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AN INVESTIGATION OF THE LONGLINE FISHERY LENGTH-FREQUENCY RESIDUAL PATTERN IN THE STOCK ASSESSMENT OF BIGEYE TUNA IN THE EASTERN PACIFIC OCEAN

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CONTENTS

SUMMARY

Recent stock assessments of bigeye in the eastern Pacific Ocean (EPO) have shown a prominent residual pattern in the model fit to the length compositions of the longline fishery. The pattern consists of a major shift from positive residuals (observations larger than model predictions) for medium-size fish prior to the late 1980s, to a period of positive residuals for larger fish after those years.

One hypothesis to explain the residual pattern is that it is due to a spatial mis-specification of the two longline fisheries assumed in the stock assessment model. A sensitivity analysis is conducted that investigates the impact on the assessment results from assuming two alternative longline fishery definitions. The first takes the same four floating-object fishery definitions used in the base case assessment, as longline fishery definitions. The second consists of a six-fishery longline definition derived from regression tree analyses using longline size composition and catch-per-unit-effort (CPUE) data to investigate the stock structure of bigeye in the EPO. The prominent residual pattern was not eliminated after spatial redefinition of the longline fisheries. In fact, the pattern persisted for most newly defined fisheries.

An alternative hypothesis to explain the prominent shift of the residual pattern around the late-1980s is that a major change occurred in the operational practices of the longline fishery around those years. This may have resulted in strong changes of catchability/selectivity over that period, and assuming two time blocks of catchability/selectivity for the longline fisheries could potentially improve the residual pattern. A sensitivity analysis was made in which two time blocks (pre- and post-1990) are assumed for the longline fisheries. This approach improved the model fit to the length compositions, but the residual pattern is still prominent in the model fit to the southern longline fishery, particularly in the later period (post-1990).

For all sensitivity analyses conducted in this paper, overfishing was found to be occurring for bigeye in the EPO.

In conclusion, prominent residual pattern is still present in the model fit to the longline length composition data. Other longline fishery definitions may be needed to improve the residual pattern, or there may be other types of mis-specification causing the pattern. A more flexible treatment of selectivity may also be needed to improve the pattern. The possibility of seasonal changes in the selectivity of the longline fishery should be investigated.

1. BACKGROUND

The stock status of bigeye in the Eastern Pacific Ocean (EPO) is evaluated using the Stock Synthesis model (SS – version 3; Methot 2005). Stock Synthesis is a statistical age-structured model fit to multiple sources of fishery data, including length composition data.

A single-unit stock of bigeye in the EPO is assumed in the current bigeye assessment (Aires-da-Silva and Maunder, 2010). An attempt is made to account for the bigeye spatial structure in the EPO by assuming individual fisheries that are spatially defined in the assessment. Several surface fisheries and two longline fisheries (northern and the southern) are assumed.

Residual analysis of the model fit to the length composition data has shown a prominent residual pattern in recent bigeye assessments (Aires-da-Silva and Maunder, 2010). Specifically, the residual plot for the southern longline fishery shows strong pattern, consisting of a major shift around the late 1980s from positive residuals (observations larger than model predictions) for medium size fish (around 75-125 cm), to a period of positive residuals for larger fish (around 125-175 cm) (see Figure 4.11c of Aires-da-Silva and Maunder, 2010, or Figure 12 in this report). This could potently be due to several types of model mis-specification such as growth, natural mortality and/or selectivity assumptions.

An alternative hypothesis to explain the residual pattern is that it is caused by a spatial mis-specification of the longline fisheries in the assessment model. The first part of this paper consists of a sensitivity analysis to investigate the impact on the bigeye stock assessment results from assuming two alternative longline fishery definitions. These are compared with the current definition that splits the longline fishery at 15°N latitude. Another hypothesis is that the pattern is caused by a major change in the operational practices of the longline fishery occurring around the late 1980s. To investigate this hypothesis, a sensitivity analysis is made which considers two temporal blocks (prior- and post 1990) for the longline fisheries.

2. SENSITIVITY ANALYSIS TO ALTERNATIVE LONGLINE FISHERY DEFINITIONS

2.1. Definition of fisheries

The bigeye model runs presented in this sensitivity analysis take the same floating-object fishery definitions as those assumed in the base case model (Aires-da-Silva and Maunder, 2010). This definition consists of two fisheries operating around unassociated schools and dolphins, and four floating object fisheries along with their respective discard fisheries (Figure 1).

With respect to the longline fisheries, the base case considers two fisheries in the EPO: Northern and Southern longline fisheries separated at 15°N (Figure 2a). An alternative longline fishery definition investigated in this paper consists of taking the same spatial definitions used in the base case model for the floating-object fisheries ("run OBJmethod"; Figure 2b). This consists of four spatially defined fisheries: Central (C), Northern (N), Southern (S), and Inshore (I).

The second longline fishery definition is drawn from a study using regression tree analyses with length-frequency distributions and longline catch rate trends to evaluate the bigeye spatial structure in the EPO (Lennert-Cody et al., 2010). Six longline fisheries were defined (Figure 2c): Northern (N), northeastern Central (Cne), northwestern Central (Cnw), southern Central (Cs), Inshore (I), and Southern (S). This model run is denoted as "run TreeAnalyses".

A comparative list of fisheries used in the bigeye base case model and the two sensitivity runs to alternative longline fishery definitions is shown in Table 1.

2.2. Fishery data and model assumptions

A detailed description of the data sources used in the bigeye stock assessment can be found in Aires-da-Silva and Maunder (2010). The longline catch was partitioned into four and six longline fisheries (runs OBJmethod and TreeAnalyses, respectively), rather than two longline fisheries only (base case; note that there are four longline fisheries but the second two only differ from the first because the catch is recorded in weight rather than numbers). The same applies to the length composition data.

Similarly, the two sensitivity runs fit to four and six longline indices of abundance (runs OBJmethod and TreeAnalyses, respectively), rather than to only two longline indices of abundance (base case). As for the base case model, the indices of abundance (standardized CPUE) derived for the new spatially defined longline fisheries were estimated using a delta-lognormal GLM approach.

The sensitivity runs take the same set of assumptions (including growth, reproduction, natural mortality) made in the base case stock assessment (see details on Aires-da-Silva and Maunder, 2010).

2.3. Results and discussion

The likelihood components obtained for the base case and sensitivity runs to alternative longline fishery definitions are shown on Table 2. As a result of the fishery redefinitions, the models are fitting to different CPUE and size composition data sets re-arranged in space. Therefore, likelihood comparisons are problematic.

Figure 3, 4 and 5 show the model fits to the CPUE indices for the base case and two sensitivity runs. Regardless of longline spatial definition, all models fit fairly well to the CPUE data, except the inshore and central areas around the mid 1980s. Specifically, the model cannot fit the high CPUE increase observed in these two fisheries around 1985.

Figures 6, 7 and 8 show the size-based selectivity curves obtained from the base case and the two sensitivity runs on fishery definitions. For comparative purposes among runs and consistency with the southern longline fishery logistic assumption taken in the base case, all non-northern fisheries were assumed to be logistic in both sensitivity runs. Only the selectivity curves of the northern fisheries are assumed dome-shape.

The bigeye length compositions observed for each longline fishery defined in the base case and two sensitivity runs are shown in Figures 9, 10 and 11, respectively. There is a large increase in the size of fish from 1985 to 1990 in many of the longline fisheries. This is likely to be caused by a large cohort growing over time. Pearson residual plots for the models fits are also shown on Figures 12, 13 and 14, respectively. The prominent residual pattern identified in recent assessments (Figure 12) was not eliminated after spatial redefinition of the longline fisheries. In fact, the pattern is found to strongly persist in all four redefined longline fisheries of sensitivity run OBJmethod (Figure 13).

With respect to the sensitivity TreeAnalyses, the residual pattern also persists after spatial redefinition, however, its degree varies among longline fisheries. While the pattern is still very strong in the southern Central fishery (F15-LL_Cs) and moderately strong in the Northern and Inshore fisheries (F12-LL_N and F16-LL_I), it is less apparent in the northeastern and northwestern Central fisheries (F13-LL_Cne and F15-LL_Cnw, respectively) (Figure 14). However, this may be due to lower sample sizes and higher variability in the data for these fisheries. Future spatial analysis could help to better understand the source of residual pattern.Considering the patterns described above and the spatial intersection between the fisheries assumed in different runs (Figure 2d), it seems that the main source of residual pattern may be somewhere localized within the southern Central (Central_S) and Inshore fisheries defined in run TreeAnalysis (Figure 2c). To a lower extent, there also seems to be source of pattern in the northern fishery (base case and run TreeAnalyses; Figure 2).

The time series of summary biomasses, the spawning biomass ratio (SBR) and recruitments estimated from the base case (Aires-da-Silva and Maunder, 2010), and the two sensitivity runs with alternative longline fishery definitions are shown in Figures 15, 16 and 17, respectively. MSY-related management quantities obtained for each run are presented on Table 3. The sensitivity TreeAnalyses produced the most pessimistic stock status evaluation. However, the two sensitivity runs assumed logistic selectivity curves for the non-northern longline fisheries for consistency and comparative purposes with the base case model. See section 3 below for a sensitivity analysis which assumes dome-shape selectivity for the early phase of the southern longline fishery.

3. SENSITIVITY ANALYSIS TO ASSUMING TWO TIME BLOCKS FOR THE LONGLINE FISHERIES

3.1. Operational changes

There is a prominent shift in the residual pattern of the length composition for the longline fisheries around the late 1980s (Figures 12, 13 and 14). This major shift could potentially be due to marked changes of catchability/selectivity of the longline fisheries that occurred around the late 1980s. In fact, the numbers of hooks between floats - which determine fishing depth and greatly affect catchability and selectivity - deployed by Japanese longliners, underwent a gradual increase over the 1970s and 1980s, and then apparently stabilized (Figure 18). The post-1990 period is characterized by a more or less stabilized and less variable numbers of hooks per basket. Although the GLM standardization of longline CPUE (Aires-da-Silva and Maunder, 2010) attempts to remove the effect of hooks per basket on relative abundance, it does not deal with selectivity changes.

3.2. Model assumptions

Defining two temporal blocks of catchability/selectivity for the longline fisheries may help to reduce the residual pattern in the model fit to the longline length composition data. A sensitivity analysis was made assuming two time blocks (pre- and post-1990) for the two longline fisheries (northern and southern) assumed in the base case model (Aires-da-Silva and Maunder, 2010).

A model was built that uses the same selectivity assumptions taken in the base case for the two time blocks: dome shape (double normal) and logistic for the northern and the southern longline fisheries, respectively. Another model was developed that allows the selectivity for the early period (pre-1990) of the southern longline fishery to be dome-shape (double normal), rather than logistic, as smaller fish were caught by this fishery relative to the later post-1990 period (Figures 9, 10 and 11). The two models were run for two assumptions on growth (von Bertalanffy and Richards), and the steepness (*h*) parameter of the stock-recruitment relationship (*h*=1 and *h*=0.75).

3.3. Results and discussion

As expected, assuming two time blocks for the longline fisheries provided better model fits than the current base case model (Table 4). The best model fit was that obtained under no relationship between stock and recruitment (*h*=1), and assuming a Richards growth curve and dome-shape selectivity for the early southern longline fishery (pre-1990s).

A comparison between the length frequency residual plots obtained for the base case and the sensitivity analyses assuming two time blocks for the longline fishery are shown in Figure 19. Assuming the time blocks helped to reduce the residual pattern in the early period of the southern longline fishery (pre-1990). In particular, the positive residuals seem to have become more evenly distributed over the full range of observed sizes, rather than being restrained to smaller-size fish only, as in the base case (Figure 19). However, assuming the time blocks was not effective in minimizing the pattern for the later period of the southern longline fishery. In fact, a residual cluster for larger fish only remains prominent. It may be necessary to model temporal variability in the selectivity parameters through random walks or other more flexible approaches.

The time series of summary biomasses, and the spawning biomass ratio (SBR, depletion with respect to SSB0) estimated from the base case (Aires-da-Silva and Maunder, 2010), and the two sensitivity runs assuming two time blocks for the longline fisheries are shown in Figures 21 and 22 (for steepness assumptions of 1 and 0.75, respectively). The time series of relative and absolute recruitments are shown in Figures 23 and 24 (for steepness assumptions of 1 and 0.75, respectively). MSY-related management quantities obtained for each run are presented on Table 5. Under the two time period assumption for the longline fishery, the stock status is more pessimistic (lower *F* multiplier estimates) than the base case results.

4. FUTURE WORK

Future work addressing the bigeye longline length-frequency residuals should investigate smaller spatial scales than those assumed in this study.

The longline fishery results presented here and additional information on the purse seine length composition data indicate that the fleets are able to target large cohorts as they grow over time. This suggests that effective selectivity can change over time. This may require modeling temporal variability in the selectivity parameters through random walks or other more flexible approaches. The changes in selectivity appear to occur for both large and small bigeye so that both the acceding and descending limbs of the selectivity may need to change over time. There is no survey data for bigeye tuna and therefore, under the above methodology, there is no selectivity that can be held constant over time, which could add additional uncertainty to the analysis. The possibility of seasonal changes in the selectivity of the longline fishery should be investigated.

The hypothesis of density-dependent or other temporal changes in growth could also be investigated thought the time block approach.

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Methot, R. D. 2005. Technical description of the Stock Synthesis II assessment program. NOAA Fisheries. http://www.sefsc.noaa.gov/sedar/download/S16_AW_04.pdf

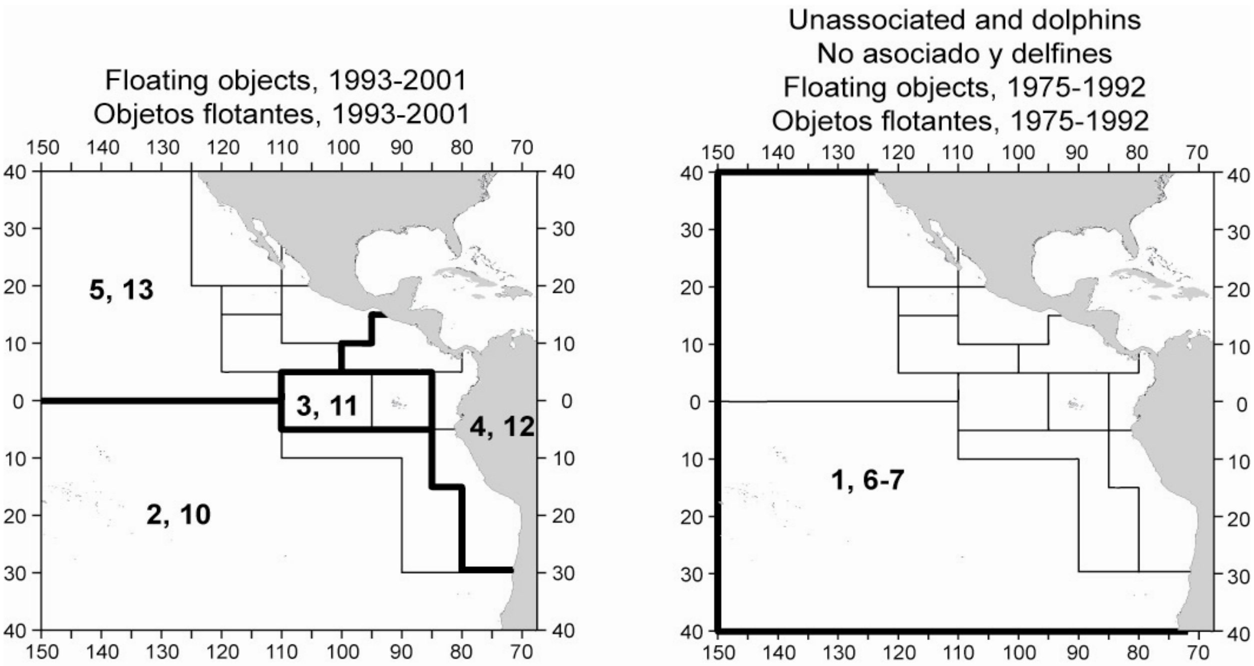

FIGURE 1. Spatial extents of the fisheries defined in the formal stock assessment of bigeye tuna in the eastern Pacific Ocean (Aires-da-Silva and Maunder, 2010). The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the bold numbers the fisheries to which the latter boundaries apply. The fisheries are described in Table 2.1 of Aires-da-Silva and Maunder (2010).

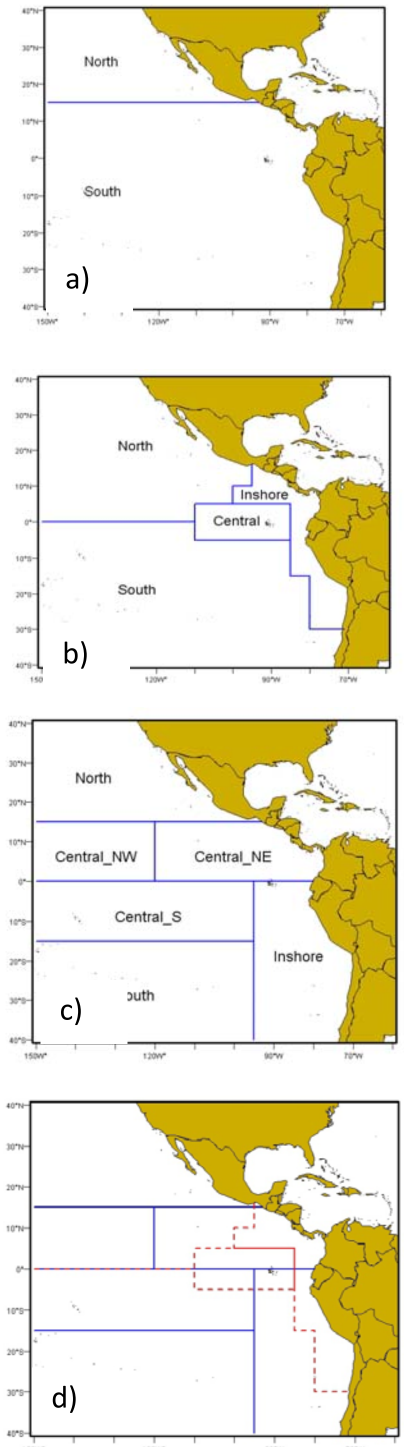

FIGURE 2. Longline fishery definitions assumed in the base case and two sensitivity runs. a) base case model; b) take same floating object fishery definitions used in base case assessment (run OBJmethod); c) fishery definitions obtained from regression tree analyses using longline length composition data and CPUE data to investigate the stock structure of bigeye in the EPO (Lennert-Cody et al., 2010) (run TreeAnalyses); d) dashed lines - run OBJmethod, solid lines - run TreeAnalyses.

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Base case (SARM10)

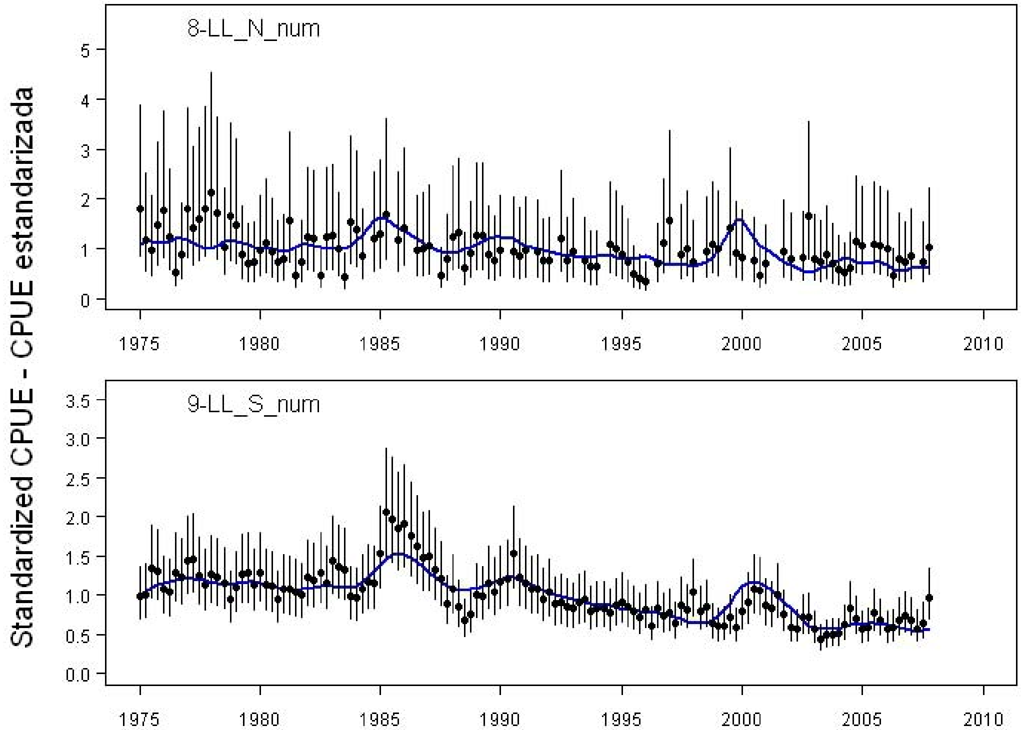

FIGURE 3. Model fit to the CPUE data from the two longline fisheries (top – northern, bottom – southern) assumed in the base case assessment (Aires-da-Silva and Maunder, 2009).

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Sensitivity OBJmethod

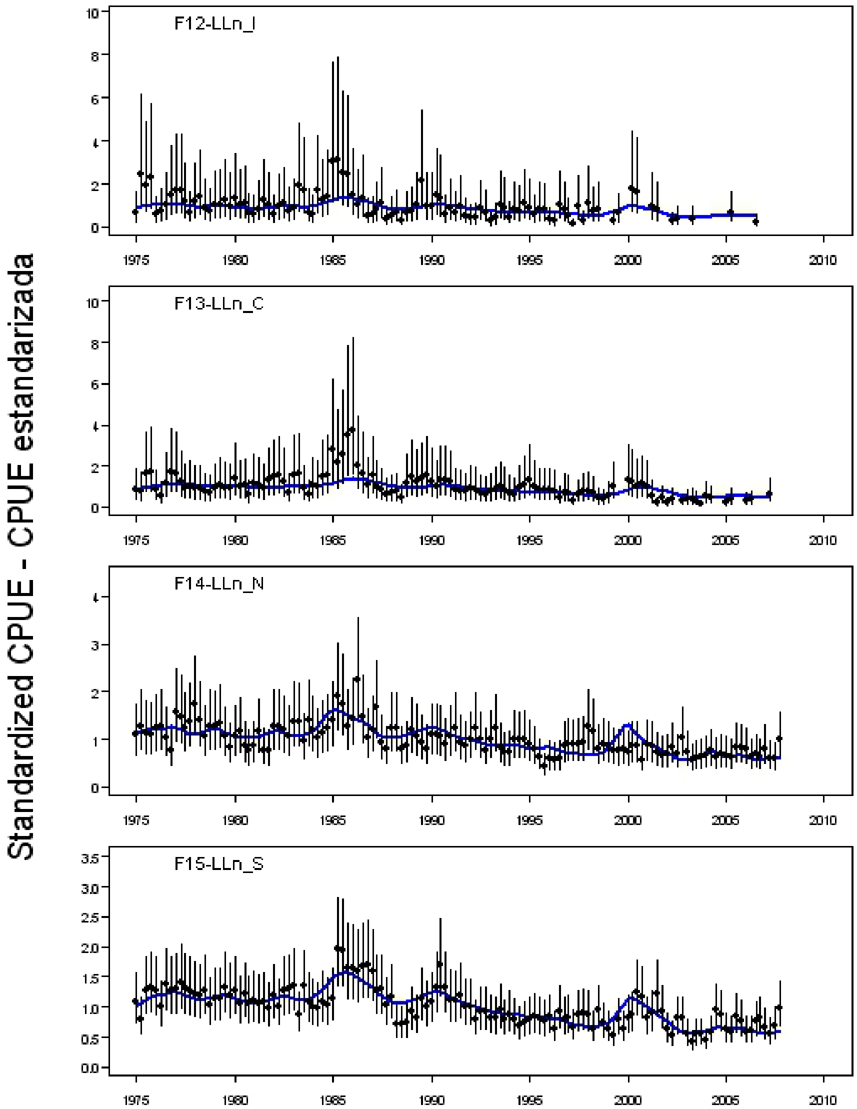

FIGURE 4. Model fit to the CPUE data from the longline fisheries assumed in the sensitivity OBJmethod. The longline fisheries are the Inshore (I), Central (C), Northern (N) and Southern (S), respectively (see Figure 2 for spatial definitions).

Sensitivity LLtreeAnalyses

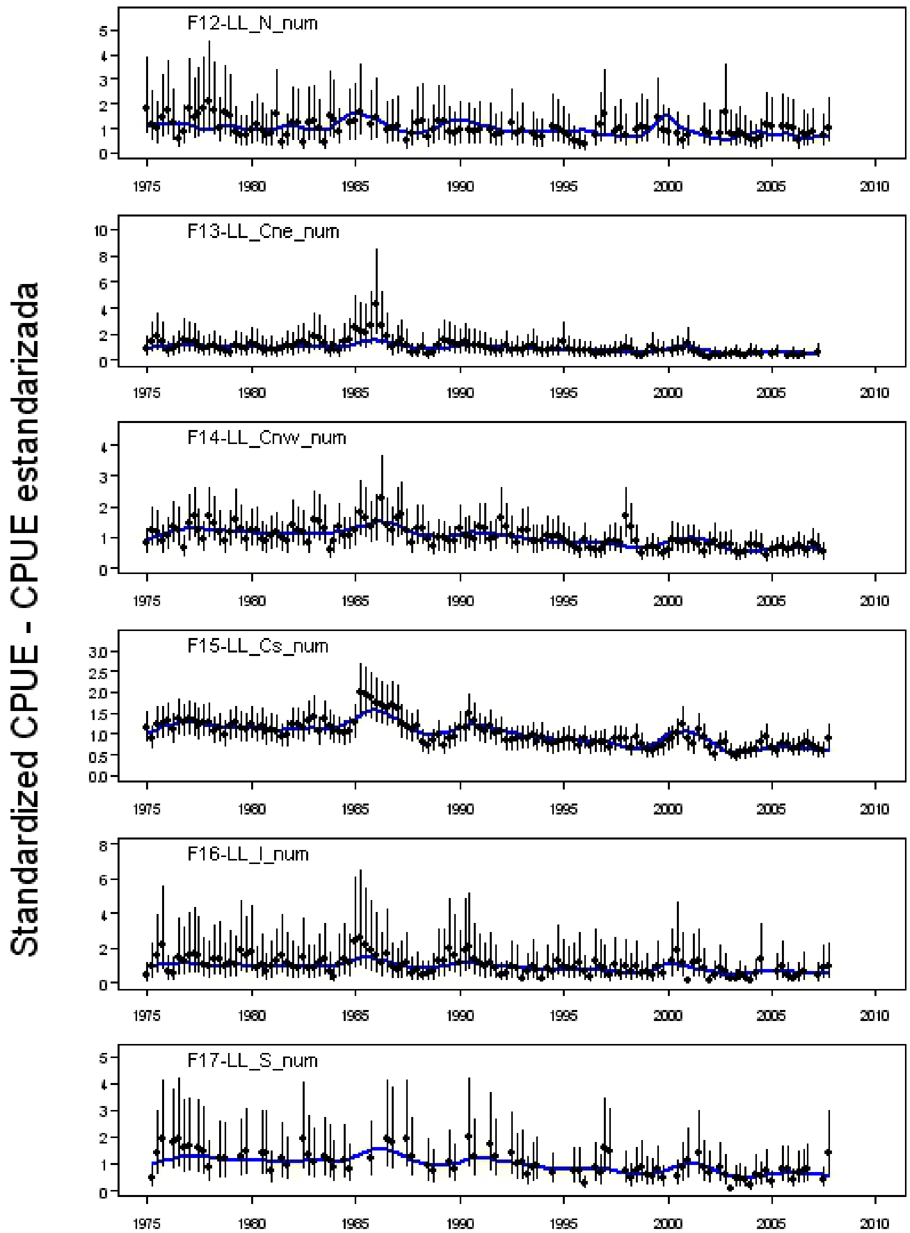

FIGURE 5. Model fit to the CPUE data from the longline fisheries assumed in the sensitivity TreeAnalyses. The longline fisheries are the Northern (N), northeastern Central (Cne), northwestern Central (Cnw), southern Central (Cs), Inshore (I), and Southern (S), respectively (see Figure 2 for spatial definitions).

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Base case (SARM10)

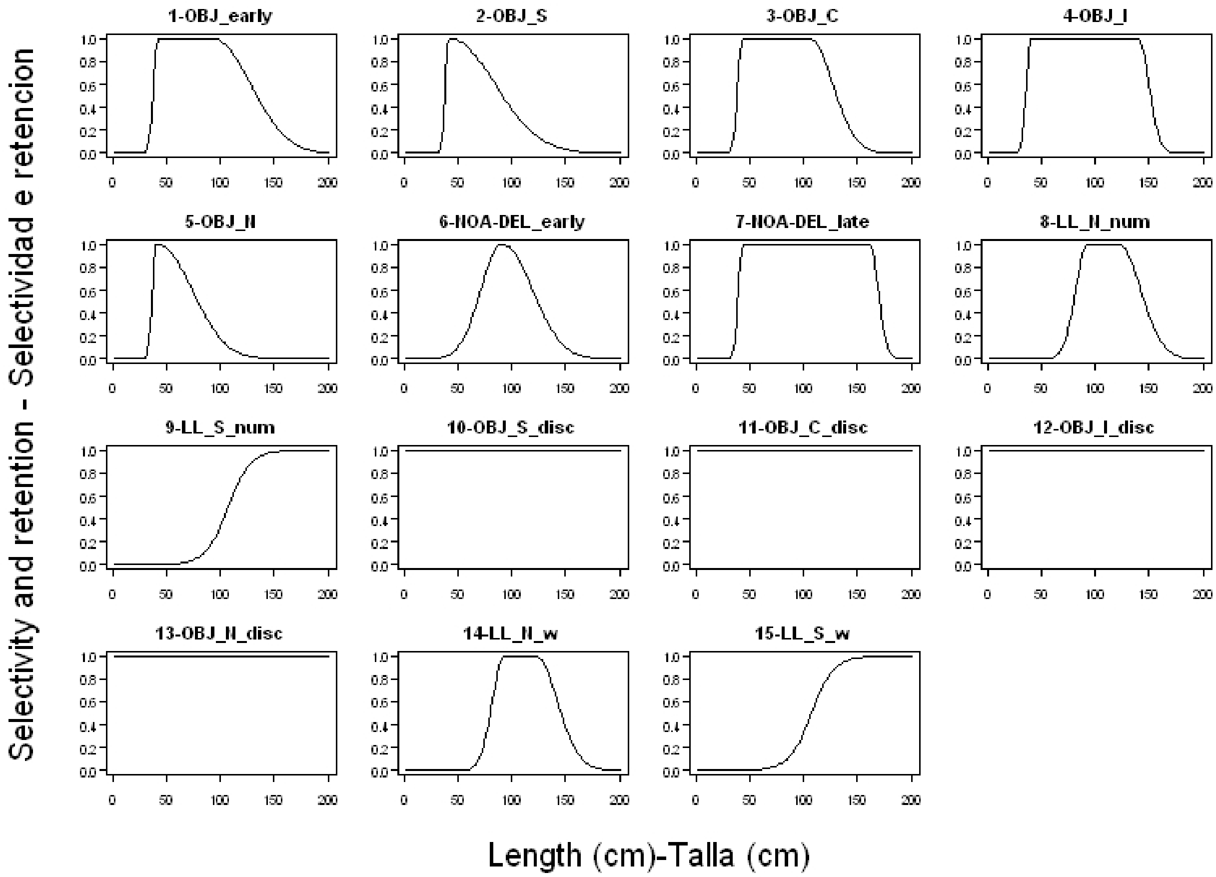

FIGURE 6. Size selectivity curves derived from the base case assessment (Aires-da-Silva and Maunder, 2010).

Sensitivity OBJmethod

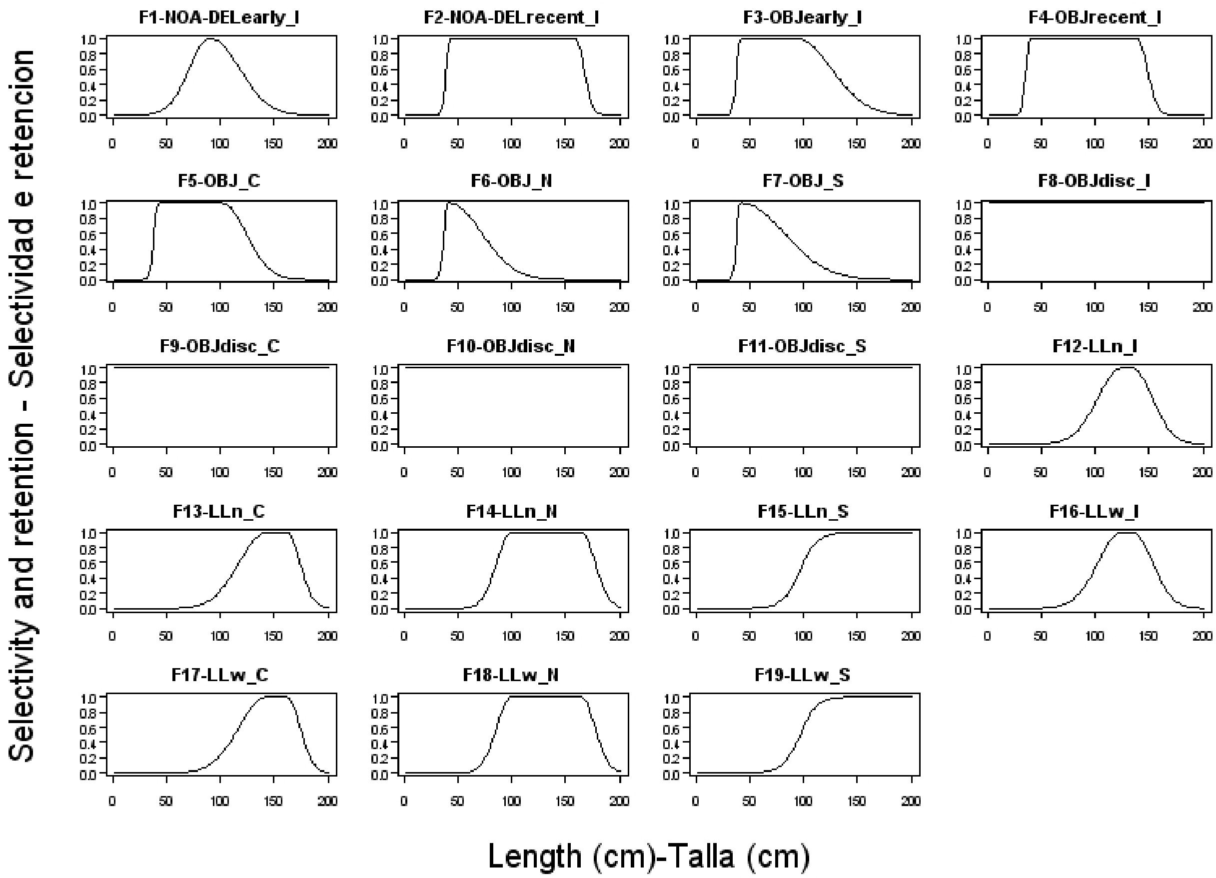

FIGURE 7. Size selectivity curves derived from sensitivity run OBJmethod.

Sensitivity LLtreeAnalyses

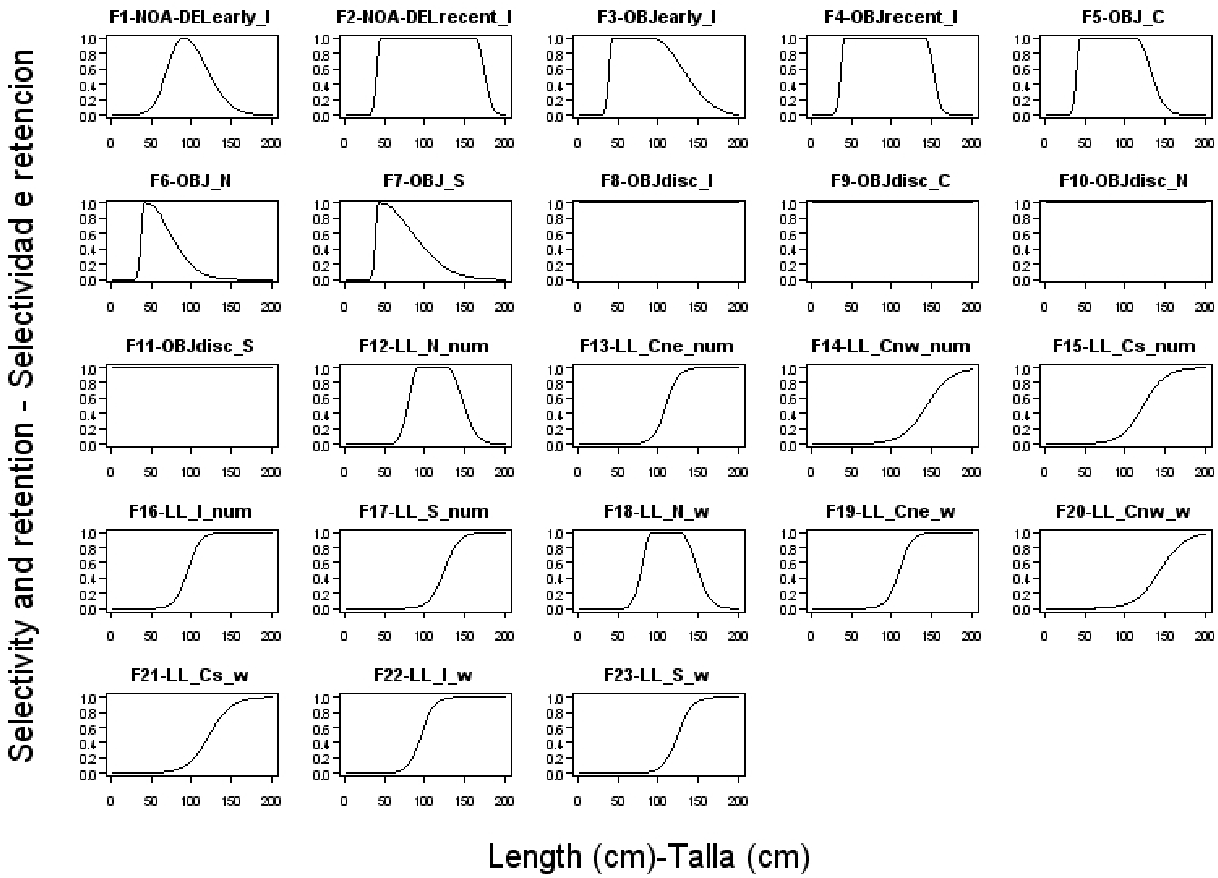

FIGURE 8. Size selectivity curves derived from sensitivity run TreeAnalyses.

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Base case (SARM10)

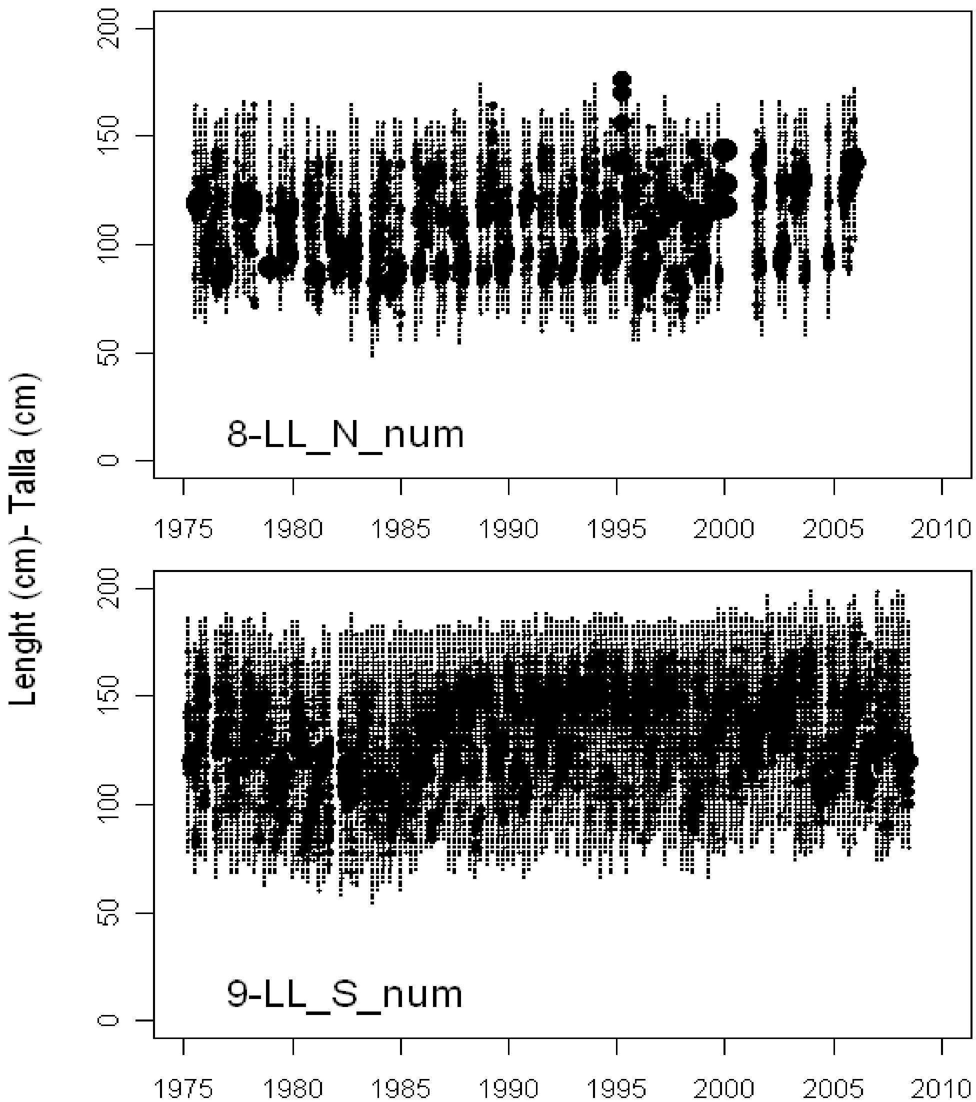

FIGURE 9. Quarterly size compositions of the catches of bigeye tuna taken by the two longline fisheries (top – northern, bottom – southern) assumed in the base case assessment (Aires-da-Silva and Maunder, 2010). The sizes of the circles are proportional to the catches.

Run OBJmethod

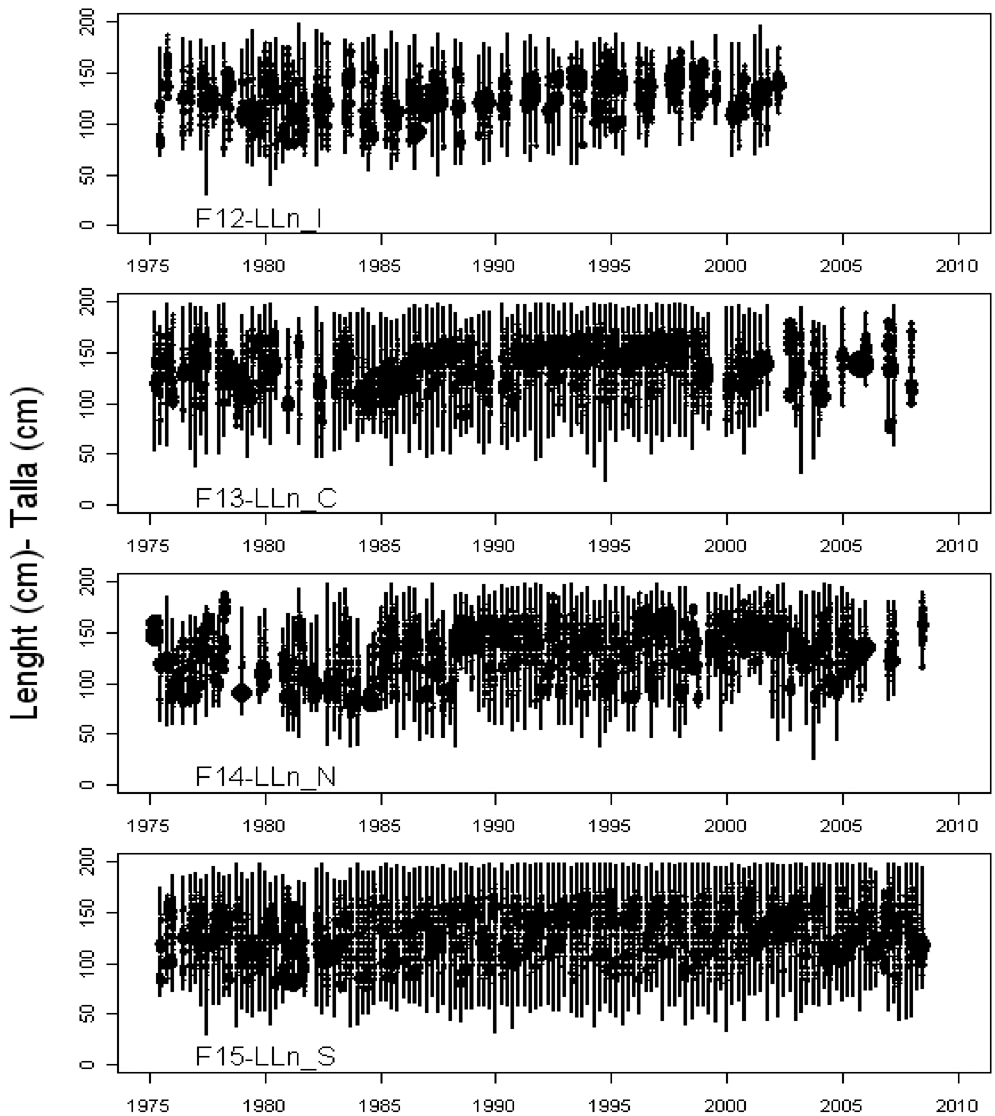

FIGURE 10. Quarterly size compositions of the catches of bigeye tuna taken by the four longline fisheries assumed in the sensitivity run OBJmethod. The longline fisheries are the Inshore (I), Central (C), Northern (N) and Southern (S), respectively (see Figure 2 for spatial definitions). The sizes of the circles are proportional to the catches.

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Run LLtreeAnalyses

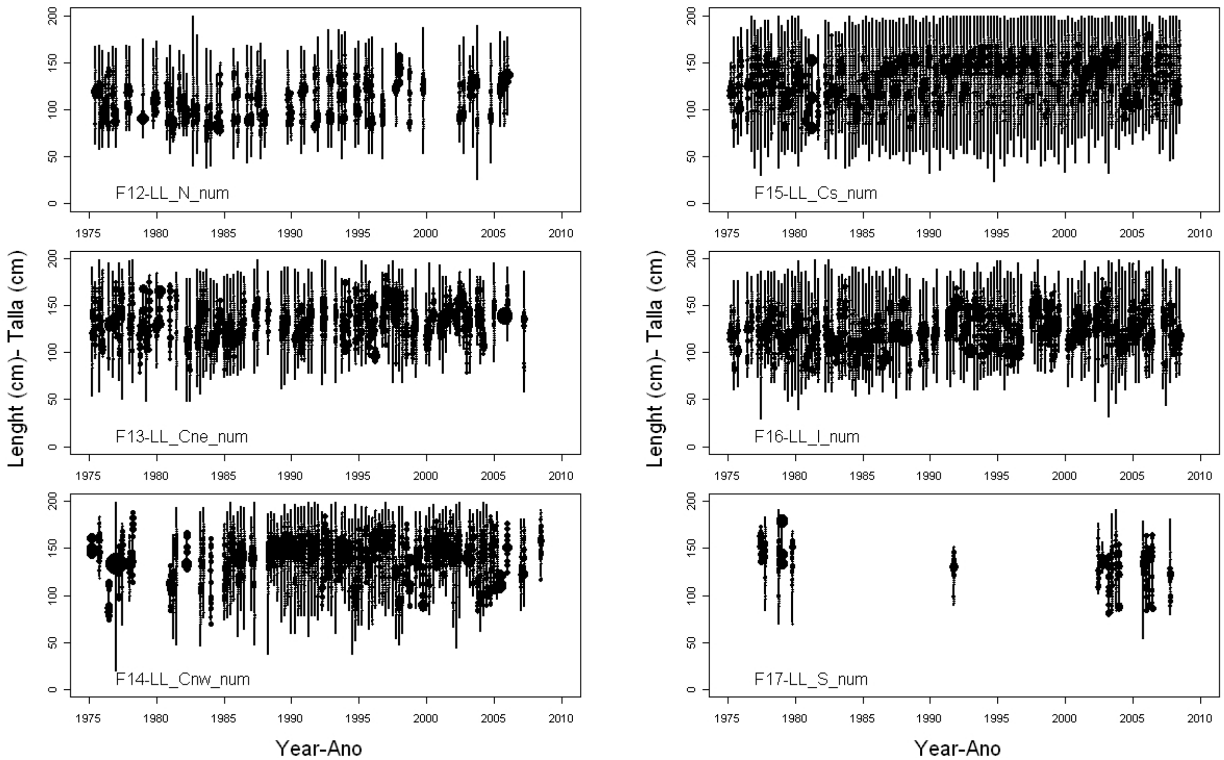

FIGURE 11. Quarterly size compositions of the catches of bigeye tuna taken by the six longline fisheries assumed in the sensitivity run OBJmethod. The longline fisheries are the Northern (N), northeastern Central (Cne), northwestern Central (Cnw), southern Central (Cs), Inshore (I), and Southern (S), respectively (see Figure 2 for spatial definitions). The sizes of the circles are proportional to the catches.

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Base case (SARM10)

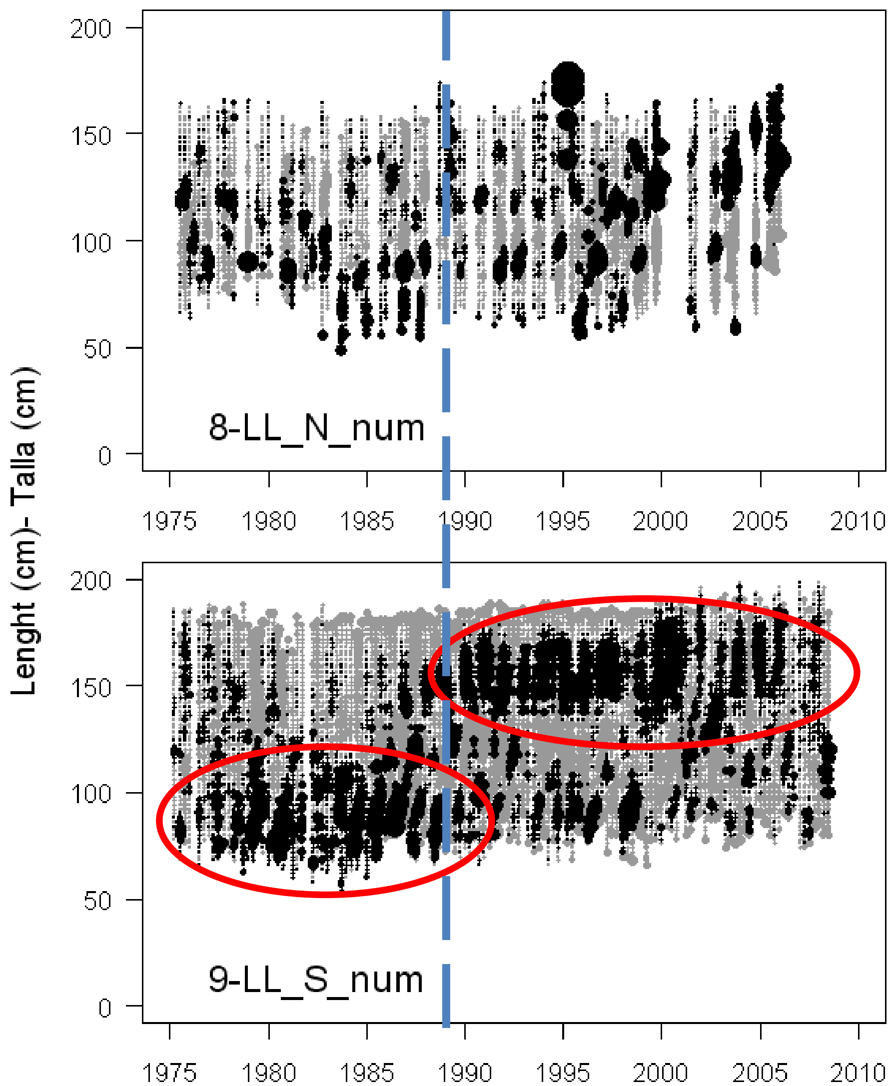

FIGURE 12. Pearson residual plots for the model fits to the length-composition data for the longline fisheries (top – northern, bottom – southern) assumed in the base case assessment (Aires-da-Silva and Maunder, 2009). The gray and black circles represent observations that are lower and higher, respectively, than the model predictions. The sizes of the circles are proportional to the absolute values of the residuals. The oval circles identify clusters of prominent residual pattern. The dashed vertical line indicates what seems to be a change in residual pattern.

Sensitivity OBJmethod

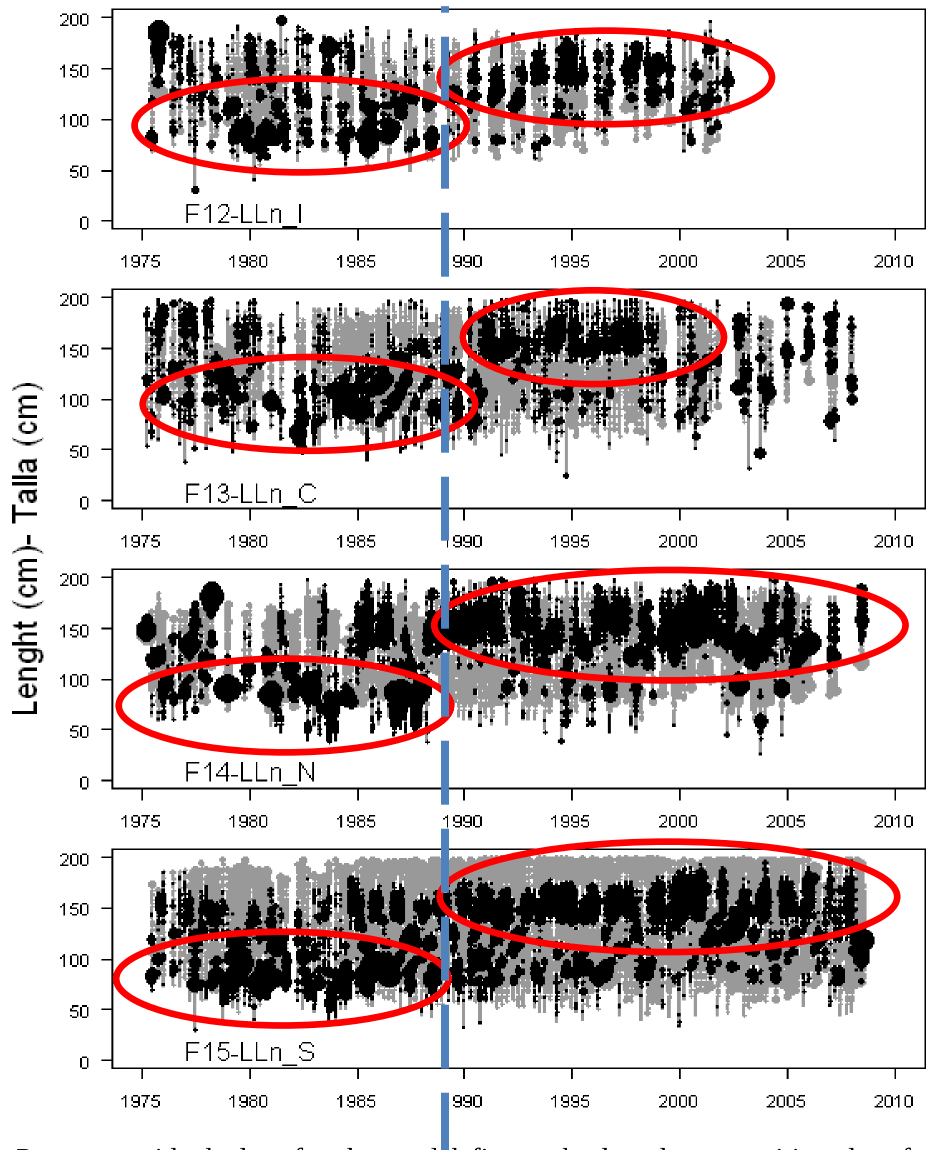

FIGURE 13. Pearson residual plots for the model fits to the length-composition data for the longline fisheries assumed in the sensitivity OBJmethod. The longline fisheries are the Inshore (I), Central (C), Northern (N) and Southern (S), respectively (see Figure 2 for spatial definitions). The gray and black circles represent observations that are lower and higher, respectively, than the model predictions. The sizes of the circles are proportional to the absolute values of the residuals. The oval circles identify clusters of prominent residual pattern. The dashed vertical line indicates what seems to be a change in residual pattern.

Sensitivity LLtreeAnalyses

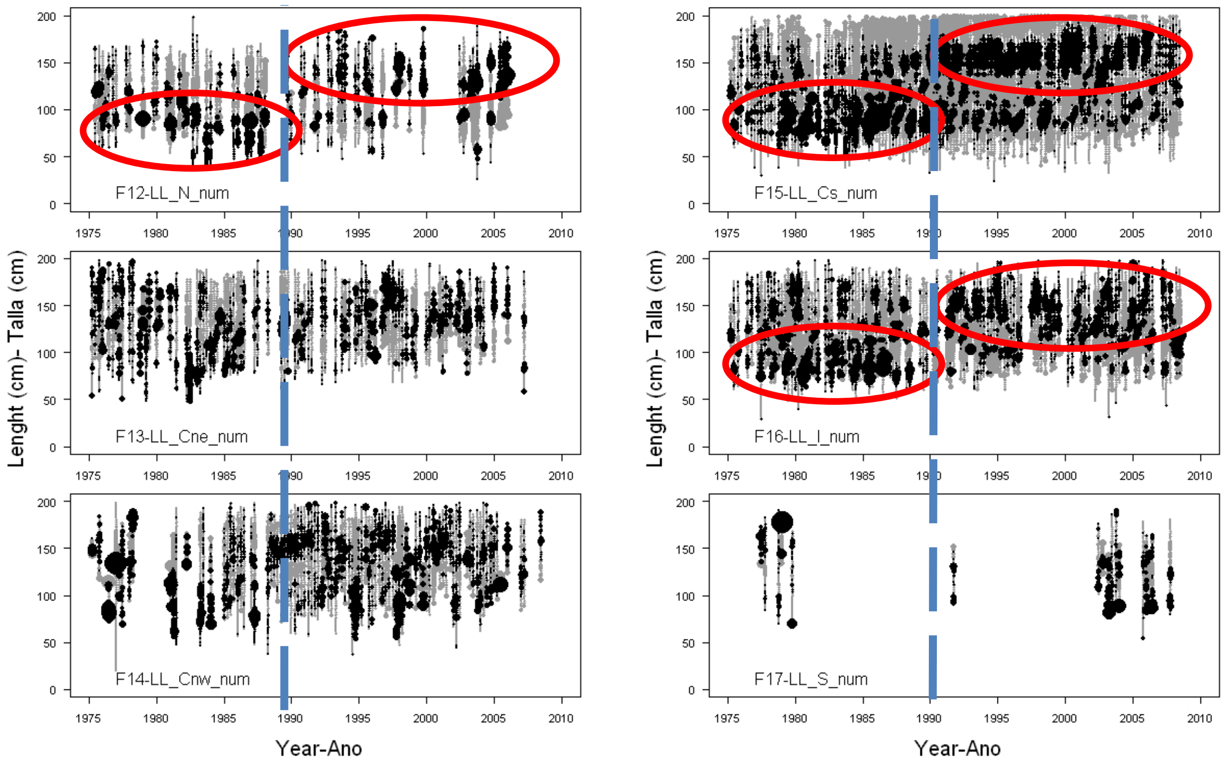

FIGURE 14. Pearson residual plots for the model fits to the length-composition data for the longline fisheries assumed in the sensitivity TreeAnalyses. The longline fisheries are the Northern (N), northeastern Central (Cne), northwestern Central (Cnw), southern Central (Cs), Inshore (I), and Southern (S), respectively (see Figure 2 for spatial definitions). The gray and black circles represent observations that are lower and higher, respectively, than the model predictions. The oval circles identify clusters of prominent residual pattern. The dashed vertical line indicates what seems to be a change in residual pattern.

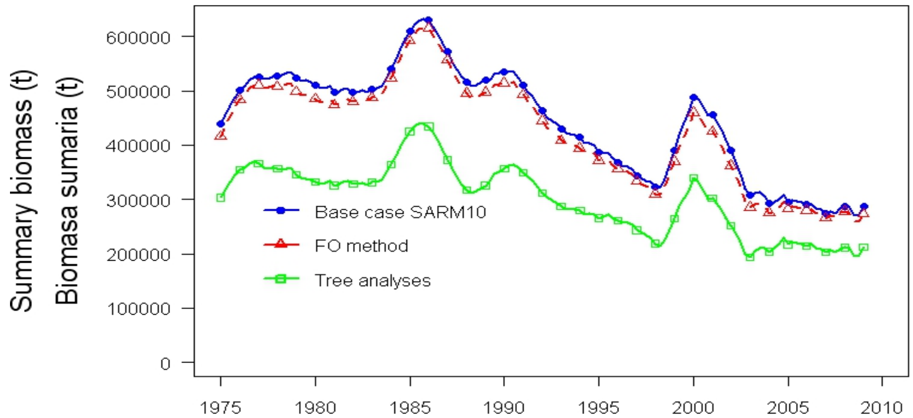

FIGURE 15. Comparison of estimates of biomass of bigeye tuna from the base case model (Aires-da-Silva and Maunder, 2010) and the two sensitivity analyses assuming different longline fishery definitions (OBJmethod and TreeAnalyses).

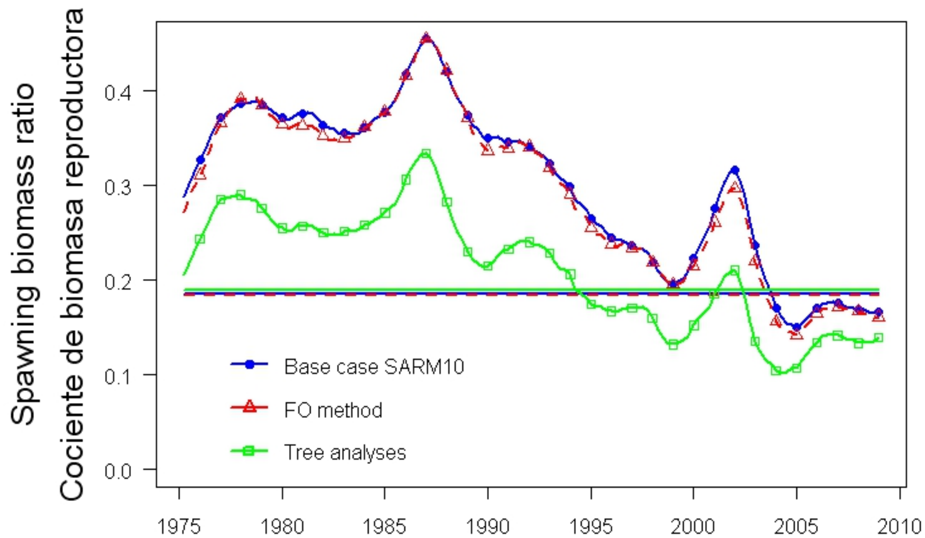

FIGURE 16. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the base case model (Aires-da-Silva and Maunder, 2010) and the two sensitivity analyses assuming different longline fishery definitions (OBJmethod and TreeAnalyses).

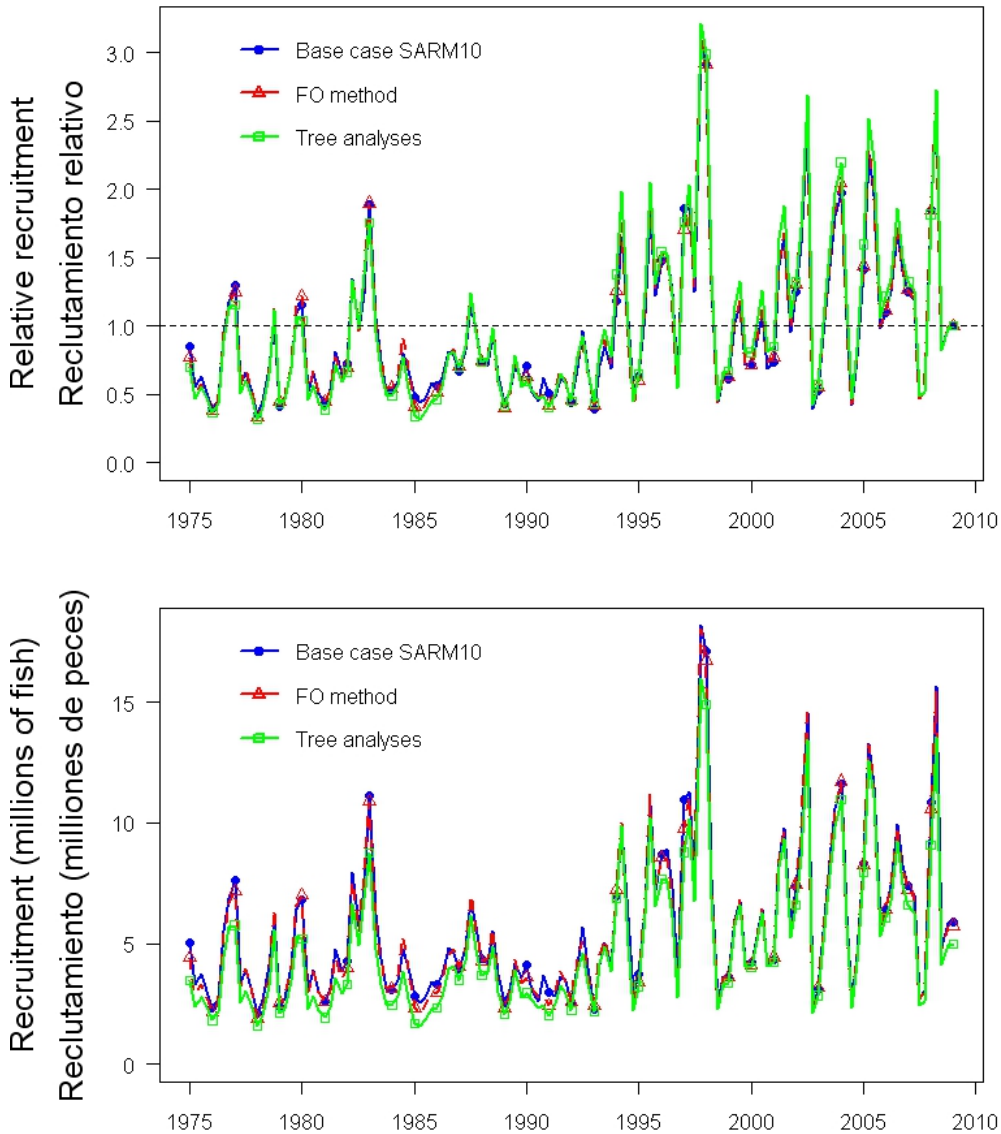

FIGURE 17. Comparison of estimates of recruitment (top – relative, bottom – absolute) of bigeye tuna from the base case model (Aires-da-Silva and Maunder, 2010) and the two sensitivity analyses assuming different longline fishery definitions (OBJmethod and TreeAnalyses).

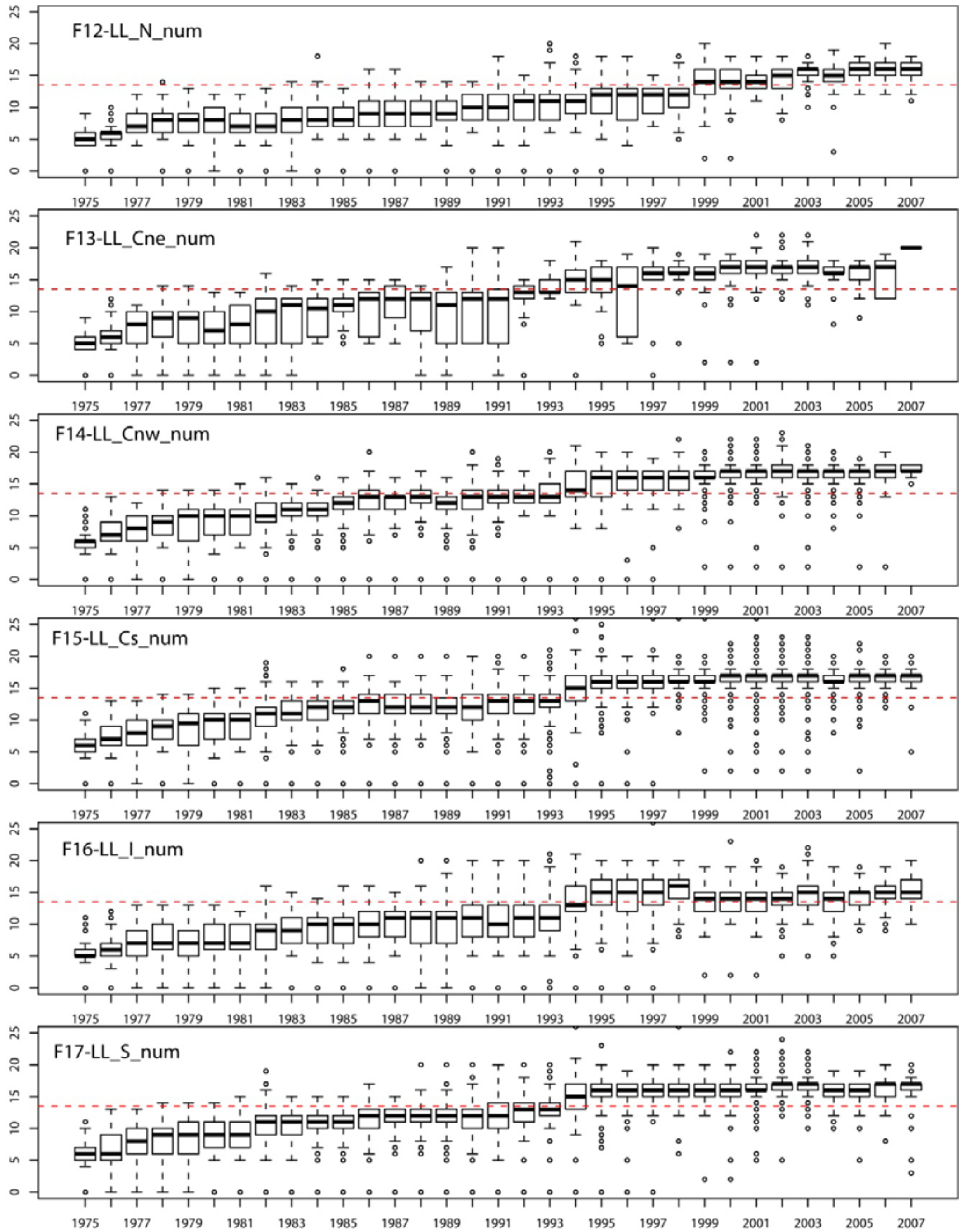

FIGURE 18. Box-whisker plots for hooks per basket deployed by Japanese longliners over time in each of the six regions assumed in the sensitivity TreeAnalyses method (see Figure 2 for spatial definitions).

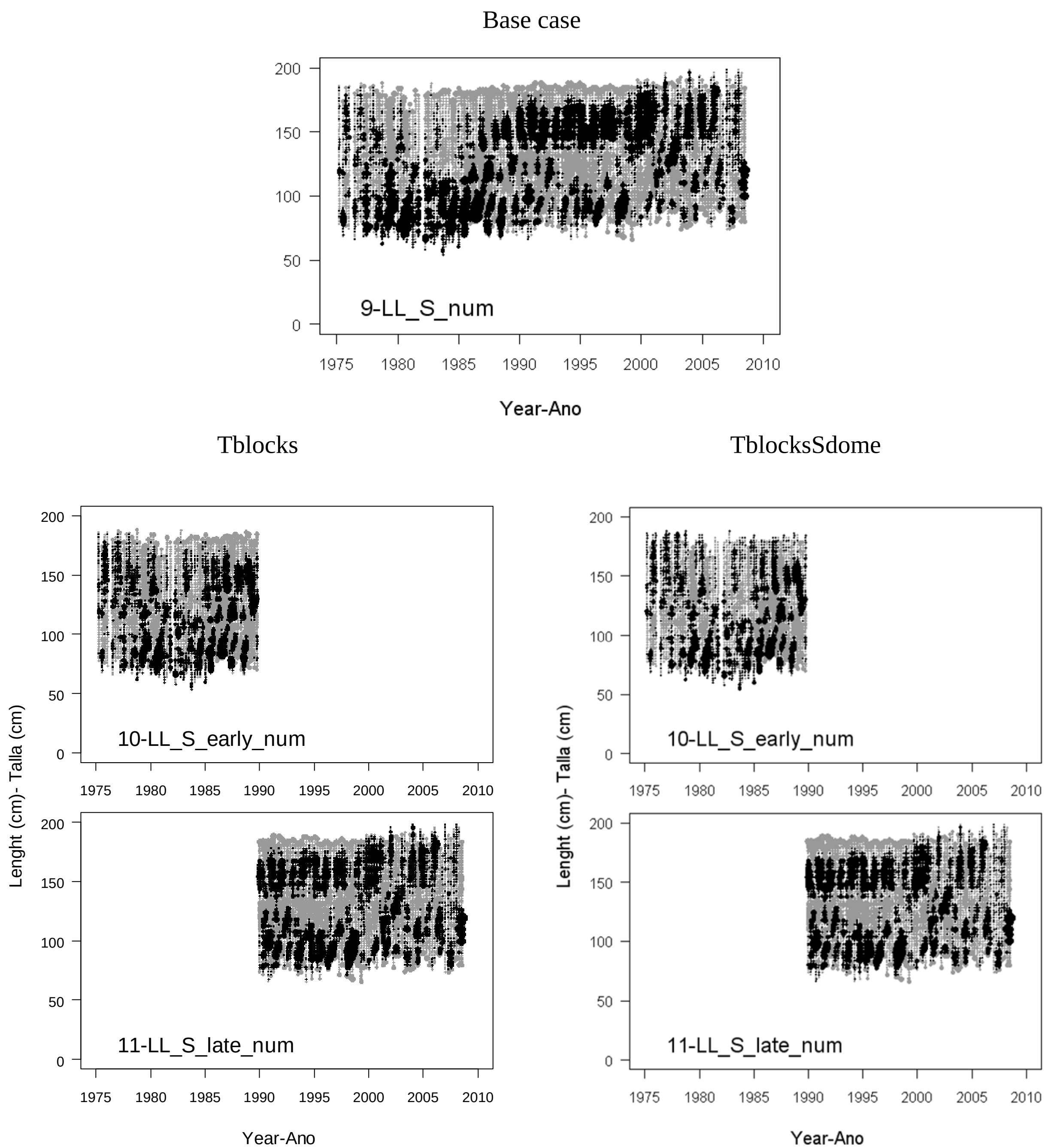

FIGURE 19. Pearson residual plots for the model fits to the southern longline length composition data from the base case and sensitivity analyses assuming two time blocks (pre- and post-1990) of selectivity and catchability for both longline fisheries (southern and northern). Tblocks (left plots) - logistic selectivity for the two periods of the southern longline fishery; TblocksSdome (right plots) - double normal (dome shape) and logistic selectivities for the early and later periods of the southern longline fishery, respectively. These model runs assume von Bertallanfy growth and stepness equals to 1. The gray and black circles represent observations that are lower and higher, respectively, than the model predictions. The sizes of the circles are proportional to the absolute values of the residuals.

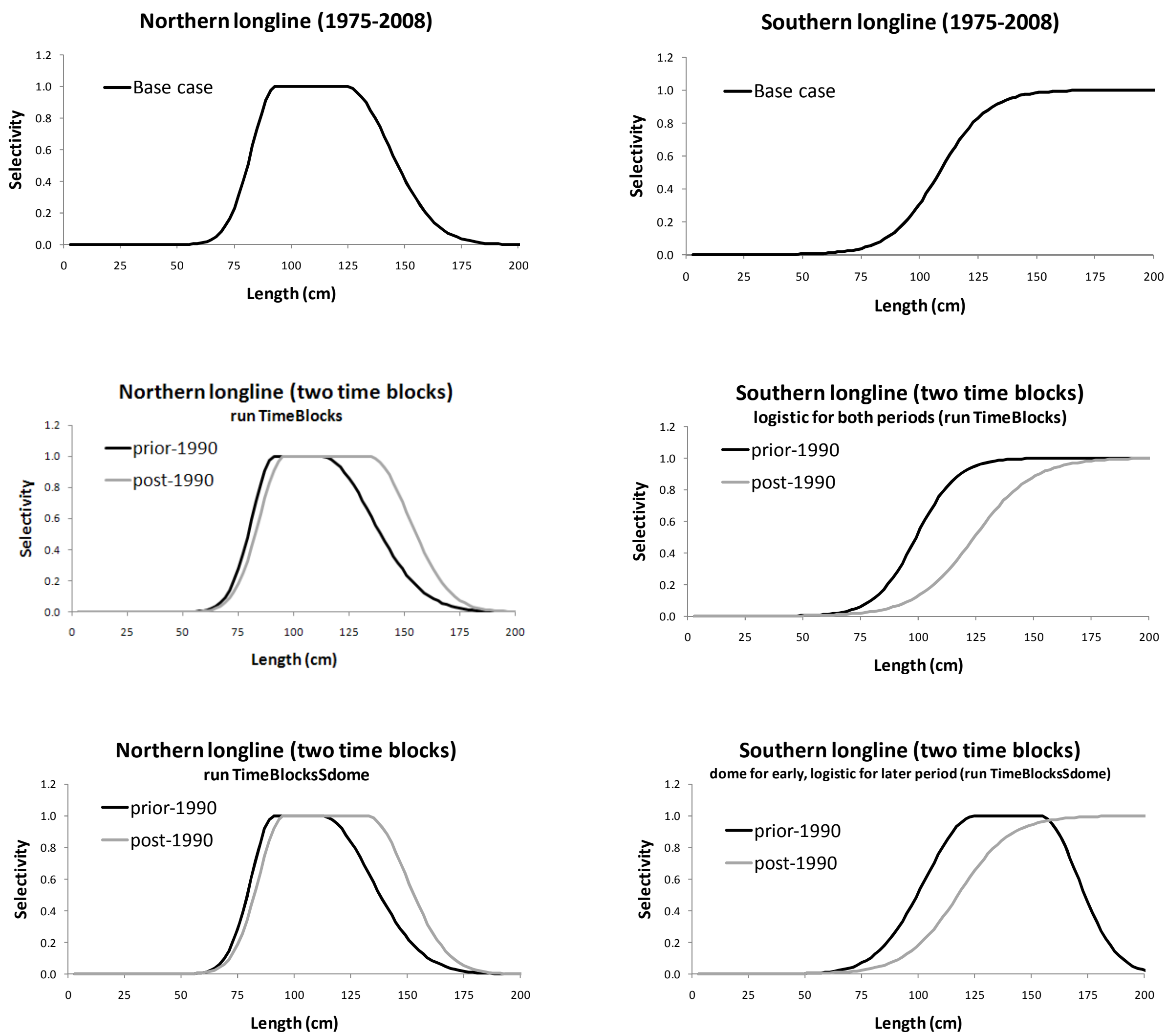

FIGURE 20. Comparison between the longline fishery size selectivities estimated from the base case model (Aires-da-Silva and Maunder, 2010) and two sensitivtiy runs assuming two time blocks (pre- and post-1990) for the northern nad southern longline fisheries: Tblocks - logistic selectivity for the two periods of the southern longline fishery; TblocksSdome - double normal (dome shape) and logistic selectivities for the early and later periods of the southern longline fishery, respectively.

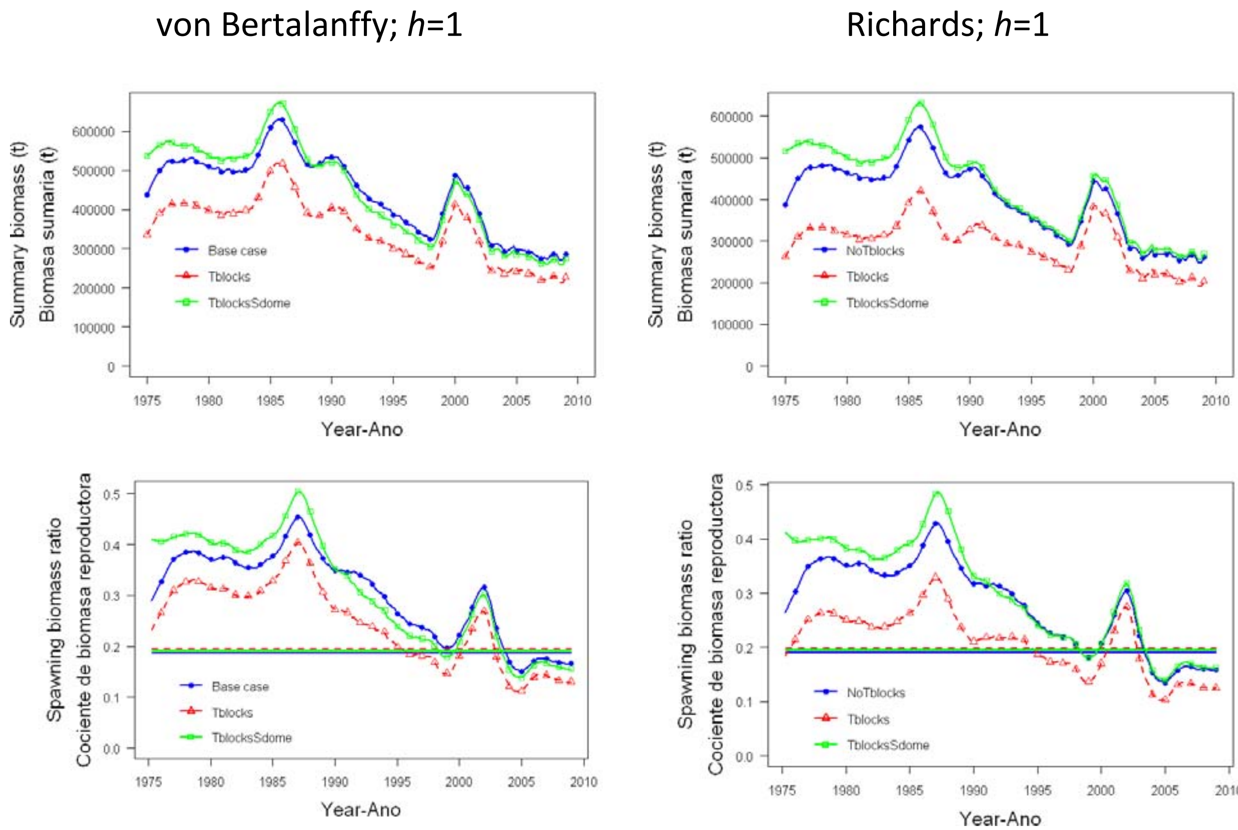

FIGURE 21. Comparison between the estimates of the summary biomass (3+ quarter old fish) and the spawning biomass ratio (SBR, depletion with respect to SSB0) of bigeye tuna from the base case model (Aires-da-Silva and Maunder, 2010), and the two sensitivity analyses assuming two time blocks for the longline fisheries. The models presented assume von Bertalanffy (left plots) or Richards (right plots) growth and steepness (*h*) of 1.

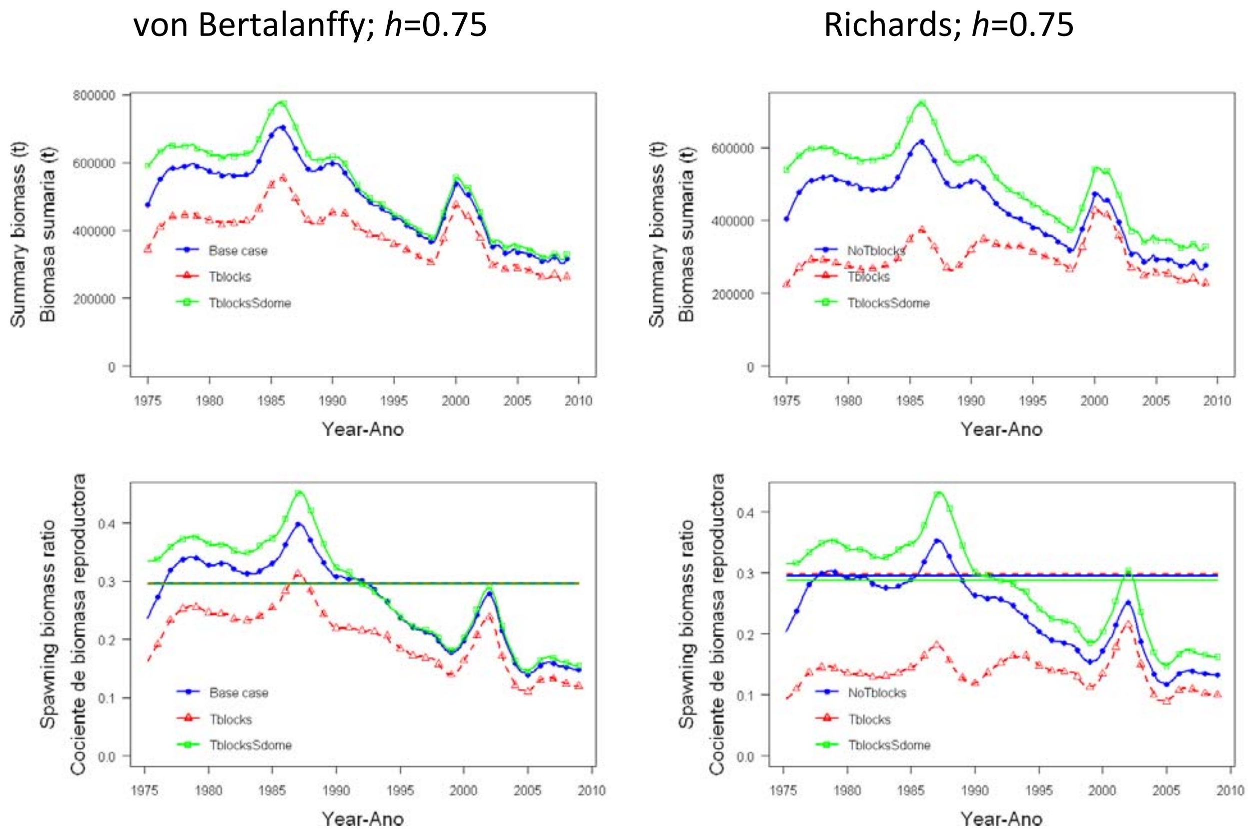

FIGURE 22. Comparison between the estimates of the summary biomass (3+ quarter old fish) and the spawning biomass ratio (SBR, depletion with respect to SSB0) of bigeye tuna from the base case model (Aires-da-Silva and Maunder, 2010), and the two sensitivity analyses assuming two time blocks for the longline fisheries. The models presented assume von Bertalanffy (left plots) or Richards (right plots) growth and steepness (*h*) of 0.75.

von Bertalanffy; *h*=1 Richards; *h*=1

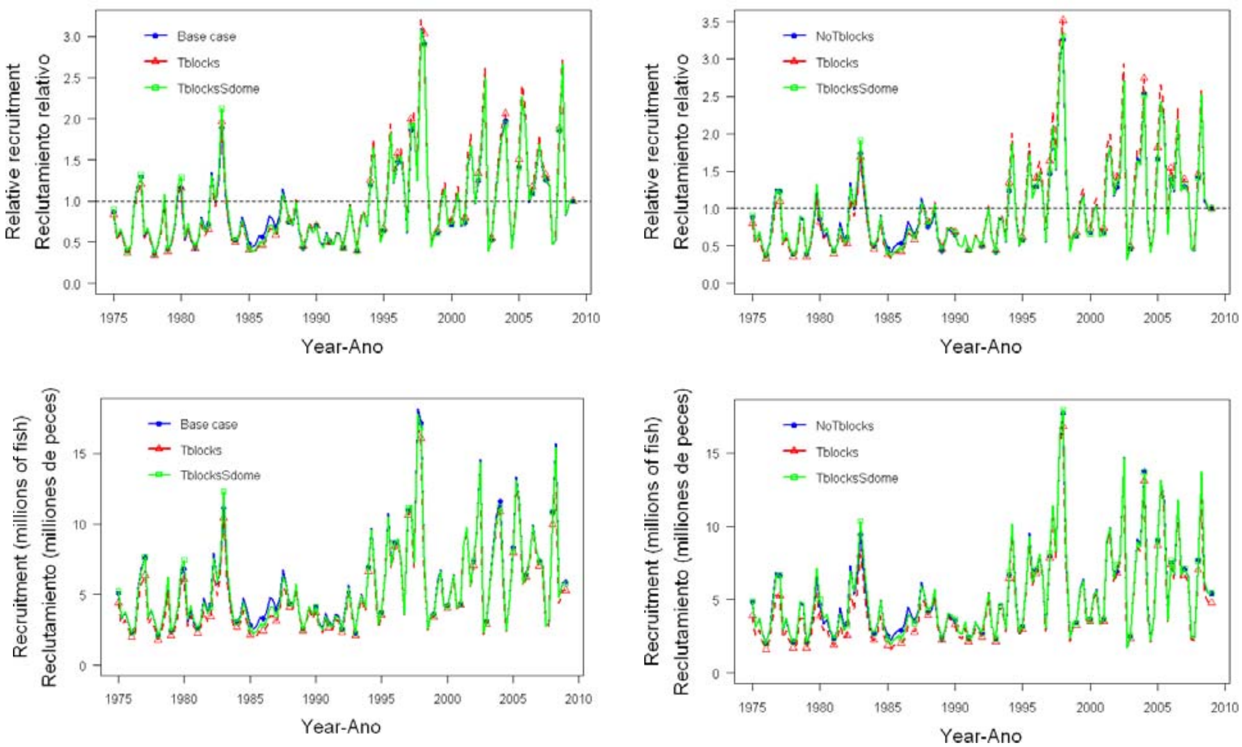

FIGURE 23. Comparison between the estimates of recruitment (top – relative, bottom – absolute) of bigeye tuna from the base case model (Aires-da-Silva and Maunder, 2010), and the two sensitivity analyses assuming two time blocks for the longline fisheries. The models presented assume von Bertalanffy (left plots) or Richards (right plots) growth and steepness (*h*) of 1.

von Bertalanffy; *h*=0.75 Richards; *h*=0.75

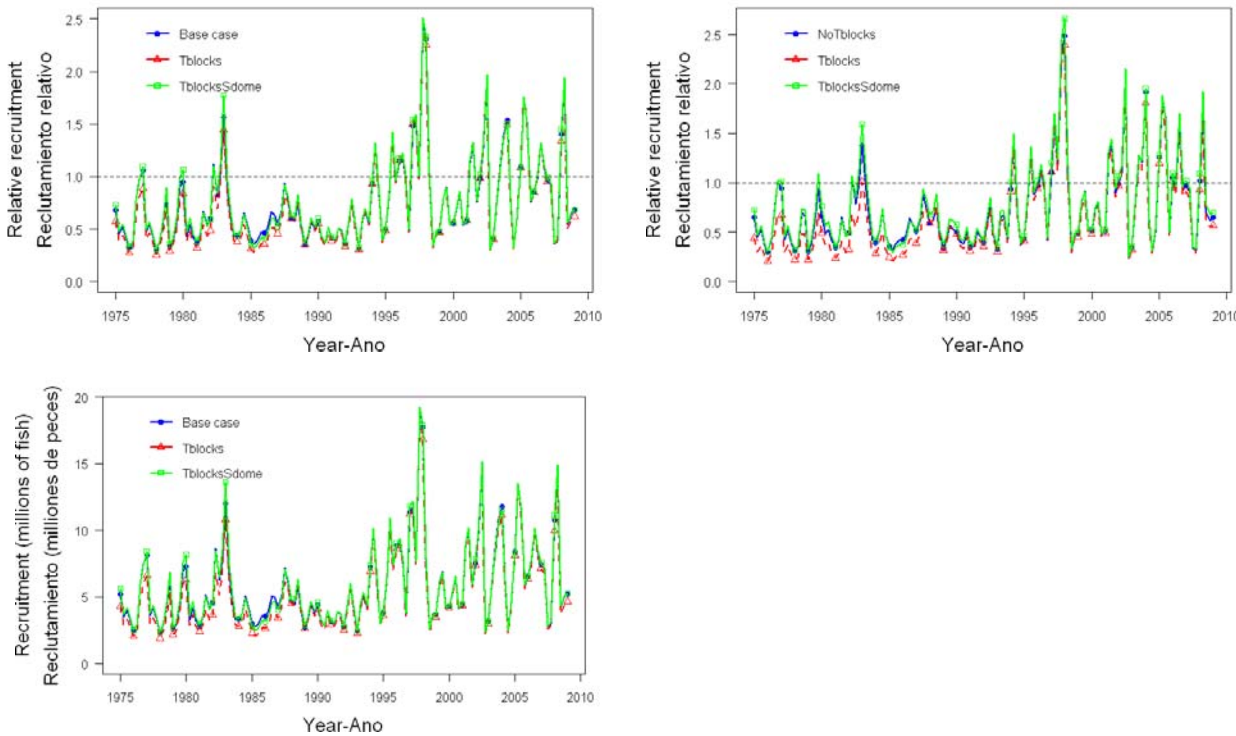

FIGURE 24. Comparison of estimates of recruitment (top – relative, bottom – absolute) of bigeye tuna from the base case model (Aires-da-Silva and Maunder, 2010), and the two sensitivity analyses assuming two time blocks for the longline fisheries. The models presented assume von Bertalanffy (left plots) or Richards (right plots) growth and steepness (*h*) of 1.

TABLE 1. Fishery definitions taken in different bigeye stock assessment model runs: base case (Aires-da-Silva and Maunder, 2010), same floating object fishery definitions applied to longline fisheries (OBJ method), and a new longline fishery definition derived from regression tree analyses with longline length composition data and CPUE trends to investigate the bigeye stock structure in the EPO (tree analyses method).

Base case (A&M, 2010)	OBJ method	Tree analyses
F1-OBJ_early	F1-NOA-DELearly_I	F1-NOA-DELearly_I
F2-OBJ_S	F2-NOA-DELrecent_I	F2-NOA-DELrecent_I
F3-OBJ_C	F3-OBJearly_I	F3-OBJearly_I
F4-OBJ_I	F4-OBJrecent_I	F4-OBJrecent_I
F5-OBJ_N	F5-OBJ_C	F5-OBJ_C
F6-NOA-DEL_early	F6-OBJ_N	F6-OBJ_N
F7-NOA-DEL_late	F7-OBJ_S	F7-OBJ_S
F8-LL_N_num	F8-OBJdisc_I	F8-OBJdisc_I
F9-LL_S_num	F9-OBJdisc_C	F9-OBJdisc_C
F10-OBJ_S_disc	F10-OBJdisc_N	F10-OBJdisc_N
F11-OBJ_C_disc	F11-OBJdisc_S	F11-OBJdisc_S
F12-OBJ_I_disc	F12-LLn_I	F12-LL_N_num
F13-OBJ_N_disc	F13- LLn_C	F13-LL_Cne_num
F14-LL_N_w	F14-LLn_N	F14-LL_Cnw_num
F15-LL_S_w	F15-LLn_S	F15-LL_Cs_num
	F16-LLw_I	F16-LL_I_num
	F17- LLw_C	F17-LL_S_num
	F18-LLw_N	F18-LL_N_w
	F19-LLw_S	F19-LL_Cne_w
		F20-LL_Cnw_w
		F21-LL_Cs_w
		F22-LL_I_w
		F23-LL_S_w

TABLE 2. Negative log-likelihood components obtained from the sensitivity analyses assuming alternative longline fishery definitions: base case (Aires-da-Silva and Maunder, 2010), same floating object fishery definitions applied to longline fisheries (OBJ method), and longline fishery definition derived from tree analyses on bigeye longline size composition data and CPUE trends (regression tree analyses method).

Data	Base case (A&M, 2010)	OBJmethod	TreeAnalyses
TOTAL	1656.33	1712.13	1556.47
Catch	0.00	0.00	0.01
Equil_catch	0.00	0.00	0.00
Survey	-269.00	-403.74	-552.13
Length_comp	1648.17	1840.13	1829.42
Age_comp	307.62	309.39	306.57
Recruitment	-30.46	-33.66	-27.42

TABLE 3. MSY related quantities from the sensitivity analyses assuming alternative longline fishery definitions: base case (Aires-da-Silva and Maunder, 2010), same floating object fishery definitions applied to the longline fisheries (sensitivity OBJmethod), and longline fishery definitions derived from tree analyses on bigeye longline size composition data and CPUE trends (sensitivity TreeAnalyses).

quant	Base case (A&M, 2010)	OBJ method	Tree analyses
msy	83,605	81,711	71,197
Bmsy	289,409	279,775	247,503
Smsy	60,612	58,237	52,010
Bmsy/Bzero	0.25	0.24	0.25
Smsy/Szero	0.19	0.18	0.19
Crecent/msy	1.19	1.24	1.19
Brecent/Bmsy	0.99	0.98	0.86
Srecent/Smsy	0.89	0.88	0.74
Fmultiplier	0.80	0.79	0.69

TABLE 4. Negative log-likelihood components obtained from the sensitivity analyses using two time blocks of catchability and selectivity for the longline fisheries. Two models were build: Tblocks – two time blocks (pre- and post-1990), logistic selectivity for the two periods of the southern longline fishery; TblocksSdome; two time blocks (pre- and post-1990), double normal (dome shape) and logistic selectivities for the early and later periods of the southern longline fishery, respectively. Results from the two models are shown for two assumptions on growth (von Bertalanffy and Richards) and the steepness parameter of the stock recruitment relationship (*h*=1 and *h*=0.75). For comparative purposes, runs are also presented assuming no time blocks (NoTblocks) as in the base case model (Aires-da-Silva and Maunder, 2010).

***h* =1**

	VON BERTALANFFY			**RICHARDS**		
Data	Base Case-NoTblocks	Tblocks	TblocksSdome	NoTblocks	Tblocks	TblocksSdome
TOTAL	1656.33	1612.86	1595.57	1564.75	1520.57	1489.67
Catch	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
Survey	-269.00	-277.97	-281.41	-274.05	-278.89	-290.43
Length_comp	1648.17	1611.04	1600.57	1576.34	1531.47	1518.75
Age_comp	307.62	303.90	305.14	288.48	285.00	285.26
Recruitment	-30.46	-24.13	-28.75	-26.04	-17.01	-23.92

***h* =0.75**

	VON BERTALANFFY			**RICHARDS**		
Data	NoTblocks	Tblocks	TblockSdome	NoTblocks	Tblocks	TblocksSdome
TOTAL	1666.28	1625.57	1605.56	1573.71	1530.52	1498.23
Catch	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
Survey	-269.21	-275.66	-281.31	-274.94	-273.49	-291.35
Length_comp	1650.89	1611.08	1603.31	1576.19	1527.58	1522.42
Age_comp	309.64	307.08	307.75	291.12	286.01	287.01
Recruitment	-25.29	-16.94	-24.21	-18.90	-9.59	-19.86

TABLE 5. MSY related quantities obtained from the sensitivity analyses using two time blocks of catchability and selectivity for the longline fisheries. Two models were build: Tblocks – two time blocks (pre- and post-1990), logistic selectivity for the two periods of the southern longline fishery; TblocksSdome; two time blocks (pre- and post-1990), double normal (dome shape) and logistic selectivities for the early and later periods of the southern longline fishery, respectively. Results from the two models are shown for two assumptions on growth (von Bertalanffy and Richards) and the steepness parameter of the stock recruitment relationship (*h*=1 and *h*=0.75). For comparative purposes, runs are also presented assuming no time blocks (NoTblocks) as in the base case model (Aires-da-Silva and Maunder, 2010).

***h* =1**

	VON BERTALANFFY			RICHARDS		
Quantity	Base Case-NoTblocks	Tblocks	TblocksSdome	NoTblocks	Tblocks	TblocksSdome
msy	83,605	81,450	84,792	79,578	76,333	80,636
Bmsy	289,409	277,863	294,770	280,013	262,713	289,466
Smsy	60,612	57,353	61,670	60,572	56,189	63,516
Bmsy/Bzero	0.25	0.26	0.25	0.25	0.26	0.25
Smsy/Szero	0.19	0.20	0.19	0.19	0.20	0.20
Crecent/msy	1.19	1.22	1.17	1.25	1.30	1.23
Brecent/Bmsy	0.99	0.82	0.93	0.93	0.78	0.93
Srecent/Smsy	0.89	0.67	0.82	0.83	0.63	0.83
Fmultiplier	0.80	0.67	0.76	0.75	0.62	0.75

***h* =0.75**

	VON BERTALANFFY			RICHARDS		
Quantity	NoTblocks	Tblocks	TblocksSdome	NoTblocks	Tblocks	TblockSdome
msy	81,979	84,054	82,199	82,188	86,996	66,170
Bmsy	525,113	514,672	524,141	521,549	531,585	490,224
Smsy	125,848	122,221	125,540	128,874	130,063	123,604
Bmsy/Bzero	0.34	0.34	0.34	0.34	0.35	0.32
Smsy/Szero	0.30	0.30	0.29	0.30	0.30	0.29
Crecent/msy	1.21	1.18	1.21	1.21	1.14	1.50
Brecent/Bmsy	0.60	0.51	0.63	0.49	0.43	0.67
Srecent/Smsy	0.50	0.41	0.53	0.40	0.33	0.56
Fmultiplier	0.49	0.47	0.54	0.46	0.42	0.50