITIVITY ANALYSIS OF BIGEYE STOCK ASSESSMENT TO ALTERNATIVE GROWTH ASSUMPTIONS

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1. SUMMARY

Modeling growth represents some challenges in the bigeye stock assessment. This paper attempts to illustrate the major issues through a series of sensitivity analyses. A major source of uncertainty is the value assumed for the mean length of the oldest age class in the growth model, the L_2 parameter. The F multiplier is the most important quantity for management of the bigeye stock in the EPO. This parameter indicates how much effort would have to be increased/decreased to achieve the maximum sustainable yield (MSY). Under the current assumption taken in the bigeye stock assessment of no relationship between stock and recruitment (steepness h =1), the bigeye stock status can rapidly change from an overfishing situation (F multiplier<1) to an underfishing status (F multiplier>0), by assuming slightly lower values of L_2 than the estimates used in the current assessment. However, the undefishing stock assessment outcome is substantially reduced if a more conservative assumption is taken on the steepness parameter of the stock recruitment relationship. Sensitivity analyses are also presented which investigate the use of the von Bertalanffy versus a more flexible Richards growth curve, estimating (rather than fixing) the variability of the length-at-age in the stock assessment model, and not fitting to the otolith age-at-length data.

2. BACKGROUND

As for many tuna species, specifying growth in the bigeye stock assessment for the eastern Pacific Ocean (EPO) presents some issues. Age-at-length observations derived from otolith readings are available up to 4 years of age only (Schaeffer and Fuller, 2006). This is a narrow spectrum of juvenile ages of a longevity estimated at 15-16 years, at least, from bigeye tagging studies (Langley et al., 2008). Otolith daily increments for large (older) fish are very difficult to interpret. Bigeye growth estimates from tagging studies are available but again these are mostly limited to juvenile ages (Schaeffer and Fuller, 2006).

Acquiring tag-recapture information for the older fish is problematic since it is difficult to capture large bigeye for tagging and few samples of larger fish are available from the longline fisheries.

The latest age and growth study available for bigeye in EPO is that provided by Schaefer and Fuller (2006). The authors used tag-recapture data and otolith daily increments to estimate growth. The two data sources provided very similar estimates, but the asymptotic length of the von Bertalanffy growth curve is much greater than any length recorded. This is reasonable as long as long as no biological meaning is given to the asymptotic parameter and that the growth model is used only as a representation of the ages of fish that were sampled. The maximum age in their data set is around 4 years (16 quarters) and hence the resulting von Bertalanffy growth curve cannot be used to predict growth beyond this age.

An attempt has been made to estimate growth internally in recent EPO bigeye stock assessment models. The growth model is fit to the age-at-length observations from otolith readings (Schaefer and Fuller, 2006) and the bigeye length composition data sampled from different fisheries. Using the A-SCALA stock assessment model (Maunder and Watters, 2003), a Richards growth curve was fit while setting the asymptotic length parameter at about the size of the largest bigeye in the data (186.5 cm; Maunder and Hoyle, 2006). This resulting curve has also been taken as a prior for all ages in the bigeye stock assessment (Maunder and Hoyle, 2007).

Previous growth studies and stock assessments for tuna indicate that rapid and almost linear growth of juvenile tuna is best fit by a Richards growth model. In two early stock assessments of bigeye (Aires-da-Silva and Maunder, 2007, 2009), a von Bertalanffy growth curve was used to predict the mean length-at-age. This was due mainly to a Richards function not being available yet in Stock Synthesis (version 2; Method 2005). The von Bertalanffy curve was then derived by obtaining the best correspondence with the mean length-at-age derived from the Richards growth curve assumed in A-SCALA by Maunder and Hoyle (2007) (Figure 1).

The latest bigeye assessment (Aires-da-Silva and Maunder, 2010) assumed the same von Bertalanffy growth function that was adopted in the two previous assessments (Aires-da-Silva and Maunder, 2007, 2009). Since a Richards growth curve recently became available in Stock Synthesis (version 3), a sensitivity analysis using the Richards curve was also presented in the latest assessment. This model improved the model fit to the data, particularly to the bigeye age-at-length (otolith readings) and the length composition data. As a result, the IATTC staff indicated that a Richards growth curve could potentially be assumed as the base case model in future assessments (Aires-da-Silva and Maunder, 2010).

Previous sensitivity analyses have shown that the bigeye stock assessment results are highly sensitive to changes of the asymptotic length parameter of the growth model (Aires-da-Silva and Maunder, 2007). Stock Synthesis offers a growth curve parameterization which takes L_2 (rather than L_∞) as a measure of the mean length of the largest/oldest fish. L_2 is defined as the mean length of an arbitrarily chosen age class, and the oldest age class is chosen in the bigeye assessment (40 quarters, a plus group). The best choice of L_2 for bigeye is somehow arbitrary and the parameter has generally been fixed at about the size of the largest fish in the data (185.5 cm). L_2 was fixed at 191.1 cm in the latest three bigeye stock assessments using Stock Synthesis (Aires-da-Silva and Maunder, 2007, 2009, 2010). This value was drawn from an external analysis to obtain the best possible correspondence between the von Bertalanffy growth curve offered by Stock Synthesis then, and the mean length-at-age of the Richards growth curve estimated early using A-SCALA (Maunder and Hoyle, 2007) (Figure 1). Due to the relative inflexibility of the von Bertalanffy growth curve, the L_2 used is higher than the Richards curve to allow better correspondence at younger ages.

The variability of the length-at-age can be just as influential as the mean length-at-age. Information on variability of the length-at-age can be obtained from age-at-length data, which is available for bigeye tuna (Schaeffer and Fuller, 2006). Unfortunately, the bigeye otolith samples were not collected randomly but were rather collected to cover a range of sizes to provide information on mean length-at-age. Therefore, this data does 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. These variability estimates have been used (fixed) in the latest bigeye Stock Synthesis assessments (Figure 2). Stock Synthesis has a similar capability.

This report attempts to illustrate the most relevant sensitivity aspects of the bigeye stock assessment results to alternative growth assumptions. The effect on management quantities from assuming different growth curves (von Bertalanffy versus Richards), and the mean length of the oldest age class (L_2) are presented. A sensitivity analysis in which the variability of the length-at-age is estimated rather than fixed in the stock assessment model is presented. In additional, results from a sensitivity analysis to fitting (or not) to the otolith age-at-length data are also presented.

3. THE IMPORTANCE OF L_2

L_2 represents the mean length of a fish of a given age. In the bigeye tuna assessment this is the mean length of the oldest age in the model (10 years or 40 quarters), which is the plus group. Because it is the mean length, there will be some individuals of this age that are larger and some individuals that are smaller. The lengths of a given age are normally distributed with the mean based on the growth curve and the standard deviation (or CV, which) is a linear function of length. The total mortality rate will determine how many individuals live to a given age and the selectivity of the gear will determine which ages are seen in the catch data. Therefore, the size of individuals observed in a length composition sample will be dependent on the growth model (mean length at age), the standard deviation of length-at-age, the total mortality, and the selectivity. Since the longline selectivity is assumed asymptotic, the L_2 and standard deviations are fixed, and the natural mortality is fixed, the fishing mortality probably has the biggest influence on the proportion of large fish caught by the southern longline fishery in the stock assessment model. Therefore, changing the L_2 parameter directly influences the estimated fishing mortality and related management parameters.

4. PROXY STATISTICS FOR THE MEAN LENGTH OF THE OLDEST AGE CLASS (L_2)

The bigeye observed length frequency distributions were inspected to obtain proxy statistics for the average length of the oldest fish parameter (L_2). Only the length frequency samples collected from the southern longline fishery were analyzed since this is the fishery that catches the largest sizes of bigeye. The quarterly time series for the 92.5th, 95th, 97.5th and 99th percentiles of the bigeye size frequency samples are shown on Figure 3.

On average, the 95th percentile of the bigeye size frequency samples is at 167.2 cm. The 92.5th and 97.5th percentiles are at 163.2 and 172.7 cm, respectively. The 99th percentile is at 178.8 cm. These sample statistics are lower than L_2 parameter estimates previously assumed in the bigeye stock assessment (L_2 =185.5 and 191.2 cm; Figure 3).

The proxy estimates derived from the length composition data should be regarded with caution. The bigeye tuna stock has been exploited in the EPO since the mid 1950s. It is very likely that the largest/oldest bigeye are highly depleted in the stock and are rarely observed or not vulnerable. In fact, bigeye tuna measuring up and even higher that 200 cm have been observed in the longline fishery, but these records are rare (K. Schaefer, IATTC, pers. comm.)

The growth estimates used in recent bigeye assessments by Stock Synthesis seem to provide a reasonable approximation beyond to the largest/older fish. The L_2 estimates that are fixed in the assessment (either 191 cm in the von Bertalanffy base case run, or 185 cm in the Richards curve sensitivity) are about the largest sizes observed in the longline fishery samples (Figure 3). In addition, the assumed estimates of variability around the mean length-at-age allows bigeye to grow over to the largest recorded observations (about 200 cm).

5. LIKELIHOOD PROFILES ON THE MEAN LENGTH OF THE OLDEST AGE CLASS (L_2)

The most recent bigeye base case stock assessment model assumes a von Bertalanffy growth curve.

However, a sensitivity analysis was also made using a more flexible Richards growth curve which improved the model fit to the fishery data, in particular to the otolith age readings and the size composition data. The IATTC staff indicated that this model could potentially be taken as the base case model in future stock assessments (Aires-da-Silva and Maunder, 2010).

In this report, the uncertainty of the bigeye mean length of the oldest age class (L_2) is evaluated for the two growth models (von Bertalanffy and Richards) by means of likelihood profiling (Figure 4). The likelihood profile obtained for the more flexible Richards growth curve is more informative on L_2 than that derived for the von Bertalanffy growth model. Not surprisingly, this result is consistent across different assumptions made about the steepness parameter of the Beverton-Holt stock recruitment relationship (h=1, 0.75 and 0.50). While the maximum likelihood estimate (MLE) for L_2 is at about 178 cm for a von Bertalanffy growth model, the MLE is considerable lower if a Richards curve is assumed (around 165 cm). These results suggest that the L_2 estimates assumed in the model are higher than the true parameter value. However, the lower maximum likelihood L_2 estimates may be biased since they are conditional on the assumptions made on mortality (natural and fishing mortality), selectivity, and the weighting given to the different data sets which may contain conflicting information.

The more flexible Richards model provided better fits (lower total negative log-likelihood values) to the bigeye fishery data, particularly to the otolith age compositions and the size frequency data. The total and partial negative log-likelihood components obtained for each model are shown on Figure 5.

6. SENSITIVITY OF MSY-RELATED QUANTITIES TO L_2

An important management quantity considered for bigeye management in the EPO is the F multiplier, which indicates how much effort would have to be effectively increased/decreased to achieve the maximum sustainable yield (MSY) in relation to the average fishing mortality of the last three years of the assessment. An analysis of the sensitivity of the F multiplier to different assumptions about the bigeye mean size of the oldest age class (L_2) was made. The analysis was conducted for two assumptions about the growth curve (von Bertalanffy and Richards) and three assumptions about the steepness parameter of the stock recruitment relationship (h=1, 0.75 and 0.50). A similar sensitivity analysis was made for MSY.

Under the base case model assumptions of no relationship between stock and recruitment (h=0), and a von Bertalanffy growth model, the bigeye stock is found to be in overfishing status (F multiplier about 0.80). However, the F multiplier is highly sensitive to changes on the assumption made about L_2 (Figure 6). Under the same model structure as used in the base case, the F multiplier rapidly increases and exceeds 1 (underfishing occuring) for lower values of L_2 (below 185 cm). If L_2 is estimated rather than fixed in the base case model, its maximum likelihood estimate is at about 180 cm (see previous section), with the F multiplier estimated at 1.13). Under a more conservative steepness assumption (h=0.75 or h=0.50), the F multiplier is less than 1 (0.75 and 0.55, respectively) when L_2 is estimated (at 178 and 177 cm respectively).

The underfished stock assessment outcome (F multiplier higher than 1) is substantially reduced if a more conservative assumption about the stock-recruitment relationship is taken (h=0.75 or h=0.50). When a Richards growth curve is assumed, which improves the model fit to the otolith age-at-length and the length composition data, the F multiplier is less than 1 for L_2 values above 175 cm, regardless of the steepness assumption. If L_2 is estimated under a Richards growth assumption, its maximum likelihood estimate is at about 165 cm regardless of the assumption on steepness. Except for the more liberal steepness assumption taken in the base case (h=1), the F multipler is estimated below 1 for assumed L_2 values above 165 cm.

7. VARIABILITY OF THE LENGTH AT AGE

A sensitivity analysis was made in which the standard deviations of length-at-age were estimated (rather than fixed) in the stock assessment model while fitting to the bigeye age-at-length and the length frequency data. Two sensitivity models assuming the von Bertalanffy (base case) and a more flexible

Richards growth curve were conducted. For both runs, very minor changes were obtained for the mean lengths-at-age when the two parameters which define the variability of the length-at-age (SD1 and SD2) were estimated (Figure 8a,b). However, the length variability for the larger fish, in particular, was estimated to be much lower than the estimates assumed (fixed) in the base case model (Figure 8c,d), which were obtained from a previous A-SCALA assessment (Maunder and Hoyle, 2007).

Estimating the standard deviations of the length-at-age slightly improved the model fit to the size composition data, but little improvement was obtained in the fit to the otolith data (Table 1). The management quantities showed little sensitivity to estimating the variability of the length at age (Table 2).

8. FITTING TO THE OTOLITH AGE-AT-LENGTH DATA

The bigeye base case assessment model fits to both length composition and age-at-length data obtained from otolith readings. A sensitivity analysis was made in which the growth model was not fit to the age-at-length data. Instead, the model was fit only to the bigeye length frequency data while estimating *K*. This sensitivity run was made while fixing the standard deviations of the length-at-age as in the base model, and also estimated.

For both von Bertalanffy and Richards growth models, the estimates of the mean length-at-age for medium to large fish (100-180 cm) decreased when the model was not fit to the otolith data while estimating *K* (Figure 9a,b). Apparently, this is mainly due to changes of the juvenile growth fit (0-15 quarters) after removal of the information provided by the otolith data. In order to explain the observations of large fish in the length frequency data under the lower estimates of mean length-at-age, the fishing mortality estimates also decrease and the stock status is more optimistic (Table 2).

Estimating the variability (SD) of the length-at-age data while not fitting to the otolith observations did not affect the estimates of mean length-at-age (Figure 9a,b). However, the length variability estimates obtained for the older fish are much lower than those assumed (fixed) in the base case model (Figure 9c,d). The later were taken from a previous A-SCALA assessment (Maunder and Hoyle, 2007).

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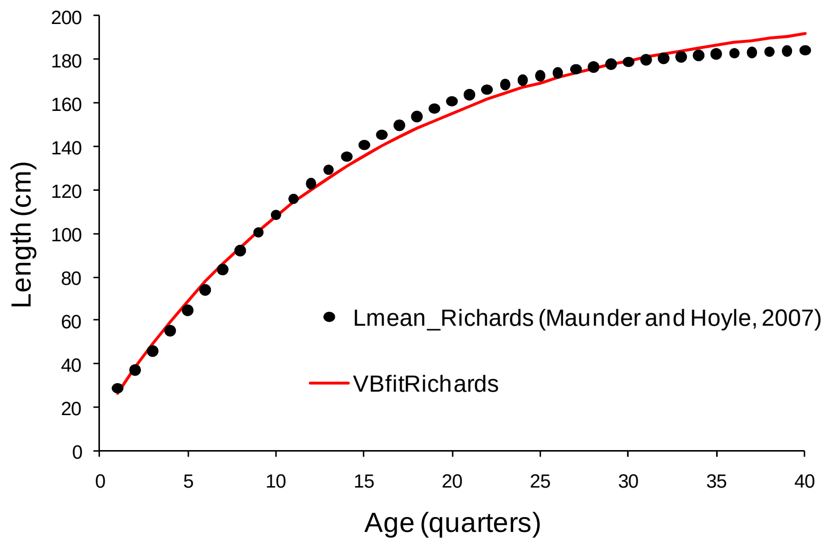

FIGURE 1. Best correspondence between the von Bertalanffy growth curve (SS base case) and the mean lengths-at-age (dots) of the Richards curve estimated using A-SCALA (Maunder and Hoyle, 2007). This approximation was necessary due to a Richards curve not being available yet in Stock Synthesis 2 (Aires-da-Silva and Maunder, 2007).

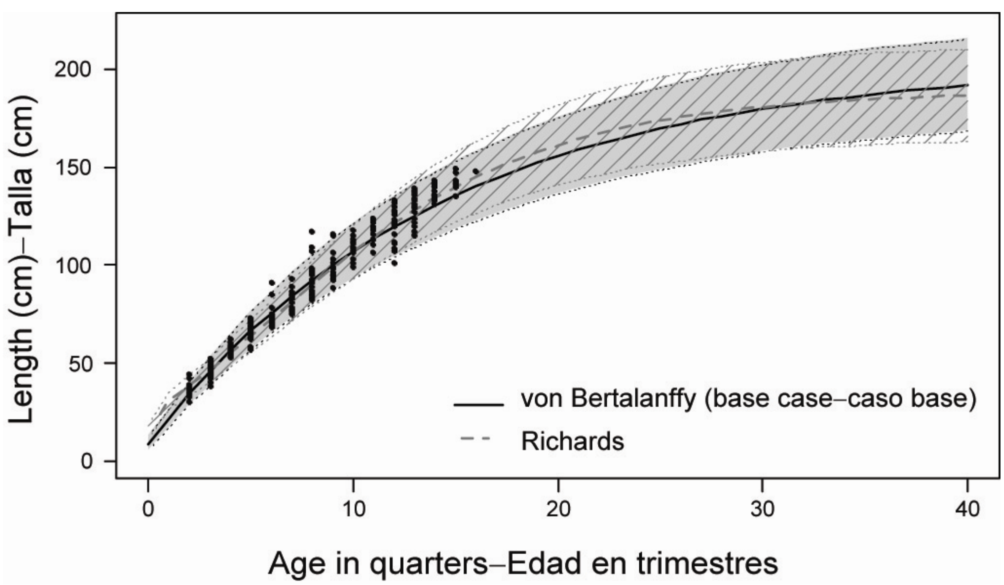

FIGURE 2. Comparison of the von Bertalanffy (base case) and the Richards growth curves (sensitivity) fitted to age-at-length observations derived from otolith readings (dots). The confidence intervals (±2 standard deviations) of the mean lengths are shown for each growth curve (shaded for the base case and solid diagonal lines for the Richards curve).

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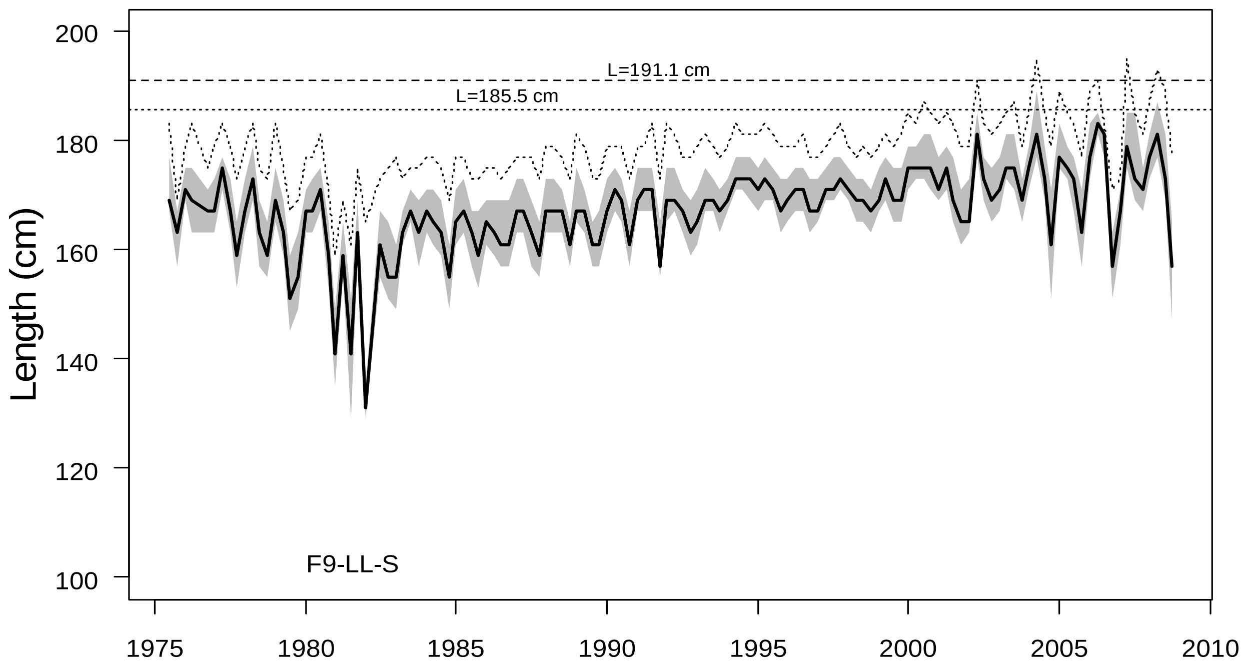

FIGURE 3. Proxy statistics for the mean length of the oldest age class (L_2). The solid line indicates the 95th percentile of the bigeye length frequency distributions for each quarter. The gray shaded area shows the size range between the 92.5th and 97.5th percentiles. The dotted line indicates the 99th percentile of the length frequency distributions. Only the length frequency samples observed by the southern longline fishery were analyzed since this is the fishery catching the largest sizes of bigeye.

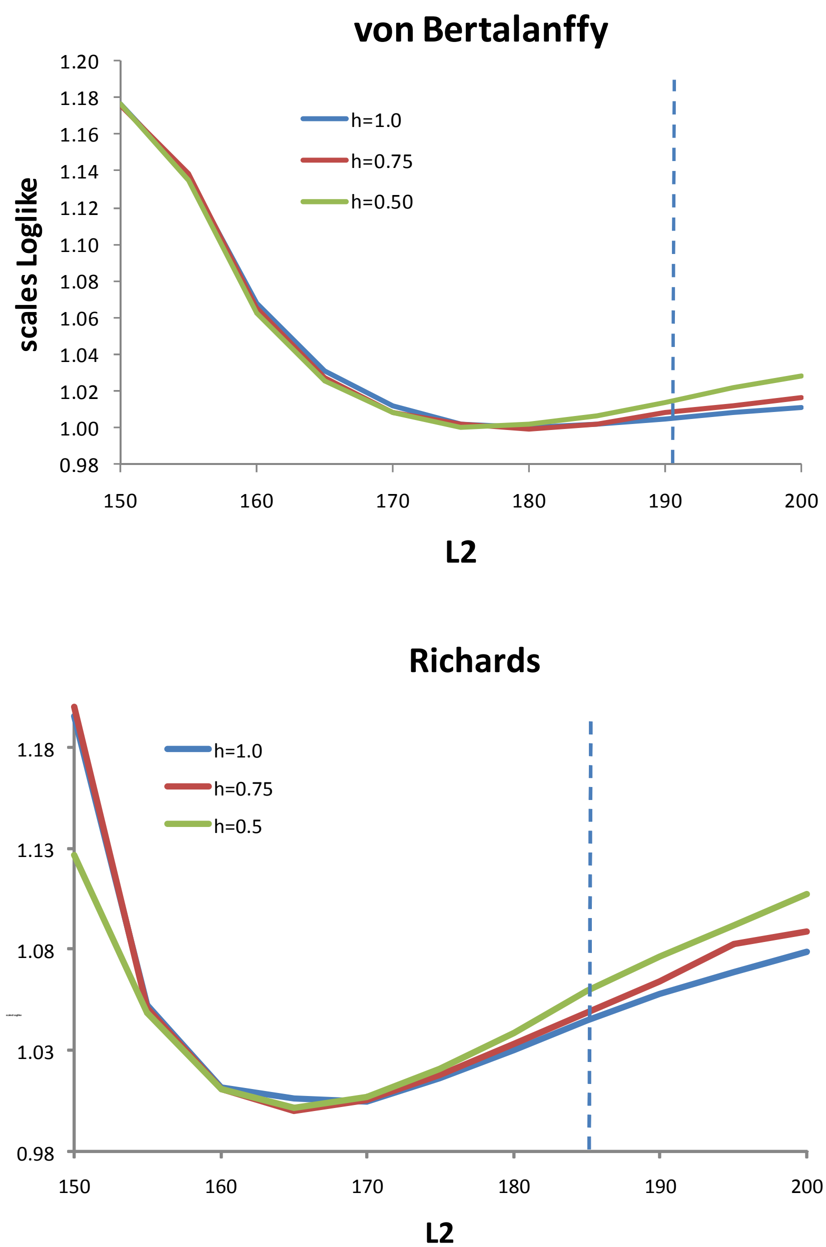

FIGURE 4. Negative log-likelihood profile on mean size of the oldest age class (L_2) for different growth assumptions (top – von Bertalanffy, bottom – Richards) and the steepness parameter of the Beverton-Holt stock-recruitment relationship (h=1, 0.75 or 0.5). The values on the negative log-likelihood are scaled to the minimum negative log-likelihood estimate (MLE). The vertical dashed lines on the figures mark the L_2 values taken in the von Bertalanffy (base case) and Richards growth models (191.2 cm and 185.5 cm, respectively).

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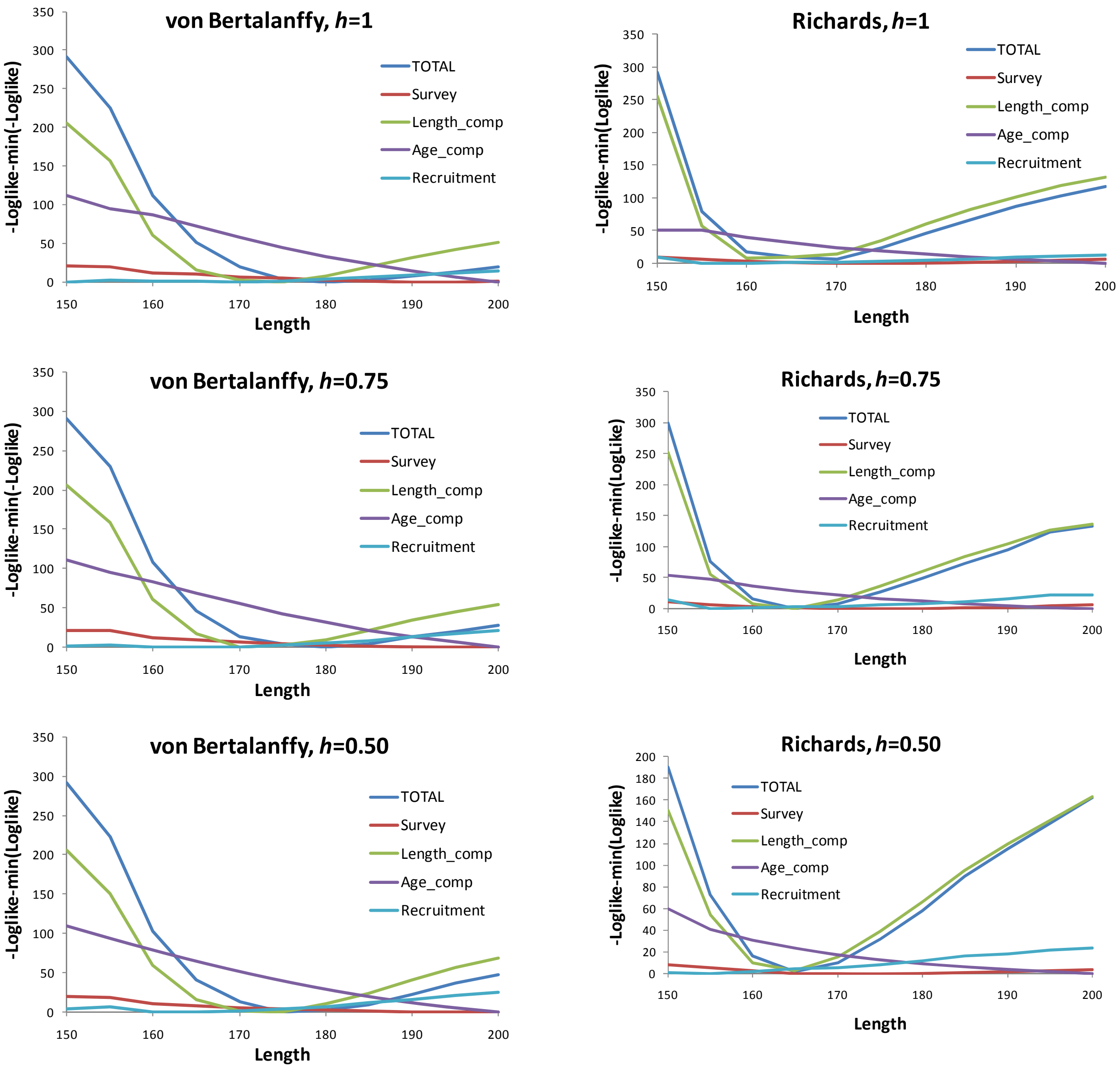
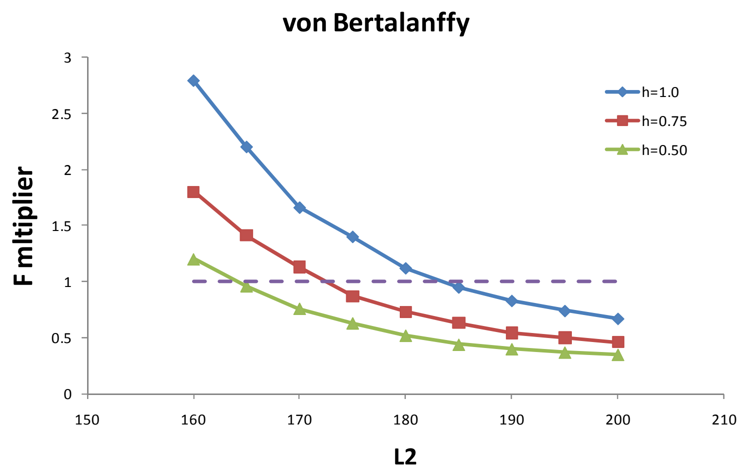


FIGURE 5. Negative log-likelihood components (subtracted to their respective minimum negative lo-likelihood) for different sensitivity runs assuming two growth curves (left – von Bertalanffy, right – Richards) and three assumptions about the steepness parameter of the Beverton-Holt stock-recruitment relationship (from top to bottom of the plot: *h*=1, 0.75 or 0.5)



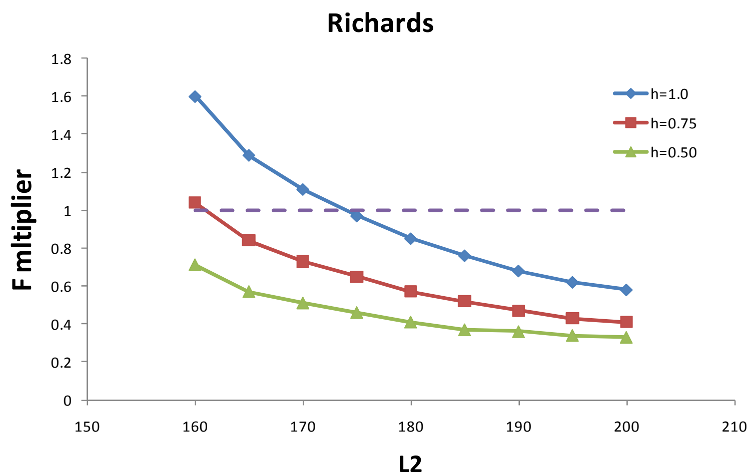


FIGURE 6. Relationship between the *F* multiplier and the assumed value of L_2. The *Fmultiplier* indicates how many times effort would have to be effectively increased/decreased to achieve the MSY in relation to the average fishing mortality of the last three years of the assessment. Two growth curve assumptions are investigated (top - von Bertalanffy, bottom - Richards). The three lines correspond to different assumptions about the steepness parameter of the Beverton-Holt stock-recruitment relationship (*h*=1, 0.75 or 0.5)

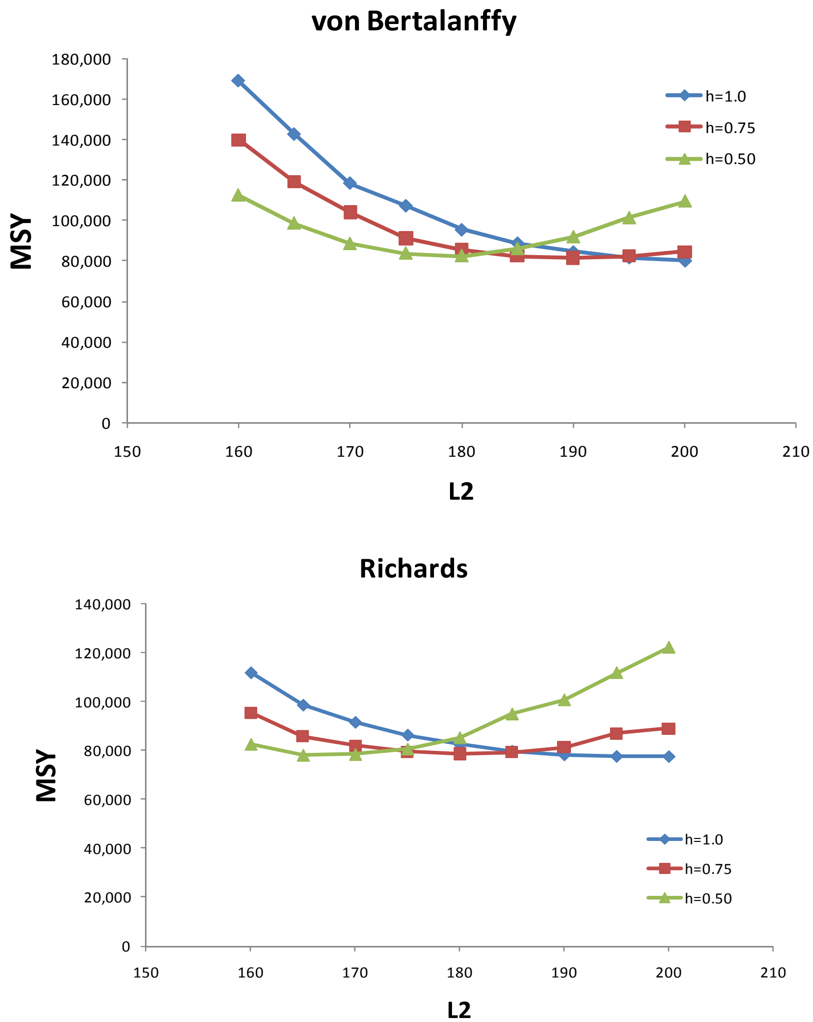


FIGURE 7. Relationship between the maximum sustainable yield (MSY) and the assumed value of L_2. Two growth curve assumptions are investigated (top - von Bertalanffy, bottom - Richards). The three lines correspond to different assumptions about the steepness parameter of the Beverton-Holt stock-recruitment relationship (h=1, 0.75 or 0.5)

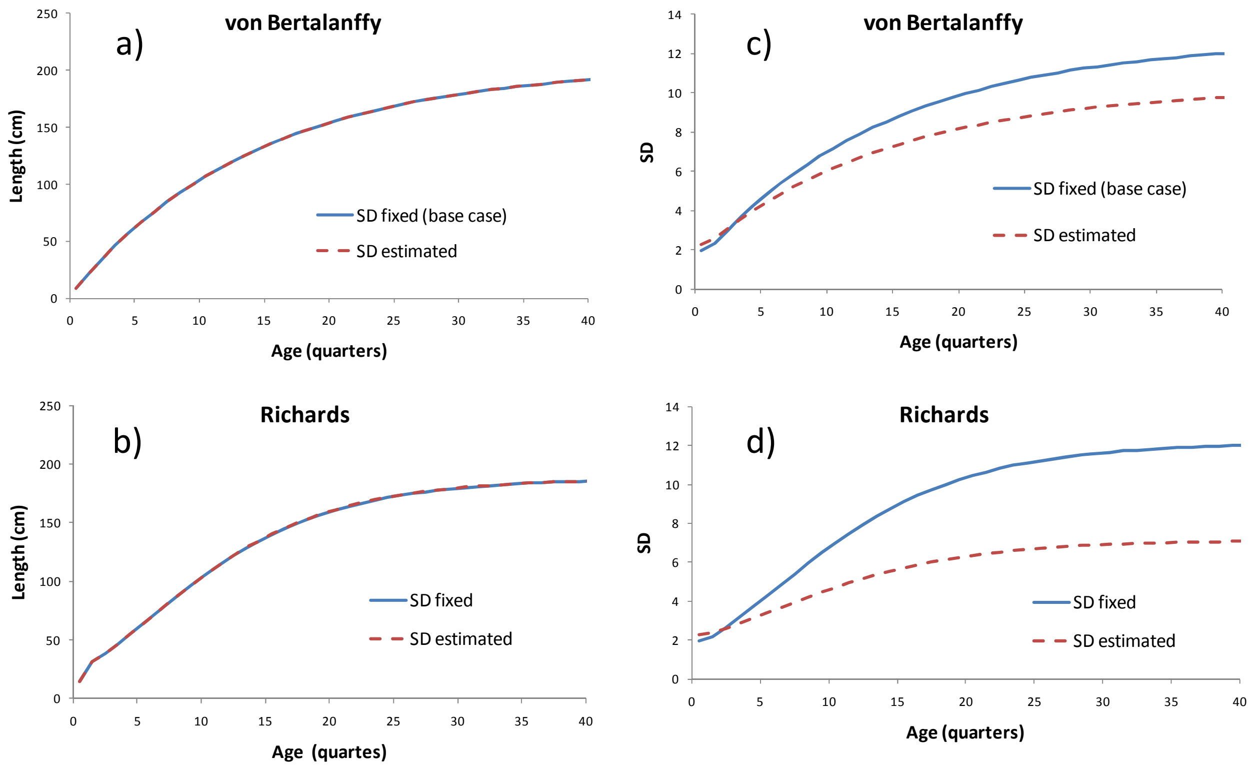


FIGURE 8. Mean lengths (left) and variability of length at age (right) of the von Bertalanffy and Richards growth curves for the following model runs: the standard deviations of the length-at-age are fixed (solid lines) or estimated (dashed lines).

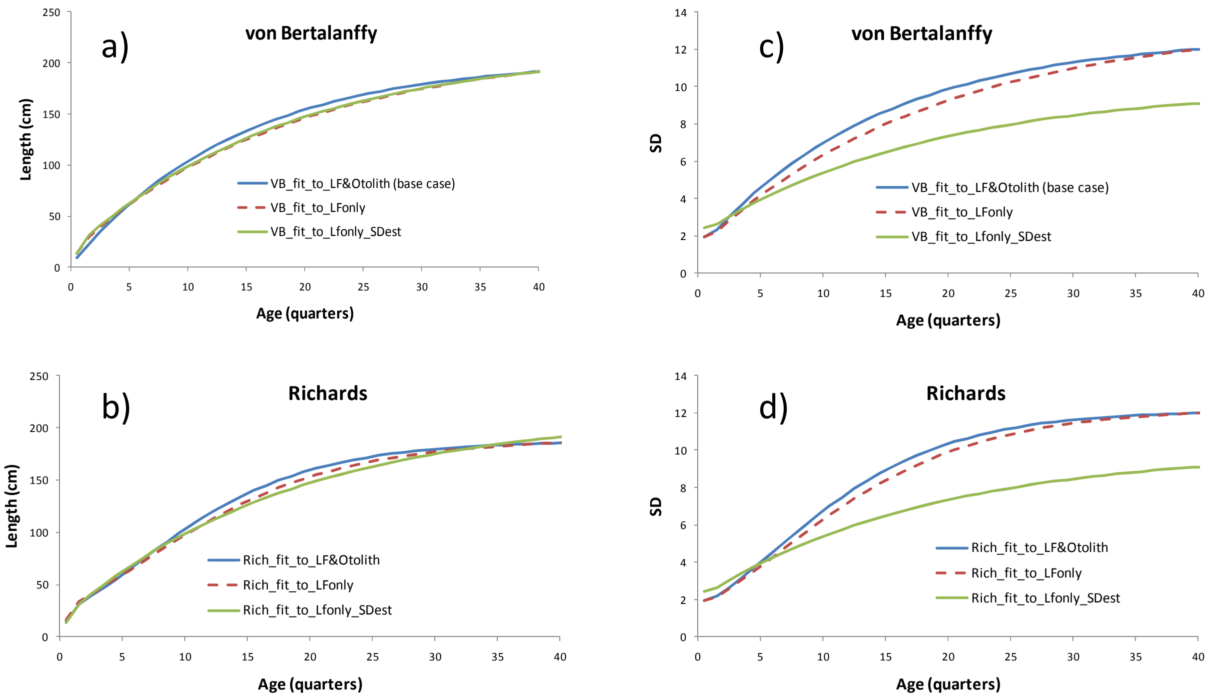


FIGURE 9. Mean lengths (left) and variability of length at age (right) of the von Bertalanffy and Richards growth curves for the following model runs: fit to both the length composition and the age-at-length data with the standard deviations (SD) of the length-at-age fixed (base case), fit to the length composition data only while fixing the SD of the length-at-age, and fit to the length composition data only while estimating the SD of the length-at-age.

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TABLE 1. Estimates of management related quantities for bigeye tuna for the base case and growth sensitivity analysis (SDest - estimating the variability of the length-at-age and, fitToLFonly – fit to the length composition data only, no fitting to the age-at-length otolith data).

	VON BERTALANFFY				RICHARDS			
	Fit to LF and otolith data		Fit to LF only		Fit to LF and otolith data		Fit to LF only	
Quantity	Base case	VB_SDest	VB_fitToLFonly	VB_fitToLFonly_SDest	Richards	Richards_SDest	Rich_fitToLFonly	Rich_fitToLFonly_SDest
msy	83,605	83,554	90,632	90,232	79,578	80,090	85,224	85,580
Bmsy	289,409	288,569	297,203	295,685	280,013	282,463	292,544	294,224
Smsy	60,612	60,336	60,237	59,315	60,572	61,102	62,732	63,130
Bmsy/Bzero	0.25	0.25	0.24	0.24	0.25	0.25	0.24	0.24
Smsy/Szero	0.19	0.19	0.18	0.18	0.19	0.19	0.18	0.18
Crecent/msy	1.19	1.19	1.10	1.10	1.25	1.24	1.17	1.16
Brecent/Bmsy	0.99	0.99	1.34	1.35	0.93	0.93	1.23	1.21
Srecent/Smsy	0.89	0.90	1.27	1.28	0.83	0.84	1.18	1.16
Fmultiplier	0.80	0.81	1.07	1.07	0.75	0.75	0.97	0.96

TABLE 2. Negative log-likelihood components obtained for the base case and growth sensitivity analysis (SDest - estimating the variability of the length-at-age and, fitToLFonly – fit to the length composition data only, no fitting to the age-at-length otolith data).

	VON BERTALANFFY				RICHARDS			
	Fit to LF and otolith data		Fit to LF only		Fit to LF and otolith data		Fit to LF only	
Quantity	Base case	VB_SDest	VB_fitToLFonly	VB_fitToLFonly_SDest	Richards	Richards_SDest	Rich_fitToLFonly	Rich_fitToLFonly_SDest
TOTAL	1656.57	1651.89	1311.01	1305.08	1564.99	1560.22	1239.37	1233.73
Catch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equil_catch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Survey	-269.00	-268.82	-259.11	-259.74	-274.05	-274.15	-270.25	-270.31
Length_comp	1648.17	1643.13	1599.54	1594.04	1576.34	1580.49	1534.33	1531.11
Age_comp	307.62	307.52	0.00	0.00	288.48	280.64	0.00	0.00
Recruitment	-30.46	-30.19	-29.42	-29.23	-26.04	-26.77	-24.71	-27.08