INTER-AMERICAN TROPICAL TUNA COMMISSION

SCIENTIFIC ADVISORY COMMITTEE

SEVENTH MEETING

La Jolla, California (USA)
09-13 May 2016

DOCUMENT SAC-07-05b

STATUS OF YELLOWFIN TUNA IN THE EASTERN PACIFIC OCEAN IN 2015 AND OUTLOOK FOR THE FUTURE

Carolina V. Minte-Vera, Alexandre Aires-Da-Silva, and Mark N. Maunder

CONTENTS

EXECUTIVE SUMMARY

1. The assessment of yellowfin tuna in the eastern Pacific Ocean in 2015 is similar to the previous assessment, except that separate series of length-frequency data for Japanese longline commercial and training vessels are now available, and both were used in the assessment.
2. There is uncertainty about recent and future levels of recruitment and biomass. There have been two, and possibly three, different productivity regimes since 1975, and the levels of maximum sustainable yield (MSY) and the biomasses corresponding to the MSY may differ among the regimes. The population may have switched in the last ten years from a high to an intermediate productivity regime. The spawning biomass ratio (SBR) has been below average since 2006, with the exception of 2008-2010, which resulted from a high recruitment in 2006.
3. The recent fishing mortality rates (*F*) are slightly below the MSY level (*F*mult = 1.02), and the recent levels of spawning biomass (*S*) are estimated to be below that level (S_{recent}/S_{MSY} = 0.95). As noted in IATTC Stock Assessment Report 16 and previous assessments, these interpretations are uncertain, and highly sensitive to the assumptions made about the steepness parameter (*h*) of the stock-recruitment relationship, the average size of the older fish (L_2), and the assumed levels of natural mortality (*M*). The results are more pessimistic if a stock-recruitment relationship is assumed, if a higher value is assumed for L_2, and if lower rates of *M* are assumed for adult yellowfin. A likelihood profile on the virgin recruitment (R_0) parameter showed that data components diverge on their information about abundance levels. Sensitivity analyses indicated that the results are more pessimistic if the weighting assigned to length-frequency data is changed, using recommended data weighting methods, and more optimistic if the model is fitted closely to the index of relative abundance based on the catch per unit of effort (CPUE) of the northern dolphin-associated purse-seine fishery rather than of the southern longline fishery.
4. The highest fishing mortality (*F*) has been on fish aged 11-20 quarters (2.75-5 years). The average annual *F* has been increasing for all age classes since 2009, but in 2015 it showed a slight decline for the 11-20 quarter age group.
5. Increasing the average weight of the yellowfin caught could increase the MSY.
6. The following topics should be a priority in future research for improving the yellowfin stock assessment:
    a. Implementation of a large-scale tagging program to address hypotheses about stock structure and regional differences in life-history parameters and depletion.
    b. Improved estimates of growth, particularly for older fish.
    c. Weighting of the different data sets that are fitted to the assessment model.
    d. Refinement of fisheries definitions within the assessment model.
    e. Implementation of time-variant selectivity, mainly for the purse-seine fisheries on floating objects.
    f. Exploration of alternative assumptions about stock structure within the assessment model.
    g. Analysis of changes in spatial distribution of effort for the Southern longline fishery, and whether they invalidate the use of the CPUE of this fishery as the main abundance index in the assessment model.

1. INTRODUCTION

Yellowfin tuna (*Thunnus albacares*) are distributed across the Pacific Ocean, but the bulk of the catch is made in the eastern and western regions. Purse-seine catches of yellowfin are relatively low in the vicinity of the western boundary of the eastern Pacific Ocean (EPO) at 150°W. The majority of the catch in the EPO is taken in purse-seine sets on yellowfin associated with dolphins and in unassociated schools. Tagging studies of yellowfin throughout the Pacific indicate that the fish tend to stay within 1800 km of their release positions. This regional fidelity, along with the geographic variation in phenotypic and genotypic characteristics of yellowfin shown in some studies, suggests that there might be multiple stocks of yellowfin in the EPO and throughout the Pacific Ocean. This is consistent with the fact that longline catch-per-unit-of-effort (CPUE) trends differ among areas in the EPO. However, movement rates between these stocks, as well as across the 150°W meridian, cannot be estimated with currently-available tagging data.

2. DATA

The stock assessment requires substantial amounts of information, including data on retained catches, discards, indices of abundance, and the size compositions of the catches of the various fisheries. Assumptions have been made about processes such as growth, recruitment, movement, natural mortality (*M*), fishing mortality (*F*), and stock structure. The assessment for 2016 is similar to that of 2015, and includes new and updated data. The major change was in the length-frequency data for the Japanese longline fleet, which are now available for commercial vessels and training vessels separately and by measurement type (weight or length) for 1975-2014 (Satoh *et al.* 2016). Weight-frequency data for the commercial longline fleet are also available, but they are not used in the assessment due to uncertainty in the conversion factors. A detailed description of these newly-submitted data and recommendations for their best use in the bigeye and yellowfin assessments is provided by Minte-Vera *et al*. (2016).

The catch data for the surface fisheries have been updated and new data added for 2015. New or updated longline catch data are available for China (2014), Japan (2013-2014), Korea (2006, 2014), Chinese Taipei (2012-2014), the United States (2013-2014), French Polynesia (2013-2014), Vanuatu (2007-2014), and other nations (2013-2015). For longline fisheries with no catch data for 2013-2015, catches were assumed to be the same as in the most recent year with available data. Surface fishery CPUE data were updated, and new CPUE data added for 2015. New or updated CPUE data are available for the Japanese longline fleet for the whole period of the assessment model (1975-2015). Japan has submitted detailed catch and effort data (including hooks-per-basket information) for the commercial vessels only, excluding training vessel data. New surface-fishery size-composition data for 2015 were added, and data for previous years were updated. New or updated length-frequency data are available for the Japanese commercial longline fleet (1986-2014). Weight frequency data are also available for the Japanese commercial longline fleet, but they are not used in the assessment due to uncertainty in the length-weight relationship. Longline size-frequency data for Japanese training vessels (1975-2014) are available separately for the first time.

3. MODEL STRUCTURE CONFIGURATIONS

An integrated statistical age-structured stock assessment model (Stock Synthesis Version 3.23b; SS) was used in the assessment, which is based on the assumption that there is a single stock of yellowfin in the EPO. This model is similar to that used in the previous assessment in 2015 (Stock Assessment Report 16), except that it now includes longline "surveys[1]". The length-composition data for the Japanese training

[1] Stock Synthesis terminology; does not represent actual surveys, but allows flexibility in how the data is modelled

vessels and the weight-composition data for the Japanese commercial vessels (not used in the model fit but included for comparative purposes), are included in the model as "surveys ", not fisheries (Minte-Vera et al. 2016). There are now 16 fisheries and two surveys defined in the model (Table 1, Figure 1). A full description of the model can be found in Aires-da-Silva and Maunder (2012a).

There is uncertainty in the results of the current stock assessment, because the observed data do not perfectly represent the population of yellowfin in the EPO. Also, the stock assessment model does not perfectly represent the dynamics of the yellowfin population, nor of the fisheries that operate in the EPO. Uncertainty is expressed as approximate confidence intervals and coefficients of variation (CVs). The confidence intervals and CVs have been estimated under the assumption that the stock assessment model perfectly represents the dynamics of the system. Since this assumption is unlikely to be satisfied, these values may underestimate the amount of uncertainty in the results of the assessment. Additional sources of structural uncertainty are investigated in analyses of sensitivity to the stock-recruitment function and growth.

A suite of approaches was used as diagnostics to determine whether the model fits the data well and is correctly specified: (a) comparison of observed data to the model predictions; (b) likelihood profile on the global scaling parameter; and (c) age-structured production model. The comparison of predicted and observed data is done through residual analyses and computation of root-mean square error (RMSE) for the CPUE indices. The likelihood profile on the global scaling parameter (virgin recruitment, the R_0 parameter; Lee *et al.* 2014, Wang *et al*. 2014) indicates the influence of each data component on the estimate of the productivity of the yellowfin stock. Apparently contradictory information among different data components (*i.e*. they favor different values for R_0) points to potential model misspecification. The age-structured production model (ASPM) diagnostic was proposed by Maunder and Piner (2015) as a way to: (i) further evaluate model misspecification, (ii) ascertain the influence of composition data on the estimates of absolute abundance and trends in abundance, and (iii) check whether catch alone can explain the trends in the indices of abundance. The ASPM diagnostic is computed as follows: (i) run the base case model; (ii) fix selectivity parameters at the maximum likelihood estimate (MLE) from the base case model, (iii) turn off the estimation of all parameters except the scaling parameters, and set the recruitment deviates to zero; (iv) fit the model to the indices of abundance only; (v) compare the estimated trajectory to the one obtained in the base case. If the ASPM is able to fit the indices of abundance that have good contrast (i.e. those that have declining and/or increasing trends) well, Maunder and Piner (2015) suggest that this is evidence of the existence of a production function, and the indices will likely provide information about absolute abundance. They refer to this situation as "the catch explains the indices well"; in the opposite case, where there is no good fit to the indices, "the catch cannot explain the indices". This can have several causes: (i) the stock is recruitment-driven; (ii) the stock has not yet declined to the point where catch is a major factor influencing abundance, (iii) the base-case model is incorrect, or (iv) the indices of relative abundance are not proportional to abundance. Checking whether the stock is recruitment-driven involves fitting the ASPM with the recruitment deviates fixed at the values estimated in the base case. If this is still not able to capture the population trajectory estimated in the integrated model, it can be concluded that the information about scale in the integrated model is coming from the composition data. Large confidence intervals on the abundance estimated by the ASPM also indicate that the index of abundance has little information on absolute abundance.

Following the diagnostics, three sensitivity analyses were conducted to assess whether the results change if (a) a different CPUE is assumed to be the main index of abundance; and (b) the weighting given to the length-composition data is modified.

The important aspects of the base case assessment (1) and the four sensitivity analyses (2-5) can be summarized as follows:

1. **Base case assessment:** Steepness (*h*) of the Beverton-Holt stock-recruitment relationship = 1 (no relationship between stock and recruitment); growth parameters are fixed to the estimates obtained in an earlier assessment (Maunder and Aires-da-Silva 2009); fitted to CPUE time series for purse-seine Fisheries 5-8 and longline Fishery 12; mirrors selectivity curves of Fisheries 9 and 12, which are assumed to be asymptotic; selectivity curves of all other fisheries assumed to be dome-shaped.
2. **Sensitivity to the steepness of the stock-recruitment relationship:** The base case assessment included an assumption that recruitment was independent of stock size (h = 1); for the sensitivity analysis, a Beverton-Holt stock-recruitment relationship with a steepness of h = 0.75 was used.
3. **Sensitivity to the average size of the older fish (L_2 parameter of the Richards growth function)**. In the base case model, L_2 is fixed at 182.3 cm, an estimate obtained in an earlier assessment (Maunder and Aires-da-Silva 2009). Two alternative fixed values of L_2 were considered for the sensitivity analysis, one lower and one higher, at 170 cm and 190 cm.
4. **Sensitivity to fitting to the CPUE of the northern dolphin-associated fishery** (F7 DEL-N) as the main index of abundance, rather than the CPUE of the southern longline fishery (F12 LL-S). For this purpose, the CV of F7 was fixed at 0.2, and the CVs of other fisheries were estimated.
5. **Sensitivity of the model to the weighting given to the length-composition data.** The weight given to these data in the model is a function of its variance. Since the length-composition data are assumed to follow a multinomial distribution in Stock Synthesis, their weights are a function of the sample sizes. In the base-case model, the input samples sizes assumed for the purse-seine fisheries are the number of wells sampled; and for the longline fisheries the number of fish sampled multiplied by a scaling factor, so that the average input sample size is similar to the average sample size of the purse-seine fishery with the largest number of wells sampled (F7 DEL-N). The sample sizes for the length-composition data were computed after the initial run of the base case assessment was completed. The new sample sizes are equal to the input sample sizes and a multiplicative weighting factor (lambda, λ) for the length-frequency data of each fishery and survey. Two methods were used to compute λ: the "Francis" method (equation TA1.8 in Francis (2011)), and the "harmonic mean" method, which is the ratio of the harmonic mean of the effective sample size to the arithmetical mean of the input sample sizes (equation T3.8 in Francis (2011)).

4. RESULTS

4.1. Base case model

4.1.1. Recruitment and biomass

In general, the recruitment of yellowfin to the fisheries in the EPO is variable, with a seasonal component. This analysis and previous analyses indicate that the yellowfin population has experienced two, or possibly three, different recruitment productivity regimes (1975-1982, 1983-2002, and 2003-2014) (Figure 2). From 2003 to 2014 the annual recruitments for all years except 2006 were estimated to be below average, and only about 25% higher than those for 1975-1982. The most recent annual recruitment (2015) is estimated to be above average. The estimated recruitments in the last quarter of 2014 and the first quarter of 2015 are among the largest since 2003, but those estimates are highly uncertain. The productivity regimes correspond to regimes in biomass, with higher-productivity regimes producing greater biomasses. The existence of a stock-recruitment relationship is also supported by the data from these regimes, but the evidence is weak, and this is probably an artifact of the apparent regime shifts.

The spawning biomass ratio (SBR; the ratio of the current spawning biomass index (S) to the virgin spawning biomass index, S_0) of yellowfin in the EPO was less than the value corresponding to MSY during 1977-1983, coinciding with the low productivity regime, but greater than that value during most of the 1984-2005 period (Figure 5.2). The spawning biomass index was above S_{MSY} during 2008-2010, following the above-average recruitment of 2006, but was below S_{MSY} for the other years since 2005. The 1984 increase in the SBR is attributed to the regime change, and the recent decrease may be a reversion to an intermediate productivity regime. The different productivity regimes may support different MSY levels and associated SBRs. The SBR at the start of 2016 was estimated to be slightly below the MSY level (0.27), as were the estimates for 2015. In fact, since 2011 the SBR has been estimated to be slightly below or at the MSY level, following the series of low recruitments since 2007, which coincided with a series of strong La Niña events.

With the current (2013-2015) fishing mortality and average recruitment, the SBR is predicted to stabilize slightly above the MSY in the future (Figure 3). However, the confidence intervals are wide, and there is a moderate probability that the SBR will be substantially above or below this level. If fishing effort continues at recent levels, and assuming average recruitment and no stock-recruitment relationship, the catches of the surface fisheries (Figure 5.8) are predicted to increase and level off, while the catches of the longline fisheries are predicted to stay about the same in the next year, then increase and level off.

4.1.2. Fishing mortality

The average weight of yellowfin taken by the fishery has been fairly consistent over time, but varies substantially among the different fisheries. In general, the floating-object, northern unassociated, and pole-and-line fisheries capture younger, smaller yellowfin than do the southern unassociated, dolphin-associated, and longline fisheries. The longline fisheries and the dolphin-associated fishery in the southern region capture older, larger yellowfin than the northern and coastal dolphin-associated fisheries.

Substantial levels of fishing mortality have been estimated for the yellowfin fishery in the EPO (Figure 4). Fishing mortality has been increasing since 2009, and is highest for middle-aged yellowfin (11-20 quarters/2.75-5 years old). For this age class, the most recent estimate of fishing mortality showed a decline from the previous year. Historically, the dolphin-associated and unassociated purse-seine fisheries have the greatest impact on the spawning biomass of yellowfin, followed by the floating-object fisheries. In more recent years, the impact of the floating-object fisheries has been greater than that of the unassociated fisheries. The impacts of the longline and purse-seine discard fisheries are much less, and have decreased in recent years (Figure 5).

4.1.3. Diagnostics

4.1.3.a Model fits

Stock Synthesis generates an extensive series of model fit diagnostics, available for the base case model in html and PDF formats. The model fits the CPUE observations for the southern longline fishery (R_{MSE} = 0.38 for F12 LL-S), and the dolphin-associated purse-seine fisheries (R_{MSE}= 0.41 for F7 DEL-N and F8 DEL-I) moderately well. However, the peak in 2001 is predicted too early in the former and too late in the latter. Also, the model fits less well to the early part of the CPUE series for the southern longline fishery. The fits to the CPUE data series for the unassociated purse-seine fisheries are less satisfactory overall (R_{MSE}= 0.58 for F5 NOA-N and R_{MSE}=0.62 for F6 NOA-S). In recent years, the CPUEs of the southern longline fishery predicted by the model are overestimated, but underestimated for the purse-seine fisheries.

4.1.3.b Likelihood profile on R_0

A likelihood profile on the virgin recruitment (R_0) parameter showed that data components diverge on their information about abundance levels within each data type (Figure A.1). The CPUEs for the Southern longline fishery (F12 LL-S) have smaller negative log-likelihoods (NLL) for larger values of R_0, while the opposite is the case in the purse-seine fisheries. For length-composition data the situation is reversed: the length-compositions for the Southern longline fishery (F12 LL-S) have smaller NLL for smaller values of $R_{0,}$ while all other length-compositions have smaller NLL for large values of R_0. The most influential data in the fit of the base-case model (*i.e.* those with the steepest NLL gradient) are the length-compositions of the southern longline fishery (F12 LL-S). This fishery is assumed to have an asymptotic selectivity, which implies that the oldest (and largest) fish will be observed in this fishery and, given that growth and natural mortality are fixed, the fishing mortality rates will be estimated in such a way that the predicted size to which the fish survive matches the largest sizes observed.

Following the modelling philosophy that the data entering the model are true, the apparently conflicting information of the different data components implies that the model is misspecified or the precision of the data is overstated, leading to the impression of data conflict (Maunder and Piner 2015). In the case of yellowfin, it might be a combination of the two. The model may be misspecified in several ways, but the most important with respect to stock structure, is process error in selectivity and growth:

1. **Stock structure:** It is very likely that the assumption of one panmictic stock is incorrect. The yellowfin tagging data suggest that there is neither complete mixing of the stock within the EPO nor real isolation of any groups. Recent tagging studies have shown that yellowfin tagged and released in the equatorial EPO at about 95°W stay between 5°S and 10°N and go as far west as 120°W (IATTC Quarterly Report, Oct-Dec 2006). Yellowfin tuna tagged with archival tags off Baja California, Mexico, remained within 1,358 km of their release locations (Schaefer *et al*. 2011, 126 tags recovered). Fish released in the Revillagigedo Archipelago Biosphere Reserve, Mexico, with archival tags showed restricted movements around the islands (Schaefer *et al*. 2014). The restricted movements and regional fidelity of tagged fish to the area of release found in the EPO (Schaefer *et al*. 2011, 2014) is similar to what has been found in the Western and Central Pacific Ocean (Sibert and Hampton 2003). It is likely that the stock is composed of heterogeneous units that are subject to local oceanographic conditions. The northern and southern areas of distribution of yellowfin in the EPO have a marked seasonality in sea-surface temperature (SST). Yellowfin were found to be in reproduction anytime when the SST is above 24^{o}C (Schaefer 1998). Those optimal SST conditions for the reproduction of yellowfin occur during June-September in the north (boreal summer) and January-March in the south (austral summer) (Hinton 2015). This seasonality may translate into marked spawning seasons at the extremes of the distribution. In the central area, where optimal conditions for spawning are more or less constant throughout the year (Hinton 2015), it is expected that yellowfin would reproduce year-round. Thus, the most likely is a stock composed of heterogeneous units that mix at rates that cannot be ascertained with the currently available tagging information.
2. **Process error in selectivity:** All selectivities in the model are assumed to be invariant over time. This is a strong assumption, especially for the floating object-fisheries. Aires-da-Silva and Maunder (2012b) modelled time-varying selectivity in the floating-object purse-seine fisheries for yellowfin and found that assuming time-varying selectivity in the last five years of the model (20 quarters) and fixed selectivity for the rest of the years produced results similar to those of a fully time-varying model, with the advantage of a reduced number of parameters to be estimated. Their approach seemed to improve the estimate of recent recruitments and fishing mortalities, and minimize the retrospective patterns on biomass estimates.

3. **Growth:** The growth of tunas seems not to be adequately described by the Richards function. The growth in length of tropical tunas, mainly bigeye and yellowfin, seems to be linear up to a certain age, then decelerates abruptly, and possibly stops altogether (see, for example, Aires-da-Silva *et al.* 2016, appendix D).

The weighting factors for the length-composition data computed after the base case model was run, using either the Francis method or the harmonic mean method, indicated that the precision assumed for the length-frequency data in the base case model may be overstated for several fisheries and surveys. For all fisheries and surveys, except for longliners (both commercial and training vessels) operating in the North, the Francis weights are less than 1, and indicate a sample size that is 20 to 50% of what was initially assumed. For the Northern longline fishery and survey, the Francis weight indicates that the sample size needs to be increased by 10 and 50%, respectively. The harmonic mean method produces different results: it indicates downweighting for the length-compositions of the floating-object and unassociated purse-seine fisheries, and upweighting for length-composition of the purse-seine fishery on dolphins and the longline fisheries, as well as for the longline survey and the pole-and-line fishery. Both methods indicate that the precision of the length-composition data for the purse-seine fisheries on floating objects is overstated. The variability in the data from the purse-seine fisheries on floating objects is not all from sampling error, but most likely from year-to-year changes in availability. Therefore, including process error in the selectivity function for these fisheries may help to reduce the model misspecification and absorb some of the inherent variability of these data, without the need to rescale the multinomial sample sizes.

4.1.3.c Age-structured production model

The age-structured production model (ASPM) function diagnostic shows a flat biomass series (Figures A.2-A.4). This indicates that the changes in the abundance indices cannot be explained by the catches alone. Therefore, there is no deterministic production function that can be estimated. The stock size seems to be driven by recruitment, as the trend in the indices is matched very well when the recruitment estimates from the base-case model are added to the ASPM, and reasonably well when recruitment deviations are estimated within the ASPM (Figures A.3 and A.4). It is likely that catch is influencing the abundance, as can be seen in the fishery impact plot (Figure 5), but a deterministic model cannot fit the large increases in abundance caused by periods of higher recruitment. In addition, there is little contrast in abundance caused by fishing because the assessment started when the stock was in an exploited state in 1975, and management has been fairly consistent over the whole time period, as shown by the relatively constant fishing mortality rates (Figure 4) in all years except around 2005 (which may be an artifact caused by model misspecification.) As the abundance trends estimated by the ASPM are very different from those estimated in the assessment model, we can conclude that the absolute scale in the base case model is being driven by the length-composition data. When the recruitment deviations are set at the values estimated from the base case, the estimates are similar to those of the base case, at least in the same order of magnitude. Therefore, given estimates of recruitment deviations, the ASPM is able to determine the absolute scale of the model.

These results indicate that the abundance information, both absolute and relative, contained in the CPUE-based indices of relative abundance cannot be interpreted without accounting for the fluctuations in recruitment. Absolute abundance information is only contained in the indices of relative abundance if the relative values of quarterly recruitment are known. It is also apparent that the composition data have a large influence on the base-case estimates of absolute abundance, and some influence on the trends in abundance, but it is not clear whether this is due to the information about recruitment or to the type of information about fishing mortality found in a catch-curve analysis.

4.2. Sensitivity analyses

Previous research indicated that the status of the stock is also sensitive to the assumptions about natural mortality (Maunder and Aires-da-Silva 2012), and more optimistic results are obtained when higher values are assumed for this parameter.

If a stock-recruitment relationship with steepness equal to 0.75 is assumed the recruitment estimates are the same as in the base-case model (Figure B.1). The outlook, however, is more pessimistic: current effort is estimated to be above the MSY level (Table 2), and the spawning biomass is predicted to remain below the MSY level (Figure 3, bottom, Figure B.2). If fishing effort continues at recent levels, both the spawning biomass (Figure 3) and the catches are predicted to stabilize at slightly lower values than those predicted for the base case if a stock-recruitment relationship with steepness of 0.75 exists (Figure 9).

Fixing the mean size of the oldest age class (L_2) at a lower value than that assumed in the base case (*e.g*. 170 cm, Figure C.1) produces recruitment estimates that are more variable (Figure C.2) and more optimistic results (Table 2), with the spawning biomass 30% above the level corresponding to MSY (Figure C.3) and current effort substantially below that level. The MSY that can be obtained is greater than for the base case. In contrast, fixing L_2 at a higher value than that assumed in the base case (*e.g*. 190 cm) produces more pessimistic results, with the spawning biomass below the MSY level and current effort above that level, but the MSY that can be obtained changes only slightly.

The sensitivity analyses showed that data weighting has a strong impact on the results. Fitting more closely to the CPUE data of the northern dolphin-associated fishery (CV = 0.2 for F7 DEL-N), rather than using the CPUE of the southern longline fishery (F12 LL-S) as the main index of abundance, produces a more optimistic perception of the status of the stock and estimates that the current catches are right at the MSY level (Table 2). In this scenario, the recruitment estimates are similar to those from the base case, with the exception of the last year (Figure D.1), and the recent fishing effort is estimated to be well below that corresponding to MSY; however, the recent spawning biomass is estimated to be at about the value corresponding to MSY, as in the base-case model (Figure D.2). Changing the weighting of the length-composition data using the Francis method improves the fit of the F12 LL-S index (R_{MSE} = 0.33) compared to the base case (R_{MSE} = 0.38), unlike the harmonic mean method (R_{MSE} = 0.40). Using either method, the fits to the other CPUEs stays the same or degrades (see Figure E.3 for the Francis method). For both scenarios, the biomass is estimated to be below, and the fishing effort above, the values corresponding to MSY (Table 2, Figure E.2). The estimates of MSY are higher when using the Francis method, and about the same when using the harmonic mean method.

4.3. Management quantities

4.3.1. Base case model

Based on the current distribution of effort among the different fisheries, effort is estimated to be slightly below the level that would support the MSY (Figure 6), and recent catches are below that level (Table 2). Both the stock size and the fishing mortality are far from the interim limit reference points of 0.28 *S_{MSY} and 2.42*F_{MSY}, which correspond to a 50% reduction in recruitment from its average unexploited level based on a conservative steepness value (h = 0.75) for the Beverton-Holt stock-recruitment relationship (Maunder and Deriso 2014).

The curve relating the average sustainable yield to the long-term fishing mortality is flat around the MSY level (Figure 7 top). Therefore, moderate changes in the long-term effort will change the long-term catches only marginally, while changing the biomass considerably. Maintaining the fishing mortality below the MSY level would result in only a marginal decrease in the long-term average yield, with the benefit of a relatively large increase in the spawning biomass. The MSY calculations indicate that, theoretically at least, catches could be increased if the fishing effort were directed toward longlining and purse-seine sets on yellowfin associated with dolphins. This would also increase the SBRs.

The MSY has been stable during the assessment period (1975-2015) (Figure 8), which suggests that the overall pattern of selectivity has not varied a great deal over time. However, the overall level of fishing effort has varied with respect to the MSY level. If fishing effort continues at recent levels, the catches of both surface and longline fisheries are predicted to stabilize at about the MSY level (Figure 9).

4.3.2. Sensitivity to alternative model configurations

The estimates of stock status are strongly dependent on the assumptions made about the steepness parameter (*h*) of the stock-recruitment relationship, the weighting assigned to the size-composition data, the growth curve, and the assumed levels of juvenile and adult natural mortality (*M*)

The sensitivity analysis that included a stock-recruitment relationship with h = 0.75 estimated the SBR required to support the MSY to be 0.35, compared to 0.27 for the base-case assessment (Table 2). The sensitivity analysis for h = 0.75 estimated an *F* multiplier of 0.65, considerably lower than that for the base case assessment (1.02). The base-case model results indicate that the recent spawning biomass level is slightly below that corresponding to MSY (S_{recent}/S_{MSY} = 0.95); this MSY-related depletion value is estimated to be much lower (0.56) for the sensitivity analysis with h = 0.75. In addition, if management is based on the base-case assessment, which assumes that there is no stock-recruitment relationship, when in fact there is such a relationship, there would be a greater loss in yield than if management is based on assuming a stock-recruitment relationship when in fact there is none (Figure 7, bottom panel).

Fixing the mean size of the oldest age class (L_2) at a lower value (170 cm, Figure C.1) than that assumed in the base case (182 cm) produces more optimistic results (Table 2), with an *F* multiplier of 1.48. In contrast, fixing L_2 at a higher value (190 cm) than that assumed in the base case produces more pessimistic results, with an *F* multiplier of 0.88.

The management quantities estimated in the stock assessment are highly sensitive to data weighting. If the relative weight among the CPUEs is changed so that the F7 DEL-N CPUE is treated as the main index of abundance, the model produces an overly optimistic *F* multiplier (1.21), but with S_{recent}/S_{MSY} at about 1 (Table 2). If the weight of the length-composition data is changed, using either the Francis or the harmonic mean method, the model produces more pessimistic management quantities (*F* multiplier = 0.88; $S_{recent}/S_{MSY} < 1$). This is due to the dominance of the size-composition data of F12 LL-S fishery (which is assumed to have a logistic selectivity) in determining absolute scale (the R_0 parameter) in the model (see section 4.1.5). This is indicative of overweighting of composition data and/or some form of model misspecification that will have to be addressed in the future in order to assign the proper weighting to datasets.

5. FUTURE DIRECTIONS

5.1. Research priorities

The following topics should be a priority in future research for improving the yellowfin stock assessment:

a. Implementation of a large-scale tagging program to address hypotheses about stock structure and regional differences in life-history parameters and depletion.

b. Improved estimates of growth, particularly for older fish.

c. Fine-tuning of the weights of the different data sets that are fitted to the assessment model.

d. Refinement of fisheries definitions within the assessment model.

e. Implementation of time-variant selectivity, mainly for the purse-seine fisheries on floating objects.

f. Exploration of alternative assumptions about stock structure within the assessment model.

g. Analysis of changes in spatial distribution of effort for the Southern longline fishery, and whether they invalidate the use of the CPUE of this fishery as the main abundance index in the assessment model.

5.2. Collection of new and updated information

The IATTC staff intends to continue its collection of catch, effort, and size-composition data for the fisheries that catch yellowfin in the EPO. New and updated data will be incorporated into the next stock assessment. Collection of biological data for age-and-growth and reproduction studies is under way. It is expected that this information could be used in future stock assessments.

5.3. Refinements to the assessment model and methods

The IATTC staff will continue developing the Stock Synthesis assessment model for yellowfin in the EPO. Much of the progress will depend on how the software is modified in the future. The following improvements will be explored in future assessments:

1. Determine appropriate weighting for the different data sets;
2. Refine the fisheries definitions.
3. Explore alternative assumptions on stock structure (spatial analysis);
4. Implement time-variant selectivity for the purse-seine fisheries on floating objects.

6. ACKNOWLEDGEMENTS

Many IATTC and member country staff provided data for the assessment. Richard Deriso, IATTC staff members, and member country scientists provided advice on the stock assessment, fisheries, and biology of yellowfin tuna. Christine Patnode and Hue Hua Lee provided assistance on the figures.

REFERENCES

Aires-da-Silva, A., and M.N. Maunder. 2012a. Status of yellowfin tuna in the eastern Pacific Ocean in 2010 and outlook for the future. Inter-Amer. Trop. Tuna Comm., Stock Asses. Rep. 12:3:110.

Aires-da-Silva, A., and M.N. Maunder. 2012b. An exploration of alternative methods to deal with time-varying selectivity in the stock assessment of yellowfin tuna in the eastern Pacific Ocean. External Review of IATTC Yellowfin Tuna Assessment. Document YFT-01-06.

Aires-da-Silva, A., C.V. Minte-Vera, and M.N. Maunder. 2016. Status of bigeye tuna in the eastern Pacific Ocean in 2015 and outlook for the future. Inter-Amer. Trop. Tuna Comm., 7th Scient. Adv. Com. Meeting. SAC-07-05a.

Francis, R.I.C.C. 2011. Data weighting in statistical stock assessment models. Can. J. Fish. Aquat. Sci. 68:1124-1138.

Hinton, M. 2015. Oceanographic conditions in the EPO and their effect on tuna fisheries. Inter-Amer. Trop. Tuna Comm. 6th Scient. Adv. Com. Meeting. SAC-06 INF-C.

Lee, *H.H*., K.R. Piner, R.D. Methot, and M.N. Maunder. . 2014. Use of likelihood profiling over a global scaling parameter to structure the population dynamics model: an example using blue marlin in the Pacific Ocean. Fish. Res. 158: 138-146.

Maunder, M.N., and R.B. Deriso. 2014. Proposal for biomass and fishing mortality limit reference points based on reduction in recruitment. Inter-Amer. Trop. Tuna Comm. 5th Scient. Adv. Com. Meeting. SAC-05-14.

Maunder, M.N., and A. Aires-da-Silva. 2009. Status of yellowfin tuna in the eastern Pacific Ocean in 2007 and outlook for the future. Inter-Amer. Trop. Tuna Comm., Stock Asses. Rep.9: 3-94.

Maunder, M.N., and A. Aires-da-Silva. 2012. A review and evaluation of natural mortality for the assessment and management of yellowfin tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm. Document YFT-01-07.

Maunder, M.N., and K.R. Piner. 2015. Contemporary fisheries stock assessment: many issues still remain. ICES Journal of Marine Science, 72: 7–18. doi:10.1093/icesjms/fsu015

Minte-Vera, C.V., A. Aires-da-Silva, K. Satoh, and M.N. Maunder. 2016. Changes in lonmgline size-frequency data and their effects on the stock assessment models for yellowfin and bigeye tunas. Inter-Amer. Trop. Tuna Comm. 7th Scient. Adv. Com. Meeting SAC-07-04a.

Minte-Vera, C.V., A. Aires-da-Silva, and M.N. Maunder. 2015. Status of yellowfin tuna in the eastern Pacific Ocean and outlook for the future. Inter-Amer. Trop. Tuna Comm., Stock Asses. Rep. 16:18-31

Satoh, K., C.V. Minte-Vera, N.W. Vogel, A. Aires-da-Silva, C.E. Lennert-Cody, M.N. Maunder, *H*. Okamoto, K. Uosaki, T. Matsumoto, Y. Semba, T. Ito. 2016. An exploration into Japanese size data of tropical tuna species because of a prominent size-frequency residual pattern in the stock assessment model. Inter-Amer. Trop. Tuna Comm., 7th Scient. Adv. Com. Meeting. SAC-07-03d

Schaefer, K.M. 1998. Reproductive biology of yellowfin tuna (*Thunnus albacares*) in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull. 21: 203-272.

Schaefer, K.M., D.W. Fuller, and B.A. Block. 2011. Movements, behavior, and habitat utilization of yellowfin tuna (*Thunnus albacares*) in the Pacific Ocean off Baja California, Mexico, determined from archival tag data analyses, including Kalman filtering. Fish. Res. 112, 22-37.

Schaefer, K.M., D.W. Fuller, and G. Aldana. 2014. Movements, behavior, and habitat utilization of yellowfin tuna (*Thunnus albacares*) in waters surrounding the Revillagigedo Islands Archipelago Biosphere Reserve, Mexico. Fish. Ocean. 23: 65-82.

Sibert, J., and J. Hampton. 2003. Mobility of tropical tunas and the implications for fisheries management. Mar. Pol. 27: 87-95.

Wang, S. P., M.N. Maunder, K.R. Piner, A. Aires-da-Silva, and H.H. Lee. 2014. Evaluation of virgin recruitment profiling as a diagnostic for selectivity curve structure in integrated stock assessment models. Fish. Res., 158: 158-164.

TABLE 1. Fisheries defined for the stock assessment of yellowfin tuna in the EPO. PS = purse seine; LP = pole and line; LL = longline; LL-T: longline training vessels; LL-C: commercial longline vessels; OBJ = sets on floating objects; NOA = sets on unassociated fish; DEL = sets on dolphin-associated schools. The sampling areas are shown in Figure 1, and the discards are described in Section 2.2.1 of Aires-da-Silva and Maunder (2012).

TABLA 1. Pesquerías definidas para la evaluación de la población de atún aleta amarilla en el OPO. PS = red de cerco; LP = caña; LL = palangre; OBJ = lances sobre objetos flotantes; NOA = lances sobre atunes no asociados; DEL = lances sobre atunes asociados con delfines. En la Figura 1 se ilustran las zonas de muestreo, y en la Sección 2.2.1 de Aires-da-Silva y Maunder (2012) se describen los descartes.

Fishery	Gear type	Set type	Years	Sampling areas	Catch data
Pesquería	**Tipo de arte**	**Tipo de lance**	**Años**	**Zonas de muestreo**	**Datos de captura**
1	PS	OBJ	1975-present	11-12	retained catch + discards from inefficiencies in fishing process–captura retenida + descartes por ineficacias en el proceso de pesca
2	PS	OBJ	1975-present	7, 9	
3	PS	OBJ	1975-present	5-6, 13	
4	PS	OBJ	1975-present	1-4, 8, 10	
5	PS	NOA	1975-present	1-4, 8, 10	retained catch + discards–captura retenida + descartes
6	PS	NOA	1975-present	5-7, 9, 11-13	
7	PS	DEL	1975-present	2-3, 10	
8	PS	DEL	1975-present	1, 4-6, 8, 13	
9	PS	DEL	1975-present	7, 9, 11-12	
10	LP		1975-present	1-13	retained catch only (in numbers)— captura retenida solamente (en número)
11	LL		1975-present	N of-de 15°N	
12	LL		1975-present	S of-de 15°N	
13	PS	OBJ	1993-present	11-12	discards of small fish from size-sorting the catch by Fishery 1–descartes de peces pequeños de clasificación por tamaño en la Pesquería 1
14	PS	OBJ	1993-present	7, 9	discards of small fish from size-sorting the catch by Fishery 2–descartes de peces pequeños de clasificación por tamaño en la Pesquería 2
15	PS	OBJ	1993-present	5-6, 13	discards of small fish from size-sorting the catch by Fishery 3–descartes de peces pequeños de clasificación por tamaño en la Pesquería 3
16	PS	OBJ	1993-present	1-4, 8, 10	discards of small fish from size-sorting the catch by Fishery 4–descartes de peces pequeños de clasificación por tamaño en la Pesquería 4

TABLE 1. (cont.)
TABLA 1. (continuación)

Survey	**Gear type**	**Set type**	**Years**	**Sampling areas**	**Catch data**
Estudio	**Tipo de arte**	**Tipo de lance**	**Años**	**Zonas de muestreo**	**Datos de captura**
S1	LL-C	-	1975-1994	N of-de 15°N	No catches, only weight-composition data (not used to fit the model) – Sin capturas, datos de composición por tallas solamente (no usados para ajustar el modelo)
S2	LL-C	-	1975-1994	S of-de 15°N	No catches, only weight-composition data (not used) – Sin capturas, datos de composición por tallas solamente (no usados para ajustar el modelo)
17 S3	LL-T	-	1975-present	N of-de 15°N	No catches, only length-composition data – Sin capturas, datos de composición por tallas solamente
18 S4	LL-T	-	1975-present	S of-de 15°N	No catches, only length-composition data – sin capturas, datos de composición por tallas solamente

TABLE 2. MSY and related quantities for the base case and the sensitivity analyses, based on average fishing mortality (*F*) for 2013-2015. B_{recent} and B_{MSY} are defined as the biomass, in metric tons, of fish 3+ quarters old at the start of the first quarter of 2016 and at MSY, respectively, and S_{recent} and S_{MSY} are defined as indices of spawning biomass (therefore, they are not in metric tons). C_{recent} is the estimated total catch for 2015.

TABLA 2. RMS y cantidades relacionadas para el caso base y los análisis de sensibilidad, basados en la mortalidad por pesca (*F*) media de 2013-2015. Se definen B_{recent} y B_{RMS} como la biomasa, en toneladas, de peces de 3+ trimestres de edad al principio del primer trimestre de 2016 y en RMS, respectivamente, y S_{recent} y S_{RMS} como índices de biomasa reproductora (por lo tanto, no se expresan en toneladas). C_{recent} es la captura total estimada de 2015.

YFT	Base case Caso base	*h* = 0.75	L_2 = 170	L_2 = 190	DEL-N	Francis	Harmonic Mean
MSY-RMS	272,841	287,476	288,672	272,782	258,468	291,982	272,782
B_{MSY}- B_{RMS}	372,010	547,238	395,744	374,461	359,854	396,185	374,461
S_{MSY}- S_{RMS}	3,528	5,897	4,152	3,627	3,429	3,809	3,627
B_{MSY}/B_0- B_{RMS}/B_0	0.32	0.37	0.32	0.33	0.31	0.33	0.33
S_{MSY}/S_0- S_{RMS}/S_0	0.27	0.35	0.26	0.28	0.26	0.28	0.28
C_{recent}/MSY- C_{recent}/RMS	0.94	0.89	0.89	0.94	1.00	0.88	0.94
$B_{\text{recent}}/B_{\text{MSY}}$- $B_{\text{recent}}/B_{\text{RMS}}$	0.96	0.64	1.18	0.82	0.88	0.98	0.82
$S_{\text{recent}}/S_{\text{MSY}}$- $S_{\text{recent}}/S_{\text{RMS}}$	0.95	0.56	1.3	0.74	1.02	0.88	0.74
F multiplier- Multiplicador de *F*	1.02	0.65	1.48	0.88	1.21	0.88	0.88

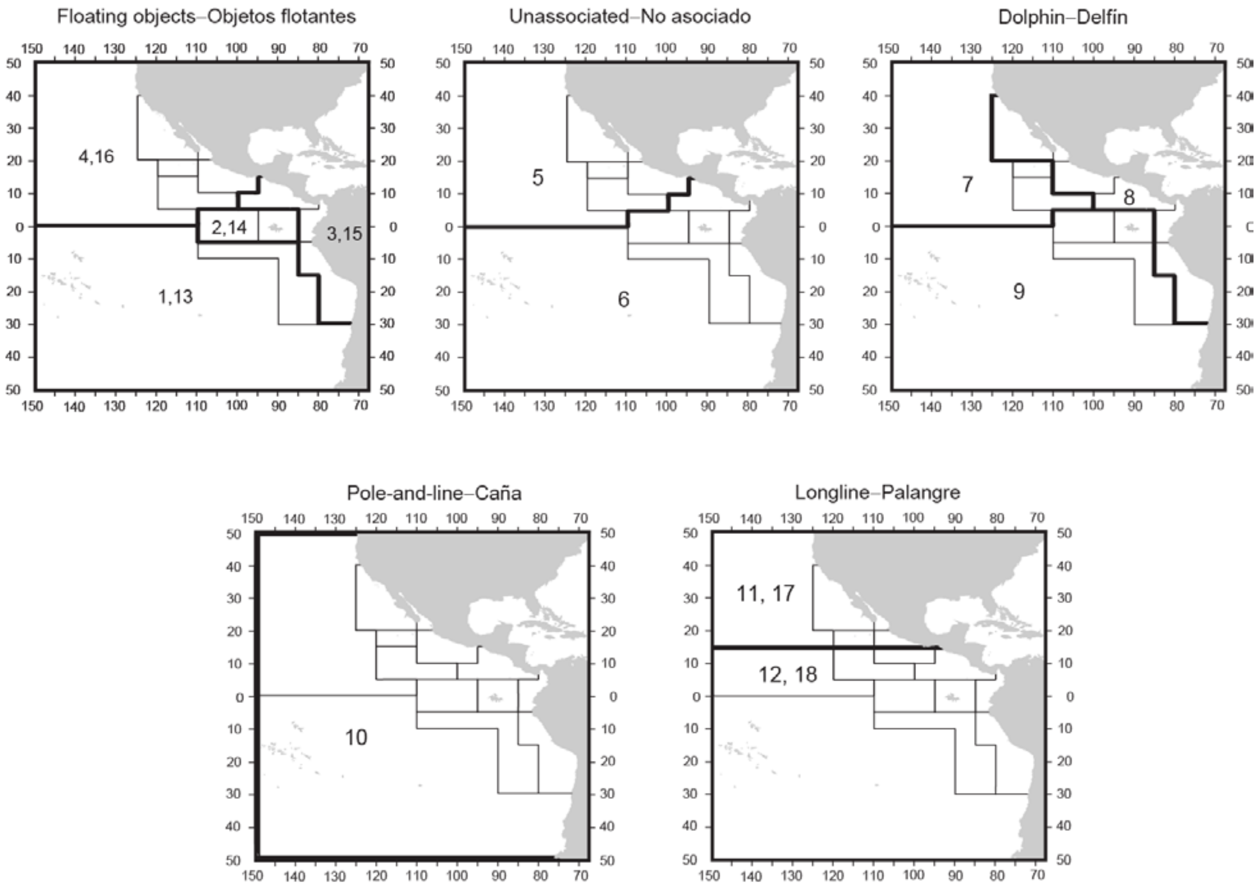

FIGURE 1. Spatial extents of the fisheries defined by the IATTC staff for the stock assessment of yellowfin tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the numbers the fisheries to which the latter boundaries apply. The fisheries are described in Table 1.

FIGURA 1. Extensión espacial de las pesquerías definidas por el personal de la CIAT para la evaluación del atún aleta amarilla en el OPO. Las líneas delgadas indican los límites de 13 zonas de muestreo de frecuencia de tallas, las líneas gruesas los límites de cada pesquería definida para la evaluación de la población, y los números las pesquerías correspondientes a estos últimos límites. En la Tabla 1 se describen las pesquerías.

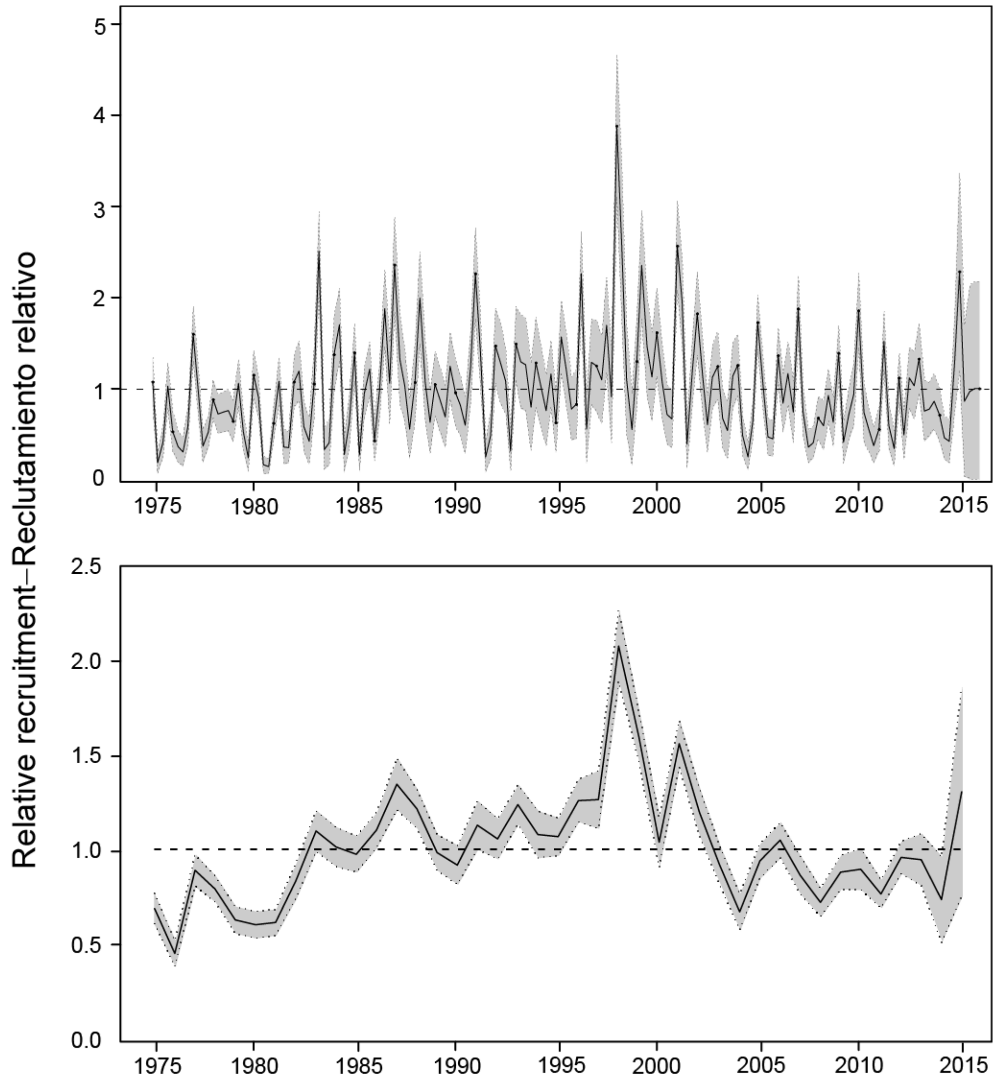

FIGURE 2. Estimated quarterly (top panel) and annual (bottom panel) recruitment of yellowfin tuna to the fisheries of the EPO. The estimates are scaled so that the average recruitment is equal to 1.0 (dashed horizontal line). The bold line illustrates the maximum likelihood estimates (MLE) of recruitment, and the shaded area indicates the approximate 95% confidence intervals around those estimates.

FIGURA 2. Reclutamiento trimestral (recuadro superior) y anual (recuadro inferior) estimado de atún aleta amarilla a las pesquerías del OPO. Se fija la escala de las estimaciones para que el reclutamiento medio equivalga a 1,0 (línea de trazos horizontal). La línea gruesa ilustra las estimaciones de verosimilitud máxima (EVM) del reclutamiento, y el área sombreada los intervalos de confianza de 95% aproximados de esas estimaciones.

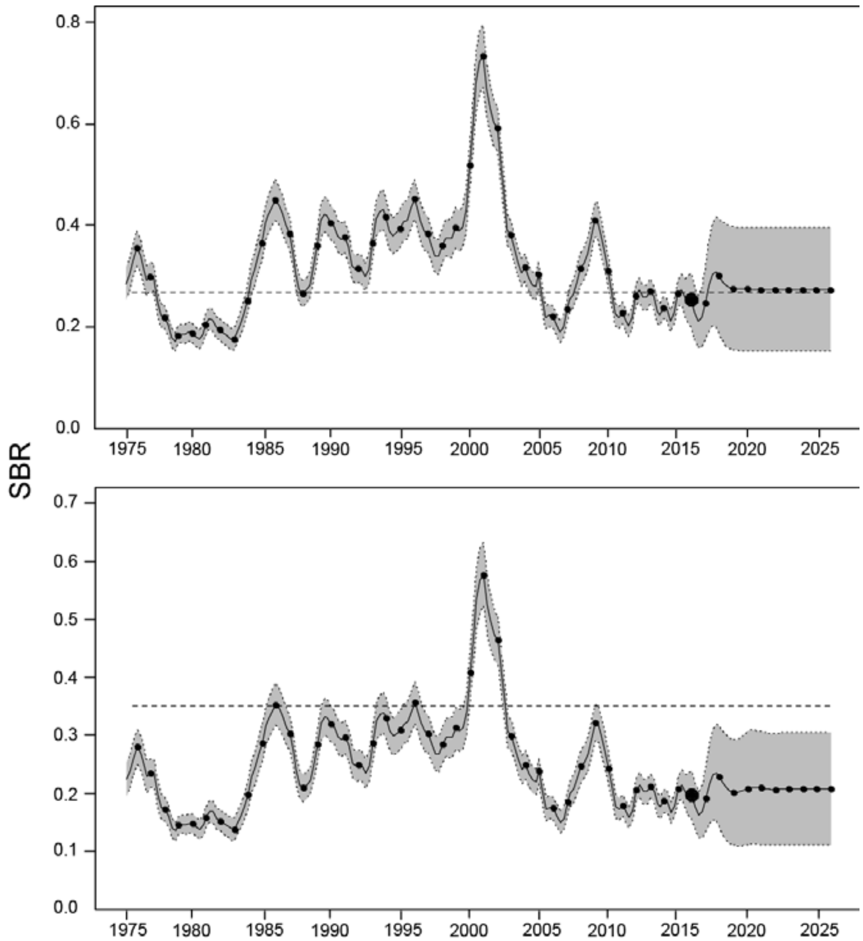

FIGURE 3. Spawning biomass ratios (SBRs) for yellowfin tuna in the EPO, including projections for 2016-2026 based on average fishing mortality rates during 2013-2015, from the base case (top) and the sensitivity analysis that assumes a stock-recruitment relationship (*h* = 0.75, bottom). The dashed horizontal line (at 0.27 and 0.35, respectively) identifies the SBR at MSY. The solid curve illustrates the maximum likelihood estimates, and the estimates after 2016 (the large dot) indicate the SBR predicted to occur if fishing mortality rates continue at the average of that observed during 2013-2015, and average recruitment occur during the next 10 years. The shaded area indicates the approximate 95% confidence intervals around those estimates.

FIGURA 3. Cocientes de biomasa reproductora (SBR) de atún aleta amarilla en el OPO, con proyecciones para 2016-2026 basadas en las tasas de mortalidad por pesca medias durante 2013-2015, del caso base (recuadro superior) y el análisis de sensibilidad que supone una relación población-reclutamiento (*h* = 0.75, recuadro inferior). La línea de trazos horizontal (en 0.27 y 0.35, respectivamente) identifica el SBR correspondiente al RMS. La curva sólida ilustra las estimaciones de verosimilitud máxima, y las estimaciones a partir de 2016 (punto grande) indican el SBR que se predice ocurrirá con tasas de mortalidad por pesca en el promedio de aquellas observadas durante 2013-2015, y con reclutamiento medio durante los 10 años próximos. El área sombreada indica los intervalos de confianza de 95% aproximados alrededor de esas estimaciones.

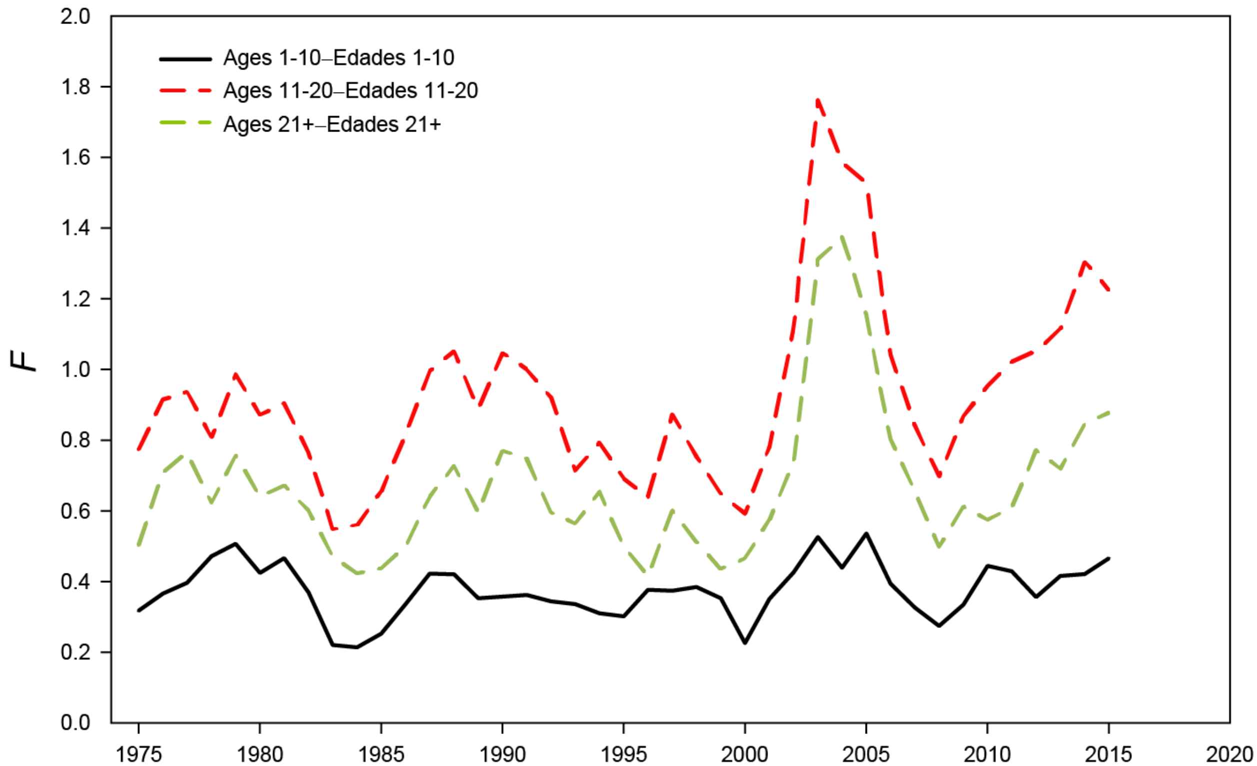

FIGURE 4. Average annual fishing mortality (*F*) by age groups, by all gears, of yellowfin tuna recruited to the fisheries of the EPO. The age groups are defined by age in quarters.

FIGURA 4. Mortalidad por pesca (*F*) anual media, por grupo de edad, por todas las artes, de atún aleta amarilla reclutado a las pesquerías del OPO. Se definen los grupos de edad por edad en trimestres.

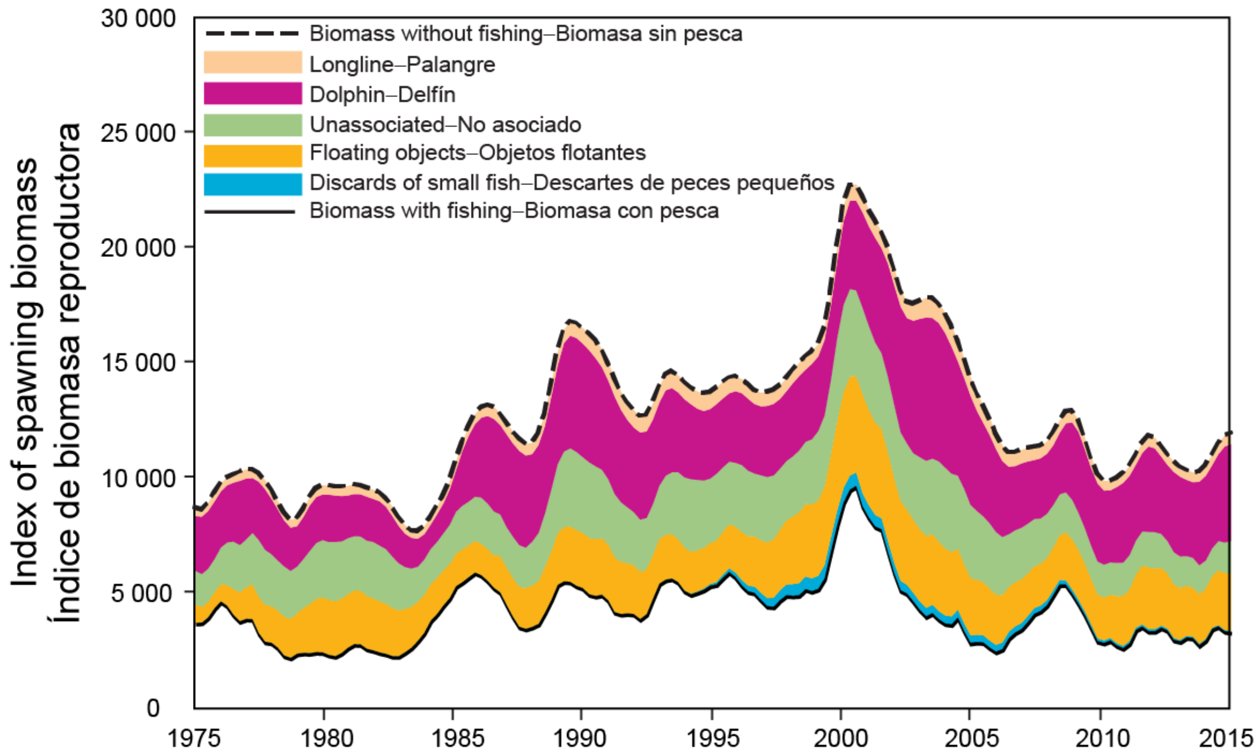

FIGURE 5. Trajectory of the spawning biomass of a simulated population of yellowfin tuna that was never exploited (top dashed line) and that predicted by the stock assessment model (bottom solid line). The shaded areas between the two lines show the portions of the impact attributed to each fishing method. t = metric tons.

FIGURA 5. Trayectoria de la biomasa reproductora de una población simulada de atún aleta amarilla nunca explotada (línea de trazos superior) y la que predice el modelo de evaluación (línea sólida inferior). Las áreas sombreadas entre las dos líneas señalan la porción del efecto atribuida a cada método de pesca. t = toneladas.

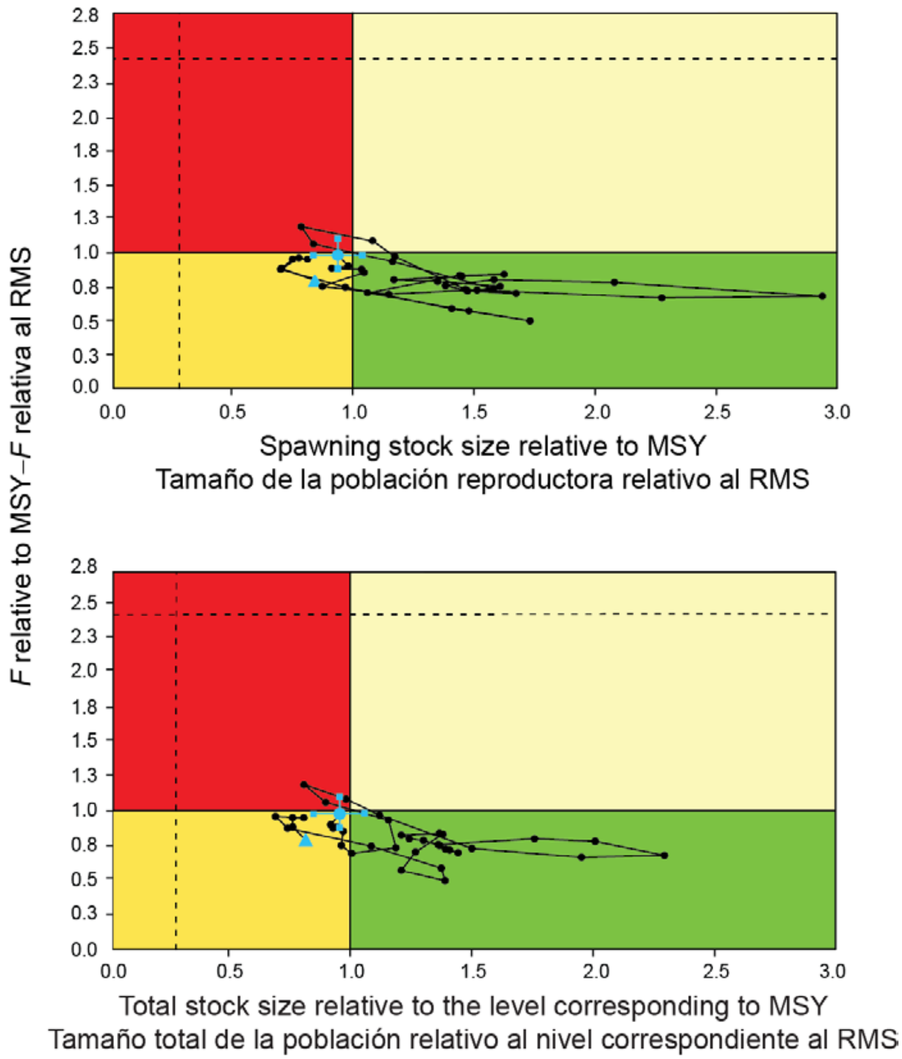

FIGURE 6. Kobe (phase) plot of the time series of estimates of stock size (top panel: spawning biomass; bottom panel: total biomass of fish aged 3+ quarters) and fishing mortality relative to their MSY reference points. The panels represent interim target reference points (S_{MSY} and F_{MSY}). The dashed lines represent the interim limit reference points of 0.28 *S_{MSY} and 2.42*F_{MSY}, which correspond to a 50% reduction in recruitment from its average unexploited level based on a conservative steepness value (*h* = 0.75) for the Beverton-Holt stock-recruitment relationship. Each dot is based on the average exploitation rate over three years; the large blue dot indicates the most recent estimate. The squares around the most recent estimate represent its approximate 95% confidence interval. The triangle represents the first estimate (1975).

FIGURA 6. Gráfica de Kobe (fase) de la serie de tiempo de las estimaciones del tamaño de la población (panel superior: biomasa reproductora; panel inferior: biomasa total de peces de 3+ trimestres de edad) y la mortalidad por pesca en relación con sus puntos de referencia de RMS. Las líneas de trazos representan los puntos de referencia límite provisionales de 0.28*S_{RMS} y 2.42*F_{RMS}, que corresponden a una reducción de 50% del reclutamiento de su nivel medio no explotado basada en un valor cauteloso de la inclinación de la relación población-reclutamiento de Beverton-Holt (*h* = 0.75). Cada punto se basa en la tasa de explotación media por trienio; el punto azul grande indica la estimación más reciente. Los cuadrados alrededor de la estimación más reciente representan su intervalo de confianza de 95% aproximado. El triángulo representa la primera estimación (1975).

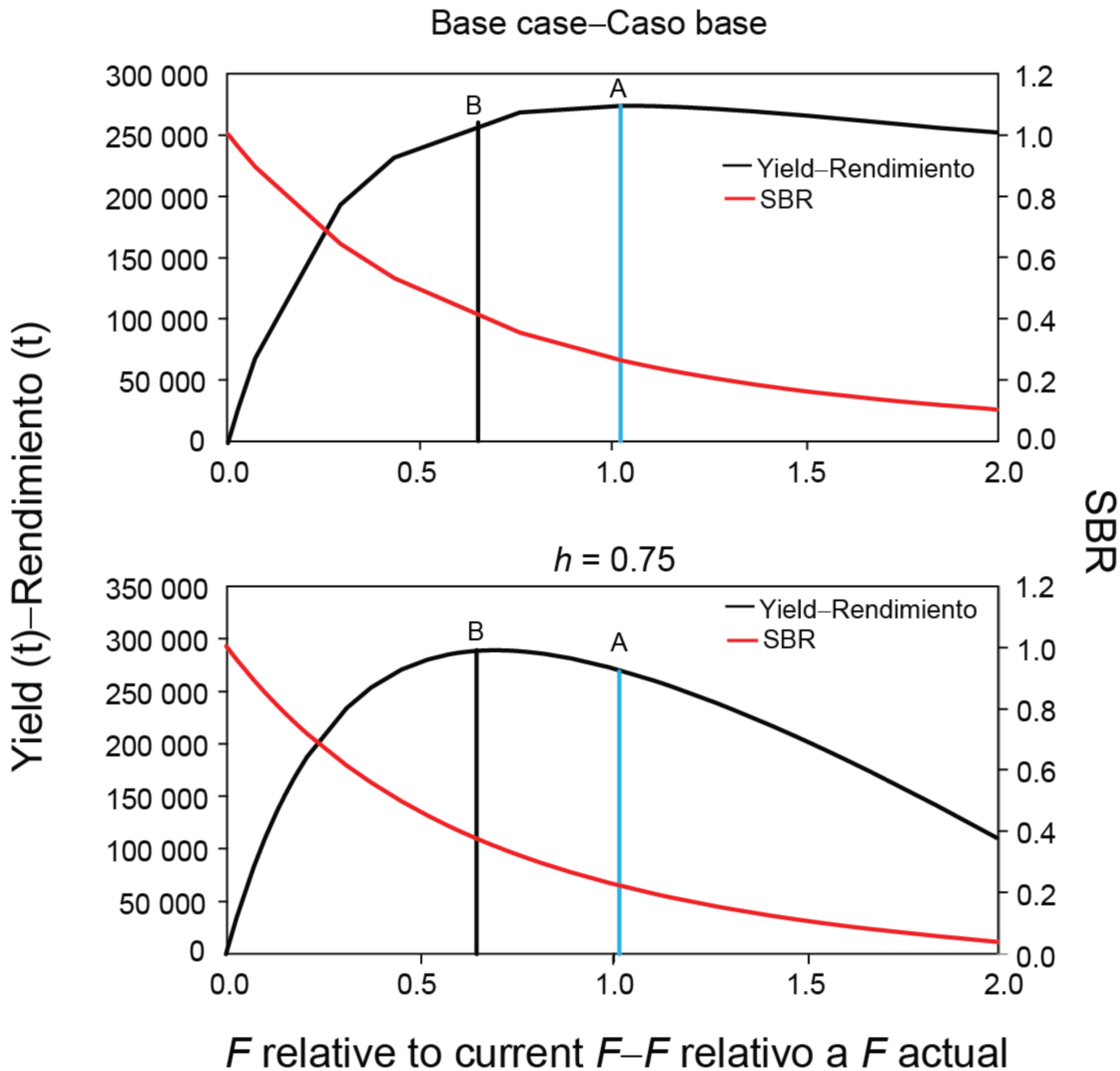

FIGURE 7. Yield and spawning biomass ratio (SBR) as a function of fishing mortality relative to the current fishing mortality. The vertical lines A and B represent the fishing mortality corresponding to MSY for the base case and the sensitivity analysis that assumes a stock-recruitment relationship (*h* = 0.75), respectively.

FIGURA 7. Rendimiento y cociente de biomasa reproductora (SBR) como función de la mortalidad por pesca relativa a la mortalidad por pesca actual. Las líneas verticales A y B representan la mortalidad por pesca correspondiente al RMS del caso base y del análisis de sensibilidad que supone una relación población-reclutamiento (*h* = 0.75), respectivamente.

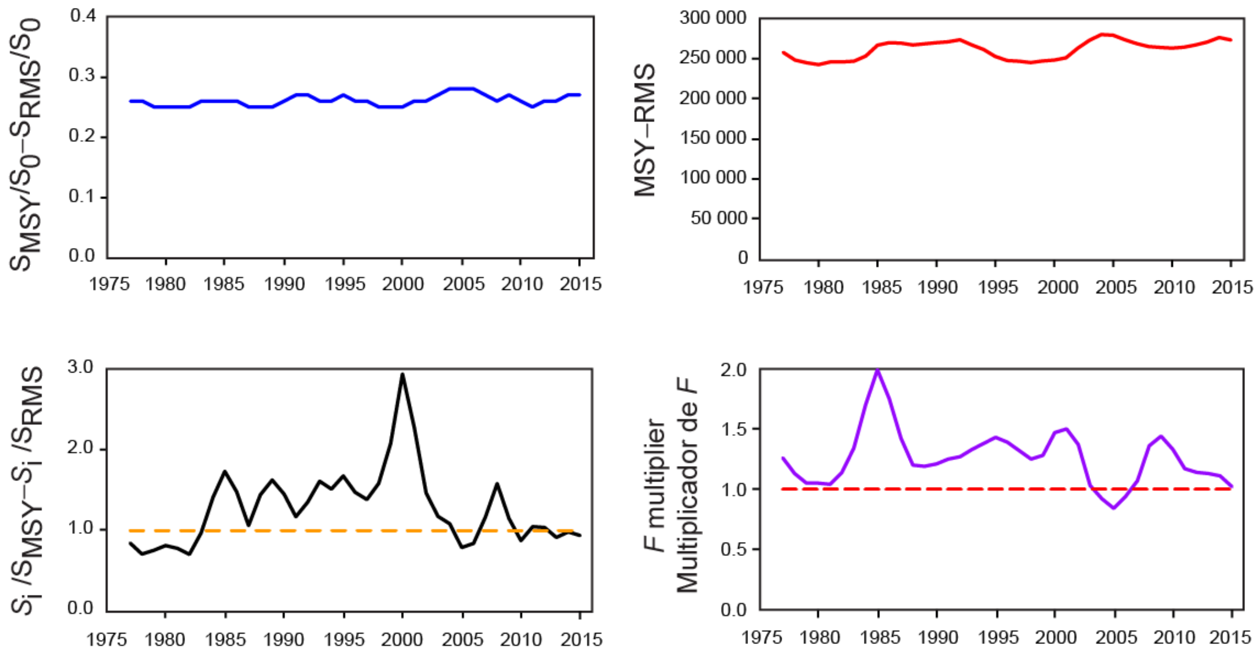

FIGURE 8. Estimates of MSY-related quantities calculated using the average age-specific fishing mortality for each year (S_i is the index of spawning biomass).

FIGURA 8. Estimaciones de cantidades relacionadas con el RMS calculadas a partir de la mortalidad por pesca media por edad para cada año. (S_i es el índice de biomasa reproductora).

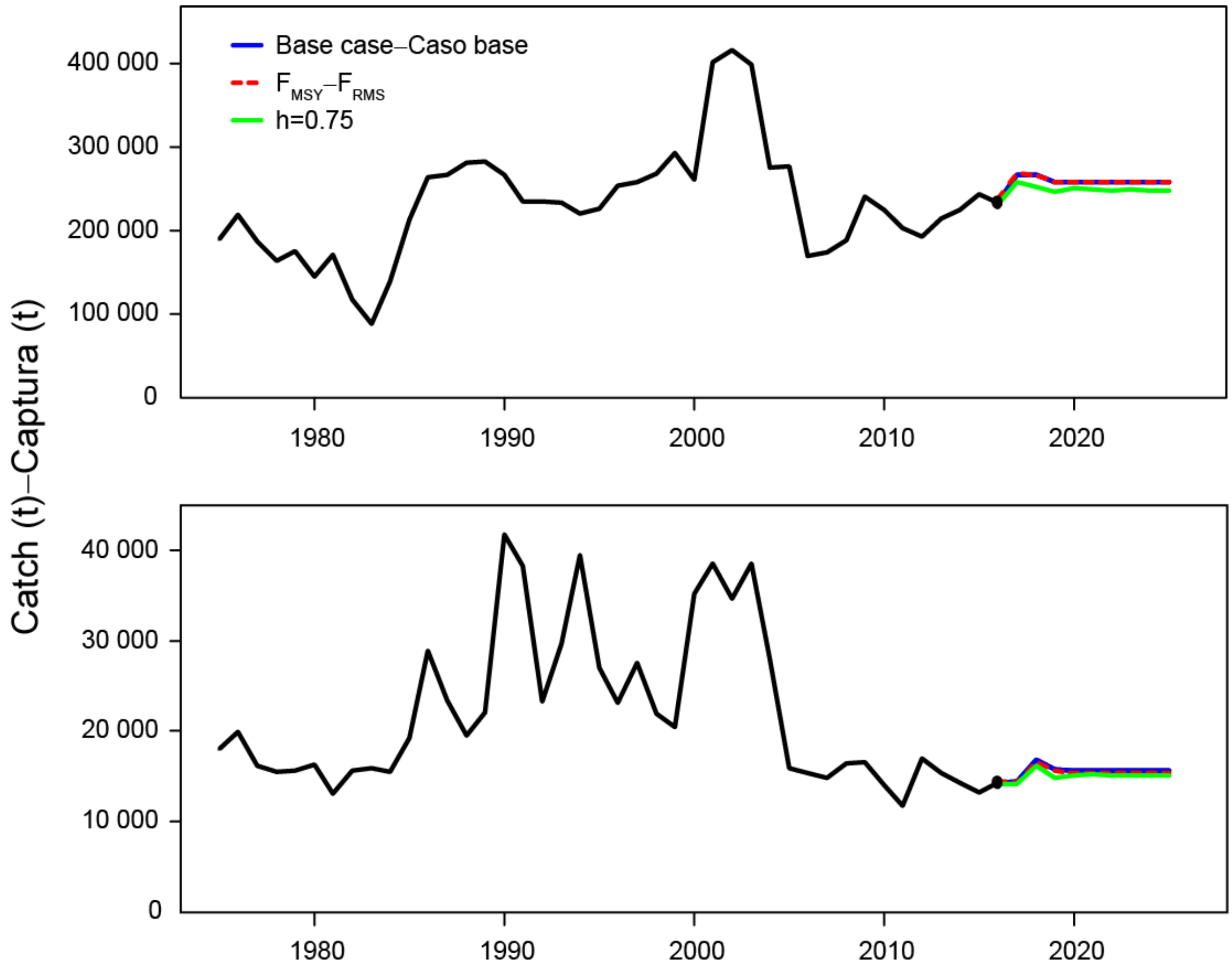

FIGURE 9. Historic and projected annual catches of yellowfin tuna by surface (top panel) and longline (bottom panel) fisheries from the base case while fishing with the current effort, the base case while fishing at the fishing mortality corresponding to MSY (F_{MSY}), and the analysis of sensitivity to steepness (h = 0.75) of the stock-recruitment relationship while fishing with the current effort. The large dot indicates the most recent catch (2015).

FIGURA 9. Capturas históricas y proyectadas de atún aleta amarilla por las pesquerías de superficie (recuadro superior) y palangre (recuadro inferior) del caso base con la pesca en el nivel actual de esfuerzo, del caso base con la pesca en la mortalidad por pesca correspondiente al RMS (F_{RMS}), y el análisis de sensibilidad a la inclinación (h = 0.75) de la relación población-reclutamiento al pescar con el esfuerzo actual. El punto grande indica la captura más reciente (2015).

APPENDICES—ANEXOS

APPENDIX A: MODEL DIAGNOSTICS
ANEXO A: DIAGNÓSTICOS DEL MODELO

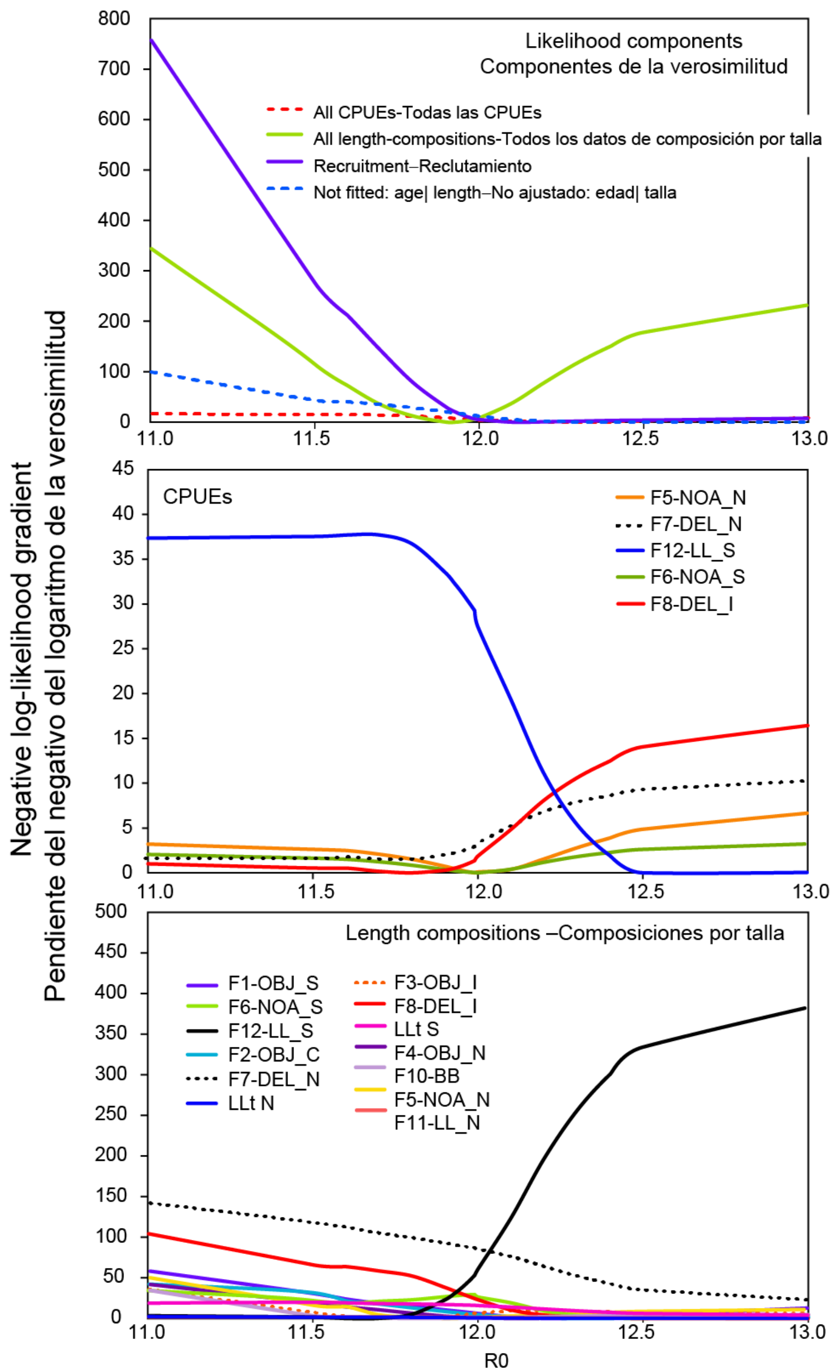

FIGURE A.1. Likelihood profile on the global scaling parameter R_0 (virgin recruitment)
FIGURA A.1. Perfil de verosimilitud para el parámetro global de escala R_0 (reclutamiento virgen)

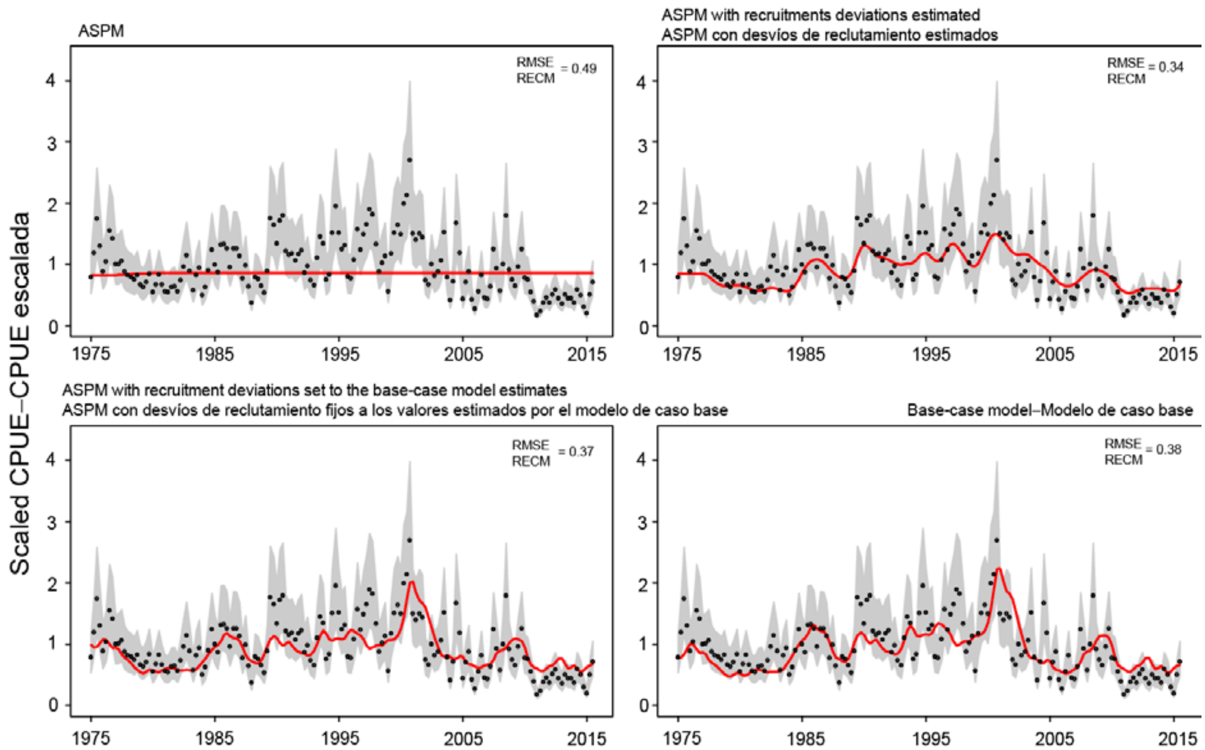

FIGURE A.2. Age-structured production model (ASPM) diagnostic: model fit (red line) to the CPUE of the Southern longline fishery (F12-LL_S). The shaded area represented the fixed confidence interval (±2 standard deviations) around the CPUE values.

FIGURA A.2. Diagnóstico de modelo de producción por edad (ASPM): ajuste del modelo (línea roja) a la CPUE de la pesquería palangrera del sur (F12-LL_S). El área sombreada representa el intervalo de confianza fijo (±2 desviaciones estándar) alrededor de los valores de CPUE.

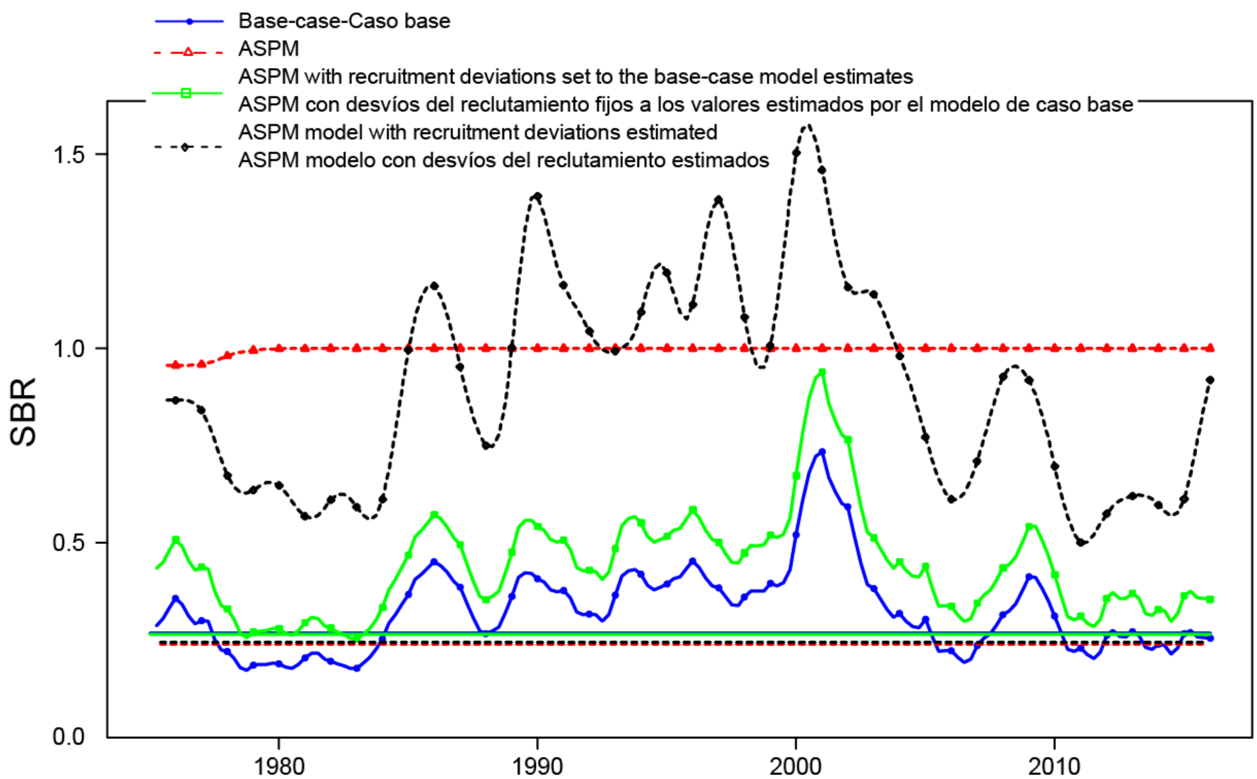

FIGURE A.3. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the age-structured production model (ASPM) diagnostic. SBR trends are shown for the a) base case, b) ASPM with no recruitment deviations estimated, c) ASPM with recruitment deviations estimated, and d) ASPM with recruitment deviations fixed at the estimates from the base-case model. The horizontal lines represent the SBRs associated with MSY for each scenario.

FIGURA A.3. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún aleta amarilla del diagnóstico del modelo de producción por edad (ASPM). Se señalan las tendencias del SBR correspondientes al caso base, ASPM sin desvíos del reclutamiento estimados, ASPM con desvíos del reclutamiento estimados, y ASPM con los desvíos del reclutamiento fijos en las estimaciones del modelo de caso base. Las líneas horizontales representan los SBR asociados al RMS para cada escenario.

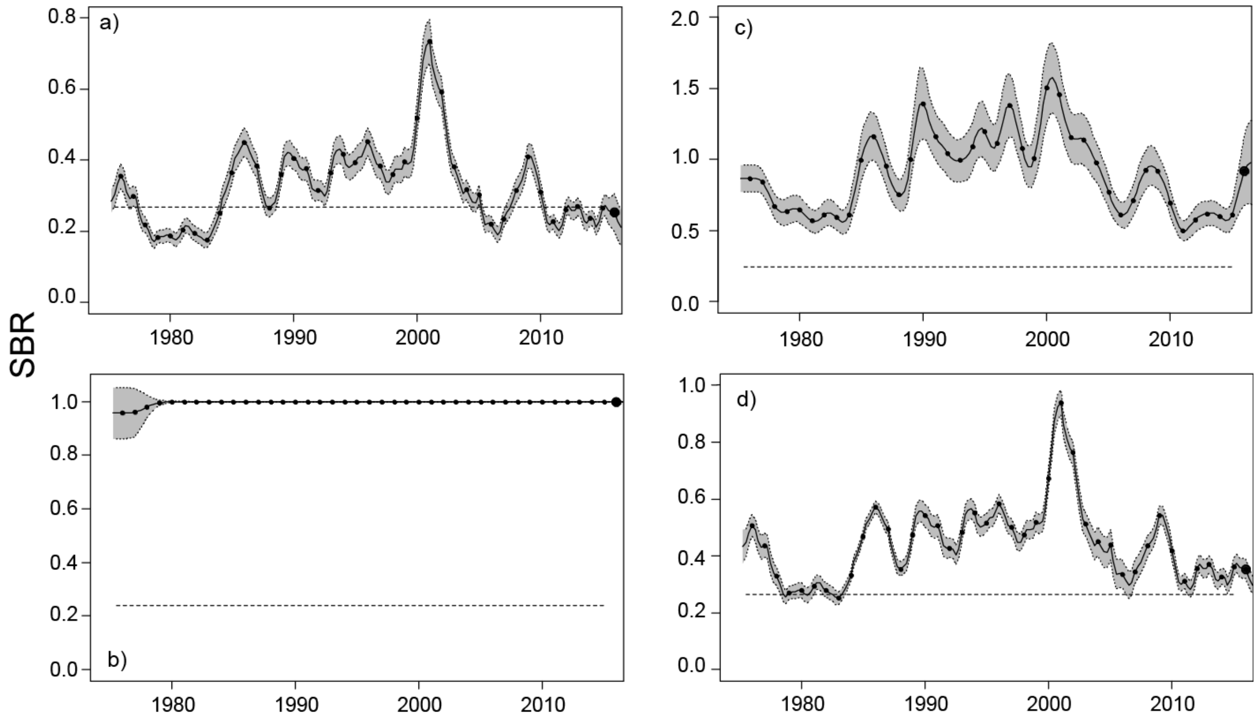

FIGURE A.4. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the age-structured production model (ASPM) diagnostic. SBR trends are shown for: a) base case, b) ASPM with no recrtuitment deviations estimated, c) ASPM with recruitment deviations estimated, and d) ASPM with recruitment deviations fixed at the estimates from the base case model. The solid line illustrates the maximum likelihood estimates. The shaded area indicates the approximate 95-percent confidence intervals around those estimates. The horizontal lines represent the SBRs associated with MSY for each scenario.

FIGURA A.4. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún aleta amarilla del diagnóstico del modelo de producción por edad (ASPM). Se señalan las tendencias del SBR correspondientes al a) caso base, b) ASPM sin desvíos del reclutamiento estimados, c) ASPM con desvíos del reclutamiento estimados, y d) ASPM con los desvíos del reclutamiento fijos en las estimaciones del modelo de caso base. El área sombreada indica los intervalos de confianza de 95% aproximados alrededor de esas estimaciones. Las líneas horizontales representan los SBR asociados al RMS para cada escenario.

APPENDIX B: SENSITIVITY ANALYSIS FOR THE STOCK-RECRUITMENT RELATIONSHIP
ANEXO B: ANÁLISIS DE SENSIBILIDAD A LA RELACIÓN POBLACIÓN-RECLUTAMIENTO

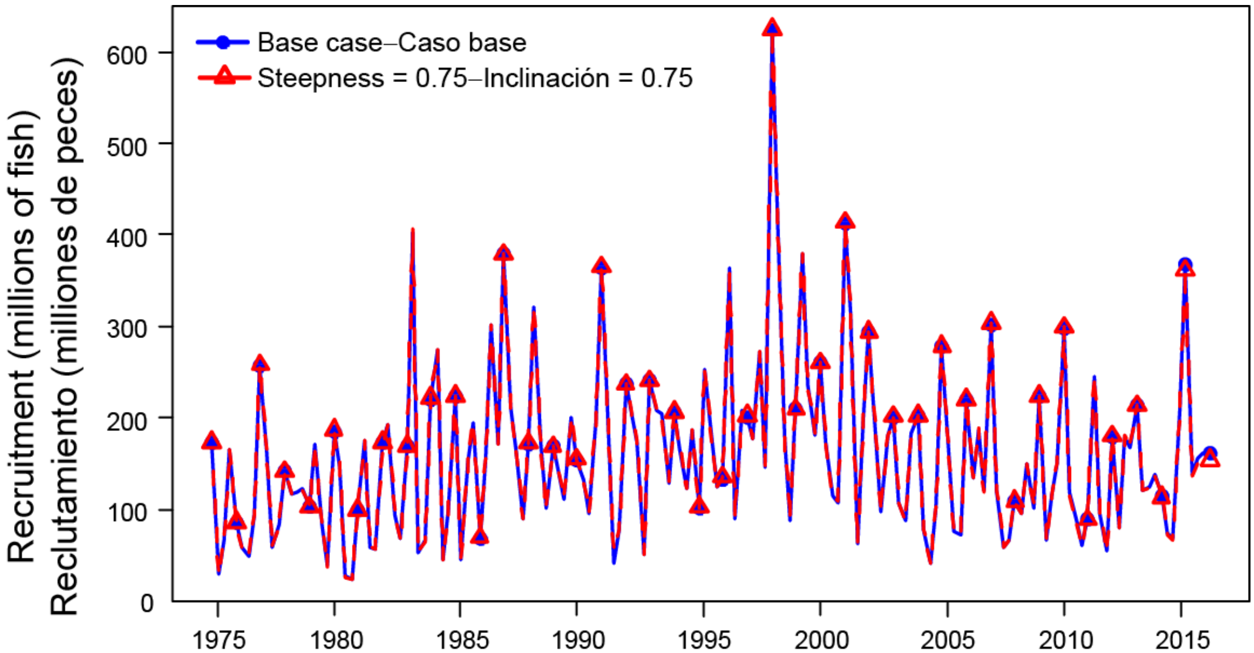

FIGURE B.1. Comparison of estimates of recruitment of yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).
FIGURA B.1. Comparación de las estimaciones de reclutamiento de atún aleta amarilla del análisis sin (caso base) y con (inclinación = 0,75) relación población-reclutamiento.

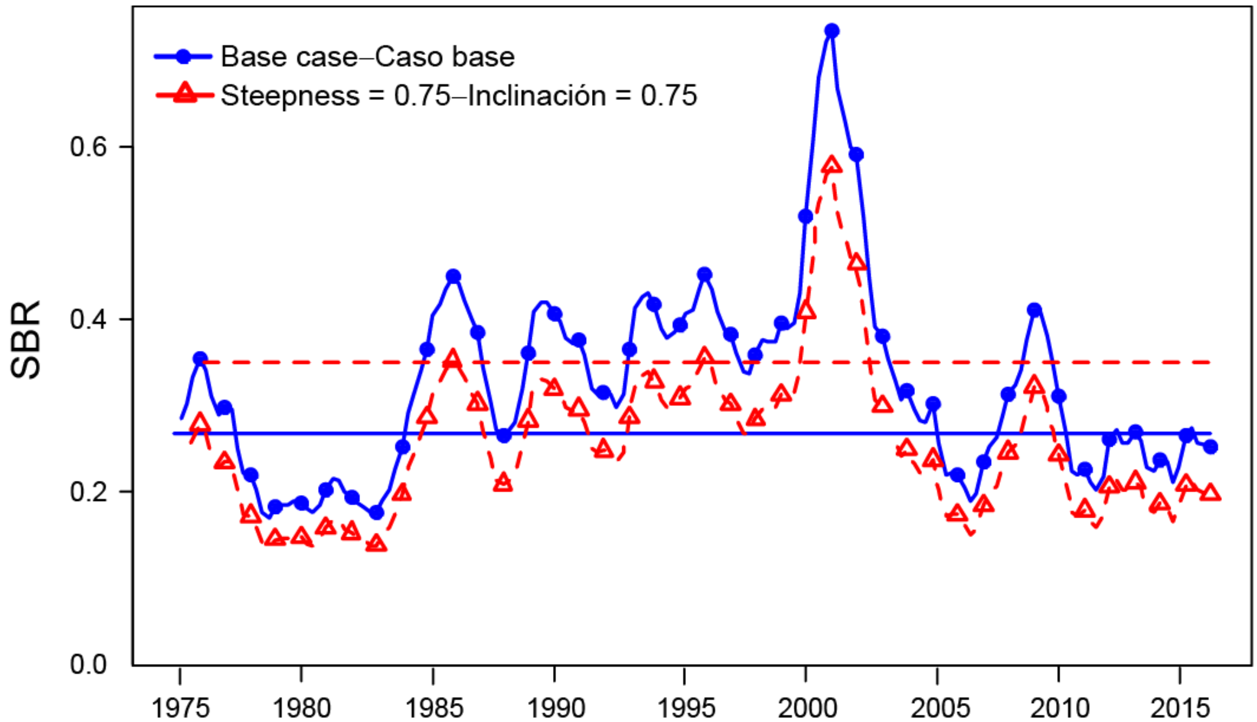

FIGURE B.2. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). The horizontal lines represent the SBR associated with MSY for each scenario.
FIGURA B.2. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún aleta amarilla del análisis sin (caso base) y con relación población-reclutamiento (inclinación = 0,75). Las líneas horizontales representan los SBR asociados al RMS en cada escenario.

APPENDIX C: SENSITIVITY ANALYSIS TO THE AVERAGE SIZE OF THE OLDEST FISH PARAMETER, L_2
ANEXO C: ANÁLISIS DE SENSIBILIDAD AL PARÁMETRO DE LA TALLA MEDIA DE LOS PECES MÁS VIEJOS, L_2

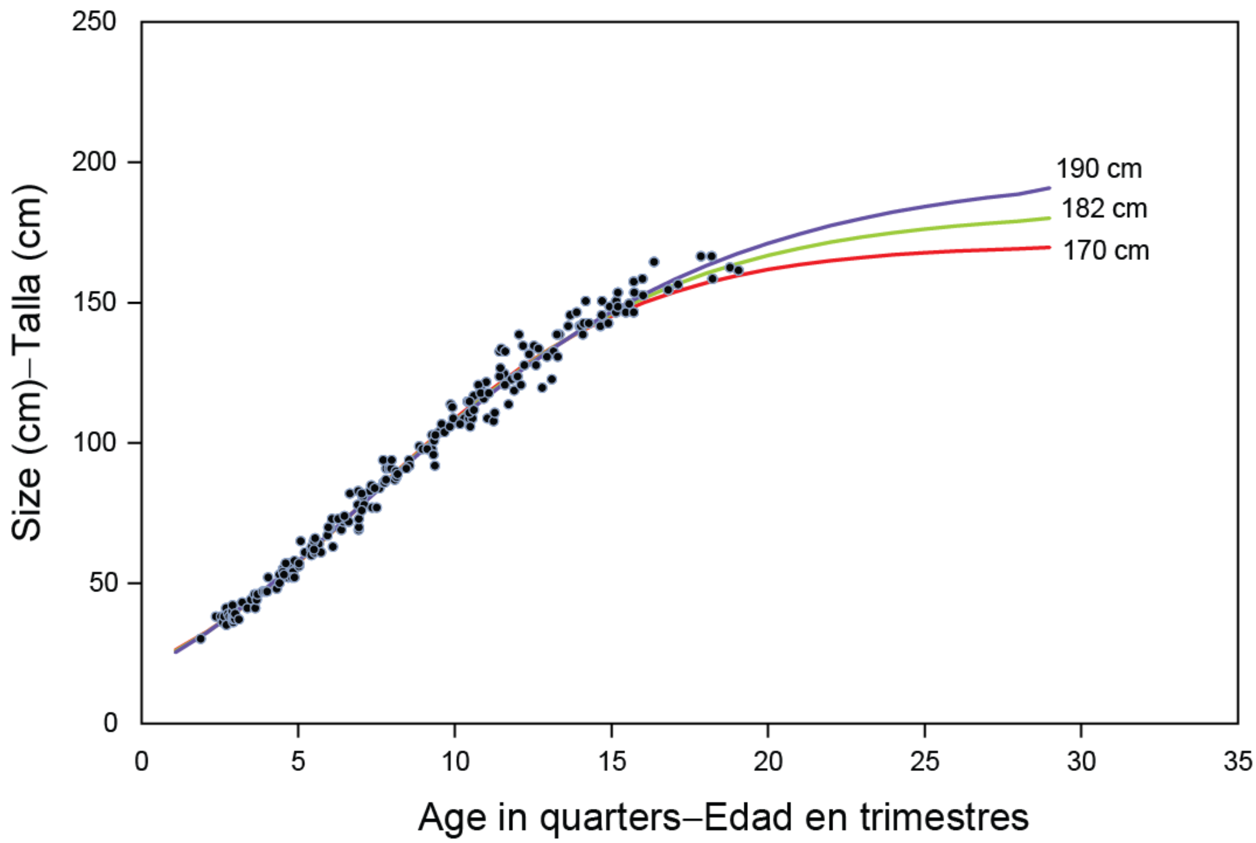

FIGURE C.1. Comparison of the Richards growth curves (sensitivity) for yellowfin tuna, assuming different fixed values for the average size of the oldest fish (L_2) parameter.

FIGURA C.1. Comparación de las curvas de crecimiento de Richards (sensibilidad) del atún alleta amarilla, con diferentes supuestos de valor fijo del parámetro de talla media de los peces más viejos (L_2).

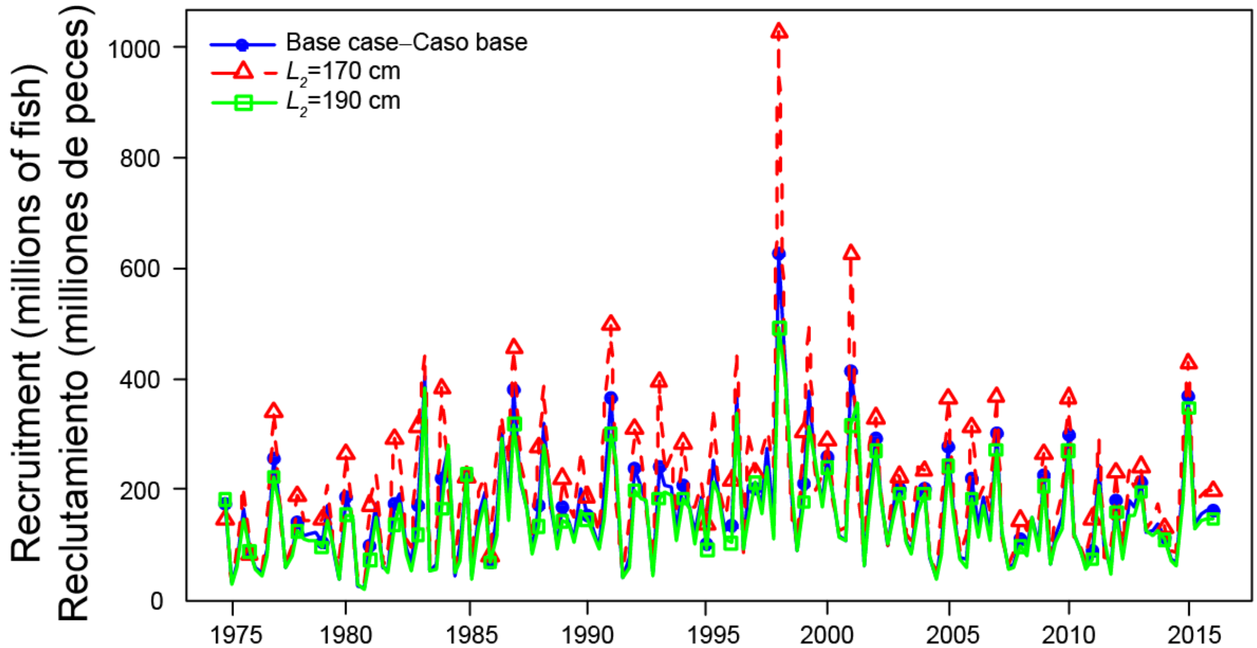

FIGURE C.2a. Comparison of estimates of absolute recruitment (in millions of fish) for yellowfin tuna from the base case analysis using a Richards growth curve with the average size of the oldest fish (L_2) fixed at 182 cm, and two alternative models with L_2 fixed at a lower (170 cm) and a higher value (190 cm).

FIGURA C.2a. Comparación de las estimaciones de reclutamiento absoluto (en millones de peces) de atún alleta amarilla del análisis del caso base que usa una curva de crecimiento de Richards con la talla promedio de los peces más viejos (L_2) fijada en 182 cm, y dos modelos alternativos con L_2 fijado en valores menor (170 cm) y mayor (190 cm).

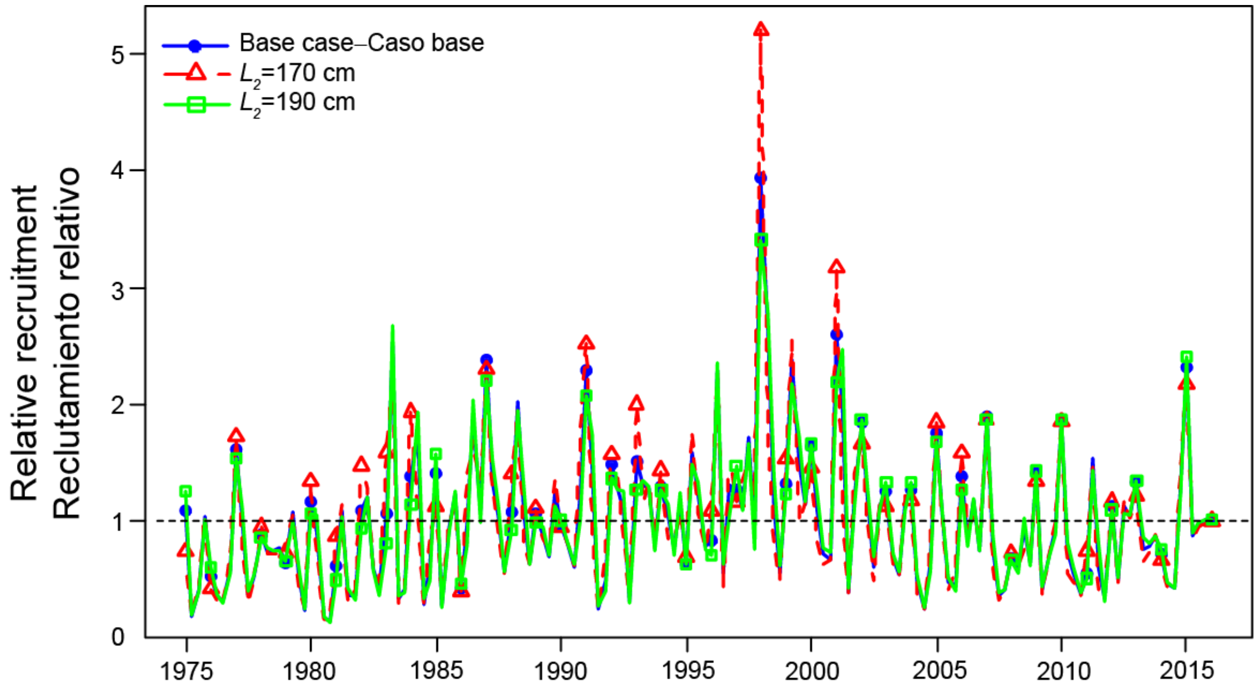

FIGURE C.2b. Comparison of estimates of relative recruitment for yellowfin tuna from the base case analysis using a Richards growth curve with the average size of the oldest fish (L_2) fixed at 182 cm, and two alternative models with L_2 fixed at a lower (170 cm) and a higher value (190 cm). The estimates are scaled so that the estimate of average recruitment is equal to 1.0 (dashed horizontal line).

FIGURA C.2b. Comparación de las estimaciones de reclutamiento relativo de atún alleta amarilla del análisis del caso base que usa una curva de crecimiento de Richards con el tamaño promedio de los peces más viejos (L_2) fijado en 182 cm, y dos modelos alternativos con L_2 fijado en valores menor (170 cm) y mayor (190 cm). Se fija la escala de las estimaciones para que la estimación de reclutamiento medio equivalga a 1,0 (línea de trazos horizontal).

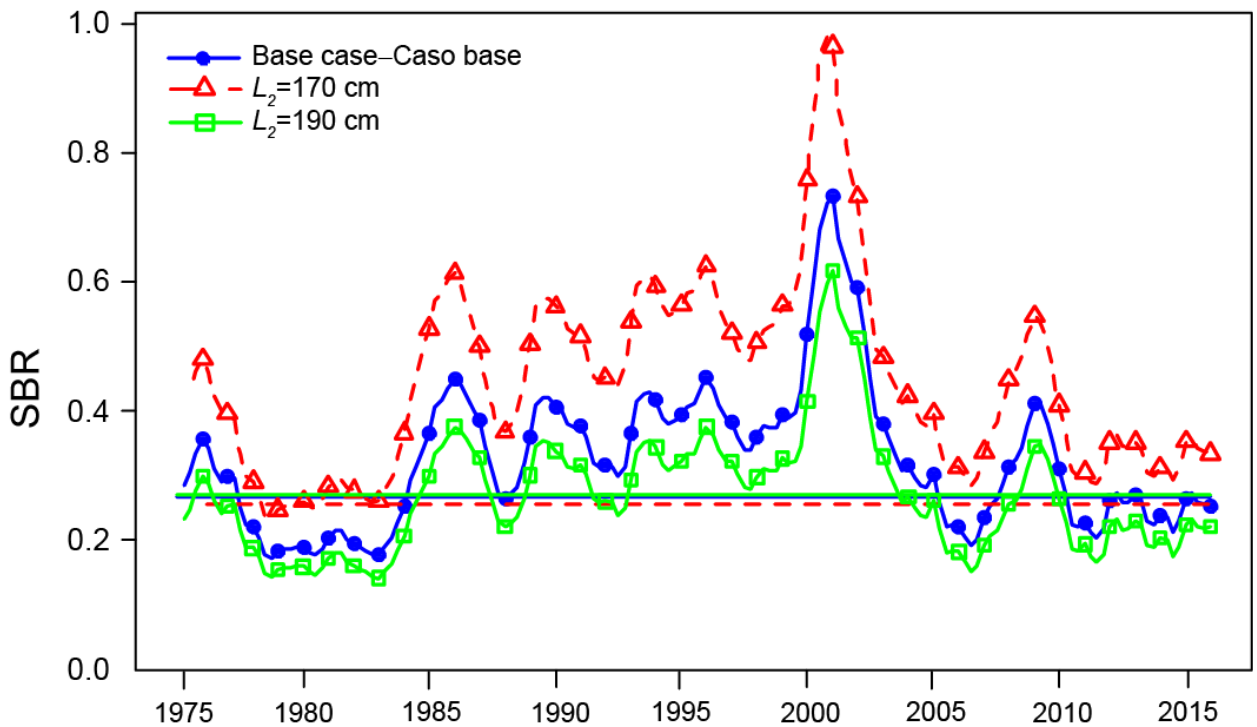

FIGURE C.3. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the base case analysis using a Richards growth curve with the average size of oldest fish (L_2) fixed at 182 cm, and two alternative models with L_2 fixed at a lower (170 cm) and a higher (190 cm) value. The horizontal lines represent the SBR associated with MSY for each scenario.

FIGURA C.3. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún aleta amarilla del análisis del caso base que usa una curva de crecimiento de Richards con el tamaño promedio de los peces más viejos (L_2) fijado en 182 cm, y dos modelos alternativos con L_2 fijado en valores menor (170 cm) y mayor (190 cm). Las líneas horizontales representan los SBR asociados al RMS correspondiente a cada escenario.

APPENDIX D: SENSITIVITY ANALYSIS TO FITTING THE CPUE OF THE NORTHERN DOLPHIN-ASSOCIATED FISHERY AS THE MAIN INDEX OF ABUNDANCE

ANEXO D: ANÁLISIS DE SENSIBILIDAD AL AJUSTE DE LA CPUE DE LA PESQUERÍA ASOCIADA A DELFINES DEL NORTE COMO ÍNDICE PRINCIPAL DE ABUNDANCIA

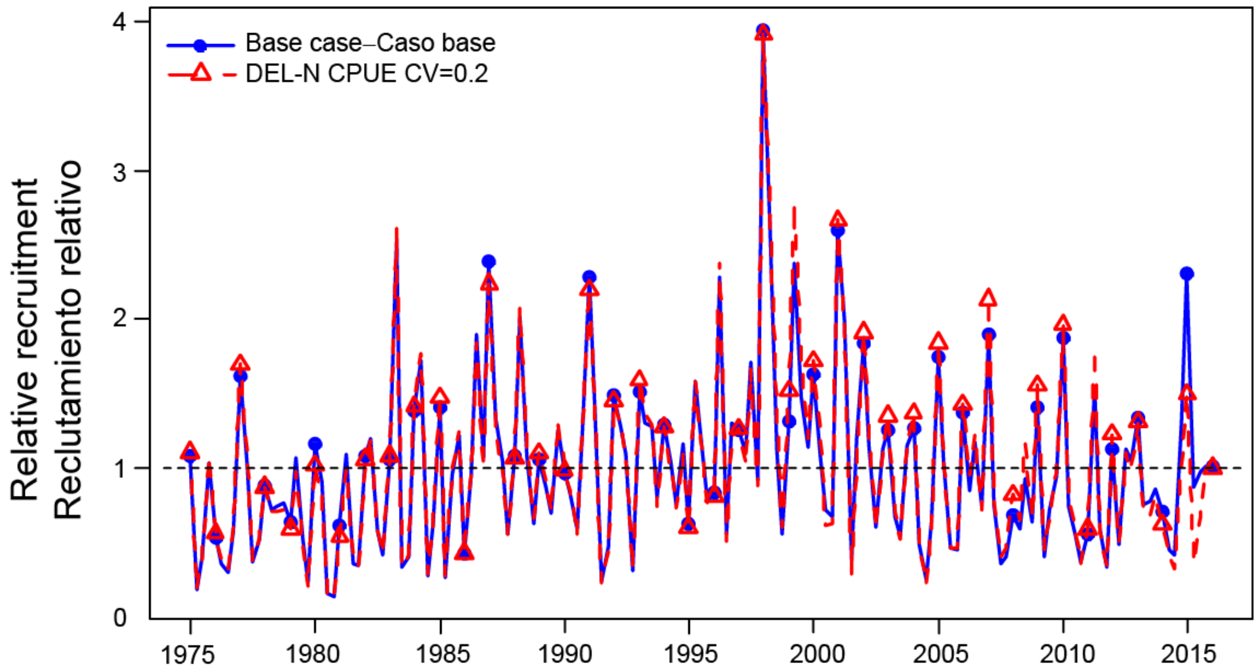

FIGURE D.1. Comparison of estimates of recruitment of yellowfin tuna from the model fitting more closely to the CPUE of the southern longline fishery (base case) and the model fitting more closely to the CPUE of the northern dolphin fishery (DEL-N).

FIGURA D.1. Comparación de las estimaciones de reclutamiento de atún aleta amarilla del modelo que se ajusta más estrechamente a la CPUE de la pesquería de palangre del sur (caso base) y el modelo que se ajusta más estrechamente a la CPUE de la pesquería sobre delfines del norte (DEL-N).

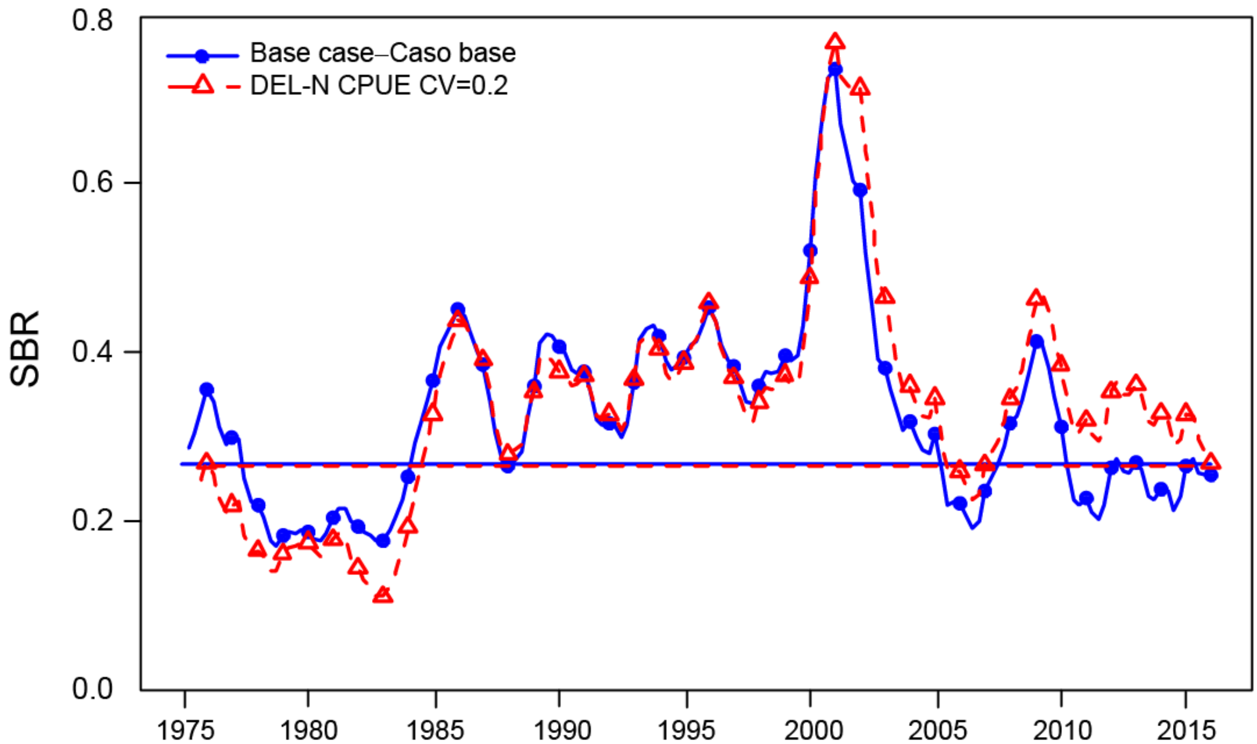

FIGURE D.2. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the model fitting more closely to the CPUE of the southern longline fishery (base case) and the model fitting more closely to the CPUE of the northern dolphin fishery (DEL-N). The horizontal lines represent the SBR associated with MSY for each scenario.

FIGURA D.2. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún aleta amarilla del modelo que se ajusta más estrechamente a la CPUE de la pesquería de palangre del sur (caso base) y el modelo que se ajusta más estrechamente a la CPUE de la pesquería sobre delfines del norte (DEL-N). Las líneas horizontales representan los SBR asociados al RMS correspondiente a cada escenario.

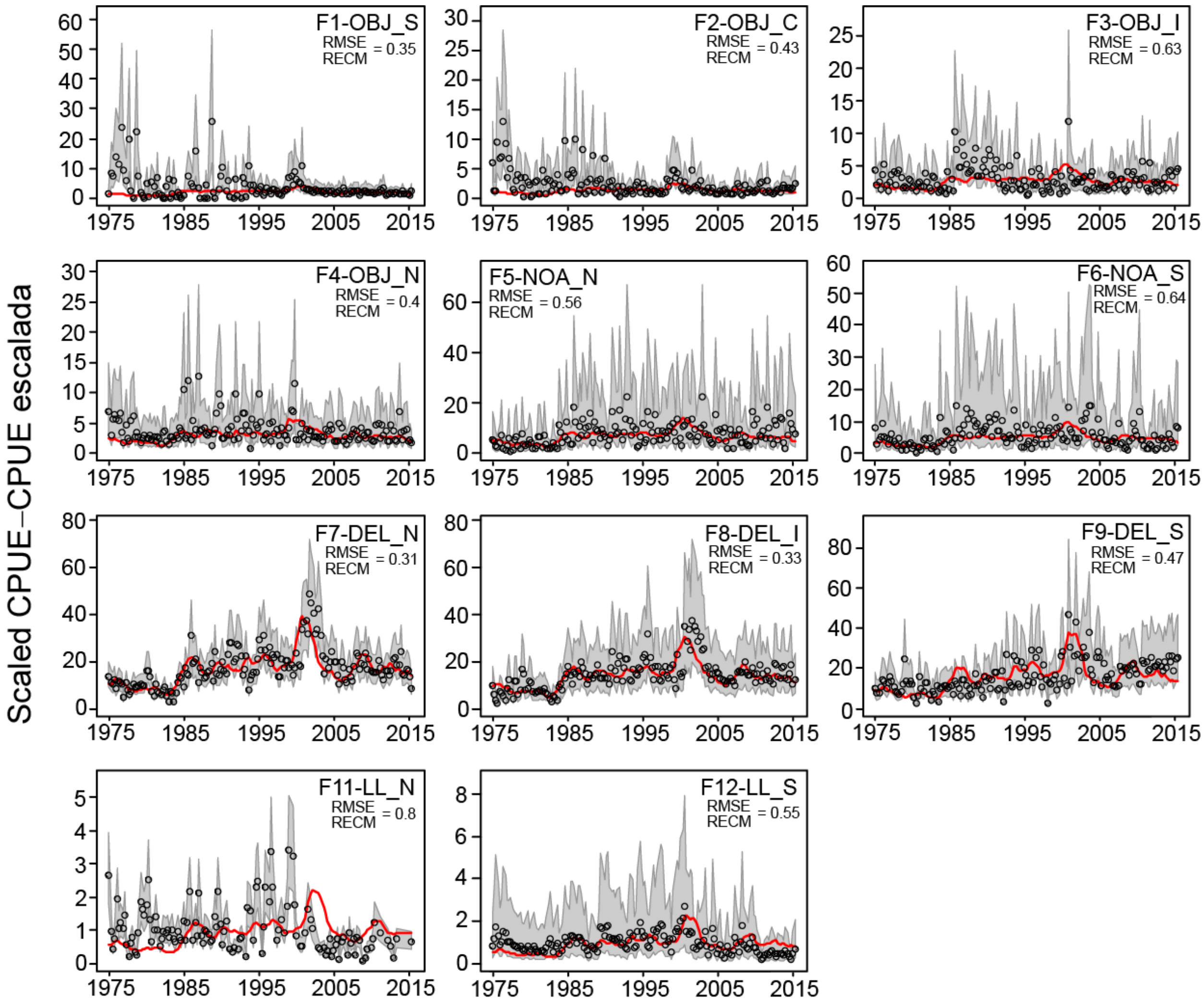

FIGURE D.3. Model fits (for F5, F6, F7, F8, and F12) and predictions (for the rest, as they are not used in the model fit) to the CPUE from the model fitting more closely to the CPUE of the northern dolphin fishery (DEL-N, F7). The shaded area represents the 95% confidence intervals for the observed data (dots) based on the assumed variability for the data or the internally-estimated standard deviations for the lognormal-based likelihood function (for F5, F6, F8, and F12).

FIGURA D.3. Ajustes del modelo (para F5, F6, F7, F8, y F12) y predicciones (para los demás, ya que no se usan en el ajuste del modelo) a la CPUE del modelo que se ajusta más estrechamente a la CPUE de la pesquería sobre delfines del norte (DEL-N, F7). El área sombreada representa los intervalos de confianza de 95% correspondientes a los datos observados (puntos) basados en variabilidad supuesta de los datos o las desviaciones estándar estimadas internamente para la función de verosimilitud log-normal (para F5, F6, F8, y F12).

APPENDIX E: SENSITIVITY ANALYSIS TO DATA WEIGHTING
ANEXO E: ANÁLISIS DE SENSIBILIDAD A LA PONDERACIÓN DE LOS DATOS

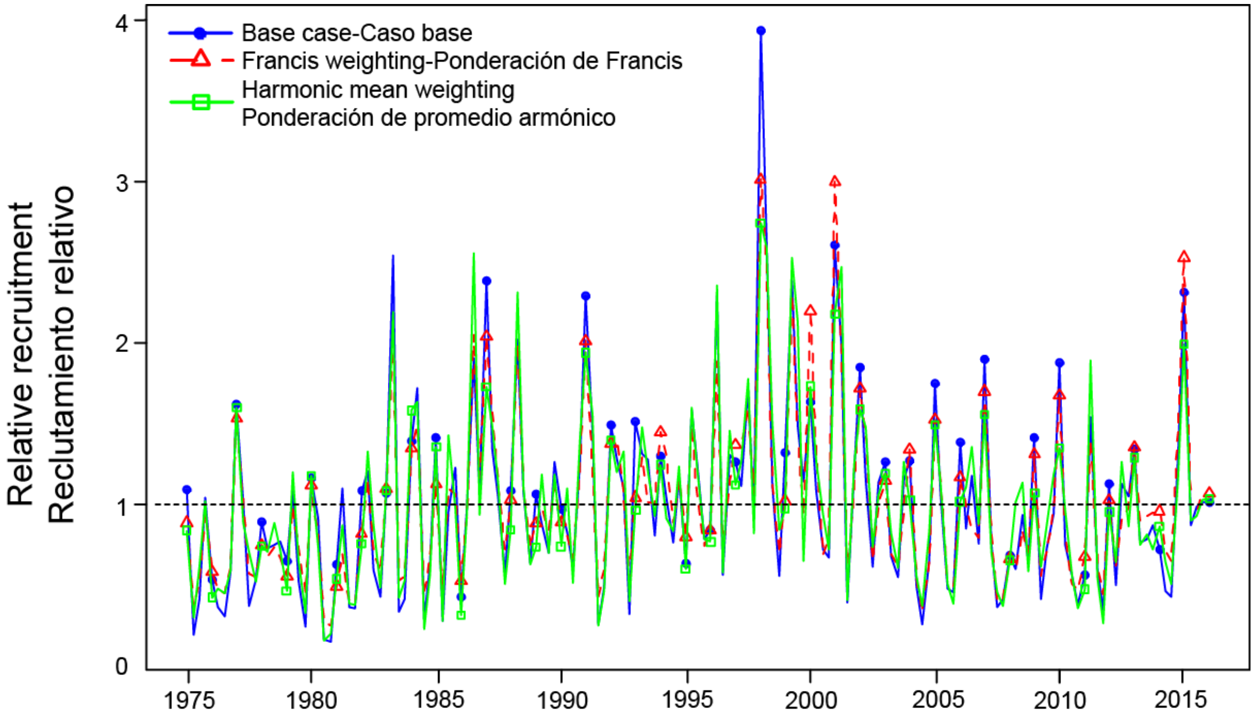

FIGURE E.1. Comparison of estimates of recruitment of yellowfin tuna, from the models with different weightings for the length-frequency data.
FIGURA E.1. Comparación de las estimaciones del reclutamiento de atún aleta amarilla, de los modelos con distintas ponderaciones de los datos de frecuencia de talla.

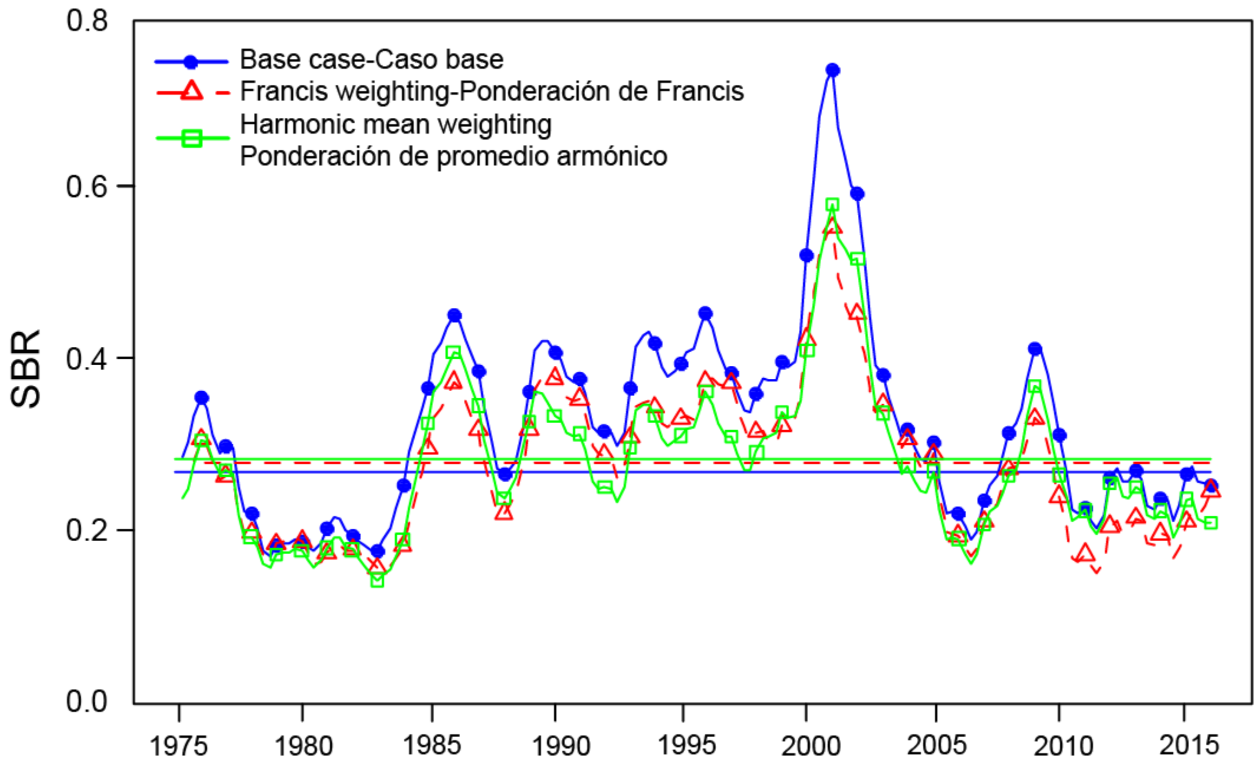

FIGURE E.2. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the models with different weightings for the length-frequency data. The horizontal lines represent the SBRs associated with MSY for each scenario.

FIGURA E.2. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún aleta amarilla, de los modelos con ponderación diferente de los datos de frecuencia de talla. Las líneas horizontales representan los SBR asociado al RMS correspondiente a cada escenario.

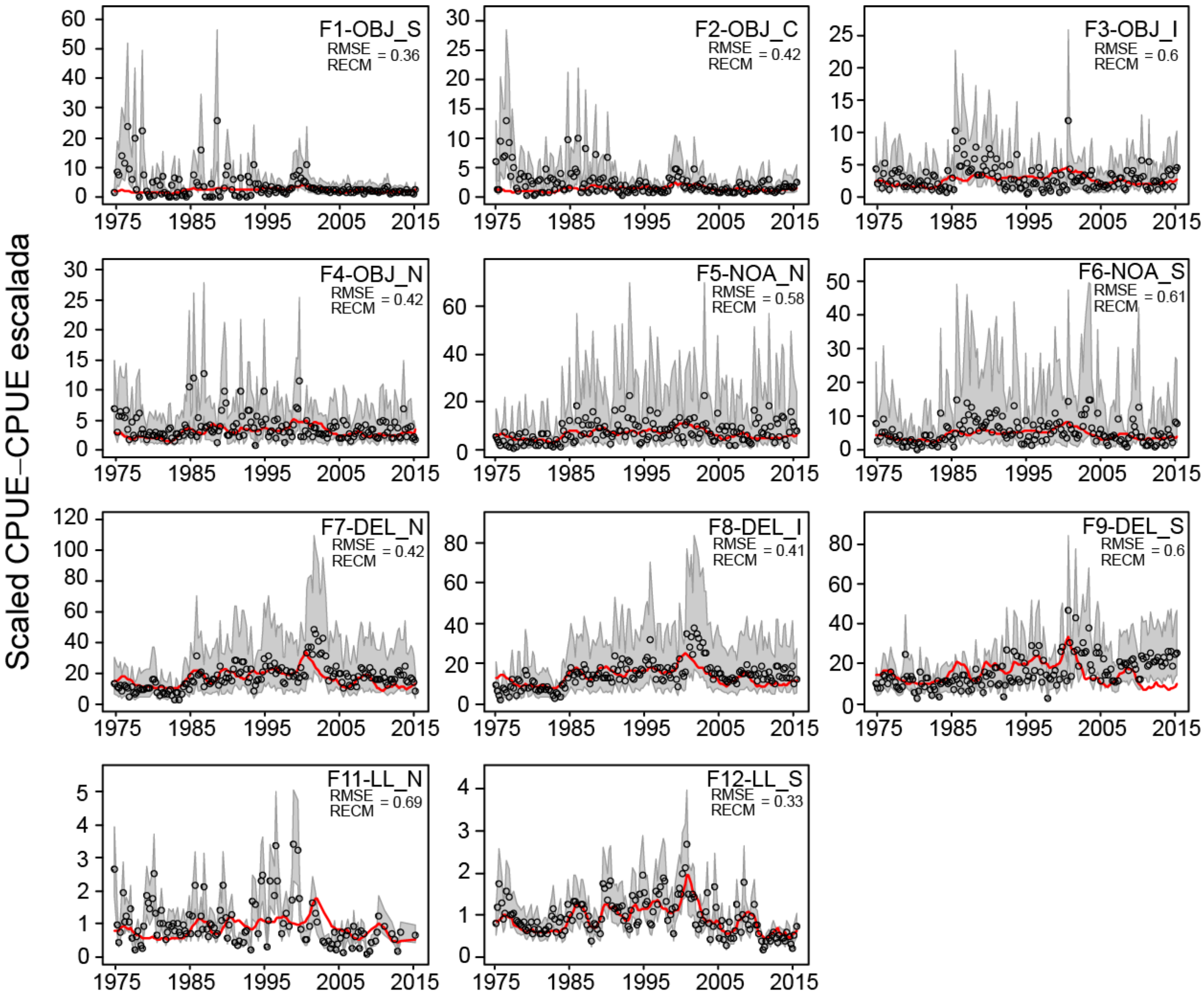

FIGURE E.3. Model fits (for F5, F6, F7, F8, and F12) and predictions (for the rest, because they are not used in the model fit) to the CPUE from the model that uses the Francis methods for weighting the length-frequency data. The shaded area represents the 95% confidence intervals for the observed data (dots) based on the assumed variability for the data or the internally-estimated standard deviations for the lognormal-based likelihood function (for F5, F6, F7, and F8).

FIGURA E.3. Ajustes del modelo (para F5, F6, F7, F8, y F12) y predicciones (para los demás, ya que no se usan en el ajuste del modelo) a la CPUE del modelo que usa los métodos de Francis para ponderar los datos de frecuencia de talla. El área sombreada representa los intervalos de confianza de 95% correspondientes a los datos observados (puntos) basados en variabilidad supuesta de los datos o las desviaciones estándar estimadas internamente para la función de verosimilitud log-normal (para F5, F6, F7, y F8).