INTER-AMERICAN TROPICAL TUNA COMMISSION

10TH STOCK ASSESSMENT REVIEW MEETING

La Jolla, California (USA)
12-15 May 2009

DOCUMENT SARM-10-06a

STATUS OF YELLOWFIN TUNA IN THE EASTERN PACIFIC OCEAN IN 2008 AND OUTLOOK FOR THE FUTURE

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CONTENTS

1. SUMMARY

This report presents the most current stock assessment of yellowfin tuna (*Thunnus albacares*) in the eastern Pacific Ocean (EPO). An integrated statistical age-structured stock assessment model (Stock Synthesis Version 3; Methot 2005, 2009) was used in the assessment, which is based on the assumption that there is a single stock of yellowfin in the EPO. This model differs from that used in previous assessments. Yellowfin are distributed across the Pacific Ocean, but the bulk of the catch is made in the eastern and western regions. The purse-seine catches of yellowfin are relatively low in the vicinity of the western boundary of the EPO. The movements of tagged yellowfin are generally over hundreds, rather than thousands, of kilometers, and exchange between the eastern and western Pacific Ocean appears to be limited. This is consistent with the fact that longline catch-per-unit-of-effort (CPUE) trends differ among areas. It is likely that there is a continuous stock throughout the Pacific Ocean, with exchange of individuals at a local level, although there is some genetic evidence for local isolation. Movement rates between the EPO and the western Pacific cannot be estimated with currently-available tagging 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, fishing mortality, and stock structure. The assessment for 2009 differs substantially from that of 2008 because it uses the Stock Synthesis program. Previous assessments have used the A-SCALA program. The main differences include: use of a sex-specific model, inclusion of indices of abundance rather than effort, and use of functional forms for selectivity. The catch and length-frequency data for the surface fisheries have been updated to include new data for 2008. New or updated longline catch data are available for China (2007), Chinese Taipei (2005-2007) and Japan (2003-2007).

In general, the recruitment of yellowfin to the fisheries in the EPO is variable, with a seasonal component. This analysis and previous analyses have indicated that the yellowfin population has experienced two, or possibly three, different recruitment productivity regimes (1975-1982, 1983-2002, and 2003-2006). The productivity regimes correspond to regimes in biomass, higher-productivity regimes producing greater biomass levels. A stock-recruitment relationship is also supported by the data from these regimes, but the evidence is weak, and is probably an artifact of the apparent regime shifts. Larger recruitments in 2007 and 2008 have caused the biomass to increase in recent years.

The average weights of yellowfin taken from the fishery have been fairly consistent over time, but vary 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 do the northern and coastal dolphin-associated fisheries.

Significant levels of fishing mortality have been estimated for the yellowfin fishery in the EPO. These levels are highest for middle-aged yellowfin. Despite more catch being taken in schools associated with dolphins than the other fisheries, the floating object and purse seine sets on unassociated schools have a greater impact on the yellowfin spawning biomass.

The estimated biomass is significantly lower than estimated in the previous assessment indicating that the results are sensitive to the changes in assessment methodology. There is also a large retrospective pattern of overestimating recent recruitment. The pattern is due to the floating object size composition data. These in combination with the large confidence intervals for estimates of recent recruitment indicate that estimates of recent recruitment and recent biomass are uncertain. The results of the assessment are also particularly sensitive to the level of natural mortality assumed for adult yellowfin.

Historically, the SBR of yellowfin in the EPO was below the level corresponding to the MSY during the lower productivity regime of 1975-1983 (Section 4.2.1), but above that level for most of the following years, except for the recent period (2004-2007). 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 two different productivity regimes may support two different MSY levels and associated SBR levels. The SBR at the start of 2009 is estimated to be above the level corresponding to the MSY. The effort levels are estimated to be less than those that would support the MSY (based on the current distribution of effort among the different fisheries), but recent catches are substantially below MSY.

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 SBR levels.

The MSY has been stable during the assessment period, which suggests that the overall pattern of selectivity has not varied a great deal through time. However, the overall level of fishing effort has varied with respect to the level corresponding to MSY.

The SBR corresponding to MSY decreased substantially from the previous assessment indicating that the results are sensitive to the change in methodology. The change is attributed to the method used to model selectivity. However, the SBR relative to SBR corresponding to MSY and the F multiplier are similar to the previous assessment.

If a stock-recruitment relationship is assumed, the outlook is more pessimistic, and current biomass is estimated to be below the level corresponding to the MSY. The status of the stock is also sensitive to the value of adult natural mortality, the method used to model selectivity, and the assumed length of the oldest age modeled (29 quarters).

Under current levels of fishing mortality (2006-2008), the spawning biomass is predicted to slightly decrease, but remain above the level corresponding to MSY. Fishing at F_{msy} is predicted to reduce the spawning biomass slightly from that under current effort and produces slightly higher catches

Key Results

1. The stock assessment method has changed to Stock Synthesis

2. The estimates of the key management quantities are similar to the previous assessments

3. Estimates of absolute biomass are lower than estimated in previous years

4. The SBR corresponding to MSY has reduced substantially from previous assessments and the reduction is attributed to the new method to model selectivity

5. There is uncertainty about recent and future recruitment and biomass levels and there are retrospective patterns of overestimating recent recruitment.

6. The recent fishing mortality rates are close to those corresponding to the MSY.

7. Increasing the average weight of the yellowfin caught could increase the MSY.

8. There have been two, and possibly three, different productivity regimes, and the levels of MSY and the biomasses corresponding to the MSY may differ between the regimes. The population may have recently switched from the high to an intermediate productivity regime.

9. The results are more pessimistic if a stock-recruitment relationship is assumed.

10. The results are sensitive to the natural mortality assumed for adult yellowfin, the method used to model selectivity, and the length assumed for the oldest fish.

2. DATA

Catch, indices of abundance, and size-composition data for January 1975-December 2008, plus biological data, were used to conduct the stock assessment of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean (EPO). The data for 2008, which are preliminary, include records that had been entered

into the IATTC databases by 15 April 2009. All data are summarized and analyzed on a quarterly basis.

2.1. Definitions of the fisheries

Sixteen fisheries are defined for the stock assessment of yellowfin. These fisheries are defined on the basis of gear type (purse seine, pole and line, and longline), purse-seine set type (sets on schools associated with floating objects, unassociated schools, and dolphin-associated schools), and IATTC length-frequency sampling area or latitude. The yellowfin fisheries are defined in Table 2.1, and their spatial extents are shown in Figure 2.1. The boundaries of the length-frequency sampling areas are also shown in Figure 2.1.

In general, fisheries are defined so that, over time, there is little change in the size composition of the catch. Fishery definitions for purse-seine sets on floating objects are also stratified to provide a rough distinction between sets made mostly on fish-aggregating devices (FADs) (Fisheries 1-2, 4, 13-14, and 16), and sets made on mixtures of flotsam and FADs (Fisheries 3 and 15).

2.2. Catch

To conduct the stock assessment of yellowfin tuna, the catch and effort data in the IATTC databases are stratified according to the fishery definitions described in Section 2.1 and shown in Table 2.1. "Landings" is catch landed in a given year even if the fish were not caught in that year. Catch that is taken in a given year and not discarded at sea is termed retained catch. Throughout the document the term "catch" will be used to reflect either total catch (discards plus retained catch) or retained catch, and the reader is referred to the context to determine the appropriate definition.

All three of these types of data are used to assess the stock of yellowfin. Removals by Fisheries 10-12 are simply retained catch (Table 2.1). Removals by Fisheries 1-4 are retained catch plus some discards resulting from inefficiencies in the fishing process (see Section 2.2.3) (Table 2.1). The removals by Fisheries 5-9 are retained catch, plus some discards resulting from inefficiencies in the fishing process and from sorting the catch. Removals by Fisheries 13-16 are only discards resulting from sorting the catch taken by Fisheries 1-4 (see Section 2.2.2) (Table 2.1).

New and updated catch data for the surface fisheries (Fisheries 1-10 and 13-16) have been incorporated into the current assessment. New catch data for 2008 and updated data for earlier years are used for the surface fisheries.

The species-composition method (Tomlinson 2002) was used to estimate catches of the surface fisheries. Comparisons of catch estimates from different sources show consistent differences between cannery and unloading data and the results of species composition sampling. Comparing the two sets of results is complex, as the cannery and unloading data are collected at the trip level, while the species-composition samples are collected at the well level, and represent only a small subset of the data. Differences in catch estimates could be due to the proportions of small tunas in the catch, differences in identification of the fish at the cannery, or even biases introduced in the species-composition algorithm in determining the species composition in strata for which no species-composition samples are available. In this assessment we calculated average quarterly and fishery-specific scaling factors for 2000-2005 and applied these to the cannery and unloading estimates for 1975-1999. Harley and Maunder (2005) compared estimates of the catches of bigeye obtained by sampling catches with estimates of the catches obtained from cannery data.

Updates and new catch data for the longline fisheries (Fisheries 11 and 12) have also been incorporated into the current assessment. In particular, New or updated catch data were available for China (2007), Chinese Taipei (2005-2007), and Japan (2003-2007).

A substantial proportion of the longline catch data for 2008 were not available so catches for the longline fisheries for the recent years for which the data were not available were set equal, by nation, to the last year for which catch data were available.

Trends in the catch of yellowfin in the EPO during each quarter from January 1975 to December 2008 are shown in Figure 2.2. It should be noted that there were substantial surface and longline fisheries for yellowfin prior to 1975 (Shimada and Schaefer 1956; Schaefer 1957; Okamoto and Bayliff 2003). The majority of the catch has been taken by purse-seine sets on yellowfin associated with dolphins and in unassociated schools. One main characteristic of the catch trends is the increase in catch taken since about 1993 by purse-seine sets on fish associated with floating objects, especially FADs in Fisheries 1 and 2. However, this is a relatively small part of the total catch.

Although the catch data in Figure 2.2 are presented as weights, the catches in numbers of fish were used to account for most of the longline catches of yellowfin in the stock assessment.

2.2.1. Discards

For the purposes of stock assessment, it is assumed that yellowfin are discarded from catches made by purse-seine vessels because of inefficiencies in the fishing process (when the catch from a set exceeds the remaining storage capacity of the fishing vessel) or because the fishermen sort the catch to select fish that are larger than a certain size. In either case, the amount of yellowfin discarded is estimated with information collected by IATTC or national observers, applying methods described by Maunder and Watters (2003a). Regardless of why yellowfin are discarded, it is assumed that all discarded fish die. Maunder and Watters (2001) describe how discards were implemented in the yellowfin assessment..

Estimates of discards resulting from inefficiencies in the fishing process are added to the retained catches (Table 2.1). No observer data are available to estimate discards prior to 1993, and it is assumed that there were no discards due to inefficiencies before that time. There are periods for which observer data are not sufficient to estimate the discards, in which case it is assumed that the discard rate (discards/retained catches) is equal to the discard rate for the same quarter in the previous year or, if not available, a proximate year.

Discards that result from the process of sorting the catches are treated as separate fisheries (Fisheries 13-16), and the catches taken by these fisheries assumed to be composed only of fish that are 2-4 quarters old. Maunder and Watters (2001) provide a rationale for treating such discards as separate fisheries. Estimates of the amounts of fish discarded during sorting are made only for fisheries that take yellowfin associated with floating objects (Fisheries 2-5) because sorting is infrequent in the other purse-seine fisheries.

Time series of discards as proportions of the retained catches for the surface fisheries that catch yellowfin in association with floating-objects are presented in Figure 2.2c. As seen in Figure 2.2c a reduction in bycatch rates occurred beginning around 2001, possibly as a consequence of a series of bycatch retention resolutions passed for the years 2001-2007. The retention resolution was not in force during 2008 but the bycatch rates continue to be low. It is assumed that yellowfin are not discarded from longline fisheries (Fisheries 11 and 12).

2.3. Indices of abundance

Indices of abundance were derived from purse-seine and longline catch and effort data. New fishing effort and catch data for the surface fisheries (Fisheries 1-9) have been added for 2008 and updated for earlier years. New or updated catch and effort data are available for the Japanese longline fisheries (2005-2007). Trends in the amount of fishing effort exerted by 11 of the 16 fisheries defined for the stock assessment of yellowfin tuna in the EPO are shown in Figure 2.3; the pole-and-line and four discard fisheries are excluded from Figure 2.3.

The CPUE for the purse-seine fisheries was calculated as catch divided by number of days fished. The number of days fished by set type was calculated from the number of sets, using a multiple regression of total days fished against number of sets by set type (Maunder and Watters, 2001).

Estimates of standardized catch per unit effort (1975-2007) were obtained for the longline fisheries

(Fisheries 11 and 12). A delta-lognormal general linear model, in which the explanatory variables were latitude, longitude, and hooks per basket, was used (Hoyle and Maunder 2006).

The CPUE time series for the different fisheries are presented in Figure 4.1. The indices of abundance that were considered appropriate for use in the assessment were those from Fisheries 5 and 6 (purse-seine sets on free swimming schools), 7 and 8 (purse-seine sets on yellowfin associated with dolphins), and 12 (the southern longline fishery). The fisheries excluded were considered inappropriate because the catch rates were extremely low, highly variable, or had variable length-frequency data and are considered not representative of yellowfin abundance.

2.4. Size-composition data

The fisheries of the EPO catch yellowfin of various sizes. The average size composition of the catch from each fishery defined in Table 2.1 is shown in Figure 4.2a and temporal variation is shown in figures 4.2b-4.2e. Maunder and Watters (2001) describe the sizes of yellowfin caught by each fishery. In general, floating-object, unassociated, and pole-and-line fisheries catch smaller yellowfin, while dolphin-associated and longline fisheries catch larger ones. New purse-seine length-frequency data were included for 2008.

New longline length-frequency data for 2007-2008 for the Japanese fleet were included. Size composition data for the other longline fleets are not used in the assessment.

2.5. Auxiliary data

Age-at-length estimates (Wild 1986) calculated from otolith data were integrated into the stock assessment model to provide information on mean length at age for a growth sensitivity analysis. Wild's data consisted of ages, based on counts of daily increments in otoliths, and lengths for 196 fish collected between 1977 and 1979. The sampling design involved collection of 15 yellowfin in each 10-cm interval in the length range of 30 to 170 cm.

Sex ratio data at length (Schaefer 1998) was integrated into the stock assessment model to provide information on natural mortality by gender for a sensitivity analysis investigating the ability to estimate the natural mortality for adult yellowfin by gender. The data comprise 8065 yellowfin caught by purse seine vessels from October 1987 to September 1989.

3. ASSUMPTIONS AND PARAMETERS

3.1. Biological and demographic information

3.1.1. Growth

The Richards growth curve is used to represent growth in the yellowfin tuna assessment. The parameters of the model are taken from the previous year's assessment, and are based on the fit to data from Wild (1986)

Expected asymptotic length (L_∞) cannot be reliably estimated from data such as those of Wild (1986) that do not include many old fish. However, Hoyle and Maunder (2007) found that the results were insensitive to the value of L_∞.

The coefficient of variation in length at age is assumed constant, and is taken from the previous year's assessment.

The following weight-length relationship, from Wild (1986), was used to convert lengths to weights in this stock assessment:

$$w = 1.387 \times 10^{-5} \cdot l^{3.086}$$

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

A more extensive unpublished data set of length and weight data gives a slightly different relationship, but inclusion of this alternative data set in the stock assessment model gives essentially identical results.

3.1.2. Recruitment and reproduction

The Stock Synthesis method allows a Beverton-Holt (1957) stock-recruitment relationship to be specified. The Beverton-Holt curve is parameterized so that the relationship between spawning biomass and recruitment is determined by estimating the average recruitment produced by an unexploited population (virgin recruitment) and a parameter called steepness. Steepness is defined as the fraction of virgin recruitment that is produced if the spawning stock size is reduced to 20% of its unexploited level, and it controls how quickly recruitment decreases when the size of the spawning stock is reduced. The base case assessment assumes that there is no relationship between stock size and recruitment. This assumption is the same as that used in the previous assessments. The influence of a Beverton-Holt stock-recruitment relationship is investigated in a sensitivity analysis.

It is assumed that yellowfin can be recruited to the fishable population during every quarter of the year. Hennemuth (1961) reported that there are two peaks of spawning of yellowfin in the EPO, but it is assumed in this study that recruitment may occur more than twice per year because individual fish can spawn almost every day if the water temperatures are in the appropriate range (Schaefer 1998).

An assumption is made about the way that recruitment can vary around its expected level, as determined from the stock-recruitment relationship. This assumption is used to penalize the temporal recruitment deviates. It is assumed that the logarithm of the quarterly recruitment deviates is normally distributed with a standard deviation of 0.6.

Recruitment is modeled at age zero in Stock Synthesis. The previous assessments modeled recruitment at age 2 quarters. Age zero is used for convenience and the assumed natural mortality for ages not vulnerable to the fisheries is not intended to represent the actual natural mortality and only arbitrarily scales the recruitment at age zero. Therefore, the assumed level of natural mortality for these ages has no impact on the assessment results.

The spawning potential of the population is estimated from the numbers of mature females adjusted for batch fecundity and spawning frequency (Schaefer 1998). The spawning potential of the population is used in the stock-recruitment relationship and to determine the spawning biomass ratios (ratios of spawning biomass to that for the unfished stock, SBRs). The relative fecundity at age is shown in Figure 3.2.

3.1.3. Movement

The evidence of yellowfin movement within the EPO is summarized by Maunder and Watters (2001) and new research is contained in Schaefer *et al.* (2007). Schaefer *et al.* (2007) found that movements of yellowfin tuna released off southern Baja California, including those at liberty in excess of one year, are geographically confined. Therefore, the level of mixing between this area and others in the EPO should be expected to be very low. This result is consistent with the results of various tagging studies (conventional and archival) of tropical tunas throughout the Pacific. This indicates that fishery-wide controls of effort or catch will most likely be ineffective to prevent localized depletions of these stocks (Schaefer *et al.* 2007). For the purposes of the current assessment, it is assumed that movement does not affect the stock assessment results. However, given the results of Schaefer *et al*. (2007), investigation of finer spatial scale or separate sub-stocks should be considered.

3.1.4. Natural mortality

For the current stock assessment, it is assumed that, as yellowfin grow older, the natural mortality rate (M) changes. This assumption is similar to that made in previous assessments, in which M was assumed to increase for females after they reached the age of 30 months (*e.g.* Anonymous 1999: 38). Males and females are treated separately in the current stock assessment, and M differs between males and females.

The values of quarterly *M* used in the current stock assessment are plotted in Figure 3.3. These values were estimated by making the assumptions described above, fitting to sex ratio at length data (Schaefer 1998), and comparing the values with those estimated for yellowfin in the western and central Pacific Ocean (Hampton 2000; Hampton and Fournier 2001). Maunder and Watters (2001) describe in detail how the age-specific natural mortality schedule for yellowfin in the EPO is estimated.

3.1.5. Stock structure

The exchange of yellowfin between the EPO and the central and western Pacific has been studied by examination of data on tagging, morphometric characters, catches per unit of effort, sizes of fish caught, *etc*. (Suzuki *et al.* 1978), and it appears that the mixing of fish between the EPO and the areas to the west of it is not extensive. Therefore, for the purposes of the current stock assessment, it is assumed that there is a single stock, with little or no mixing with the stock(s) of the western and central Pacific.

3.2. Environmental influences

Recruitment of yellowfin in the EPO has tended to be greater after El Niño events (Joseph and Miller 1989). Previous stock assessments have included the assumption that oceanographic conditions might influence recruitment of yellowfin in the EPO (Maunder and Watters 2001, 2002; see Maunder and Watters 2003b for a description of the methodology). This assumption is supported by observations that spawning of yellowfin is temperature dependent (Schaefer 1998). To incorporate the possibility of an environmental influence on recruitment of yellowfin in the EPO, a temperature variable was incorporated into previous stock assessment models to determine whether there is a statistically-significant relationship between this temperature variable and estimates of recruitment. Previous assessments (Maunder and Watters 2001, 2002) showed that estimates of recruitment were essentially identical with or without the inclusion of the environmental data. Maunder (2002a) correlated recruitment with the environmental time series outside the stock assessment model. For candidate variables, Maunder (2002) used the sea-surface temperature (SST) in an area consisting of two rectangles from 20°N-10°S and 100°W-150°W and 10°N-10°S and 85°W-100°W, the total number of 1°x1° areas with average SST≥24°C, and the Southern Oscillation Index. The data were related to recruitment, adjusted to the period of hatching. However, no relationship with these variables was found. No investigation using environmental variables was carried out in this assessment.

In previous assessments it has also been assumed that oceanographic conditions might influence the efficiency of the various fisheries described in Section 2.1 (Maunder and Watters 2001, 2002). It is widely recognized that oceanographic conditions influence the behavior of fishing gear, and several different environmental indices have been investigated. However, only SST for the southern longline fishery was found to be significant. Therefore, because of the use of standardized longline CPUE, environmental effects on catchability were not investigated in this assessment.

4. STOCK ASSESSMENT

The Stock Synthesis model (Methot 2005, 2009) is used for the first time to assess the status of yellowfin tuna in the EPO. It consists of an integrated (fitted to many different types of data) statistical age-structured stock assessment model. The model uses quarterly time steps to describe the population dynamics.

The model is fitted to the observed data (indices of relative abundance based on CPUE and size compositions) by finding a set of population dynamics and fishing parameters that maximize a penalized (for recruitment temporal deviates) likelihood, given the amount of catch taken by each fishery. Many aspects of the underlying assumptions of the model are described in Section 3. It also includes the following important assumptions:

1. Yellowfin tuna are recruited to the discard fisheries (Fisheries 13-16) one quarter after hatching, and these discard fisheries catch only fish of the first few age classes.

2. As yellowfin tuna age, they become more vulnerable to fisheries 6, 9, 11, and 12, and the oldest fish are the most vulnerable to these gears (i.e. asymptotic selectivity is assumed).

3. The data for fisheries that catch yellowfin tuna on floating-objects (Fisheries 1-4), associated with dolphins in the south (Fishery 9), the bait boat fishery (Fishery 10), the longline fishery in the north (Fishery 11), and fisheries whose catch is composed of the discards from sorting (Fisheries 13-16) provide relatively little information about biomass levels, because they do not direct their effort at yellowfin or there is too much variability in the fishery. For this reason, the CPUE time series for these fisheries were not used as indices of abundance. The CPUE time series fitted in the assessment are series from fisheries 5, 6, 7, 8, and 12.

4. The data for fishery associated with dolphins in the south (Fishery 9), the bait boat fishery (Fishery 10), and the longline fishery in the north (Fishery 11) are considered too variable and therefore their selectivity curves are assumed equal to other fisheries (Fisheries 12, 3, and 12, respectively) and their size composition data not fit in the model.

The following parameters have been estimated for the current stock assessment of yellowfin in the EPO:

1. recruitment to the fishery in every quarter from the first quarter of 1975 through the first quarter of 2009 (average recruitment and quarterly recruitment deviates);

2. catchability and the standard deviation for the likelihood function for the 5 CPUE time series that are used as indices of abundance;

3. Selectivity curves for 9 of the 16 fisheries (Fishery 10 mirrors the selectivity of Fishery 3, Fisheries 9 and 11 mirror the selectivity of fishery 12, and Fisheries 13-16 have assumed selectivity curves);

4. initial population size and age-structure (recruitment offset, initial fishing mortality, and deviates for ages 1 to 16 quarters);

The values of the following parameters are assumed to be known for the current stock assessment of yellowfin in the EPO:

1. fecundity of females at age (Figure 3.2);

2. natural mortality at age (Figure 3.3);

3. selectivity curves for the discard fisheries (Fisheries 13-16);

4. steepness of the stock-recruitment relationship (steepness = 1 for the base case assessment).

5. mean length at age (Section 3.1.1., Figure 3.1);

6. parameters of a linear model relating the coefficient of variation of length at age to age.

The estimates of management quantities and future projections were computed based on 3-year average fishing mortality rates, by gear, for 2006-2008. The sensitivity of estimates of key management quantities to including the last year (2008) in the 3-year average fishing mortality rate estimate was tested. For this purpose, a 2 year (2006-2007) average fishing mortality rate was used in the calculations.

There is uncertainty in the results of the current stock assessment. This uncertainty arises because the observed data do not perfectly represent the population of yellowfin in the EPO. Also, the stock assessment model may 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 it is unlikely that this assumption is satisfied, these values may underestimate the amount of uncertainty in the results of the current assessment. Additional sources of uncertainty are investigated in seven sensitivity analyses.

1. Sensitivity to the steepness of the stock-recruitment relationship. The base case assessment included an assumption that recruitment was independent of stock size, and a Beverton-Holt stock-recruitment relationship with a steepness of 0.75 was used for the sensitivity analysis.

2. Sensitivity to the data used in the model. Similarly to the previous years assessment, the model is fit to CPUE data for all fisheries and years (except the bait boat and the discard fisheries), the length frequency data for all fisheries and years, and asymptotic selectivity is estimated for the southern dolphin associated fishery and the northern longline fishery. However, unlike the previous assessment, the standard deviations of the likelihood functions for the CPUE data were estimated and therefore the weighting of the CPUE data in the model differs from the previous assessment.

3. Sensitivity to the natural mortality of mature yellowfin. The natural mortality for mature females and the natural mortality for mature males are estimated. Data on sex ratio was included in the model to provide information on the difference in natural mortality between the genders. The natural mortality was parameterized using a five parameter broken stick with the ages of the break points fixed and parameters of the initial age and the first two breakpoints fixed. The parameter of the third break point was estimated and was allowed to differ between the genders. The value for the oldest age was set equal to the value of the third breakpoint.

4. Sensitivity to the selectivity curves. A sensitivity analysis was carried out to investigate the difference in selectivity parameterizations used in the current assessment compared to the previous assessment. The selectivity was parameterized using a parameter for each age that was an exponential offset from the previous age. A normal prior with a standard deviation of 0.4 was put on the parameters to smooth the selectivity curve. The selectivity curve for the southern longline fishery was not changed and remained asymptotic. The selectivity curves for fisheries 9, 10, and 11 were estimated and the model was fit to their length-frequency data. The selectivity was forced to zero at old ages for many of the fisheries as done in previous assessments.

5. Sensitivity to the length at the maximum age (29 quarters) in the model. The maximum length is fixed at 175cm and the remaining three parameters of the Richard's growth equation are estimated. The model is fit to age conditioned on length data from otoliths.

6. Sensitivity to excluding the floating object size composition data from the analysis. In this sensitivity the selectivity curves for the floating object fisheries (Fisheries 1-4) are fixed equal to the selectivity curve estimated for the northern purse seine fishery on free swimming schools (Fishery 5).

7. Sensitivity to including a change in selectivity for the floating object fisheries starting in 2001 due to Resolution C-00-08 that prohibited the discarding of yellowfin tuna resulting from sorting by size. The parameters for the left hand limb and the peak of the selectivity curve had different values estimated for the periods 1975-2000 and 2001-2008.

4.1. Assessment results

The results of the base case assessment and sensitivity analyses are described below. The results presented in the following sections are likely to change in future assessments because (1) future data may provide evidence contrary to these results, and (2) the assumptions and constraints used in the assessment model may change. Future changes are most likely to affect absolute estimates of biomass, recruitment, and fishing mortality.

4.1.1. Fishing mortality

There is variation in fishing mortality exerted by the fisheries that catch yellowfin in the EPO, with fishing mortality being higher before 1984, during the lower productivity regime (Figure 4.3a), and since 2003. Fishing mortality changes with age (Figure 4.3b). The fishing mortalities for younger and older

yellowfin are low. There is a peak at around ages of 14-15 quarters, which corresponds to peaks in the selectivity curves for fisheries on unassociated and dolphin-associated yellowfin (Figures 4.3b and 4.4). The fishing mortality of young fish has not greatly increased in spite of the increase in effort associated with floating objects that has occurred since 1993 (Figure 4.3b).

The fishing mortality rates vary over time because the amount of effort exerted by each fishery changes over time, because different fisheries catch yellowfin of different ages (the effect of selectivity), and because the efficiencies of various fisheries change over time (the effect of catchability). The first effect (changes in effort) was addressed in Section 2.2.1 (also see Figure 2.3).

Selectivity curves estimated for 9 of the 16 fisheries defined in the stock assessment of yellowfin are shown in Figure 4.4. Purse-seine sets on floating objects tend to select smaller yellowfin, except for the southern fishery, which catches larger fish (Figure 4.4, Fisheries 1-4). Purse-seine sets on unassociated schools of yellowfin in the north select fish similar in size to those caught by sets on floating objects (Figure 4.4, Fishery 5) Purse-seine sets on unassociated schools of yellowfin in the south and on yellowfin associated with dolphins select larger yellowfin (Figure 4.4, Fisheries 6-8). The longline fisheries for yellowfin also select mainly larger individuals (Figure 4.4, Fishery 12). The selectivity curves for the southern dolphin associated fishery, the pole-and-line fishery, and the northern longline fishery were not estimated, and mirrored other fisheries.

Discards resulting from sorting purse-seine catches of yellowfin taken in association with floating objects are assumed to be composed only of fish ages 2-4 quarters (Fisheries 13-16). (Additional information regarding the treatment of discards is given in Section 2.2.3.)

4.1.2. Recruitment

Over the range of predicted biomasses shown in Figure 4.9b, the abundance of yellowfin recruits appears to be related to the relative potential egg production at the time of spawning (Figure 4.6). The apparent relationship between biomass and recruitment is due to an apparent regime shift in productivity (Tomlinson 2001). The increased productivity caused an increase in recruitment, which, in turn, increased the biomass. Therefore, in the long term, above-average recruitment is related to above-average biomass and below-average recruitment to below-average biomass.

A sensitivity analysis was carried out, fixing the Beverton-Holt (1957) steepness parameter at 0.75 (Appendix A). This means that recruitment is 75% of the recruitment from an unexploited population when the population is reduced to 20% of its unexploited level. Given the information currently available, the hypothesis of two regimes in recruitment is as plausible as an effect of population size on recruitment. The results when a stock-recruitment relationship is used are described in Section 4.3.

The estimated time series of yellowfin recruitment is shown in Figure 4.7a and 4.7b, and the estimated annual total recruitments are listed in Table 4.1. The large cohort spawned in the first quarter of 1998 was estimated to be the strongest cohort of the 1975-2008 period. A sustained period of high recruitment was estimated for 1999 until the start of 2002. A large recruitment was estimated for the first quarter of 2007.

Another characteristic of the recruitment, which was also apparent in previous assessments, is the regime change in the recruitment levels, starting during the second quarter of 1983. The recruitment was, on average, consistently greater after 1983 than before. This change in recruitment levels produces a similar change in biomass (Figure 4.9a). There is an indication that the recruitments from 2002-2006 were at low levels, similar to those prior to 1983, perhaps indicating a lower productivity regime.

The confidence intervals for recruitment are relatively narrow, indicating that the estimates are fairly precise, except for that of the most recent year (Figure 4.7a,b). The estimates of uncertainty are surprisingly small, considering the inability of the model to fit modes in the length-frequency data (Figure 4.8a-d). These modes often appear, disappear, and then reappear.

4.1.3. Biomass

Biomass is defined as the total weight of yellowfin that are three quarters or more years old. The trends in the biomass of yellowfin in the EPO are shown in Figure 4.9a, and estimates of the biomass at the beginning of each year are listed in Table 4.1. Between 1975 and 1983 the biomass of yellowfin was at low levels; it then increased rapidly during 1983-1985, remaining relatively constant from 1986-1999, then increased rapidly again peeking in 2001, but subsequently declined to levels similar to those prior to 1984 in 2006. The biomass has increased in recent years to levels similar to those seen in 1986-1999.

The spawning biomass is defined as the relative total egg production of all the fish in the population. The estimated trend in spawning biomass is shown in Figure 4.9b, and estimates of the spawning biomass ratio at the beginning of each year in Table 4.1. The spawning biomass has generally followed a trend similar to that for biomass, described in the previous paragraph. The confidence intervals on the index of spawning biomass estimates indicate that it is well estimated.

It appears that trends in the spawning biomass of yellowfin can be explained by the trends in fishing mortality and recruitment. Simulation analysis is used to illustrate the influence of fishing and recruitment on the spawning biomass trends (Maunder and Watters, 2001). The simulated index of spawning biomass trajectories with and without fishing are shown in Figure 4.10a. The large difference in the two trajectories indicates that fishing has a major impact on the spawning biomass of yellowfin in the EPO. The large increase in spawning biomass during 1983-1984 was caused initially by an increase in average size (Anonymous 1999), followed by an increase in average recruitment (Figure 4.7), but increased fishing pressure prevented the spawning biomass from increasing further during the 1986-1990 period.

The impact of each major type of fishery on the yellowfin stock is shown in Figure 4.10b. The estimates of index of spawning biomass in the absence of fishing were computed as above, and then the biomass trajectory was estimated by setting the effort for each fisheries group, in turn, to zero. The spawning biomass impact for each fishery group at each time step is derived as this index of spawning biomass trajectory minus the index of spawning biomass trajectory with all fisheries active. When the impacts of individual fisheries calculated by this method are summed, they are greater than the combined impact calculated when all fisheries are active. Therefore, the impacts are scaled so that the sum of the individual impacts equals the impact estimated when all fisheries are active. Despite more catch being taken in schools associated with dolphins than the other fisheries, the floating object and purse seine sets on unassociated schools have a greater impact on the yellowfin spawning biomass.

4.1.4. Average weights of fish in the catch

The overall average weights of the yellowfin caught in the EPO predicted by the analysis have been consistently around 10 to 15 kg for most of the 1975-2008 period, but have differed considerably among fisheries (Figure 4.11). The average weight was high during the 1985-1992 period, when the effort for the floating-object and unassociated fisheries was less (Figure 2.3). The average weight was also high in 1975-1977 and in 2001-2004. The average weight of yellowfin caught by the different gears varies widely, but remains fairly consistent over time within each fishery (Figure 4.11). The lowest average weights occur in the floating-object and pole and line fisheries, followed by the unassociated fisheries, then the dolphin-associated, and the longline fisheries catch the largest. The average weight caught also varies within these fisheries groups as indicated by the selectivity curves (Figure 4.4).

4.2. Comparisons to external data sources

The mean length at age assumed in the model corresponds well with the otolith age at length data, but the assumed variation of length at age is much wider than indicated by the otolith data (Figure 3.1). The narrower variation of length at age seen in the otolith data may be due to the limited temporal and spatial characteristics of the data.

The proportion female predicted by the model declines at a younger age than indicated by the otolith data

(Figure C.5).

4.3. Diagnostics

Diagnostics of the model are presented as residual plots and retrospective analysis.

4.3.1. Residual plots

The model fits to the CPUE data from different fisheries are presented in Figure 4.2j. The model fits the dolphin associated and southern longline CPUE observations closely. However, the peak in 2001 is predicted too early in the dolphin associated fisheries and too late in the longline fishery. The fits to the unassociated CPUE data series are less satisfactory. The ability of the model to fit the different CPUE data sets is also illustrated in the estimates of the standard deviations for the likelihood functions. They indicate that the best fits are to the dolphin fisheries CPUE. The model also corresponds well to the southern floating-object fishery CPUE, which is not explicitly fit in the model.

	Fleet	Standard deviation	Used
1	OBJ_S	0.37	No
2	OBJ_C	0.47	No
3	OBJ_I	0.75	No
4	OBJ_N	0.41	No
5	NOA_N	0.56	Yes
6	NOA_S	0.66	Yes
7	DEL_N	0.37	Yes
8	DEL_I	0.34	Yes
9	DEL_S	0.60	No
11	LL_N	0.83	No
12	LL_S	0.47	Yes

Pearson residual plots are presented for the model fits to the length composition data (Figures 4.2f to 4.2i). The grey and black circles represent observations that are less and greater than the model predictions, respectively. The area of the circles is proportional to the absolute value of the residuals. There are several notable characteristics of the residuals. The model underestimates the large and small fish for the floating-object fisheries. Conversely, the model underestimates medium-sized fish for the southern longline fishery. There are substantial residual patterns for the southern dolphin associated fishery and the bait boat fishery, but this is expected because the selectivity curves are mirrored with other fisheries and the model is not fit to their catch-at-length data. For all fisheries, the model fits the length-frequency data better than the assumed sample size used in the model, even the fisheries for which the length-frequency data are not explicitly fitted in the model.

	Fleet	Mean effective sample size	Mean input sample size	Used
1	OBJ_S	41	17	Yes
2	OBJ_C	38	18	Yes
3	OBJ_I	26	13	Yes
4	OBJ_N	68	13	Yes
5	NOA_N	67	26	Yes
6	NOA_S	41	21	Yes
7	DEL_N	123	31	Yes
8	DEL_I	136	30	Yes
9	DEL_S	51	8	No
10	OBJ_BB	12	12	No

| 11 | LL_N | 40 | 2 | No |
| 12 | LL_S | 111 | 33 | Yes |

The appearance, disappearance, and subsequent reappearance of strong cohorts in the length-frequency data is a common phenomenon for yellowfin in the EPO. This may indicate spatial movement of cohorts or fishing effort, limitations in the length-frequency sampling, or fluctuations in the catchability of the fish. Bayliff (1971) observed that groups of tagged fish have also disappeared and then reappeared in this fishery, which he attributed to fluctuations in catchability.

4.3.2. Retrospective analysis

Retrospective analysis is a useful method to determine how consistent a stock assessment method is from one year to the next. Inconsistencies can often highlight inadequacies in the stock assessment method. The estimated biomass and SBR (defined in Section 3.1.2) from the previous assessment and the current assessment are shown in Figure 4.12a and 4.12b. However, the data and methodology differ between these assessments, so differences may be expected. The current assessment estimates biomass (Figure 4.12a) and index of spawning biomass (4.12b) much lower than in the previous assessment. However, the trends are similar. Trends in relative recruitment are similar to the previous assessment (4.12c). Comparison of previous assessments has shown a tendency to overestimate recent recruitment strengths.

Retrospective analyses are usually carried out by repeatedly eliminating one year of data from the analysis while using the same stock assessment method and assumptions. This allows the analyst to determine the change in estimated quantities as more data are included in the model. Estimates for the most recent years are often uncertain and biased. Retrospective analysis can be used to determine if there are consistent patterns in the estimates. These patterns are often viewed as biases by assuming that the estimates are more accurate when more years of data are included in the analysis. However, they really only indicate a model misspecification because it is possible that the estimates are biased when additional years of data are added to the analyses depending on the model misspecification. The retrospective analysis indicates a tendency to overestimate recent recruitment strengths (Figure 4.14b) and consequently over estimate recent and projected abundance (Figures 4.14a and 4.14c). Removing the floating object fishery (Fisheries 1-4) size composition data from the analyses removes this retrospective pattern (Figures F.1-F.3) indicating that the floating object size composition data is inconsistent with the size composition data of the other fisheries at older ages. Resolution C-00-08 prohibited the discarding of yellowfin tuna due to size and this changed the selectivity curves of the floating object fisheries in 2001 (Figure G.4) and could potentially cause the retrospective pattern. However, incorporating this into the stock assessment did not remove the retrospective pattern (Figure G.1-G.3).

4.4. Sensitivity to assumptions

Sensitivity analyses were carried out to investigate the incorporation of a Beverton-Holt (1957) stock-recruitment relationship (Appendix A), inclusion of all the data (Appendix B), natural mortality (Appendix C), selectivity (Appendix D), growth (Appendix E), exclusion of the floating object size composition data (Appendix F), and a change in the floating object fisheries selectivity starting in 2001 (Appendix G).

1. The base case analysis assumed no stock-recruitment relationship, and an alternative analysis was carried out with the steepness of the Beverton-Holt stock-recruitment relationship fixed at 0.75. This implies that when the population is reduced to 20% of its unexploited level, the expected recruitment is 75% of the recruitment from an unexploited population. As in previous assessments, (Maunder and Watters 2002, Hoyle and Maunder 2006a) the analysis with a stock-recruitment relationship fits the data better than the analysis without the stock-recruitment relationship. However, the regime shift could also explain the result, since the period of high recruitment is associated with high spawning biomass, and vice versa. When a Beverton-Holt stock-recruitment relationship (steepness = 0.75) is included, the estimated biomass (Figure A.1) and recruitment (Figure A.2) are almost identical to

2. The estimate biomass (Figure B.1) and the relative recruitment (Figure B.2) from the sensitivity analysis that includes all the data (i.e. size composition and CPUE data for all fisheries except the discard fisheries and the CPUE for the pole and line fishery) in the model are similar to the base case.

3. The model that estimates the natural mortality for mature yellowfin produces a substantially better fit to the data with a reduction in the negative log likelihood of 46 units for two additional parameters. The estimated biomass is much higher than the base case (Figure C.1). The relative recruitment is similar to the base case (Figure C.2). The natural mortality was estimated to be slightly higher for adult females, but was also estimated to increase substantially for males.

4. When age-specific selectivity is used, the estimated abundance (D1) and recruitment (D2) is similar to the base case, but the SBR corresponding to MSY is substantially higher (Table 5.1 and Figure D3). The estimated age-specific selectivity curves show peaks at around 10-15 quarters similar to those estimated in the previous assessment (Figure D4).

5. The model that fixes the length at the maximum age to 175cm produces a better fit to the length-frequency data, but a worse fit to the CPUE data. However, the total negative log likelihood can not be compared because of the additional sex ratio data. Nether the less, removing the otolith data component of the negative log likelihood indicates that the lower length at the maximum age fit the other data better. The estimated biomass is moderately higher than the base case (Figure E.1) and the relative recruitment is similar (Figure E.2).

6. Excluding the floating object size composition data from the analysis has very little impact on the results except for lowering the most recent recruitment and biomass estimates (Figures F.1-F.3). However, it does remove the retrospective pattern of recent recruitment and biomass being estimated higher when recent data is dropped from the analysis (Figures F.4-F.6).

7. Including a change in selectivity for the floating object fisheries starting in 2001 has negligible impact on the results (Figures G1-G3), despite the improved fit to the data as represented by a reduction in the negative log likelihood. The selectivity for three of the floating object fisheries catch more smaller yellowfin as would be expected due to the ban on discarding small fish (Figure G4). However, due to the implementation of the selectivity curves in the assessment model, this also causes a reduction of selectivity for the large yellowfin.

	Base	h = 0.75	All data	M	Age-specific selectivity	Growth	No OBJ size composition	Change in OBJ selectivity
Total	7248.64	7242.74	8238.06	7202.12	7776.94	7286.35	5257.32	7198.88
Survey	-181.52	-182.33	-222.80	-164.83	-202.26	-179.59	-201.96	-184.60
Length composition	7433.90	7434.62	8465.17	7349.04	7979.78	7355.15	5468.39	7387.08
Otolith	0.00	0.00	0.00	0.00	0.00	108.41	0.00	0.00
Recruitment	-3.75	-9.57	-4.57	1.69	-0.84	2.37	-9.36	-3.85
Sex ratio	0.00	0.00	0.00	15.97	0.00	0.00	0.00	0.00

Several other sensitivity analyses have been carried out in previous assessments of yellowfin tuna. Increasing the sample size for the length frequencies based on iterative re-weighting to determine the effective sample size gave similar results, but narrower confidence intervals (Maunder and Harley 2004). The use of cannery and landings data to determine the surface fishery catch and different size of the selectivity smoothness penalties (if set at realistic values) gave similar results (Maunder and Harley 2004). The results were not sensitive to the value for the asymptotic length parameter of the Richards growth curve or to the link function used in the general linear model (GLM) standardization of the longline effort data (Hoyle and Maunder 2007).

4.5. Summary of the results from the assessment model

In general, the recruitment of yellowfin to the fisheries in the EPO is variable, with a seasonal component. This analysis and previous analyses have indicated that the yellowfin population has experienced two, or possibly three, different recruitment productivity regimes (1975-1982, 1983-2002, and 2003-2006). The productivity regimes correspond to regimes in biomass, higher-productivity regimes producing greater biomass levels. A stock-recruitment relationship is also supported by the data from these regimes, but the evidence is weak, and is probably an artifact of the apparent regime shifts. Larger recruitments in 2007 and 2008 have caused the biomass to increase in recent years.

The average weights of yellowfin taken from the fishery have been fairly consistent over time, but vary 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 do the northern and coastal dolphin-associated fisheries.

Significant levels of fishing mortality have been estimated for the yellowfin fishery in the EPO. These levels are highest for middle-aged yellowfin. Despite more catch being taken in schools associated with dolphins than the other fisheries, the floating object and purse seine sets on unassociated schools have a greater impact on the yellowfin spawning biomass (Figure 4.10b).

The estimated biomass is significantly lower than estimated in the previous assessment indicating that the results are sensitive to the changes in assessment methodology. There is also a large retrospective pattern of overestimating recent recruitment. This pattern is due to the floating object size composition data. These in combination with the large confidence intervals for estimates of recent recruitment indicate that estimates of recent recruitment and recent biomass are uncertain. The results of the assessment are also particularly sensitive to the level of natural mortality assumed for adult yellowfin.

5. STATUS OF THE STOCK

The status of the stock of yellowfin in the EPO is assessed by considering calculations based on the spawning biomass, yield per recruit, and MSY. Maintaining tuna stocks at levels that will permit the MSY is the management objective specified by the IATTC Convention.

5.1. Assessment of stock status based on spawning biomass

The spawning biomass ratio, SBR, defined in Section 3.1.2, is compared to an estimate of SBR for a population that is producing the MSY ($SBR_{MSY} = S_{MSY}/S_{F=0}$).

Estimates of quarterly SBR_t for yellowfin in the EPO have been computed for every quarter represented in the stock assessment model (the first quarter of 1975 to the first quarter of 2009). Estimates of the index of spawning biomass during the period of harvest (S_t) are discussed in Section 4.2.3 and presented in Figure 4.9b. The equilibrium index of spawning biomass after a long period with no harvest ($S_{F=0}$) was estimated by assuming that recruitment occurs at an average level expected from an unexploited population. SBR_{MSY} is estimated to be about 0.27. This is lower than estimated in the previous assessment (0.34) and the lower estimate is mainly a consequence of using different selectivity curves.

At the beginning of 2009 the spawning biomass of yellowfin in the EPO had increased relative to 2006, which was probably its lowest level since 1983. The estimate of SBR at the beginning of 2009 was about 0.35, with lower and upper 95% confidence limits of 0.27 and 0.43, respectively (Figure 5.1a).

In general, the SBR estimates for yellowfin in the EPO are reasonably precise. The relatively narrow confidence intervals around the SBR estimates suggest that for most quarters during 1985-2003 the spawning biomass of yellowfin in the EPO was greater than S_{MSY} (see Section 5.3). This level is shown as the dashed horizontal line drawn at 0.27 in Figure 5.1a. For most of the early period (1975-1984) and the most recent period (2005-2007, excluding 2008), however, the spawning biomass was estimated to be less than S_{MSY}. The spawning biomass at the start of 2009 is estimated to be above the level corresponding to

MSY.

5.2. Assessment of stock status based on MSY

MSY is defined as the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions. To calculate MSY, the current fishing mortality rate is scaled so that it maximizes the catch. The value F multiplier scales the "current" fishing mortality, which is taken as the average over 2006-2008.

At the beginning of 2009, the biomass of yellowfin in the EPO appears to have been above the level corresponding to the MSY, and the recent catches have been substantially below the MSY level (Table 5.1).

If the fishing mortality is proportional to the fishing effort, and the current patterns of age-specific selectivity (Figure 4.4) are maintained, the current (average of 2006-2008) level of fishing effort is below that estimated to produce the MSY. The effort at MSY is 109% of the current level of effort. Due to reduced fishing mortality in 2008, repeating the calculations based on a fishing mortality averaged over 2006-2007 indicates that current effort is at the level that would produce MSY. It is important to note that the curve relating the average sustainable yield to the long-term fishing mortality is very flat around the MSY level (Figure 5.2). Therefore, changes in the long-term levels of effort will only marginally change the long-term catches, while considerably changing the biomass. Reducing fishing mortality below the level at MSY would provide only a marginal decrease in the long-term average yield, with the benefit of a relatively large increase in the spawning biomass. In addition, fishing at levels corresponding to MSY estimated from the base case, which assumes recruitment is independent of spawning biomass, when the true dynamics includes a stock recruitment relationship causes a greater loss in yield than fishing at levels corresponding to MSY estimated from the stock-recruitment relationship sensitivity when recruitment is in fact independent of spawning biomass (Figure 5.2).

The historical status of the population with respect to both the SBR and fishing mortality reference points is shown in Figure 5.1b. The fishing mortality has generally been below that corresponding to the MSY, except for the period before 1984 and during 2004-2007 (Figure 4.12c).

5.3. Comparisons with previous assessments

Estimates of management quantities are compared to estimates from previous assessments in Figure 4.13a. This figure simply takes the estimates of each management quantity from each previous stock assessment and plots them. The estimates differ because each consecutive year has additional data, the mix of fishing effort by gear and the total changes over time, recruitment changes over time, and the assumptions used in the assessments can differ from year to year as the understanding of the stock dynamics improves. A second figure (Figure 4.13b) presents the management quantities calculated using the same model assumptions and data used in the base case, but calculates the quantities based on the fishing effort and mix of effort among gears. The management quantities are calculated using the three year average of fishing mortality including the year on the x-axis and the two prior years.

The estimates of the management quantities differ from the previous assessment (Figure 4.13a). The SBR corresponding to MSY is lower than the previous assessment. The level is similar to that estimated in assessments carried out in 2000 and 2001. The change in the current assessment from the previous assessment is attributed to the change in how selectivity is modeled (see the sensitivity that estimates age-specific selectivity). However, the current assessment estimates lower biomass which does not appear to be attributable to the change in method used to model selectivity. The estimates of MSY and the F multiplier appear to be consistent from assessment to assessment (compare Figures 4.13a and 4.13b).

5.4. Inpact of fishing methods

The estimation of the MSY, and its associated quantities, is sensitive to the age-specific pattern of selectivity that is used in the calculations. To illustrate how MSY might change if the effort is reallocated

among the various fisheries (other than the discard fisheries) that catch yellowfin in the EPO, the previously-described calculations were repeated, using the age-specific selectivity pattern estimated for groups of fisheries. If the management objective is to maximize the MSY, the age-specific selectivity of the longline fisheries will perform the best, followed by that of the dolphin-associated fisheries, the unassociated fisheries, and finally the floating-object fisheries (Table 5.2a). If an additional management objective is to maximize the S_{MSY}, the order is similar with dolphin-associated fisheries slightly better than longline. It is not plausible, however, that the longline fisheries, which would produce the greatest MSYs, would be efficient enough to catch the full MSYs predicted. On its own, the effort by the purse-seine fishery for dolphin-associated yellowfin would have to more than double to achieve the MSY.

MSY and S_{MSY} have been very stable during the modeled period (Figure 4.12b). This suggests that the overall pattern of selectivity has not varied a great deal through time. The overall level of fishing effort, however, has varied with respect to the fishing effort corresponding to MSY.

5.5. Impact of environmental conditions

The apparent regime shift in productivity that began in 1984 and the recent lower level of productivity suggests alternative approaches to estimating the MSY, as different regimes will give rise to different values for the MSY (Maunder and Watters 2001). The MSY and spawning biomass corresponding to MSY are directly proportional to the average recruitment used, but the fishing mortality corresponding to MSY is not impacted. For example, if the average recruitment from 1985 to 2008 was used instead of using the whole time period, MSY and the spawning biomass corresponding to MSY would be increased. This would mean that higher yields would be possible, but the fishery would be over exploited (the current biomass does not change while the spawning biomass corresponding to MSY increases). If the most recent low average recruitment was used, the opposite would occur. An alternative approach is to calculate the dynamic SBR (dSBR) by comparing the index of spawning biomass with the index of spawning biomass simulated over time in the absence of fishing (Figure 4.10). This approach takes the fluctuations of recruitment into consideration.

5.6. Sensitivity analyses

As shown in Table 5.1, including a stock-recruitment relationship in the stock assessment produces more pessimistic results with the current spawning biomass being below that corresponding to MSY and fishing effort being higher than that corresponding to MSY. However, it increases the level of MSY that can be achieved. Included all the data only has a small impact on the results. Estimating the adult natural mortality produces more optimistic results with the spawning biomass being substantially greater than that corresponding to MSY, current effort being substantially below that corresponding to MSY, and increases the level of MSY that can be obtained. Estimating age-specific selectivity increases the SBR corresponding to MSY and therefore the spawning biomass is less than that corresponding to MSY and the effort levels are higher than those corresponding to MSY. Fixing the length at the maximum age to 175cm produces more optimistic results with the spawning biomass being substantially greater than that corresponding to MSY and current effort being substantially below that corresponding to MSY, but the level of MSY that can be obtained is about the same. The sensitivity analyses that excluding the floating object size composition data and included a change in the selectivities for the floating object fisheries had negligible changes in the management quantities (results not presented).

5.7. Summary of stock status

Historically, the SBR of yellowfin in the EPO was below the level corresponding to the MSY during the lower productivity regime of 1975-1983 (Section 4.2.1), but above that level for most of the following years, except for the recent period (2004-2007). 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 two different productivity regimes may support two different MSY levels and associated SBR levels. The SBR at the start of 2009 is estimated to be above the level corresponding to the MSY. The effort levels

are estimated to be less than those that would support the MSY (based on the current distribution of effort among the different fisheries), but recent catches are substantially below MSY.

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 SBR levels.

The MSY has been stable during the assessment period, which suggests that the overall pattern of selectivity has not varied a great deal through time. However, the overall level of fishing effort has varied with respect to the level corresponding to MSY.

The SBR corresponding to MSY decreased substantially from the previous assessment indicating that the results are sensitive to the change in methodology. The change is attributed to the method used to model selectivity. However, the SBR relative to SBR corresponding to MSY and the F multiplier are similar to the previous assessment.

If a stock-recruitment relationship is assumed, the outlook is more pessimistic, and current biomass is estimated to be below the level corresponding to the MSY. The status of the stock is also sensitive to the value of adult natural mortality, the method used to model selectivity, and the assumed length of the largest age.

6. SIMULATED EFFECTS OF FUTURE FISHING OPERATIONS

A simulation study was conducted to gain further understanding as to how, in the future, hypothetical changes in the amount of fishing effort exerted by the surface fleet might simultaneously affect the stock of yellowfin in the EPO and the catches of yellowfin by the various fisheries.

6.1. Assumptions about fishing operations

6.1.1. Fishing effort

Future projection studies were carried out to investigate the influence of different levels of fishing effort on the biomass and catch. The projected fishing mortality was based on the averages during 2006-2008.

The scenarios investigated were:

1. Quarterly fishing mortality for each year in the future equal to the average for 2006-2008;

2. Quarterly fishing mortality for each year in the future was set to that corresponding to MSY.

6.2. Results of the simulation

The simulations were used to predict future levels of the SBR, total biomass, and the total catch taken by the fisheries. There is probably more uncertainty in the future levels of these outcome variables than is suggested by the results presented in Figures 6.1-6.5. The amount of uncertainty is probably underestimated because the simulations were conducted under the assumption that the stock assessment model accurately describe the dynamics of the system, and because no account is taken for variation in catchability.

These simulations were carried out using the average recruitment for the 1975-2008 period. If they had been carried out using the average recruitment for the 1984-2001 period, the projected trend in SBR and catches would have been more positive. Conversely, if they had been carried out with the average recruitment for the 2002-2006 period, the projected trend in SBR and catches would have been more negative.

6.2.1. Current effort levels

Under current levels of fishing mortality (2006-2008), the spawning biomass is predicted to slightly decrease, but remain above the level corresponding to MSY (Figure 6.1). However, the confidence intervals are wide, and there is a moderate probability that the SBR will be substantially above or below

this level. It is predicted that the catches will be higher over the near term than in 2008, but will decline slightly in the future .

6.2.2.   Fishing at F_{MSY}

Fishing at F_{msy} is predicted to reduce the spawning biomass slightly from that under current effort (Figure 6.2) and produces slightly higher catches.

6.3. Summary of the simulation results

Under current levels of fishing mortality (2006-2008), the spawning biomass is predicted to slightly decrease, but remain above the level corresponding to MSY. Fishing at F_{msy} is predicted to reduce the spawning biomass slightly from that under current effort and produces slightly higher catches

7.   FUTURE DIRECTIONS

7.1. 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.

7.2. Refinements to the assessment model and methods

The IATTC staff plans to conduct research on the influence of spatial structure on the EPO yellowfin tuna assessment. On 14-17 October 2008 the IATTC held a workshop on spatial analysis for stock assessment and the report from that workshop (http://iattc.org/PDFFiles2/Spatial-Analysis-Workshop-2008-Report.pdf) will be used to guide the research.

8.   ACKNOWLEDGEMENTS
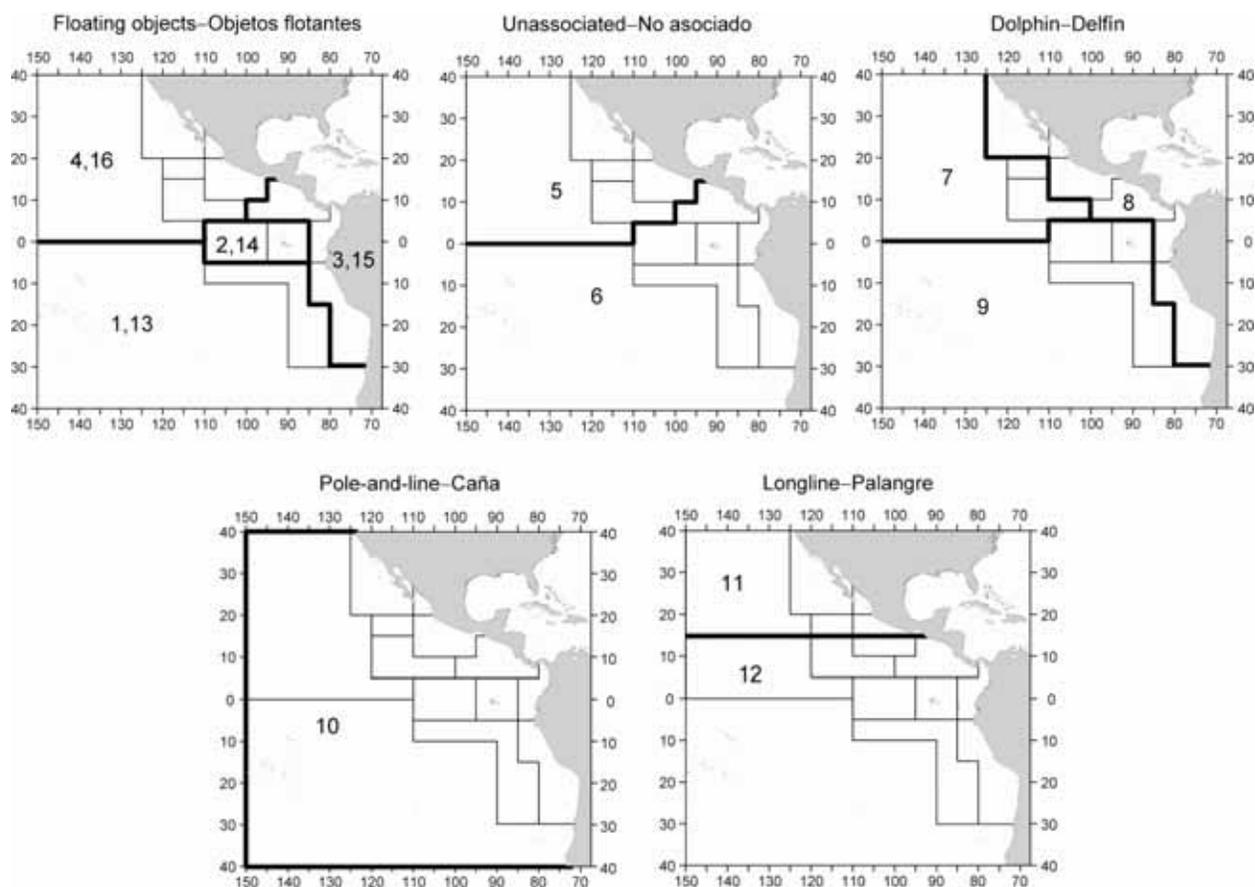
FIGURE 2.1. Spatial extents of the fisheries defined by the IATTC staff for the stock assessment of yellowfin tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the bold numbers the fisheries to which the latter boundaries apply. The fisheries are described in Table 2.1.

FIGURA 2.1. 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 del stock, y los números en negritas las pesquerías correspondientes a estos últimos límites. En la Tabla 2.1 se describen las pesquerías.
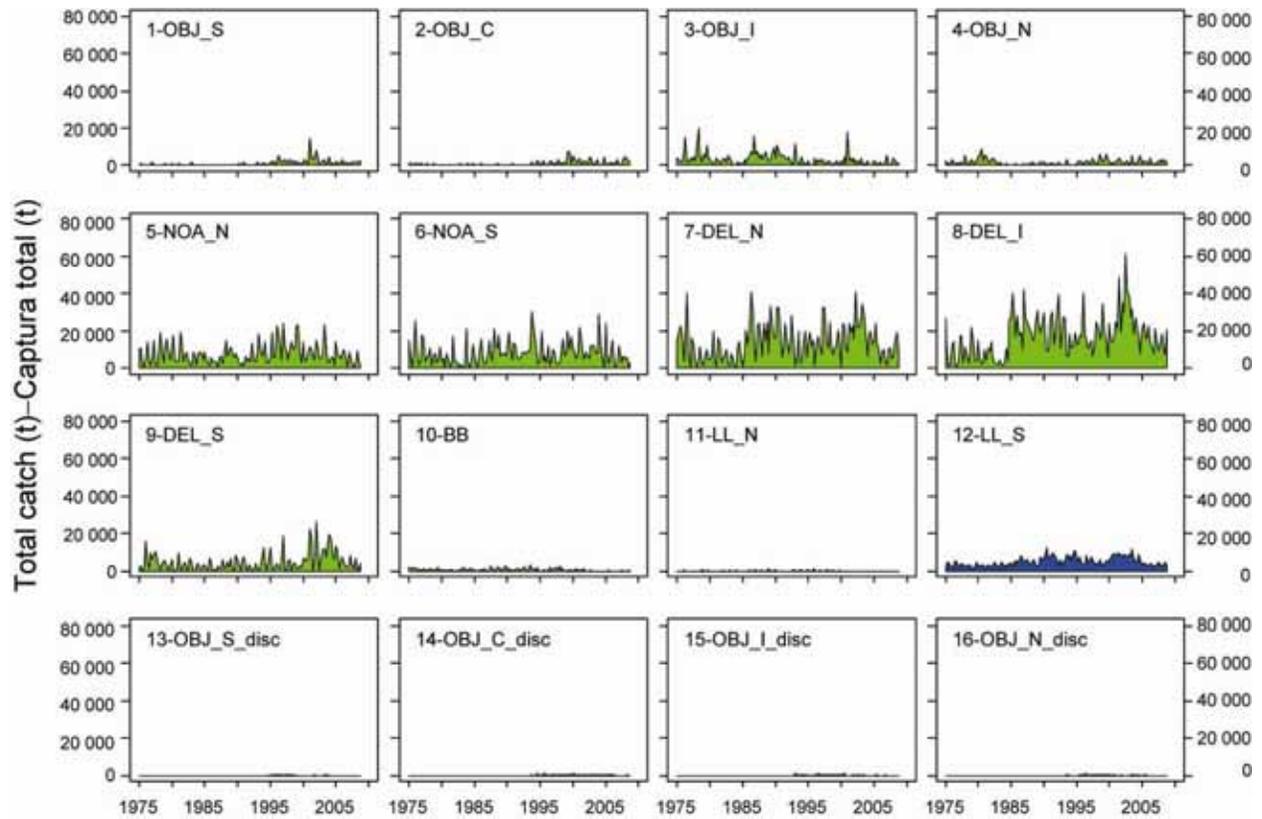
**FIGURE 2.2a.** Quarterly catches by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were analyzed on a quarterly basis, there are four observations of catch for each year. Although all the catches are displayed as weights, the stock assessment model uses catches in numbers of fish for Fisheries 11 and 12. Catches in weight for Fisheries 11 and 12 are estimated by multiplying the catches in numbers of fish by estimates of the average weights. t = metric tons.

FIGURA 2.2a. Capturas trimestrales de las pesquerías definidas para la evaluación de la población del atún aleta amarilla en el OPO (Tabla 2.1). Ya que se analizaron los datos por trimestre, hay cuatro observaciones de captura para cada año. Se expresan todas las capturas en peso, pero el modelo de evaluación de la población usa captura en número de peces para las Pesquerías 11 y 12. Se estiman las capturas de las Pesquerías 11 y 12 en peso, multiplicando las capturas en número de peces por estimaciones del peso promedio. t = toneladas métricas.
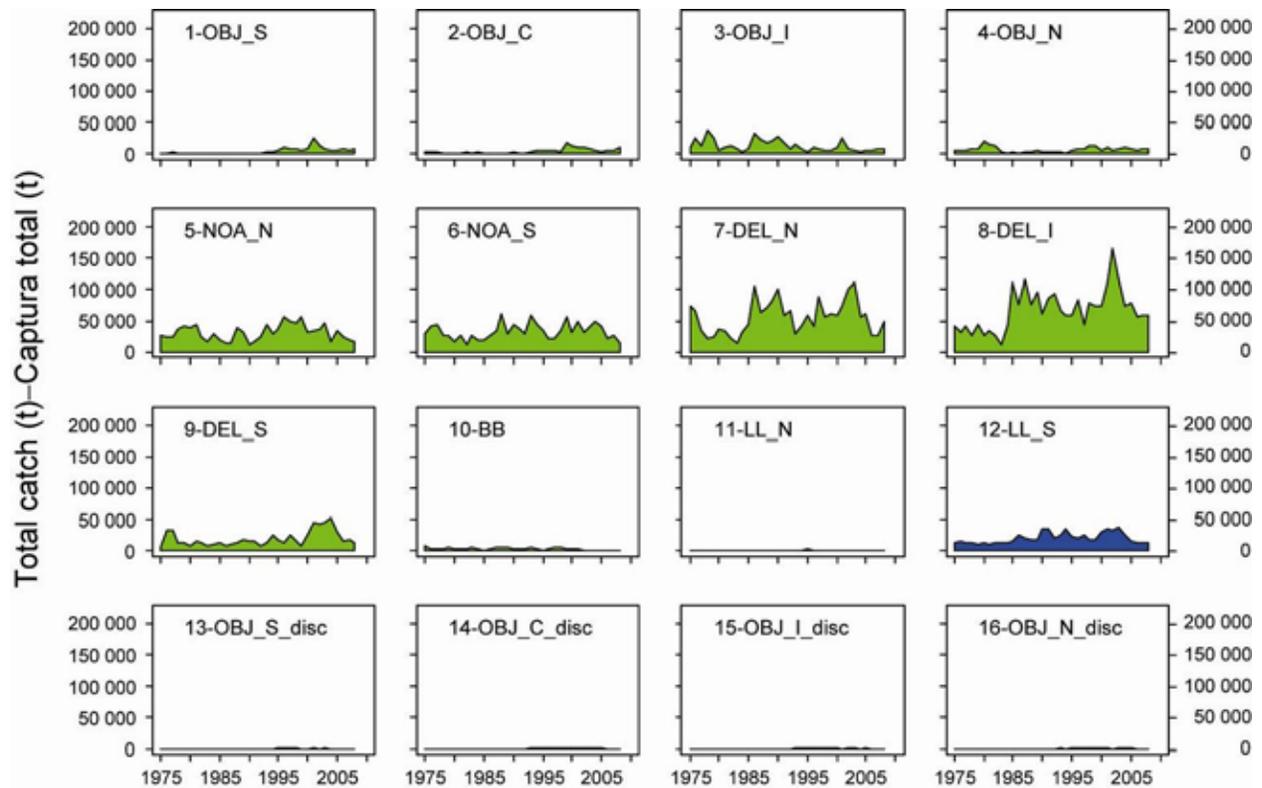
FIGURE 2.2b. Annual catches by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Although all the catches are displayed as weights, the stock assessment model uses catches in numbers of fish for Fisheries 11 and 12. Catches in weight for Fisheries 11 and 12 are estimated by multiplying the catches in numbers of fish by estimates of the average weights. t = metric tons.

FIGURA 2.2b. Capturas anuales de las pesquerías definidas para la evaluación de la población del atún aleta amarilla en el OPO (Tabla 2.1). Aunque se expresan todas las capturas en peso, el modelo de evaluación de poblaciones usa captura en número de peces para las Pesquerías 11 y 12. Se estiman las capturas de las Pesquerías 11 y 12 en peso multiplicando las capturas en número de peces por estimaciones del peso promedio. t = toneladas métricas.
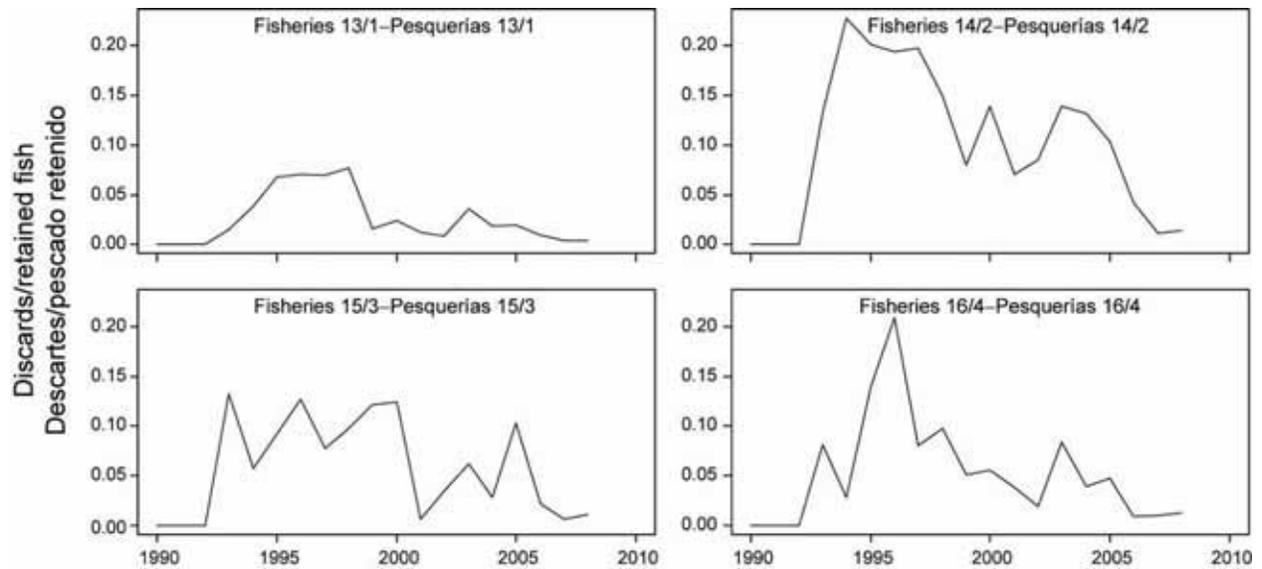
FIGURE 2.2c. Annual ratio of the discards of small fish from the floating-object fisheries to the landed catch.

FIGURA 2.2c. Cociente anual de los descartes de pescado pequeño de las pesquerías sobre objetos flotantes a la captura descargada.
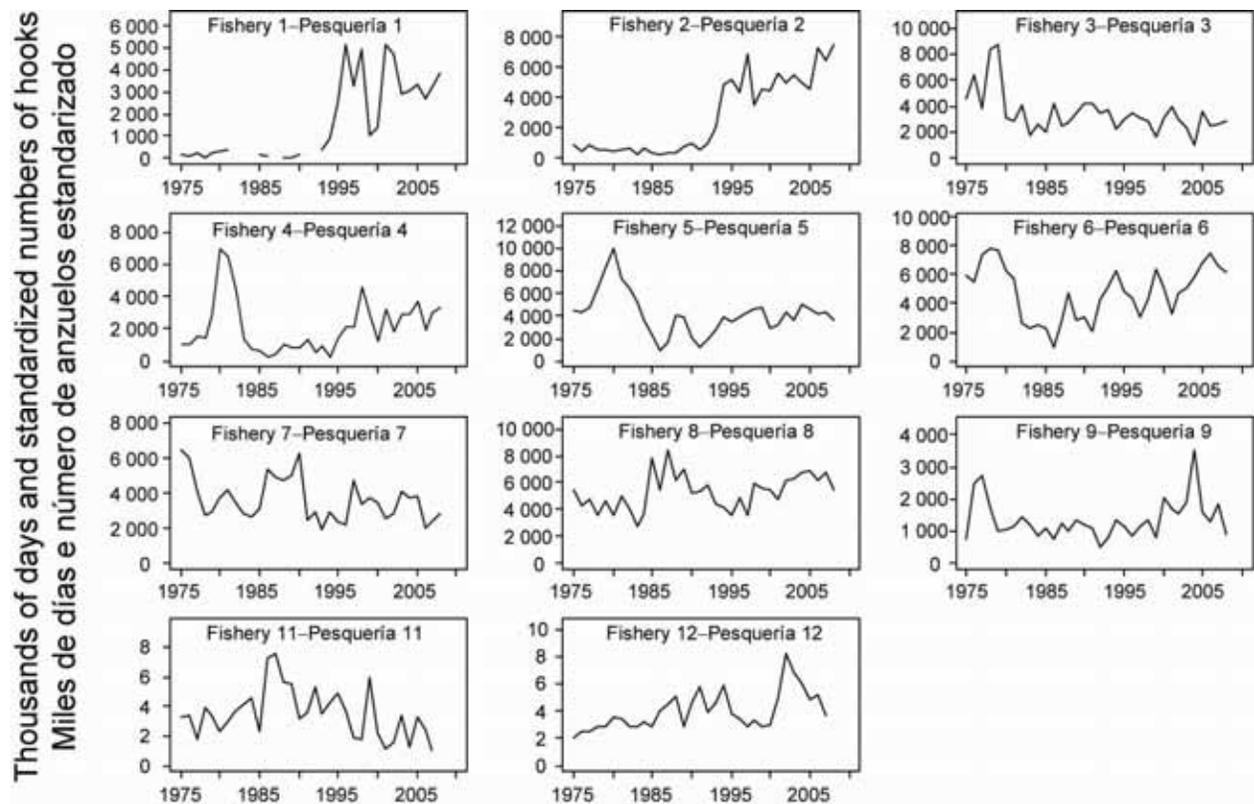
FIGURE 2.3. Annual fishing effort exerted by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). The effort for Fisheries 1-10 and 13-16 is in days fished, and that for Fisheries 11 and 12 is in standardized numbers of hooks. Note that the vertical scales of the panels are different.

FIGURA 2.3. Esfuerzo de pesca anual ejercido por las pesquerías definidas para la evaluación de la población de atún aleta amarilla en el OPO (Tabla 2.1). Se expresa el esfuerzo de las Pesquerías 1-10 y 13-16 en días de pesca, y el de las Pesquerías 11 y 12 en número estandardizado de anzuelos. Nótese que las escalas verticales de los recuadros son diferentes.
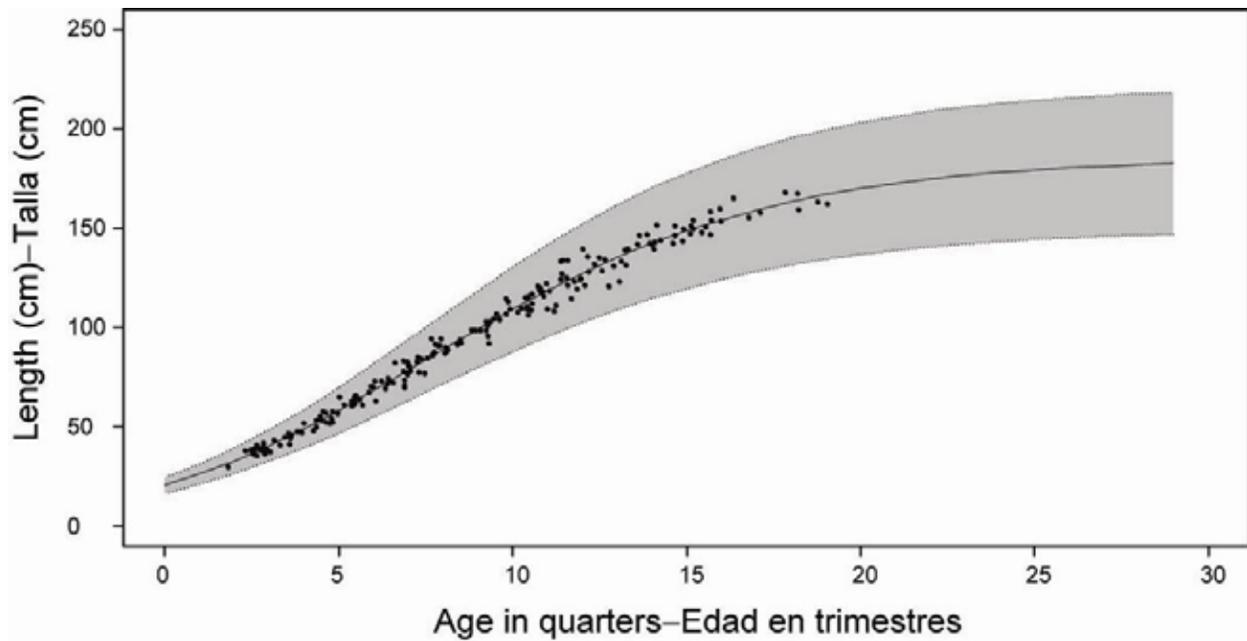
FIGURE 3.1. Growth curve estimated for the assessment of yellowfin tuna in the EPO (solid line). The connected points represent the mean length-at-age prior used in the assessment. The crosses represent length-at-age data from otoliths (Wild 1986). The shaded region represents the assumed variation in length at age (± 2 standard deviations).

FIGURA 3.1. Curva de crecimiento estimada para la evaluación del atún aleta amarilla en el OPO (línea sólida). Los puntos conectados representan la distribución previa (*prior*) de la talla media por edad usada en la evaluación. Las cruces representan datos de otolitos de talla por edad (Wild 1986). La región sombreada representa la variación de la talla por edad (± 2 desviaciones estándar).

FIGURE 3.2. Relative fecundity-at-age curve (from Schaefer 1998) used to estimate the index of spawning biomass of yellowfin tuna in the EPO.

FIGURA 3.2. Curva de fecundidad relativa por edad (de Schaefer 1998) usada para estimar el índice de la biomasa reproductora del atún aleta amarilla en el OPO.
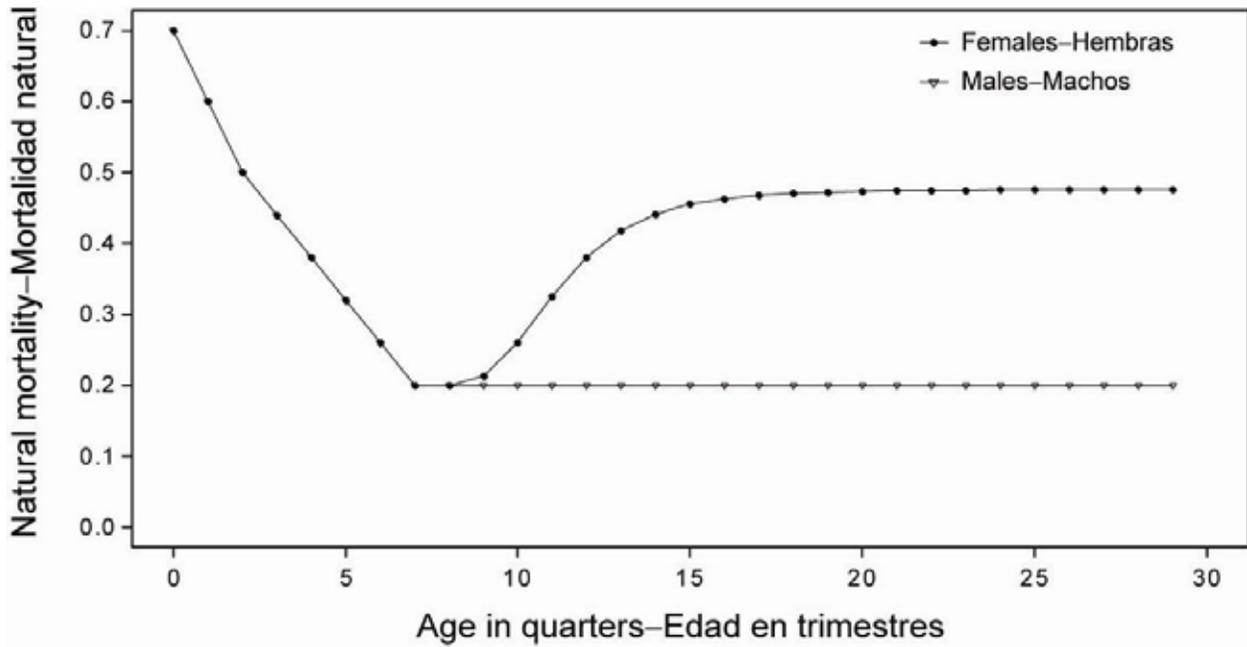
FIGURE 3.3. Quarterly natural mortality (*M*) rates, at quarterly intervals, used for the assessment of yellowfin tuna in the EPO. Descriptions of the three phases of the mortality curve are provided in Section 3.1.4.

FIGURA 3.3. Tasas de mortalidad natural (*M*), por intervalo trimestral, usadas para la evaluación del atún aleta amarilla en el OPO. En la Sección 3.1.4 se describen las tres fases de la curva de mortalidad.
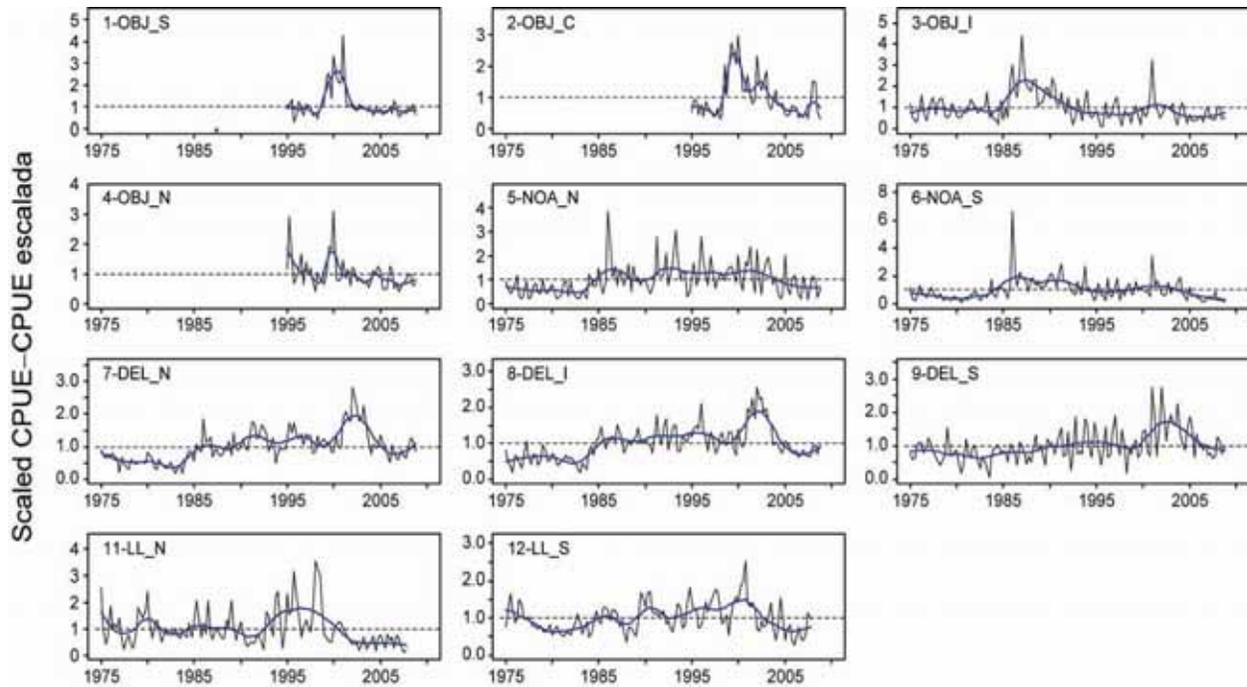
FIGURE 4.1. Quarterly CPUEs for the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of CPUE for each year. The CPUEs for Fisheries 1-9 are in kilograms per day fished, and those for Fisheries 11 and 12 are standardized units based on numbers of hooks. The data are adjusted so that the mean of each time series is equal to 1.0. Note that the vertical scales of the panels are different. The thick line is a smoother to illustrate the general CPUE trend.

FIGURA 4.1. CPUE trimestrales de las pesquerías definidas para la evaluación de la población de atún aleta amarilla en el OPO (Tabla 2.1). Ya que se resumieron los datos por trimestre, hay cuatro observaciones de CPUE para cada año. Se expresan las CPUE de las Pesquerías 1 a 9 en kilogramos por día de pesca, y las de las Pesquerías 11 y 12 en unidades estandarizadas basadas en el número de anzuelos. Se ajustaron los datos para que el promedio de cada serie de tiempo equivalga a 1,0. Nótese que las escalas verticales de los recuadros son diferentes. La línea gruesa representa un suavizador para ilustrar la tendencia general de la CPUE.
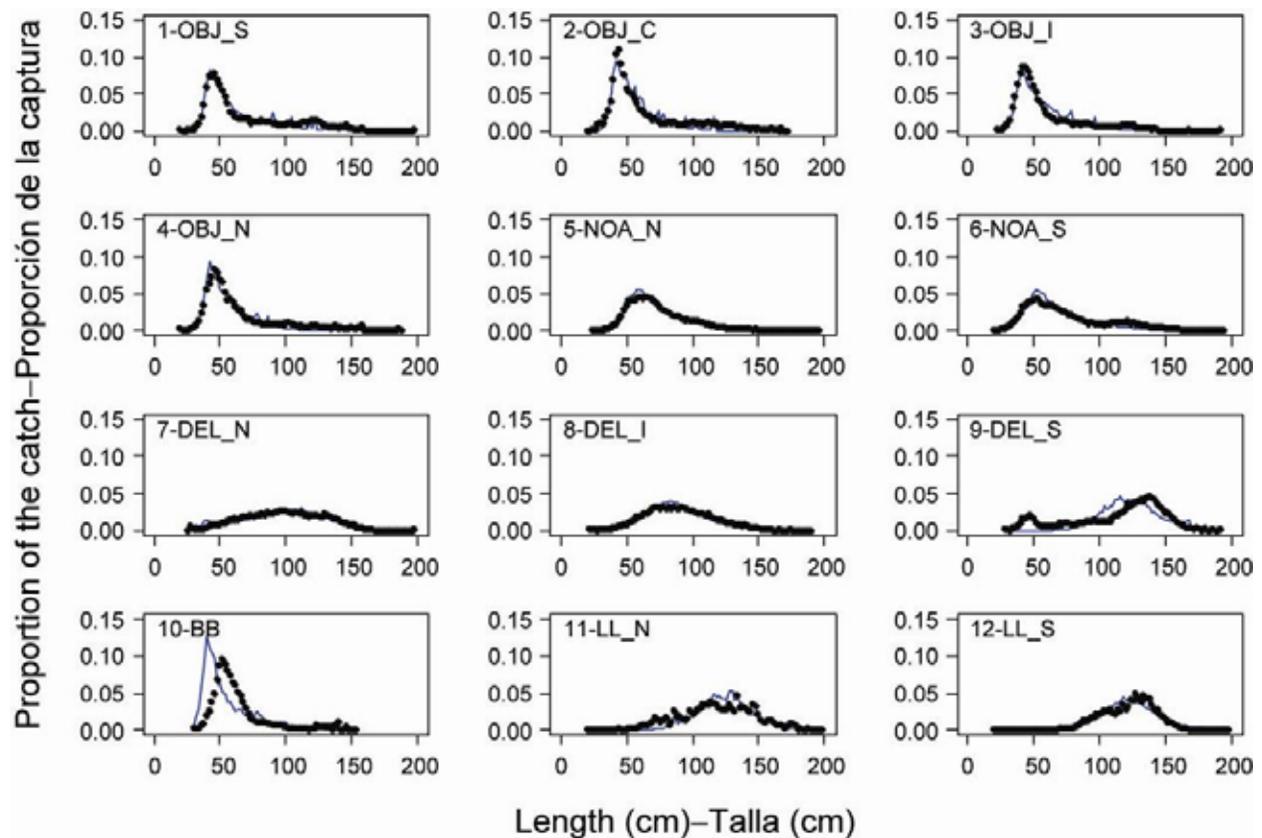
FIGURE 4.2a. Average observed (dots) and predicted (curves) size compositions of the catches taken by the fisheries defined for the stock assessment of yellowfin tuna in the EPO.

FIGURA 4.2a. Composición por tamaño media observada (puntos) y predicha (curvas) de las capturas realizadas por las pesquerías definidas para la evaluación de la población de atún aleta amarilla en el OPO.
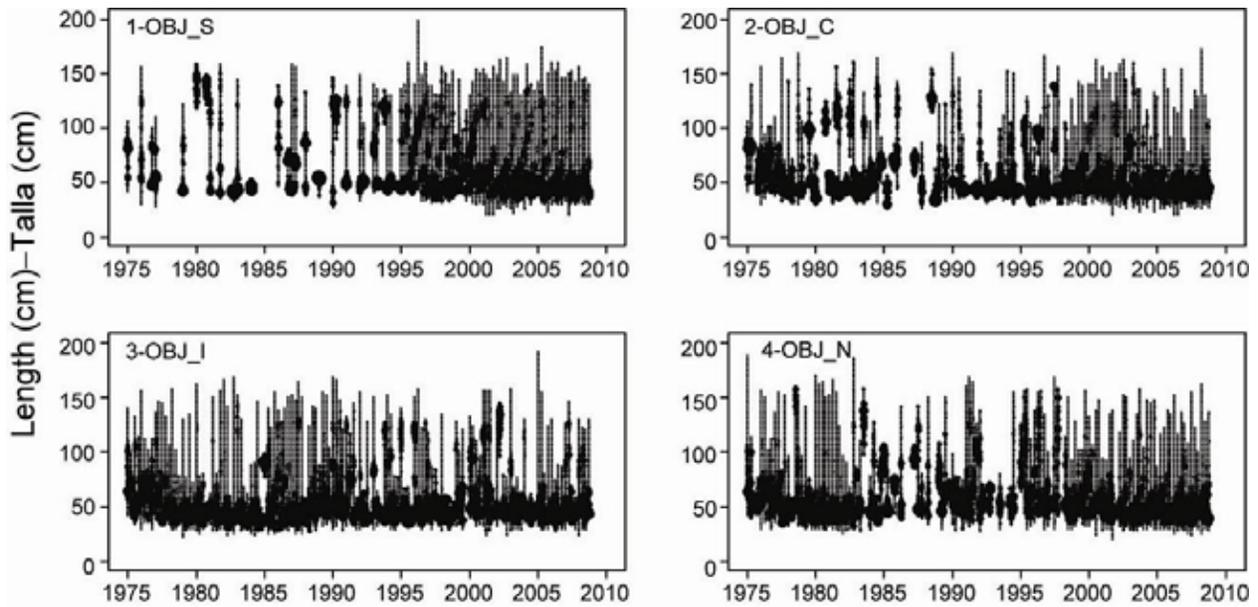
FIGURE 4.2b. Observed size compositions of the catches of yellowfin tuna taken by the floating-object fisheries, by quarter. The areas of the circles are proportional to the catches.

FIGURA 4.2b. Composición por talla observada de las capturas de atún aleta amarilla por las pesquerías sobre objetos flotantes, por trimestre. El tamaño de los círculos es proporcional a las capturas.
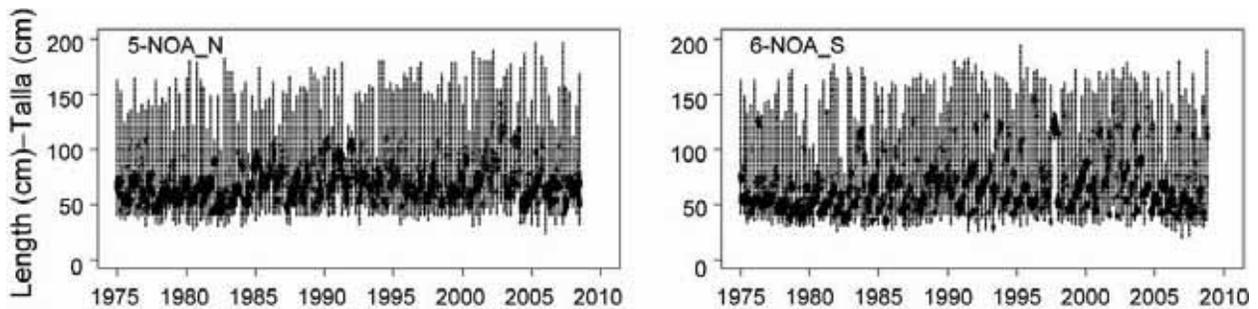
FIGURE 4.2c. Observed size compositions of the catches of yellowfin tuna taken by the unassociated fisheries, by quarter. The areas of the circles are proportional to the catches.

FIGURA 4.2c. Composición por talla observada de las capturas de atún aleta amarilla por las pesquerías no asociadas, por trimestre. El tamaño de los círculos es proporcional a las capturas.
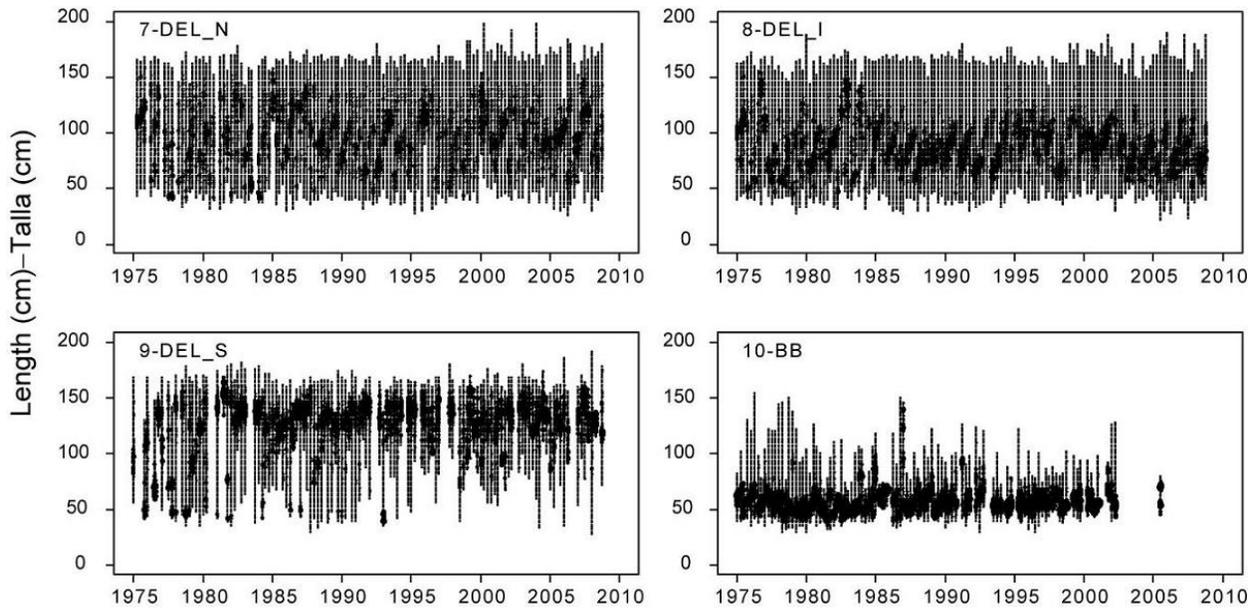
FIGURE 4.2d. Observed size compositions of the catches of yellowfin tuna taken by the dolphin associated fisheries and the pole and line fishery, by quarter. The areas of the circles are proportional to the catches.

FIGURA 4.2d. Composición por talla observada de las capturas de atún aleta amarilla por las pesquerías asociadas con delfines y cañeras, por trimestre. El tamaño de los círculos es proporcional a las capturas.
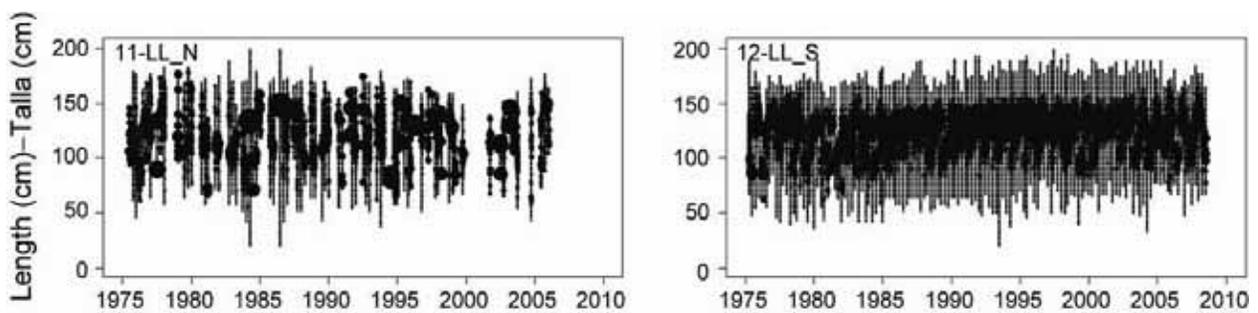
FIGURE 4.2e. Observed size compositions of the catches of yellowfin tuna taken by the longline fisheries, by quarter. The areas of the circles are proportional to the catches.

FIGURA 4.2e. Composición por talla observada de las capturas de atún aleta amarilla por las pesquerías de palangre, por trimestre. El tamaño de los círculos es proporcional a las capturas.
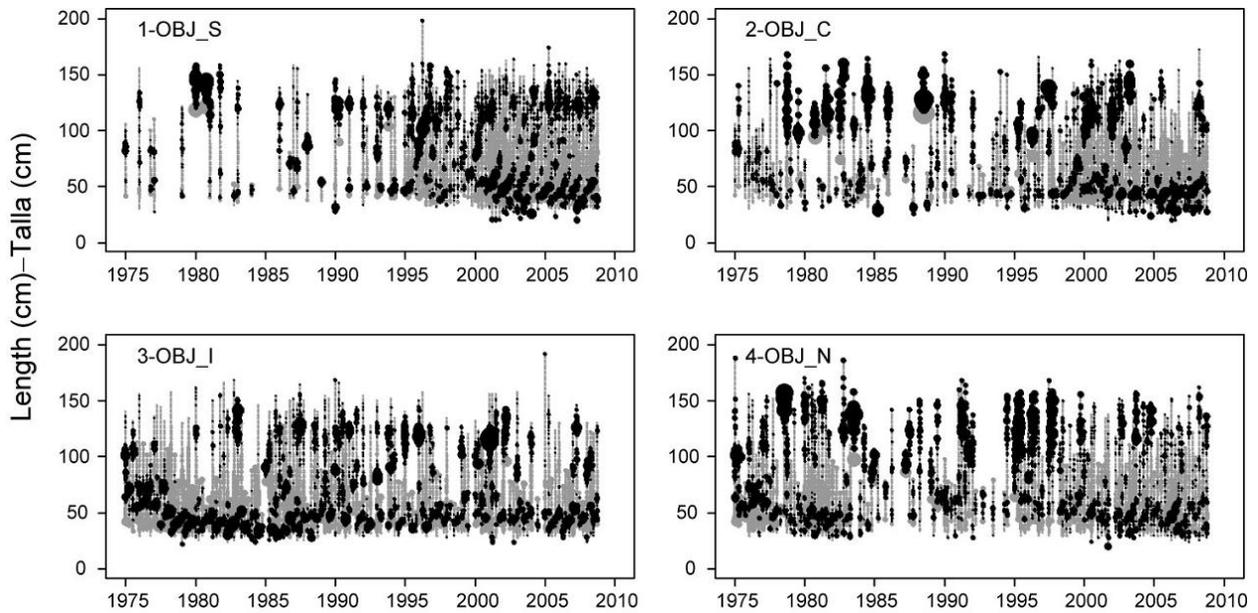
FIGURE 4.2f. Pearson residual plots for the model fits to the length composition data for the floating object fisheries. The black and grey circles represent observations that are higher and lower, respectively, than the model predictions. The areas of the circles are proportional to the absolute values of the residuals.

FIGURA 4.2f. Gráficas de residuales de Pearson de los ajustes del modelo a los datos de composición por talla de las pesquerías sobre objetos flotantes. Los círculos negros y grises representan observaciones que son mayores y menores, respectivamente, que las predicciones del modelo. El tamaño de los círculos es proporcional a los valores absolutos de los residuales.
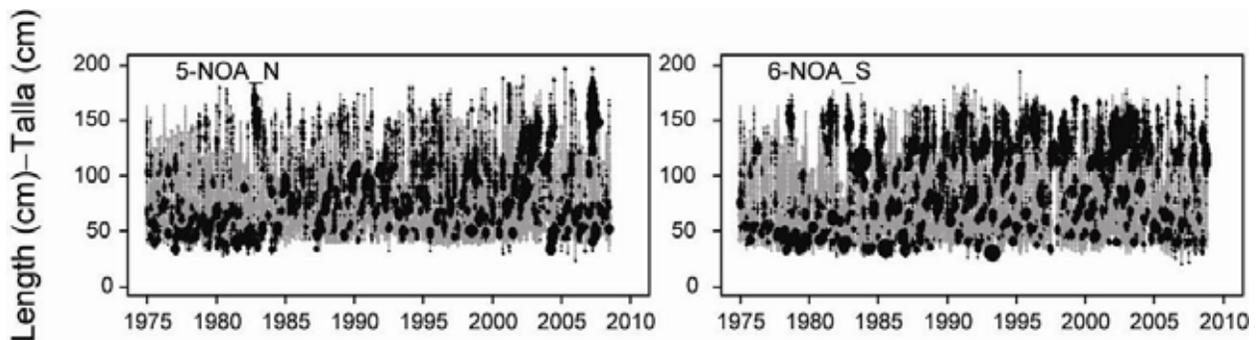
FIGURE 4.2g. Pearson residual plots for the model fits to the length composition data for the unassociated fisheries. The black and grey circles represent observations that are higher and lower, respectively, than the model predictions. The areas of the circles are proportional to the absolute values of the residuals.

FIGURA 4.2g. Gráficas de residuales de Pearson de los ajustes del modelo a los datos de composición por talla de las pesquerías no asociadas. Los círculos negros y grises representan observaciones que son mayores y menores, respectivamente, que las predicciones del modelo. El tamaño de los círculos es proporcional a los valores absolutos de los residuales.
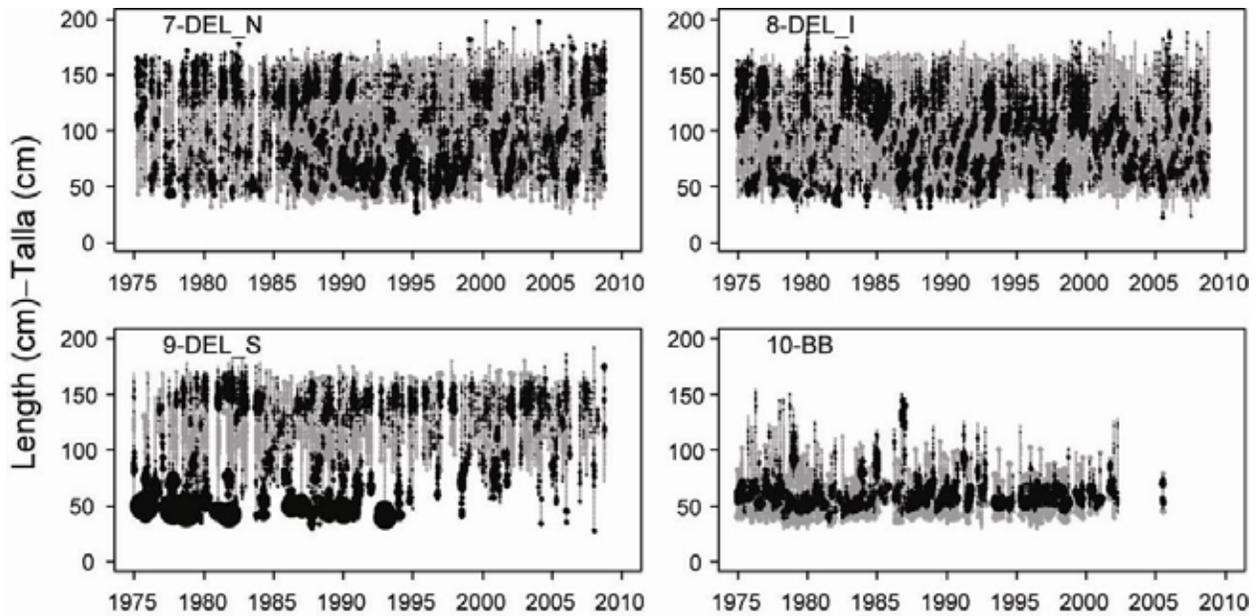
FIGURE 4.2h. Pearson residual plots for the model fits to the length composition data for the dolphin associated fisheries and the pole and line fishery. The black and grey circles represent observations that are higher and lower, respectively, than the model predictions. The areas of the circles are proportional to the absolute values of the residuals.

FIGURA 4.2h. Gráficas de residuales de Pearson de los ajustes del modelo a los datos de composición por talla de las pesquerías asociadas con delfines y la pesquería de caña. Los círculos negros y grises representan observaciones que son mayores y menores, respectivamente, que las predicciones del modelo. El tamaño de los círculos es proporcional a los valores absolutos de los residuales.
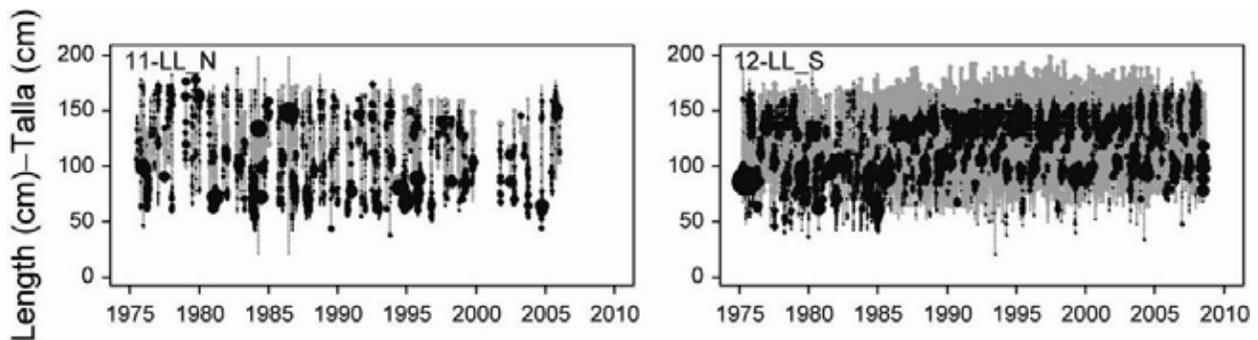
FIGURE 4.2i. Pearson residual plots for the model fits to the length composition data for the longline fisheries. The black and grey circles represent observations that are higher and lower, respectively, than the model predictions. The areas of the circles are proportional to the absolute values of the residuals.

FIGURA 4.2i. Gráficas de residuales de Pearson de los ajustes del modelo a los datos de composición por talla de las pesquerías de palangre. Los círculos negros y grises representan observaciones que son mayores y menores, respectivamente, que las predicciones del modelo. El tamaño de los círculos es proporcional a los valores absolutos de los residuales.
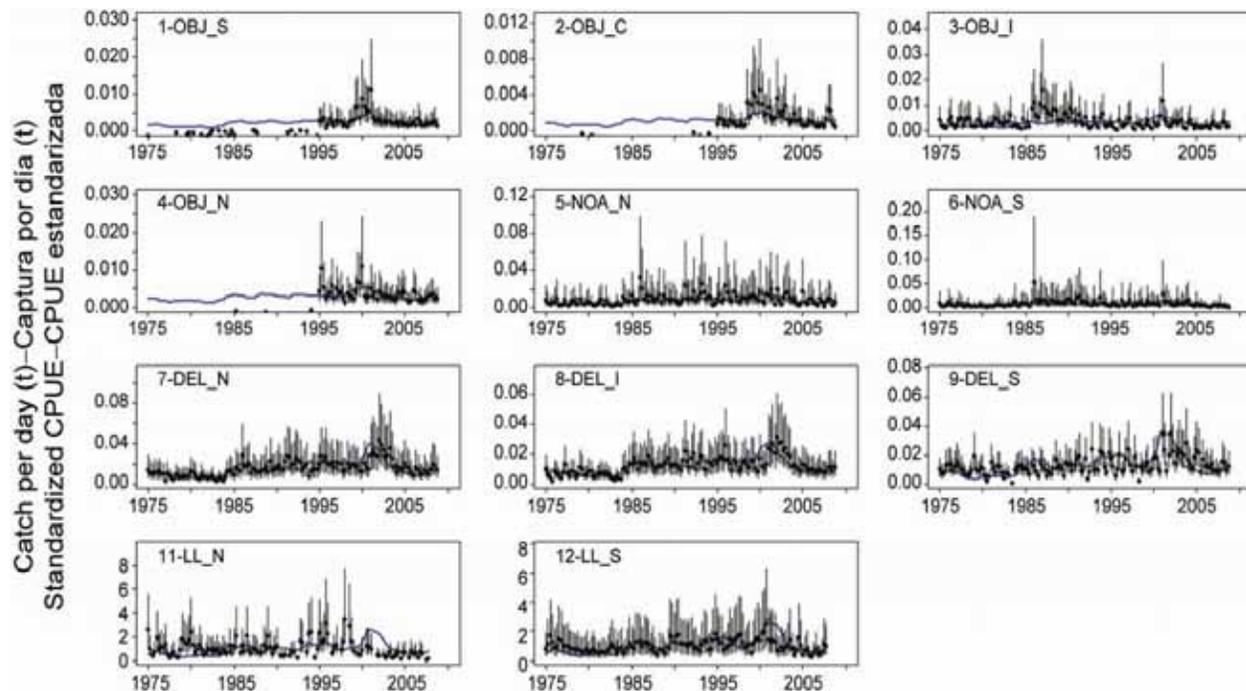
FIGURE 4.2j. Fits to the CPUE based indices of abundance. The vertical lines are the 95% confidence intervals for the observed data based on the internally-estimated standard deviations for the lognormal-based likelihood function.

FIGURA 4.2j. Ajustes a los índices de abundancia basados en CPUE. Las líneas verticales representan los intervalos de confianza de 95% correspondientes a los datos observados basados en las desviaciones estándar estimadas internamente para la función de verosimilitud basada en logaritmos normales.
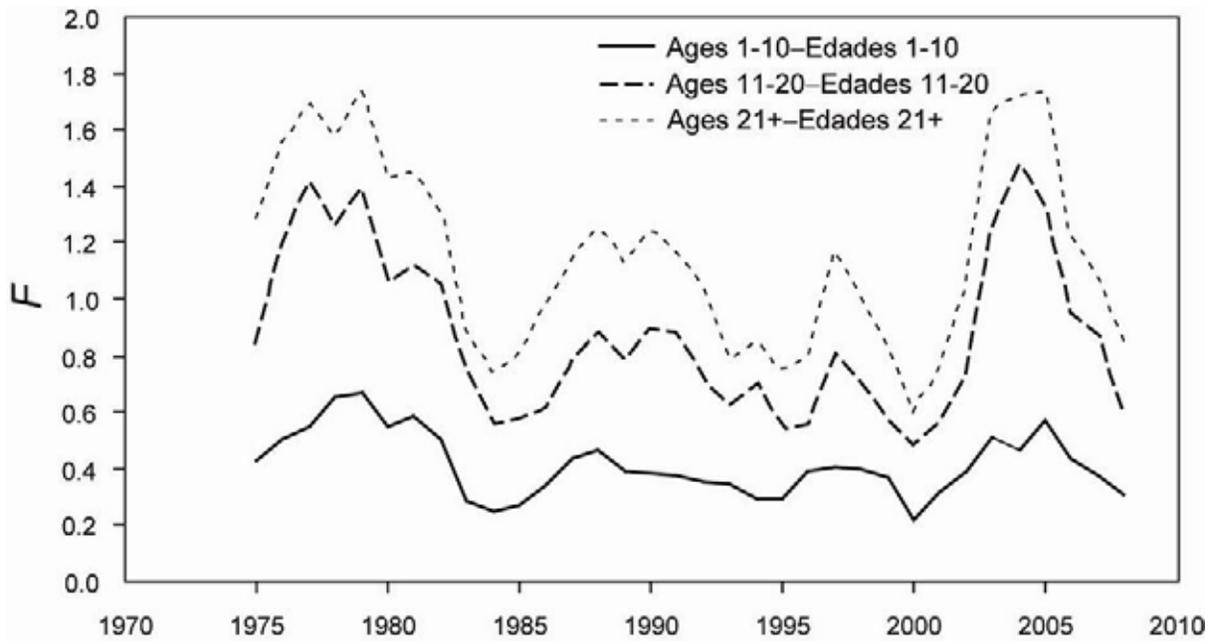
FIGURE 4.3a. Average annual fishing mortality (*F*) by age groups, by all gears, of yellowfin tuna recruited to the fisheries of the EPO. The age groups are defined by age in quarters.

FIGURA 4.3a. 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.
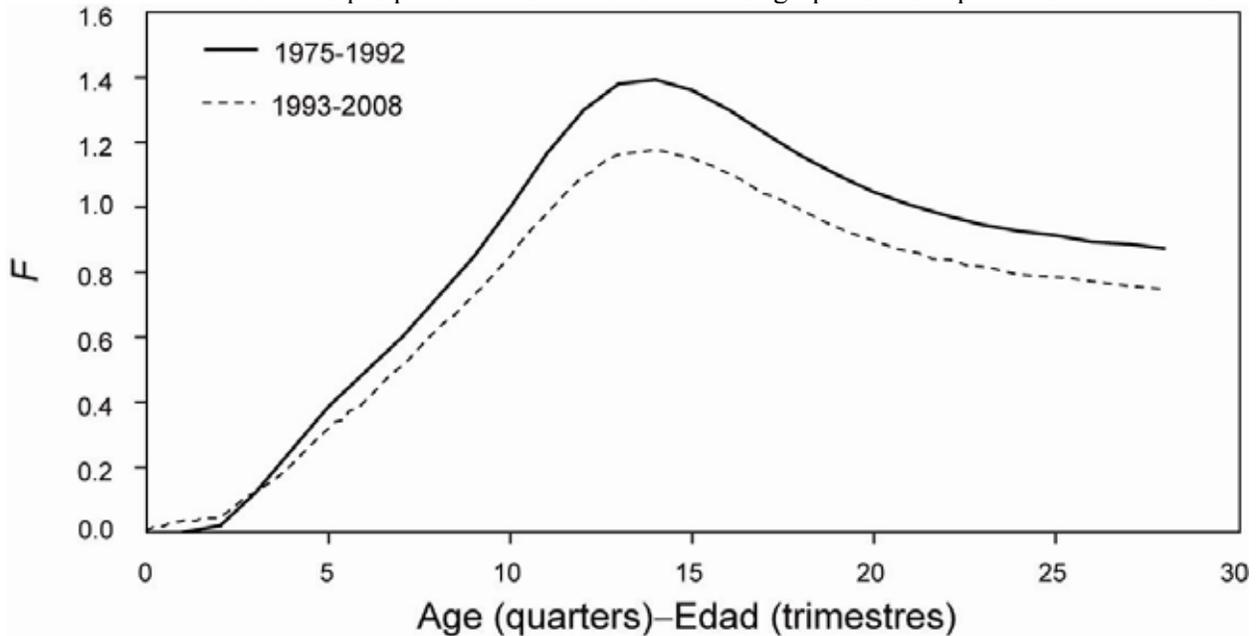
FIGURE 4.3b. Average annual fishing mortality (*F*) of yellowfin tuna by age in the EPO, by all gears. The estimates are presented for two periods, before and after the increase in effort associated with floating objects.

FIGURA 4.3b. Mortalidad por pesca (*F*) anual media de atún aleta amarilla por edad en el OPO, por todas las artes. Se presentan estimaciones para dos períodos, antes y después del aumento del esfuerzo asociado con objetos flotantes.
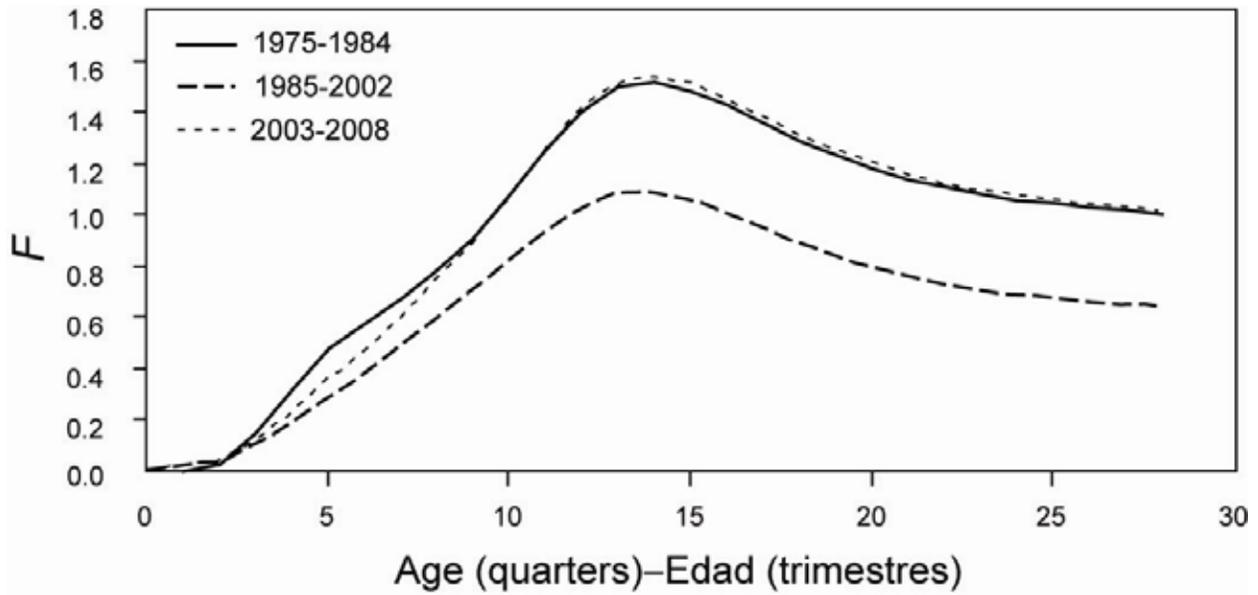
FIGURE 4.3c. Average annual fishing mortality (*F*) of yellowfin tuna by age in the EPO, by all gears. The estimates are presented for three periods corresponding to possible productivity regimes.

FIGURA 4.3c. Mortalidad por pesca (*F*) anual media de atún aleta amarilla por edad en el OPO, por todas las artes. Se presentan estimaciones para tres períodos correspondientes a posibles regimenes de productividad.
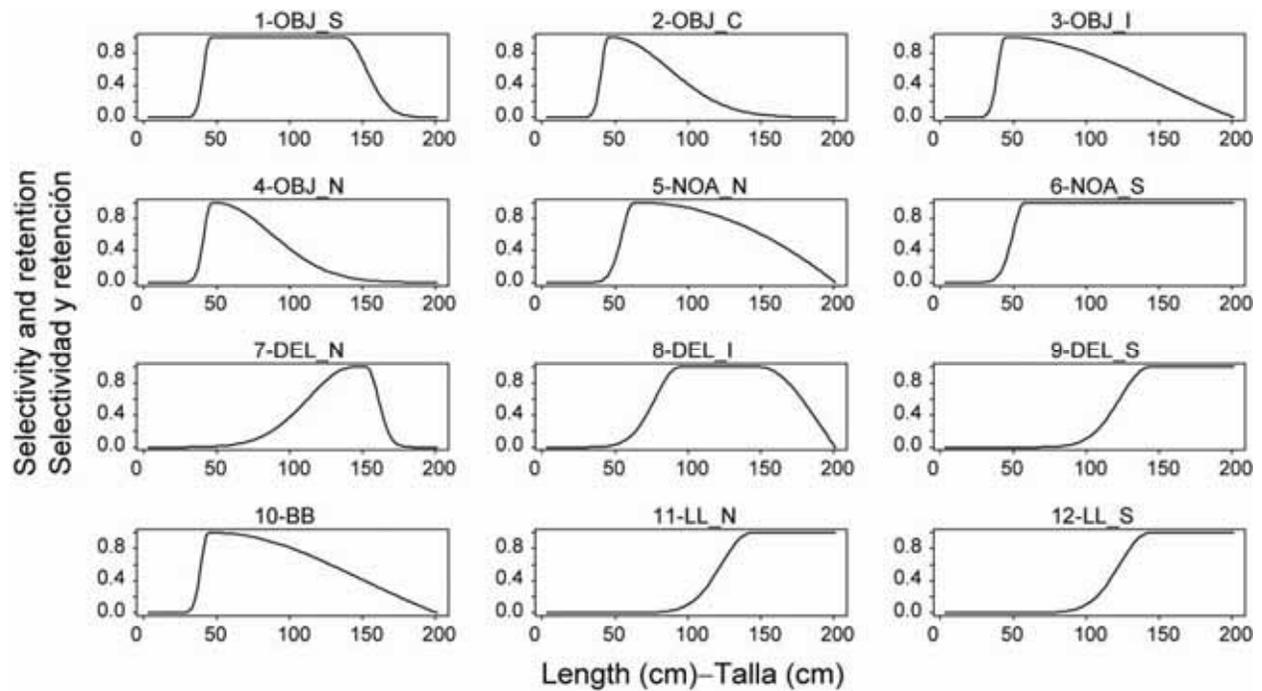
FIGURE 4.4. Selectivity curves for 12 of the 16 fisheries that take yellowfin tuna in the EPO. The selectivity curves for the discard fisheries (Fisheries 13-16) are fixed at assumed values.
FIGURA 4.4. Curvas de selectividad para 12 de las 16 pesquerías que capturan atún aleta amarilla en el OPO. Se fijan las curvas de selectividad de las pesquerías de descartes (Pesquerías 13-16) en valores supuestos.
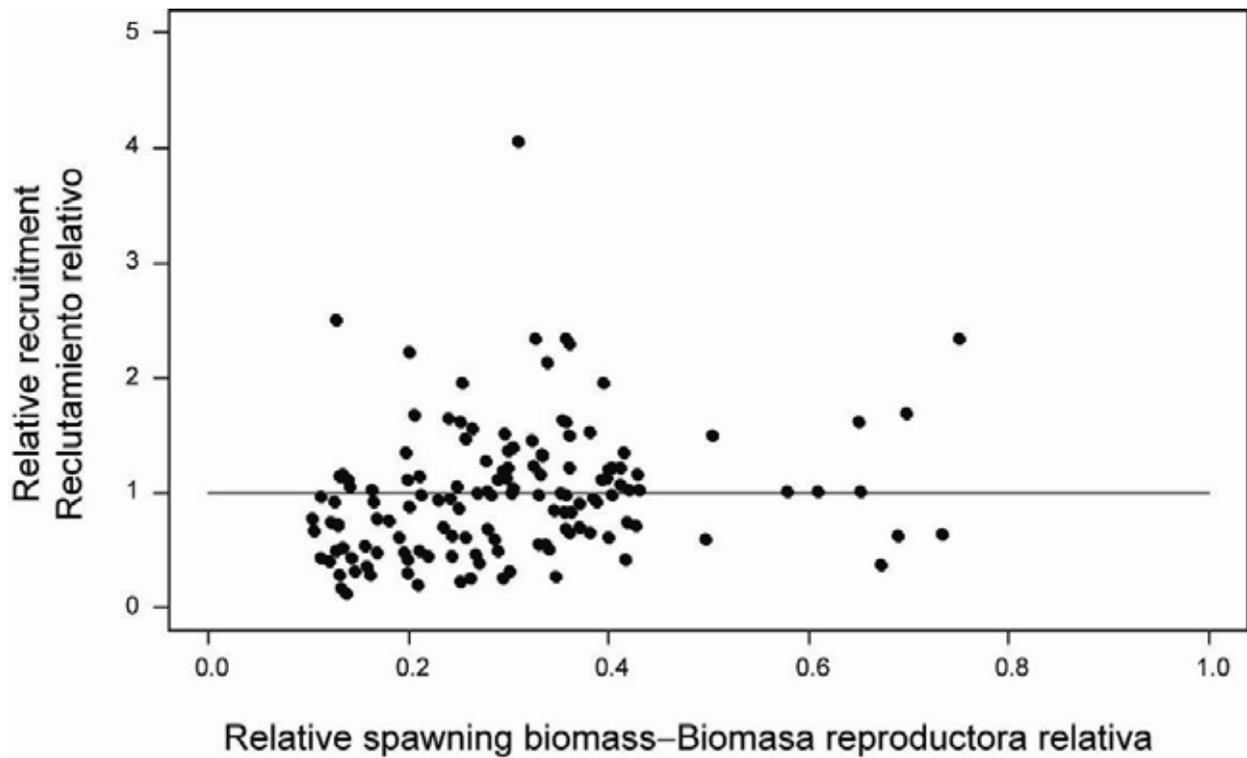
FIGURE 4.6. Estimated relationship between recruitment of yellowfin tuna and spawning biomass. The recruitment is scaled so that the average recruitment is equal to 1.0. The spawning biomass is scaled so that the average unexploited spawning biomass is equal to 1.0.

FIGURA 4.6. Relación estimada entre el reclutamiento y la biomasa reproductora del atún aleta amarilla. Se escala el reclutamiento para que el reclutamiento medio equivalga a 1,0, y la biomasa reproductora para que la biomasa reproductora media no explotada equivalga a 1,0.
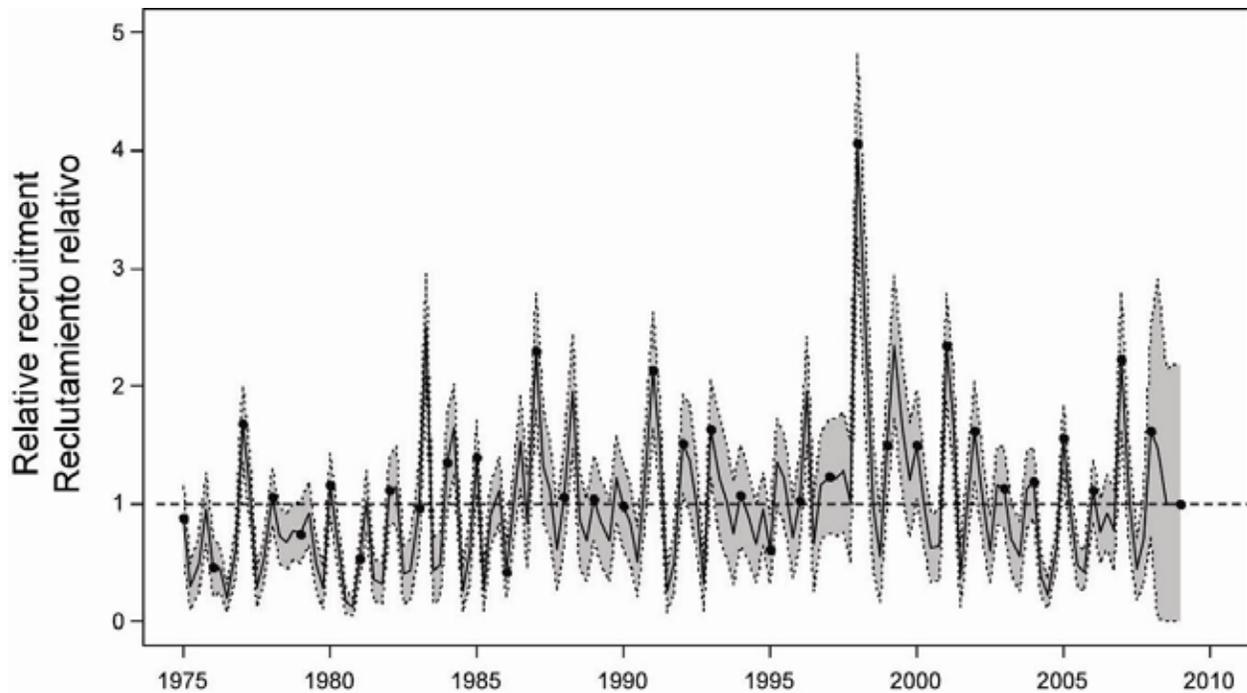
FIGURE 4.7a. Estimated quarterly recruitment of yellowfin tuna to the fisheries of the EPO. The estimates are scaled so that the average recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the shaded area indicates the approximate 95% confidence intervals around those estimates. The labels on the time axis are drawn at the start of each year, but, since the assessment model represents time on a quarterly basis, there are four estimates of recruitment for each year.

FIGURA 4.7a. Reclutamiento trimestral estimado de atún aleta amarilla a las pesquerías del OPO. Se escalan las estimaciones para que el reclutamiento medio equivalga a 1,0. La línea gruesa ilustra las estimaciones de verosimilitud máxima del reclutamiento, y el área sombreada los intervalos de confianza de 95% aproximados de esas estimaciones. Se dibujan las leyendas en el eje de tiempo al principio de cada año pero, ya que el modelo de evaluación representa el tiempo por trimestres, hay cuatro estimaciones de reclutamiento para cada año.
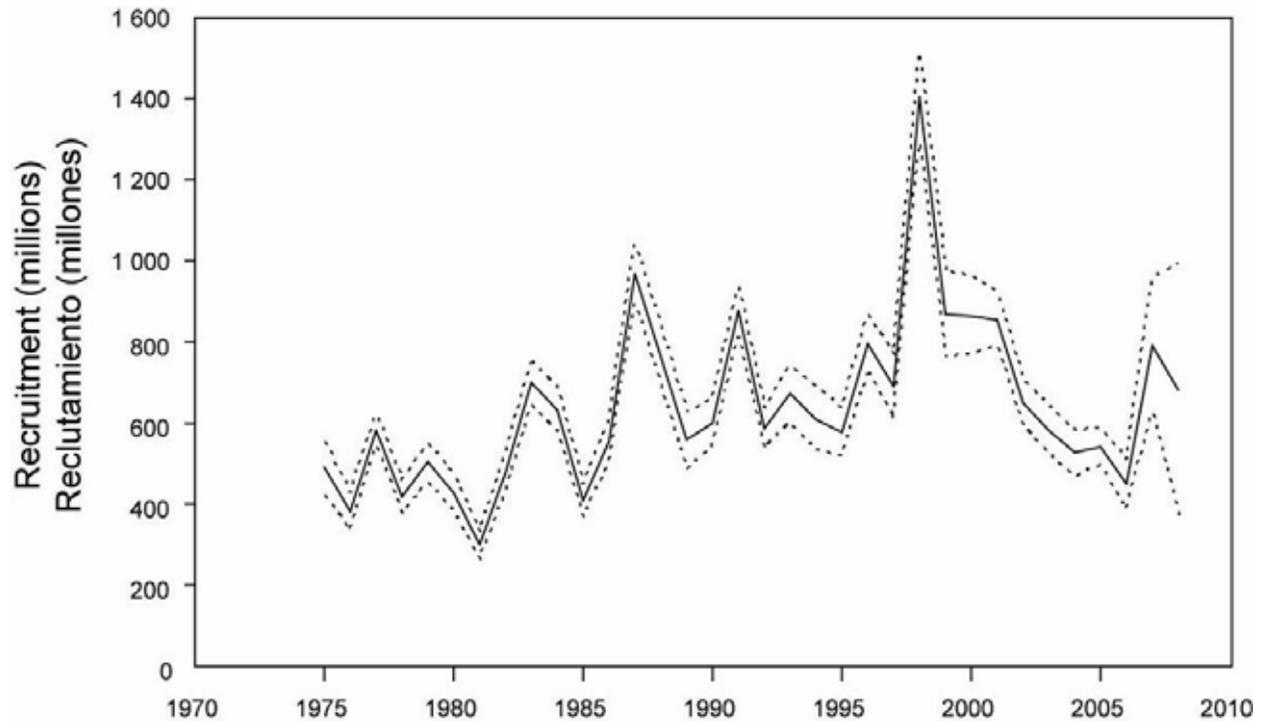
FIGURE 4.7b. Estimated annual recruitment at age zero of yellowfin tuna to the fisheries of the EPO. The solid line illustrates the maximum likelihood estimates of recruitment, and the dashed lines indicate the approximate 95% confidence intervals around those estimates. The solid line illustrates the maximum likelihood estimates of recruitment, and the dashed lines the approximate 95% confidence intervals around those estimates.

FIGURA 4.7b. Reclutamiento anual estimado a edad cero del atún aleta amarilla a las pesquerías del OPO. La línea sólida indica las estimaciones de verosimilitud máxima del reclutamiento, y las líneas de trazos los límites de confianza de 95% aproximados de las estimaciones. La línea sólida indica las estimaciones de verosimilitud máxima del reclutamiento, y las líneas de trazos los límites de confianza de 95% aproximados de las estimaciones.
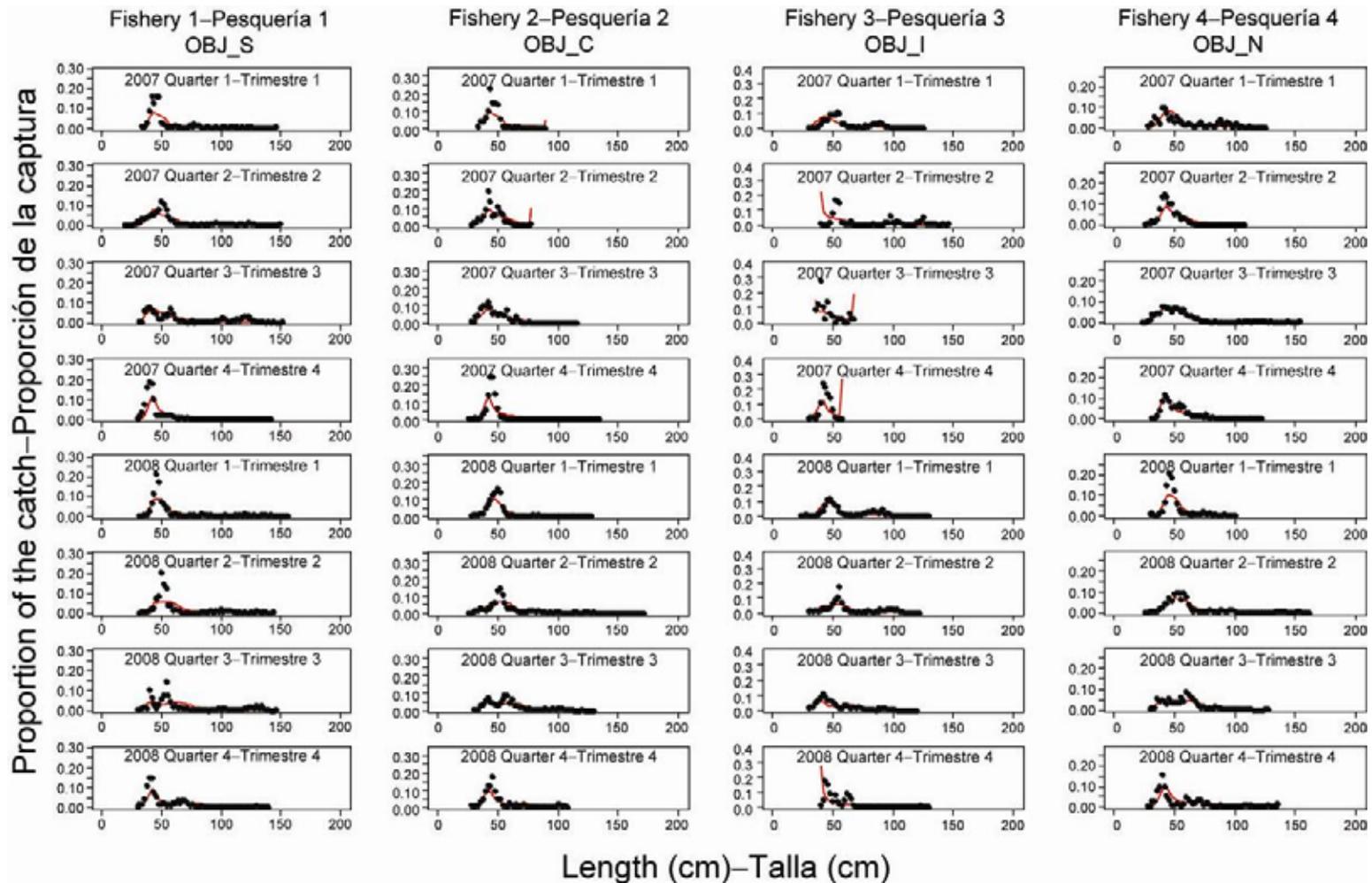
FIGURE 4.8a. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin by the fisheries that take tunas in association with floating objects (Fisheries 1-4).

FIGURA 4.8a. Composición por talla observada (puntos) y predicha (curvas) de las capturas recientes de aleta amarilla por las pesquerías que capturan atún en asociación con objetos flotantes (Pesquerías 1-4).
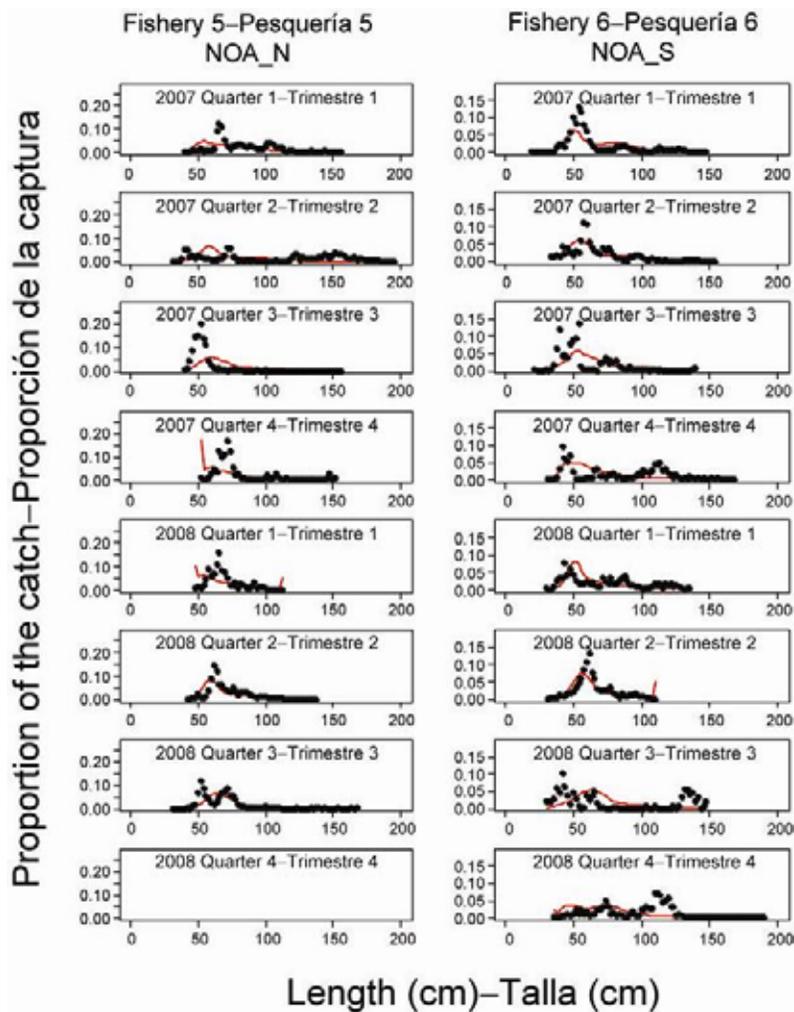
FIGURE 4.8b. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin tuna by the fisheries that take tunas in unassociated schools (Fisheries 5 and 6).

FIGURA 4.8b. Composición por talla observada (puntos) y predicha (curvas) de las capturas recientes de atún aleta amarilla por las pesquerías que capturan atún en cardúmenes no asociados (Pesquerías 5 y 6).
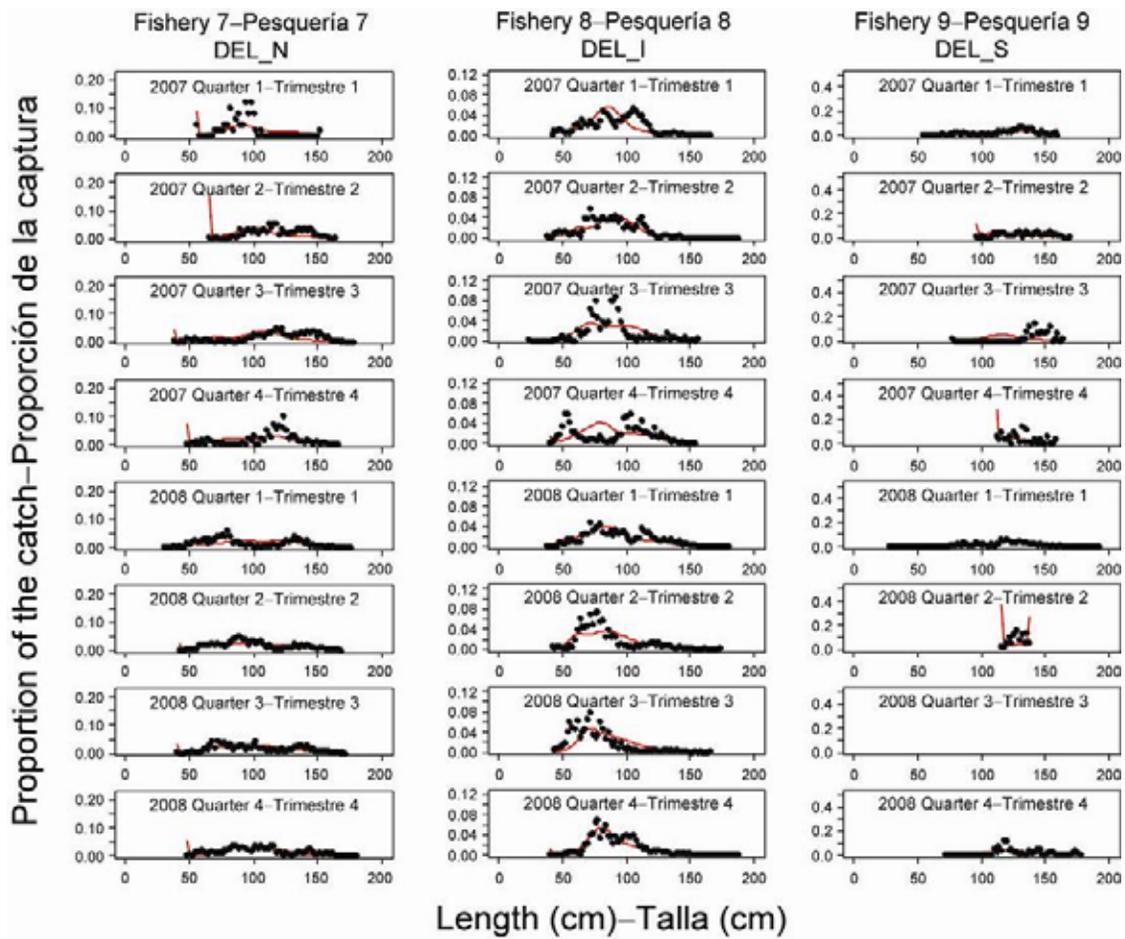
FIGURE 4.8c. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin tuna by the fisheries that take tunas in association with dolphins (Fisheries 7-9).
FIGURA 4.8c. Composición por talla observada (puntos) y predicha (curvas) de las capturas recientes de atún aleta amarilla por las pesquerías que capturan atún en asociación con delfines (Pesquerías 7-9).
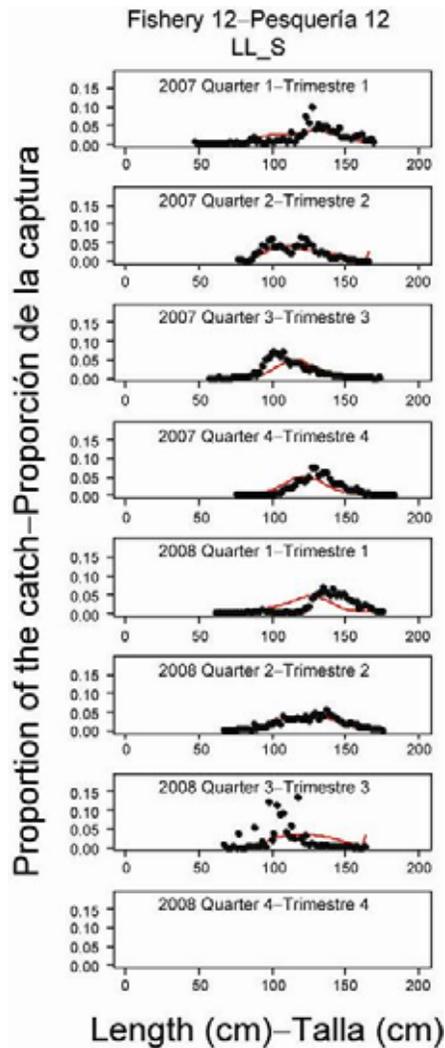
FIGURE 4.8d. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin tuna by the southern longline fishery (Fishery 12). There are no recent size composition data for the northern longline fishery.

FIGURA 4.8d. Composición por talla observada (puntos) y predicha (curvas) de las capturas recientes de atún aleta amarilla por la pesquería de palangre del sur (Pesquería 12). No se cuenta con datos recientes de composición por talla de la pesquería de palangre del norte.

FIGURE 4.9a. Estimated biomass of yellowfin tuna aged three quarters and older in the EPO. The line illustrates the maximum likelihood estimates of the biomass. Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year. t = metric tons.

FIGURA 4.9a. Biomasa estimada de atún aleta amarilla de tres trimestres y más de edad en el OPO. La línea ilustra las estimaciones de verosimilitud máxima de la biomasa. Ya que el modelo de evaluación representa el tiempo por trimestres, hay cuatro estimaciones de biomasa para cada año. t = toneladas métricas.
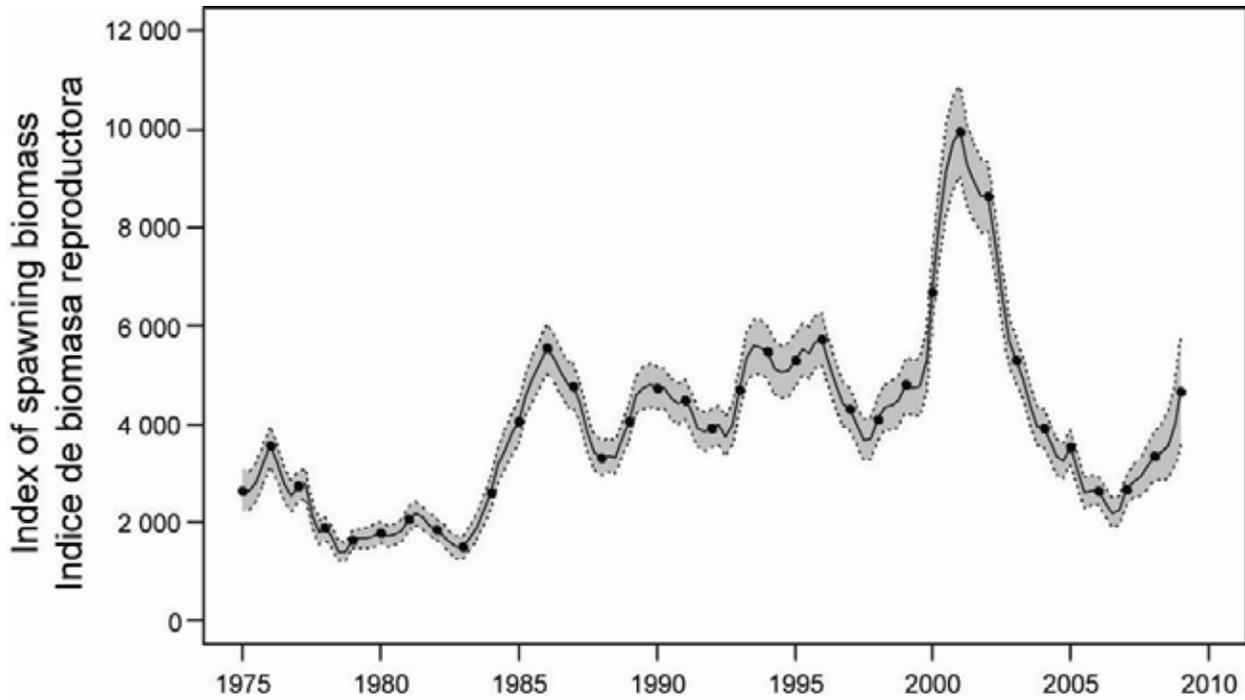
FIGURE 4.9b. Estimated index of spawning biomass of yellowfin tuna in the EPO. The solid line illustrates the maximum likelihood estimates of the biomass, and the dashed lines the approximate 95% confidence intervals around those estimates. Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year.

FIGURA 4.9b. Índice estimado de la biomasa reproductora del atún aleta amarilla en el OPO. La línea sólida ilustra las estimaciones de verosimilitud máxima de la biomasa, y las líneas delgadas de trazos los límites de confianza de 95% aproximados de las estimaciones. Ya que el modelo de evaluación representa el tiempo por trimestres, hay cuatro estimaciones de biomasa para cada año.
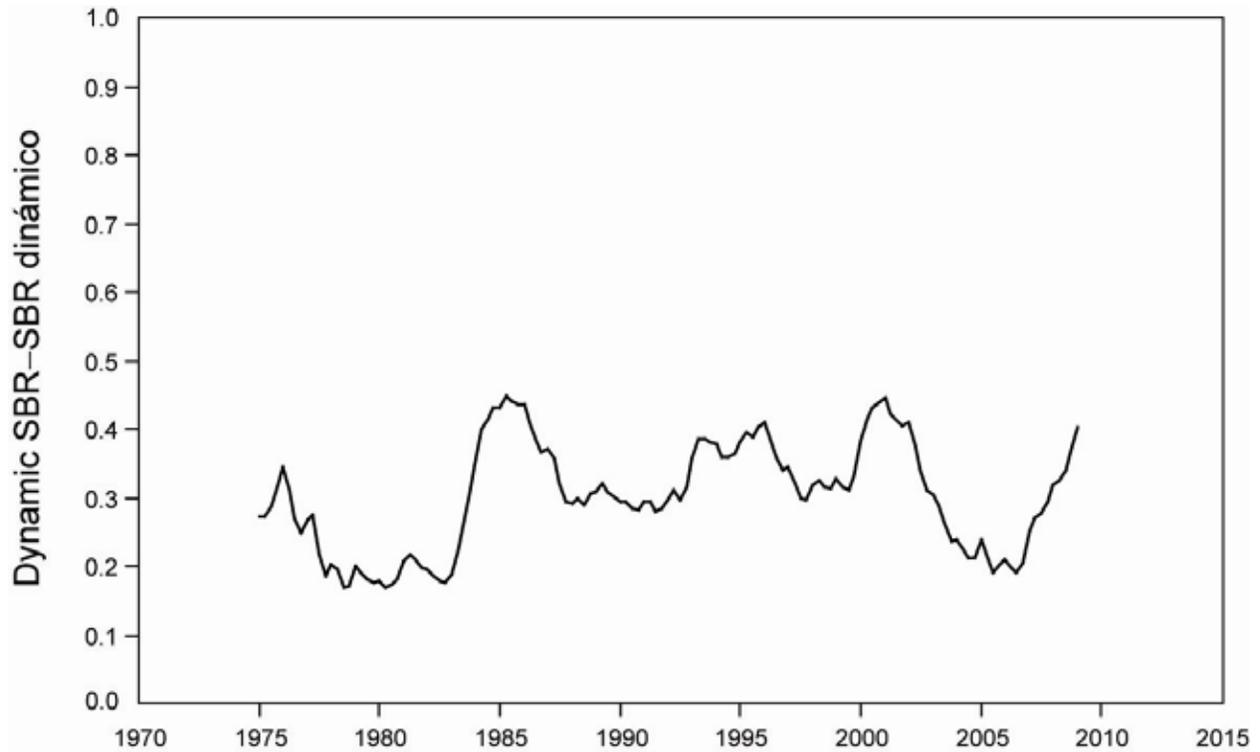
FIGURE 4.10a. Spawning biomass as a ratio of the trajectory of spawning biomass simulated from a population of yellowfin tuna that was never exploited. Dynamic SBR is the spawning biomass as a ratio of the unfished spawning biomass calculated by modeling the population over time in the absence of fishing.

FIGURA 4.10a. Biomasa reproductora como cociente de la trayectoria de la biomasa reproductora simulada de una población de atún aleta amarilla que nunca fue explotada. El SBR dinámico es la biomasa reproductora como cociente de la biomasa reproductora no explotada calculada mediante el modelado de la población con el tiempo en la ausencia de pesca.
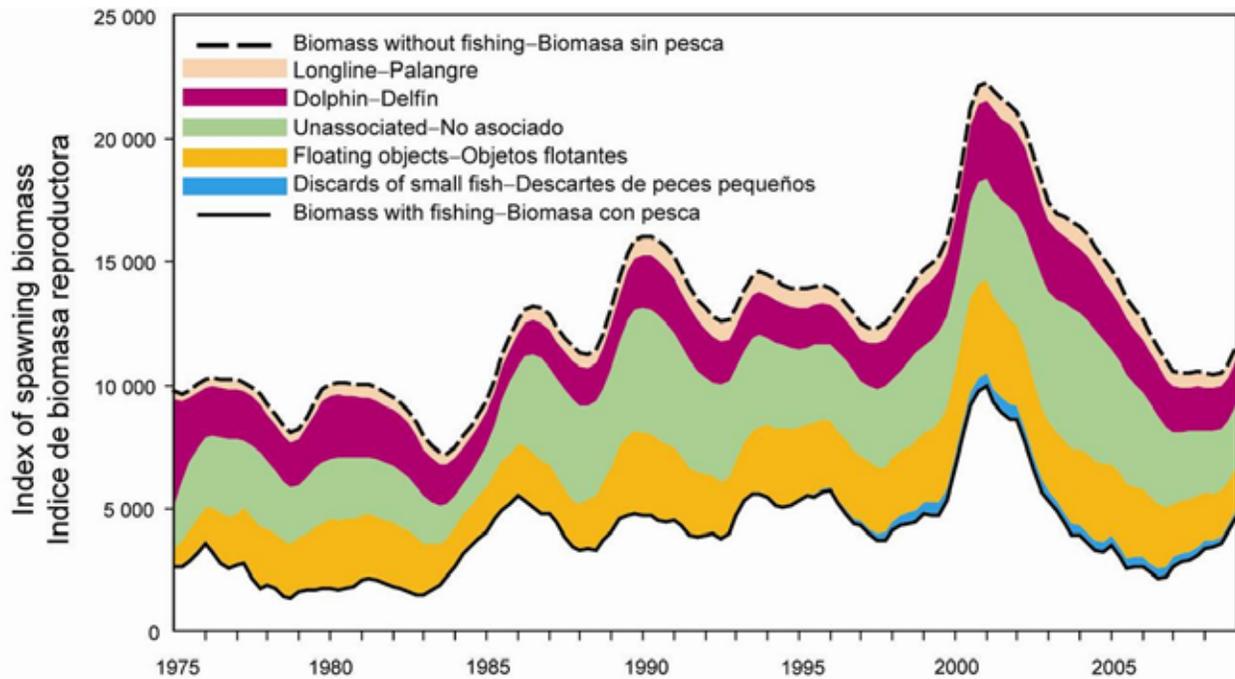
FIGURE 4.10b. Biomass trajectory of a simulated population of yellowfin tuna that was never exploited (dashed line) and that predicted by the stock assessment model (solid line). The shaded areas between the two lines show the portions of the fishery impact attributed to each fishing method.

FIGURA 4.10b. Trayectoria de la biomasa de una población simulada de atún aleta amarilla que nunca fue explotada (línea de trazos) y aquélla predicha por el modelo de evaluación de la población (línea sólida). Las áreas sombreadas entre las dos líneas represantan la porción del impacto de la pesca atribuida a cada método de pesca.
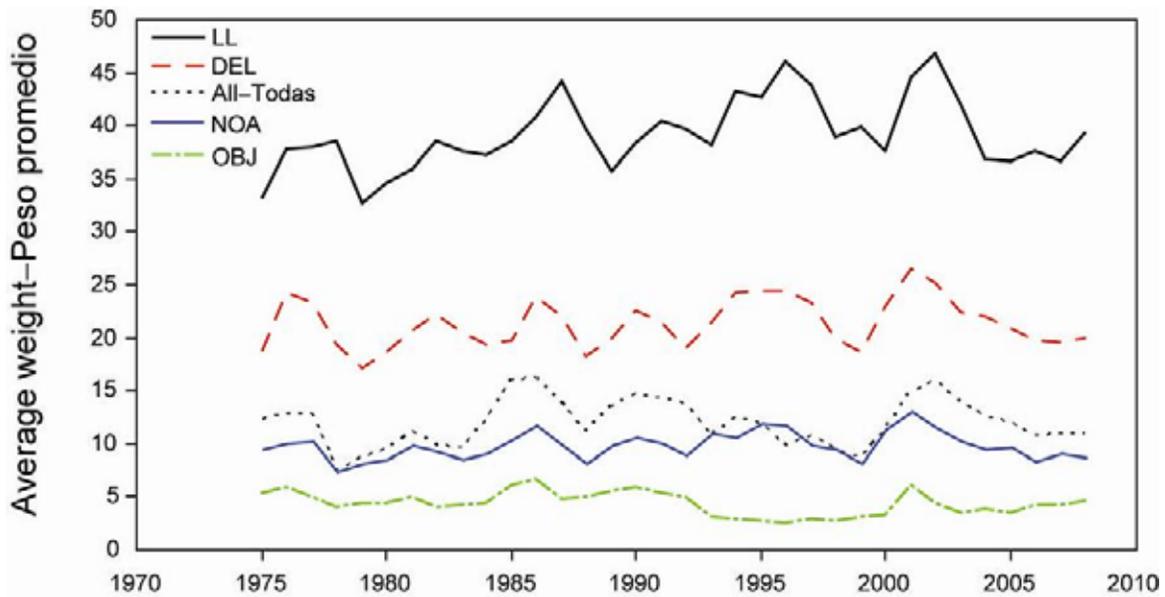
FIGURE 4.11. Estimated average weights of yellowfin tuna caught by the fisheries of the EPO (OBJ = purse-seine sets on floating objects; NOA = purse-seine sets on unassociated schools; DEL = purse-seine sets on schools associated with dolphins; LL = longline; All = all fisheries combined).

FIGURA 4.11. Peso promedio estimado de atún aleta amarilla capturado en las pesquerías del OPO. (OBJ = lances cerqueros sobre objetos flotantes; NOA = lances cerqueros sobre atunes no asociados; DEL = lances cerqueros sobre atunes asociados con delfines; LL = palangre; Todas = todas las pesquerías combinadas).

FIGURE 4.12a. Comparison of estimated biomasses of yellowfin tuna aged three quarters and older in the EPO from the most recent previous assessment (dashed line) and the current assessment (solid line). t = metric tons.

FIGURA 4.12a. Comparación de la biomasa estimada de atún aleta amarilla de tres trimestres y más de edad en el OPO de la evaluación previa más reciente y de la evaluación actual. t = toneladas métricas.
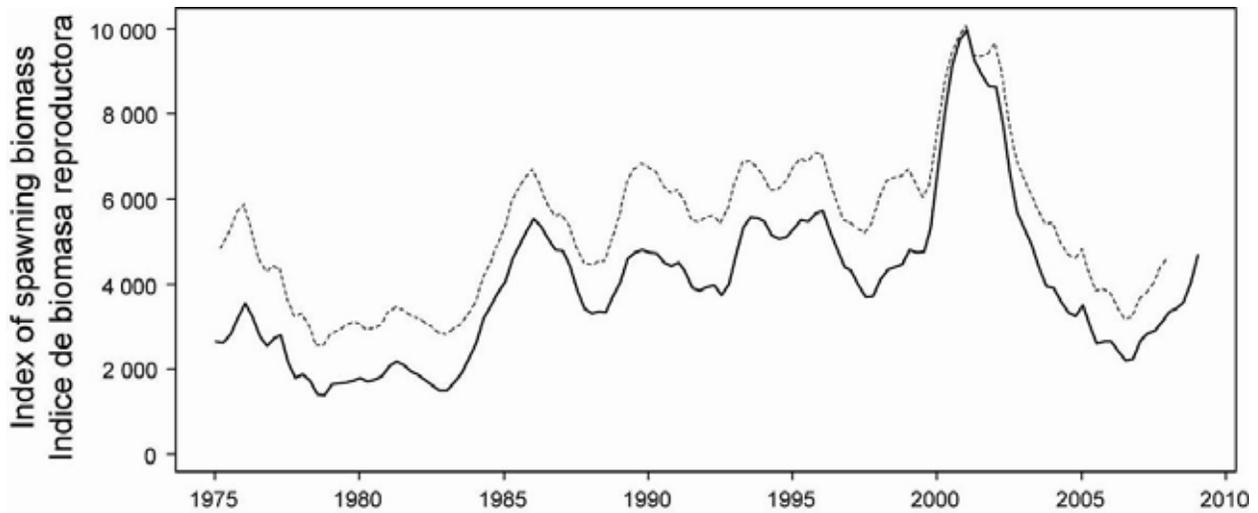
FIGURE 4.12b. Comparison of estimated indices of spawning biomass of yellowfin tuna in the EPO from the most recent previous assessment (dashed line) and the current assessment (solid line).
FIGURA 4.12b. Comparación de los índices estimados de biomasa reproductora del atún aleta amarilla en el OPO de la evaluación previa más reciente (línea de trazos) y la evaluación actual (línea sólida).
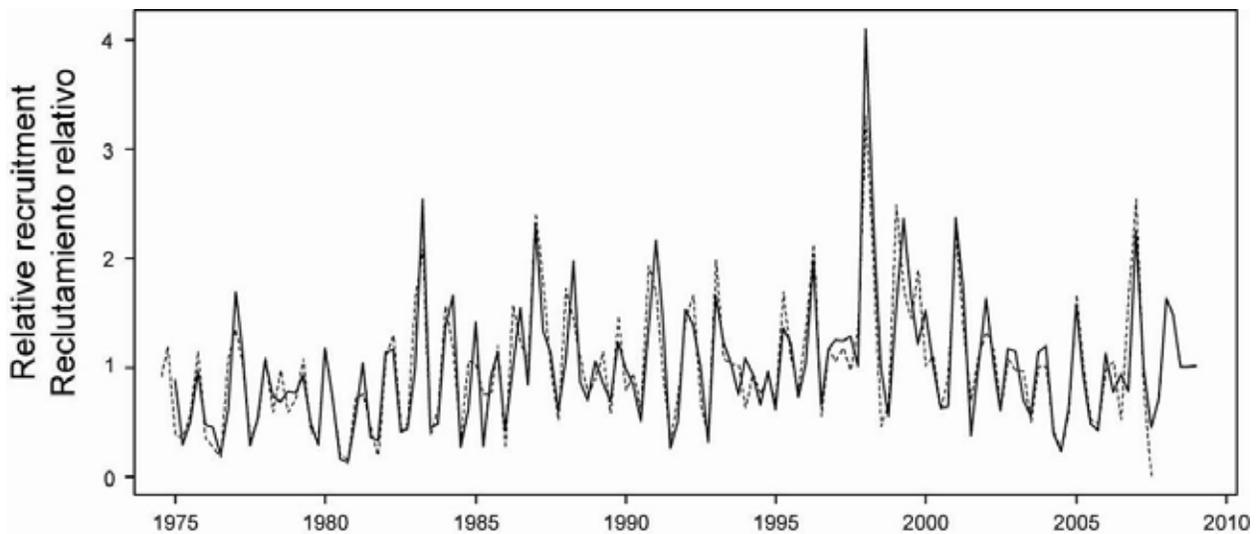
FIGURE 4.12c. Comparison of estimated relative recruitment of yellowfin in the EPO from the most recent previous assessment (dashed line) and the current assessment (solid line).
FIGURA 4.12c. Comparación del reclutamiento relativo estimado de aleta amarilla en el OPO de la evaluación previa más reciente (línea de trazos) y la evaluación actual (línea sólida).
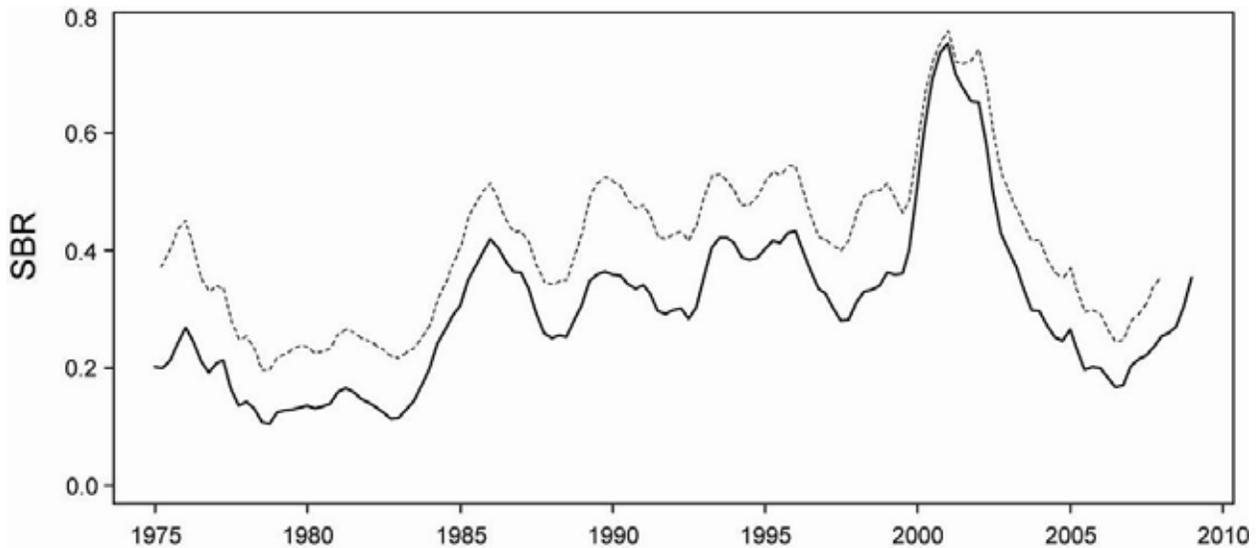
FIGURE 4.12d. Comparison of estimated spawning biomass ratios (SBRs) of yellowfin tuna from the current assessment (solid line) with the most recent previous assessments (dashed line). The horizontal lines identify the SBRs at MSY.

FIGURA 4.12d. Comparación del cociente de biomasa reproductora (SBR) estimado de atún aleta amarilla de la evaluación actual (línea sólida) y las evaluaciones previas más recientes (línea de trazos). Las líneas horizontales identifican el SBR en RMS.

Year of assessment–Año de la evaluación
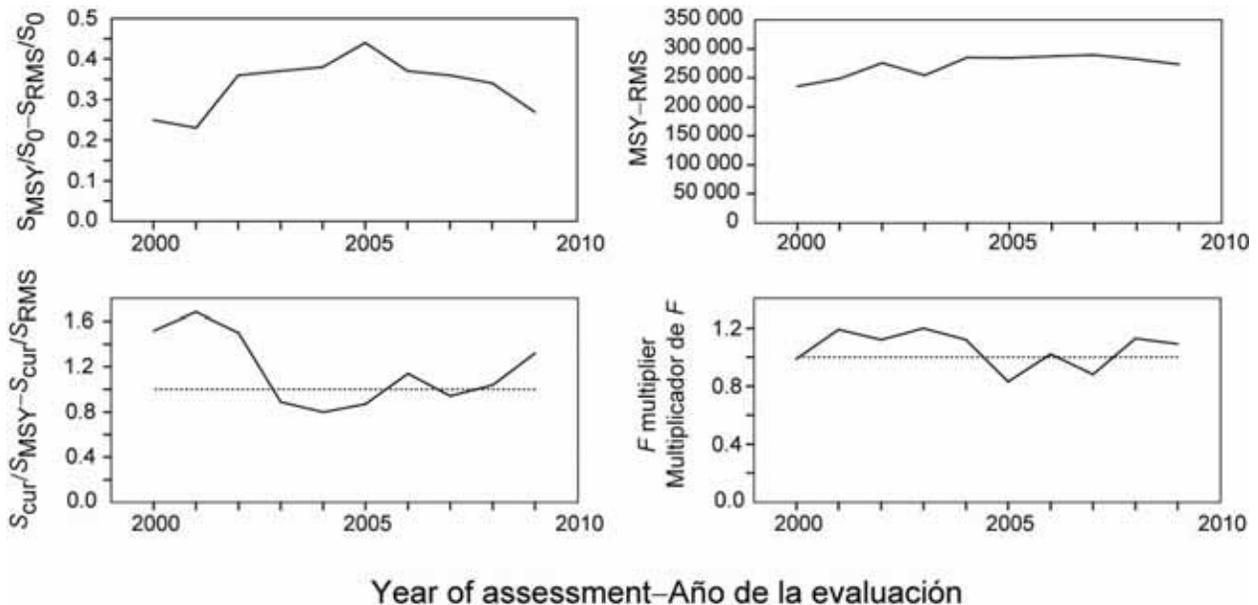
FIGURE 4.13a. Estimates of MSY-related quantities from the current assessment compared to those estimated in previous assessments. (S_{cur} is the index of spawning biomass at the start of 2009). See the text for definitions.

FIGURA 4.13a. Estimaciones de cantidades relacionadas con el RMS de la evaluación actual comparadas con aquéllas estimadas en evaluaciones previas. (S_{cur} es el índice de la biomasa reproductora al principio de 2009). Ver definiciones en el texto.
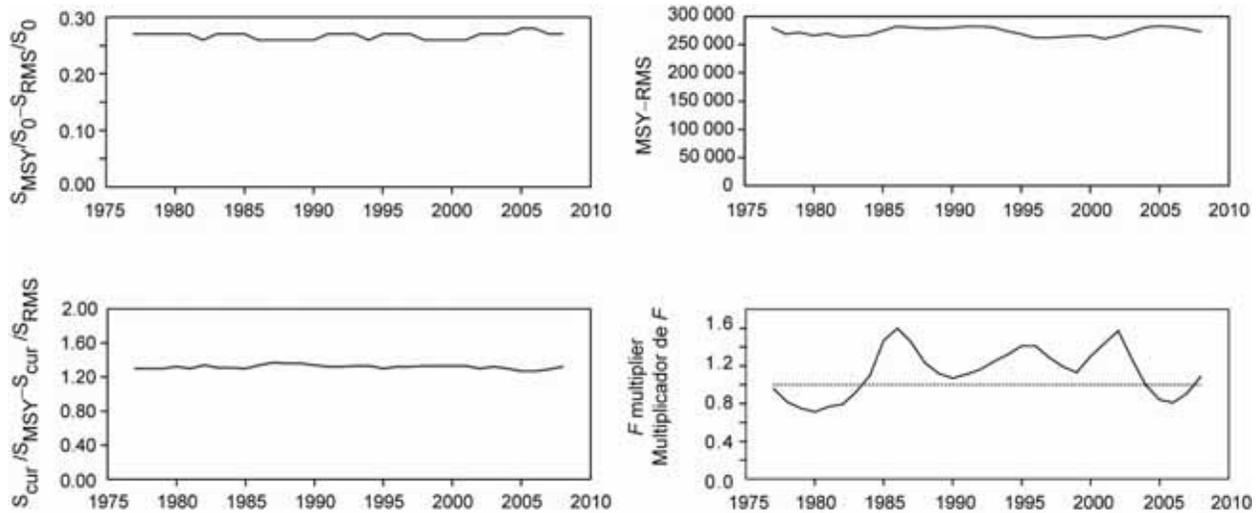
FIGURE 4.13b. Estimates of MSY-related quantities calculated using the average age-specific fishing mortality for each year (*i.e.* the values for 2006 are calculated using the average age-specific fishing mortality in 2006 scaled by the quantity *F*scale, which maximizes the equilibrium yield). (S_{cur} is the index of spawning biomass at the end of the last year in the assessment). See the text for definitions.

FIGURA 4.13b. Estimaciones de cantidades relacionadas con el RMS calculadas a partir de la mortalidad por pesca media por edad para cada año (o sea, se calculan los valores de 2006 usando la mortalidad por pesca media por edad escalada por la cantidad *F*scale, que maximiza el rendimiento de equilibrio). (S_{curt} es el índice de la biomasa reproductora al fin del último año en la evaluación). Ver definiciones en el texto.
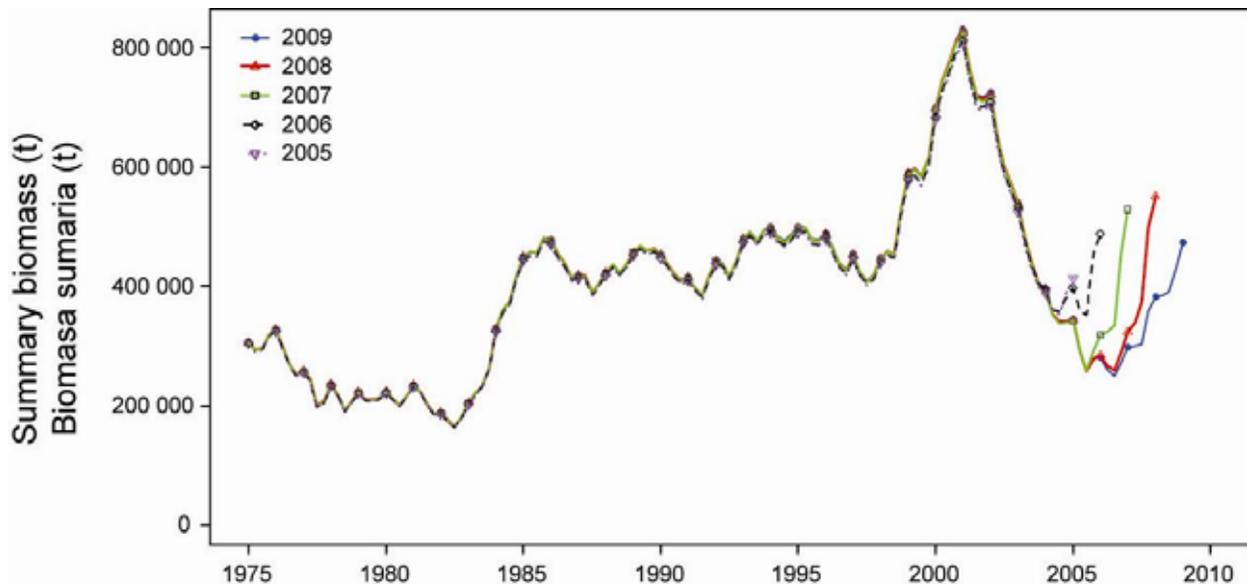
FIGURE 4.14a. Comparison of estimated biomasses of yellowfin tuna aged three quarters and older in the EPO from the current assessment compared to retrospective analyses that remove recent data. t = metric tons.

FIGURA 4.14a. Comparación de las biomasas estimadas de atunes aleta amarilla de tres trimestres y más de edad en el OPO de la evaluación actual y los análisis retrospectivos que eliminan los datos recientes. t = toneladas métricas.
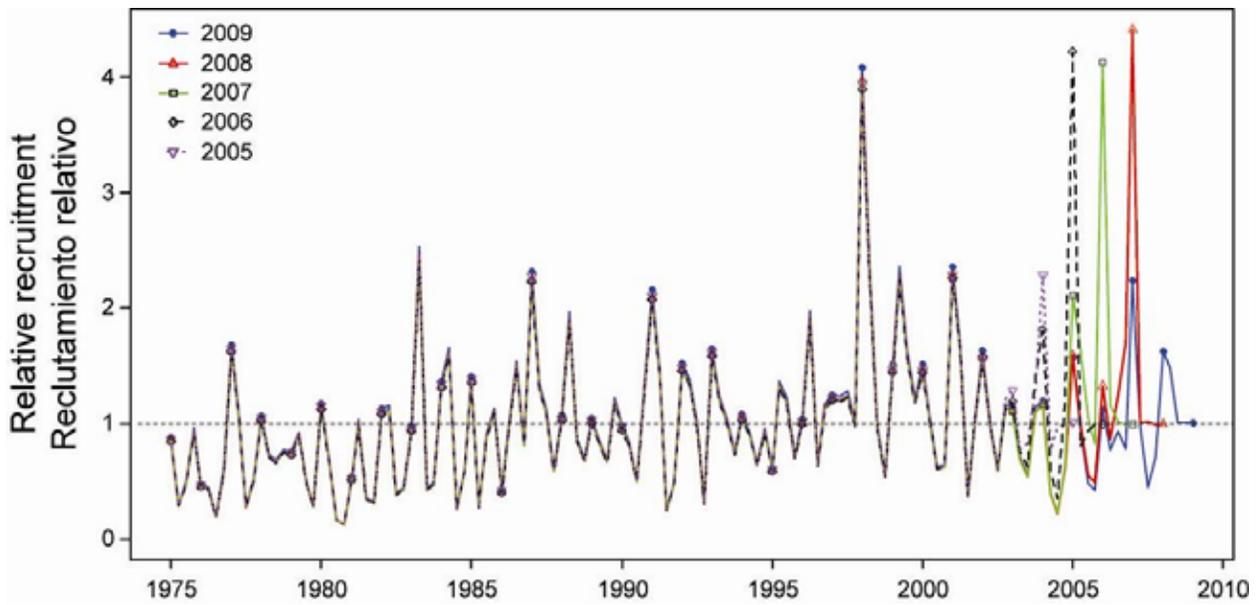
FIGURE 4.14b. Comparison of estimated recruitment of yellowfin tuna in the EPO from the current assessment compared to retrospective analyses that remove recent data

FIGURA 4.14b. Comparación del reclutamiento estimado de atún aleta amarilla en el OPO de la evaluación actual con los análisis retrospectivos que eliminan los datos recientes.
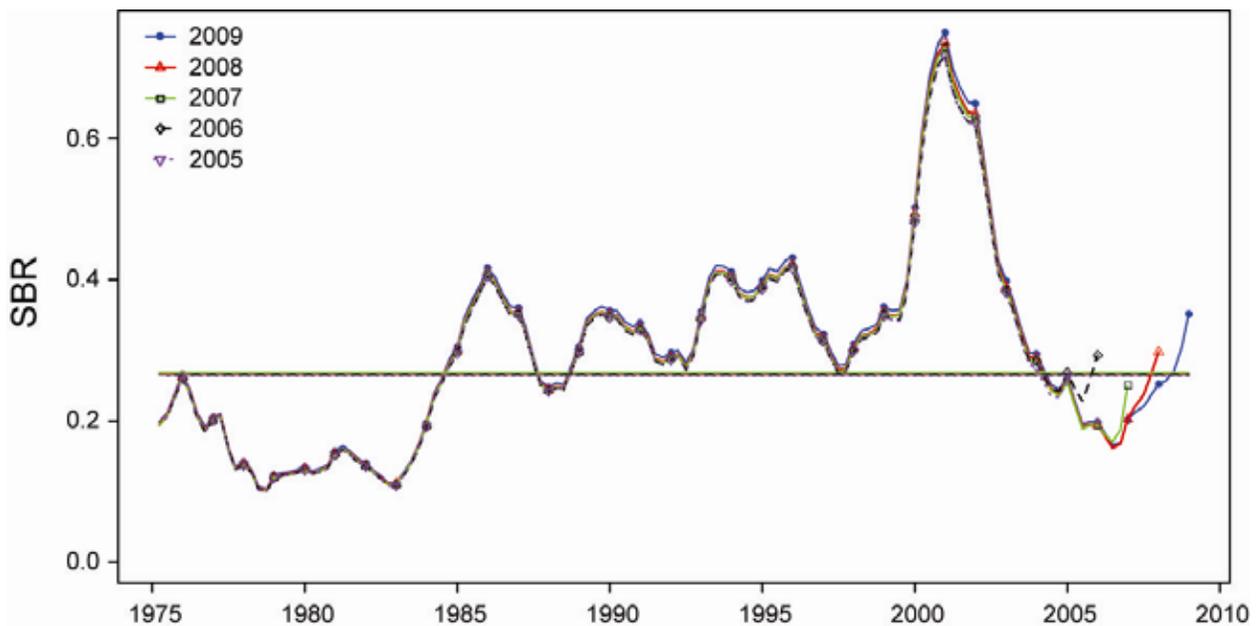

FIGURE 4.14c. Comparison of estimated spawning biomass ratio (SBR) of yellowfin tuna in the EPO from the current assessment compared to retrospective analyses that remove recent data. The horizontal line represents the SBR that corresponds to MSY estimated in the current assessment.

FIGURA 4.14c. Comparación del cociente de biomasa reproductora (SBR) estimado del atún aleta amarilla en el OPO de la evaluación actual con los análisis retrospectivos que eliminan los datos recientes. La línea horizontal representa el SBR que corresponde al RMS estimado en la evaluación actual.
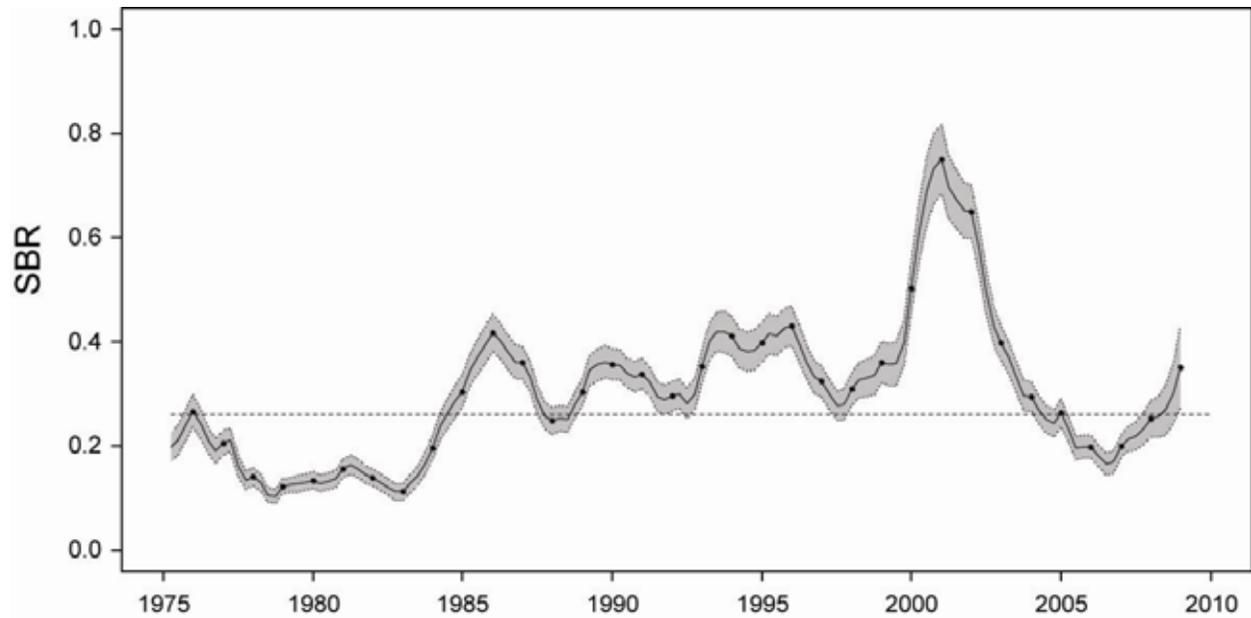
FIGURE 5.1a. Estimated spawning biomass ratios (SBRs) for yellowfin tuna in the EPO. The thin dashed lines represent approximate 95% confidence intervals. The dashed horizontal line identifies the SBR at MSY.

FIGURA 5.1a. Cocientes de biomasa reproductora (SBR) estimados del atún aleta amarilla en el OPO. Las líneas delgadas de trazos representan los intervalos de confianza de 95% aproximados. La línea de trazos horizontal identifica el SBR en RMS.
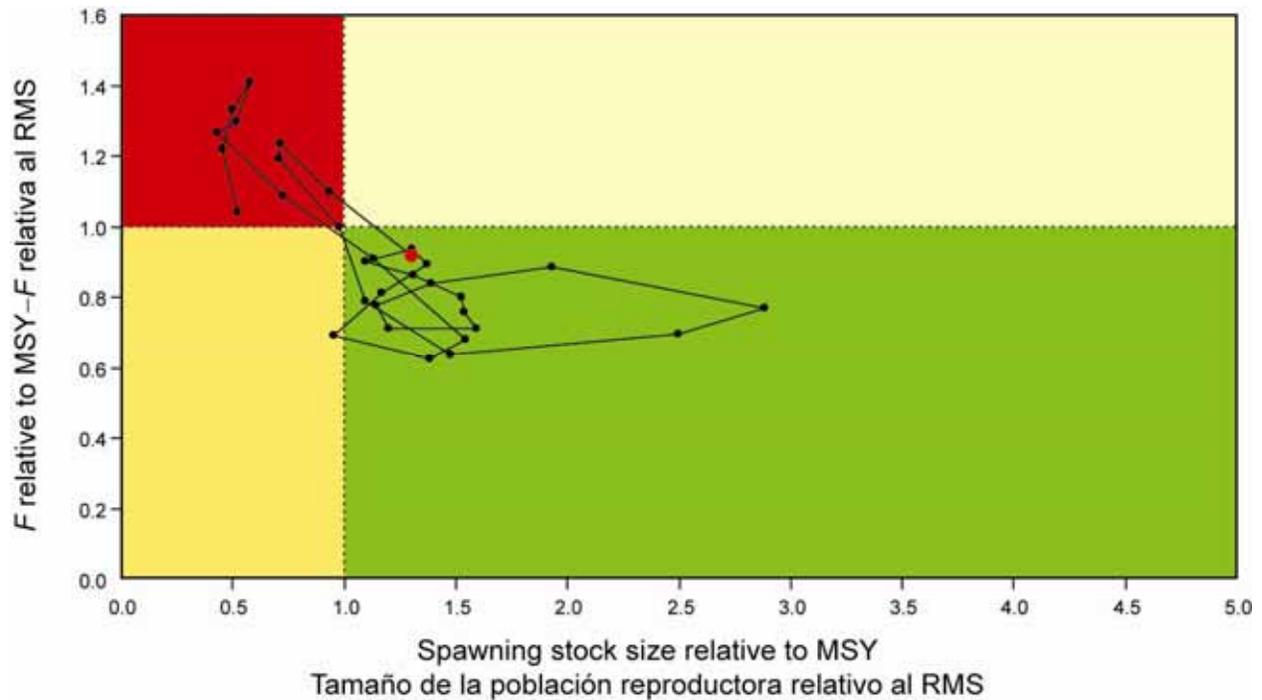
FIGURE 5.1b. Phase plot of the time series of estimates for stock size and fishing mortality relative to their MSY reference points. Each dot is based on the average exploitation rate over three years; the large red dot indicates the most recent estimate. The squares represent approximate 95% confidence intervals.

FIGURA 5.1b. Gráfica de fase de la serie de tiempo de las estimaciones del tamaño de la población y la mortalidad por pesca en relación con sus puntos de referencia de RMS. Cada punto se basa en la tasa de explotación media de tres años; el punto rojo grande indica la estimación valor más reciente. Los puntos cuadrados representan los intervalos de confianza de 95% aproximados.
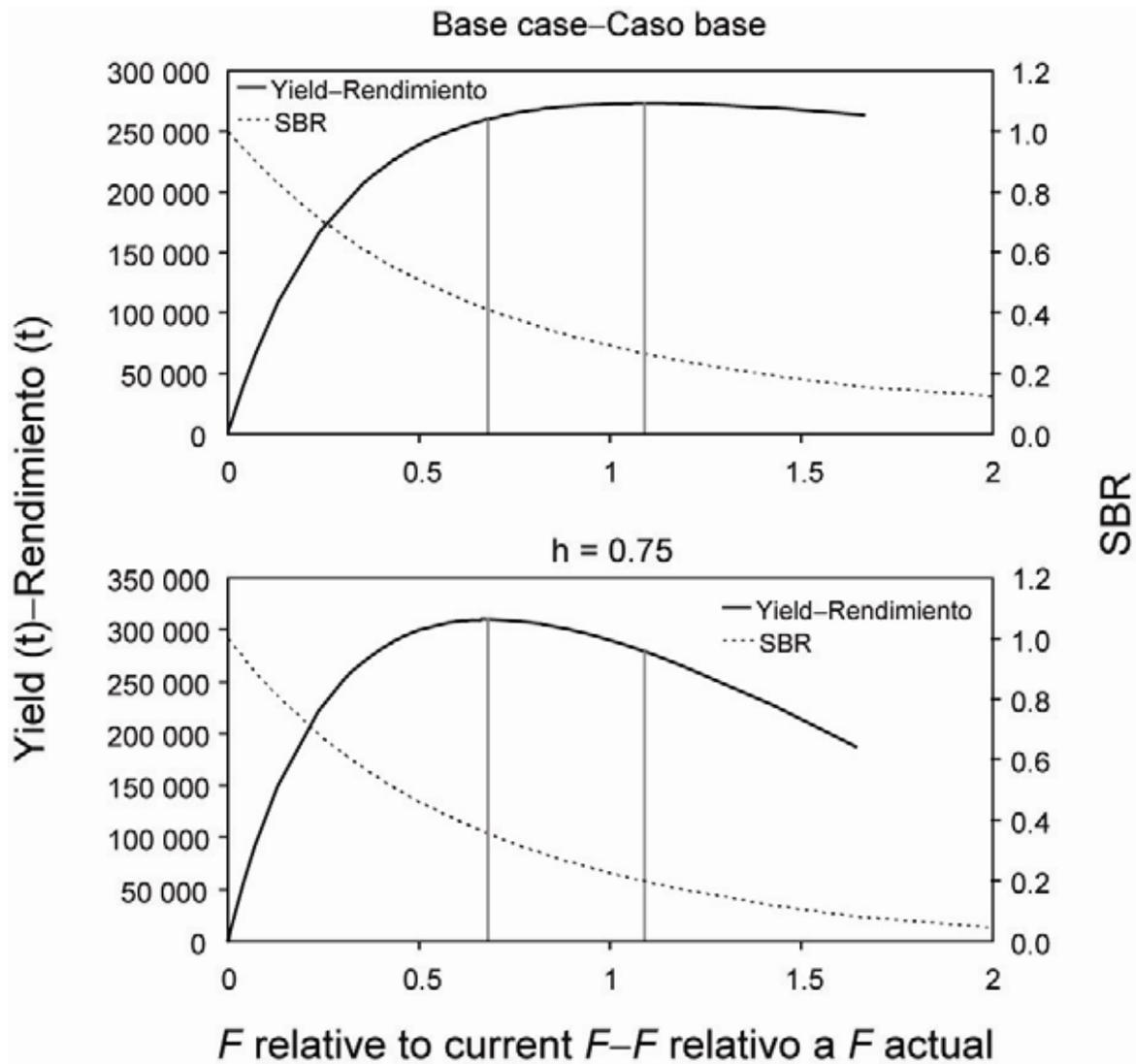
FIGURE 5.2. Yield and spawning biomass ratio (SBR) as a function of fishing mortality relative to the current fishing mortality. The vertical lines represent the fishing mortality corresponding to MSY for the base case and the sensitivity analysis that uses a stock-recruitment relationship (h = 0.75).

FIGURA 5.2. Rendimiento y cociente de biomasa reproductora (SBR) como función de la mortalidad por pesca relativa a la mortalidad por pesca actual. Las líneas verticales representan la mortalidad por pesca correspondiente al RMS del caso base y el análisis de sensibilidad que usa una relación población-reclutamiento (h = 0.75).
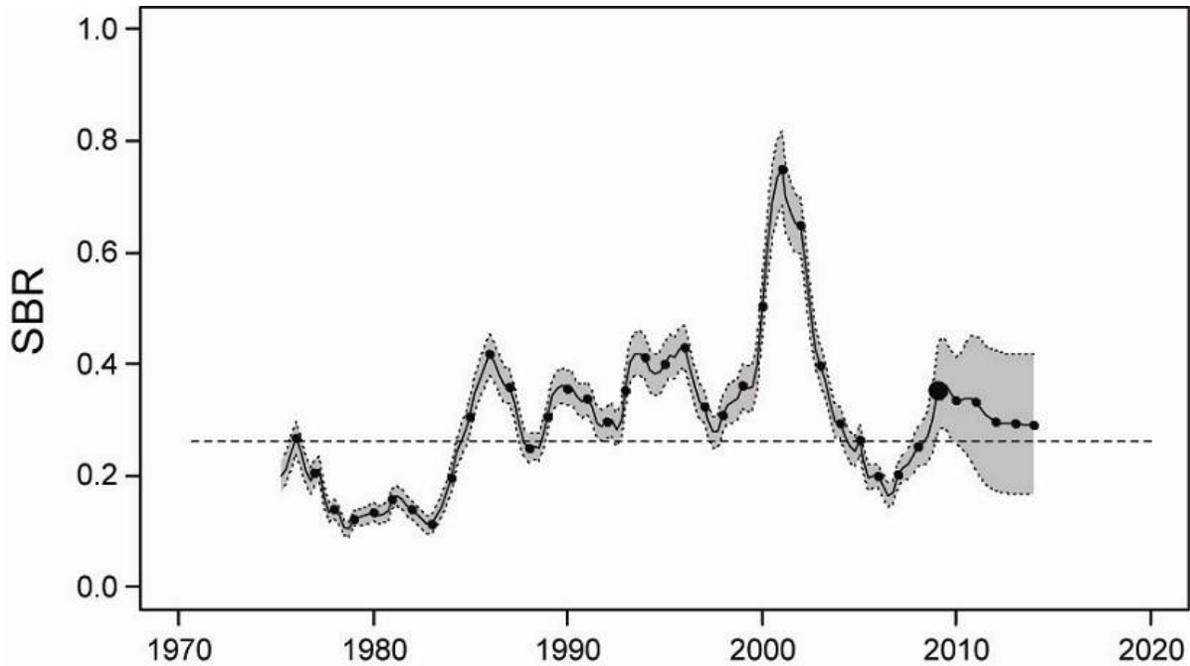
FIGURE 6.1. Spawning biomass ratios (SBRs) for 1975-2008 and SBRs projected during 2009-2012 for yellowfin tuna in the EPO. The dashed horizontal line identifies SBR$_{MSY}$ (Section 5.3), and the thin dashed lines represent the 95% confidence intervals of the estimates. The estimates after 2008 indicate the SBR predicted if the fishing mortality continues at the average of that observed during 2006-2008, and average environmental conditions occur during the next 5 years.

FIGURA 6.1. Cocientes be biomasa reproductora (SBR) de 1975-2008 y SBR proyectados durante 2009-2012 para el atún aleta amarilla en el OPO. La línea de trazos horizontal identifica el SBR$_{RMS}$ (Sección 5.3), y las líneas delgadas de trazos representan los intervalos de confianza de 95% de las estimaciones. Las estimaciones a partir de 2008 señalan el SBR predicho si la mortalidad por pesca continúa en el nivel medio observado durante 2006-2008 y con condiciones ambientales promedio en los 5 años próximos.
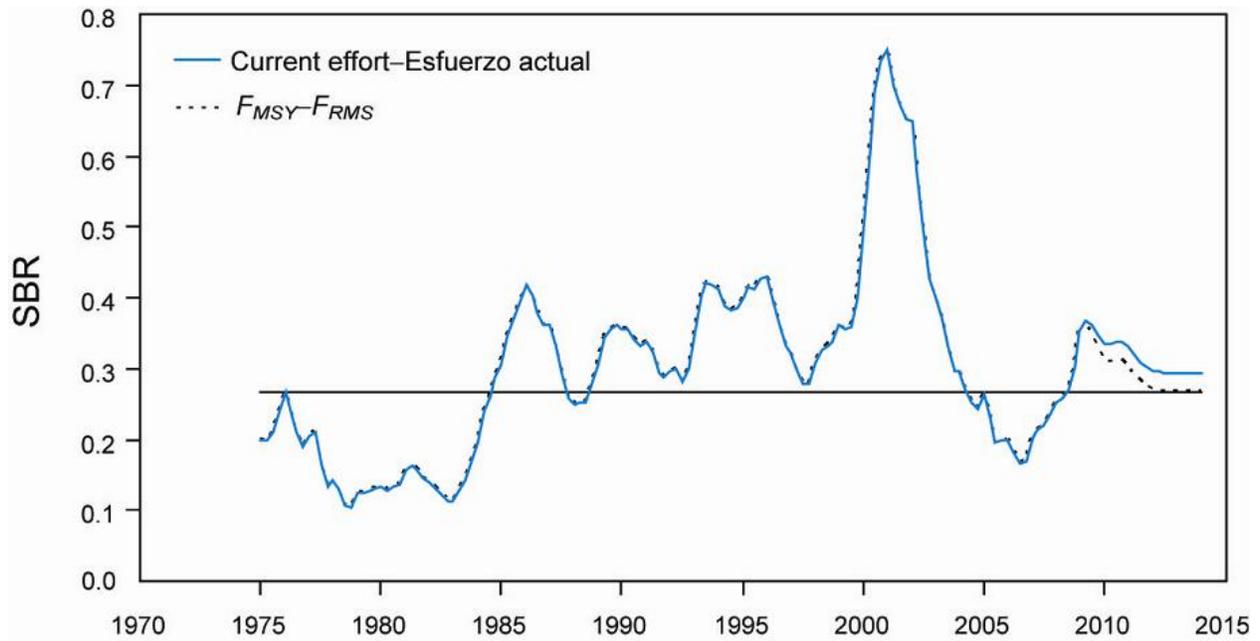
FIGURE 6.2. Spawning biomass ratios (SBRs) projected for yellowfin tuna in the EPO during 2009-2013 under current effort and under effort corresponding to MSY. The horizontal line (at 0.27) identifies SBR_{MSY} (Section 5.3).

FIGURA 6.2. Cocientes de biomasa reproductora (SBR) de atún aleta amarilla en el OPO proyectados durante 2009-2013, con el esfuerzo actual y con el esfuerzo correspondiente al RMS. La línea horizontal (en 0.27) identifica SBR_{RMS} (Sección 5.3).
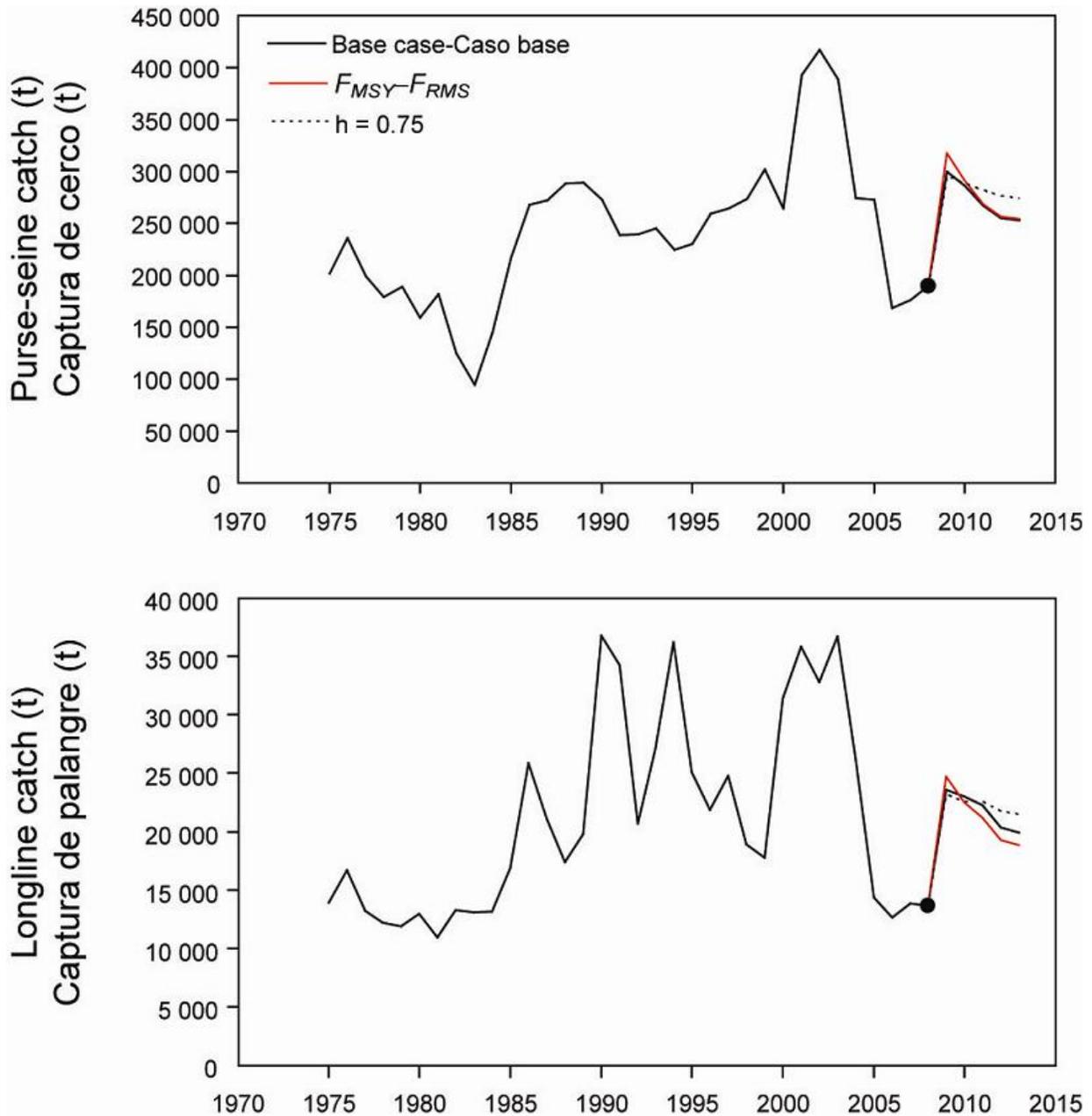
FIGURE 6.3. Historic and projected purse-seine and longline catch from the base case while fishing with the current effort, the base case while fishing at the fishing mortality corresponding to MSY (F_{MSY}), and the analysis of sensitivity to steepness of the stock-recruitment relationship while fishing with the current effort.

FIGURA 6.3. Capturas de cerco y de palangre históricas y proyectadas 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 de la relación población-reclutamiento al pescar con el esfuerzo actual.

TABLE 2.1. Fisheries defined by the IATTC staff for the stock assessment of yellowfin tuna in the EPO. PS = purse seine; LP = pole and line; LL = longline; OBJ = sets on floating objects; NOA = sets on unassociated fish; DEL = sets on dolphin-associated schools. The sampling areas are shown in Figure 3.1, and descriptions of the discards are provided in Section 2.2.2.

TABLA 2.1. Pesquerías definidas por el personal de la CIAT 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 3.1 se ilustran las zonas de muestreo, y en la Sección 2.2.2 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	1975-2008	11-12	retained catch + discards from inefficiencies in fishing process–captura retenida + descartes por ineficacias en el proceso de pesca
2	PS	OBJ	1975-2008	7, 9	
3	PS	OBJ	1975-2008	5-6, 13	
4	PS	OBJ	1975-2008	1-4, 8, 10	
5	PS	NOA	1975-2008	1-4, 8, 10	retained catch + discards– captura retenida + descartes
6	PS	NOA	1975-2008	5-7, 9, 11-13	
7	PS	DEL	1975-2008	2-3, 10	
8	PS	DEL	1975-2008	1, 4-6, 8, 13	
9	PS	DEL	1975-2008	7, 9, 11-12	
10	LP		1975-2008	1-13	retained catch only— captura retenida solamente
11	LL		1975-2008	N of-de 15°N	
12	LL		1975-2008	S of-de 15°N	
13	PS	OBJ	1993-2008	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	1993-2008	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	1993-2008	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	1993-2008	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 4.1. Estimated total annual recruitment to the fishery at the time of spawning (thousands of fish), biomass (metric tons present at the beginning of the year), and spawning biomass ratio of yellowfin tuna in the EPO. Biomass is defined as the total weight of yellowfin aged three quarters or more.

TABLA 4.1. Reclutamiento anual total estimado a la pesquería en el momento de desove (en miles de peces), biomasa (toneladas métricas presentes al principio de año), y cociente de biomasa reproductora del atún aleta amarilla en el OPO. Se define la biomasa como el peso total de aleta amarilla de tres trimestres o más de edad.

Year / Año	Total recruitment / Reclutamiento total	Biomass of 3 quarters+ fish / Biomasa de peces de edad 3 trimestres+	Spawning biomass ratio / Cociente de biomasa reproductora
1975	423,716	306,339	0.20
1976	275,836	328,007	0.27
1977	583,883	258,056	0.21
1978	521,449	235,997	0.14
1979	394,501	223,592	0.12
1980	350,406	223,863	0.13
1981	360,883	234,530	0.16
1982	502,414	188,496	0.14
1983	710,449	204,902	0.11
1984	622,977	329,014	0.20
1985	598,360	450,740	0.30
1986	607,576	478,177	0.42
1987	863,006	419,395	0.36
1988	738,223	423,740	0.25
1989	613,806	457,885	0.30
1990	588,962	454,097	0.36
1991	700,743	416,701	0.34
1992	675,556	444,071	0.30
1993	749,233	480,754	0.35
1994	581,684	499,617	0.41
1995	628,460	499,562	0.40
1996	774,611	489,512	0.43
1997	766,539	455,281	0.32
1998	1,281,864	448,045	0.31
1999	1,077,337	591,379	0.36
2000	611,490	701,257	0.50
2001	876,235	831,944	0.75
2002	709,457	725,815	0.65
2003	568,787	541,361	0.40
2004	391,430	395,293	0.29
2005	549,603	345,452	0.26
2006	577,594	280,609	0.20
2007	702,257	298,197	0.20
2008	819,789	383,904	0.25
2009		474,308	0.35

TABLE 4.2. Estimates of the average sizes of yellowfin tuna. The ages are expressed in quarters after hatching.

TABLA 4.2. Estimaciones del tamaño medio de atún aleta amarilla. Se expresan las edades en trimestres desde la cría.

Age (quarters) Edad (trimestres)	Average length (cm) Talla media (cm)	Average weight (kg) Peso medio (kg)	Age (quarters) Edad (trimestres)	Average length (cm) Talla media (cm)	Average weight (kg) Peso medio (kg)
1	26.42	0.35	16	154.31	81.12
2	33.04	0.70	17	159.16	89.20
3	40.64	1.32	18	163.33	96.52
4	49.17	2.38	19	166.91	103.00
5	58.48	4.06	20	169.95	108.63
6	68.38	6.58	21	172.52	113.45
7	78.66	10.14	22	174.69	117.51
8	89.05	14.87	23	176.51	120.91
9	99.31	20.82	24	178.04	123.73
10	109.22	27.92	25	179.31	126.07
11	118.59	36.00	26	180.37	128.00
12	127.30	44.80	27	181.26	129.58
13	135.24	54.00	28	181.99	130.89
14	142.39	63.31	29	182.60	131.97
15	148.74	72.43			

TABLE 5.1. MSY and related quantities for the base case and the stock-recruitment relationship sensitivity analysis, based on average fishing mortality (F) for 2006-2008. The quantities are also given based on average F for 2006-2007. B_{recent} and B_{MSY} are defined as the biomass of fish 3+ quarters old at the start of the first quarter of 2009 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 2008.

TABLA 5.1. RMS y cantidades relacionadas para el caso base y los análisis de sensibilidad a la relación población-reclutamiento, basados en la mortalidad por pesca (F) media de 2006-2008. Se presentan también las cantidades basadas en la F media de 2006-2007. Se definen B_{recent} y B_{RMS} como la biomasa de peces de 3+ trimestres de edad al principio del primer trimestre de 2009 y en RMS, respectivamente, y S_{recent} y S_{RMS} como índices de biomasa reproductora (por lo tanto, no se expresan en toneladas métricas). C_{recent} es la captura total estimada de 2008.

	Base case Caso base	h = 0.75	Average F F promedio 2006-2007	All data Todos los datos	Natural mortality Mortalidad natural	Selectivity Selectividad	Growth Crecimiento
MSY–RMS	273,159	310,073	274,944	269,296	327,475	267,222	274,688
$B_{MSY}-B_{RMS}$	372,909	594,909	373,750	376,590	395,803	434,769	368,475
$S_{MSY}-S_{RMS}$	3,522	6,436	3,523	3,626	3,259	4,764	3,163
C_{recent}/MSY—C_{recent}/RMS	0.75	0.66	0.74	0.76	0.62	0.76	0.74
$B_{recent}/B_{MSY}-B_{recent}/B_{RMS}$	1.27	0.78	1.27	1.12	1.9	0.81	1.5
$S_{recent}/S_{MSY}-S_{recent}/S_{RMS}$	1.32	0.71	1.32	1.16	2.56	0.81	1.66
$S_{MSY}/S_{F=0}-S_{RMS}/S_{F=0}$	0.27	0.36	0.27	0.28	0.2	0.38	0.24
F multiplier—Multiplicador de F	1.09	0.68	1.00	1.06	2.27	0.68	1.39

TABLE 5.2a. Estimates of the MSY and its associated quantities, obtained by assuming that each fishery is the only fishery operating in the EPO and that each fishery maintains its current pattern of age-specific selectivity (Figure 4.4). The estimates of the MSY and B_{MSY} are expressed in metric tons. OBJ = sets on floating objects; NOA = sets on unassociated fish; DEL = sets on dolphin-associated fish; LL = longline.
TABLA 5.2a. Estimaciones del RMS y sus cantidades asociadas, obtenidas suponiendo que cada pesquería es la única que opera en el OPO y que cada pesquería mantiene su patrón actual de selectividad por edad (Figura 4.4). Se expresan las estimaciones de RMS y B_{RMS} en toneladas métricas. OBJ = lances sobre objetos flotantes; NOA = lances sobre atunes no asociados; DEL = lances sobre atunes asociados con delfines; LL = palangre.

Fishery / Pesquería	MSY / RMS	B_{MSY} / B_{RMS}	S_{MSY} / S_{RMS}	$B_{MSY}/B_{F=0}$ / $B_{RMS}/B_{F=0}$	$S_{MSY}/S_{F=0}$ / $S_{RMS}/S_{F=0}$	F multiplier / Multiplicador de F
All—Todas	273,159	372,909	3,522	0.32	0.27	1.09
OBJ	170,566	222,646	1,783	0.19	0.13	9.21
NOA	233,398	312,460	2,653	0.27	0.2	4.98
DEL	319,183	378,976	3,304	0.32	0.25	2.52
LL	421,316	391,291	3,205	0.33	0.24	57.63

Appendices—Anexos

APPENDIX A: SENSITIVITY ANALYSIS FOR THE STOCK-RECRUITMENT RELATIONSHIP
ANEXO A: ANÁLISIS DE SENSIBILIDAD A LA RELACIÓN POBLACIÓN-RECLUTAMIENTO
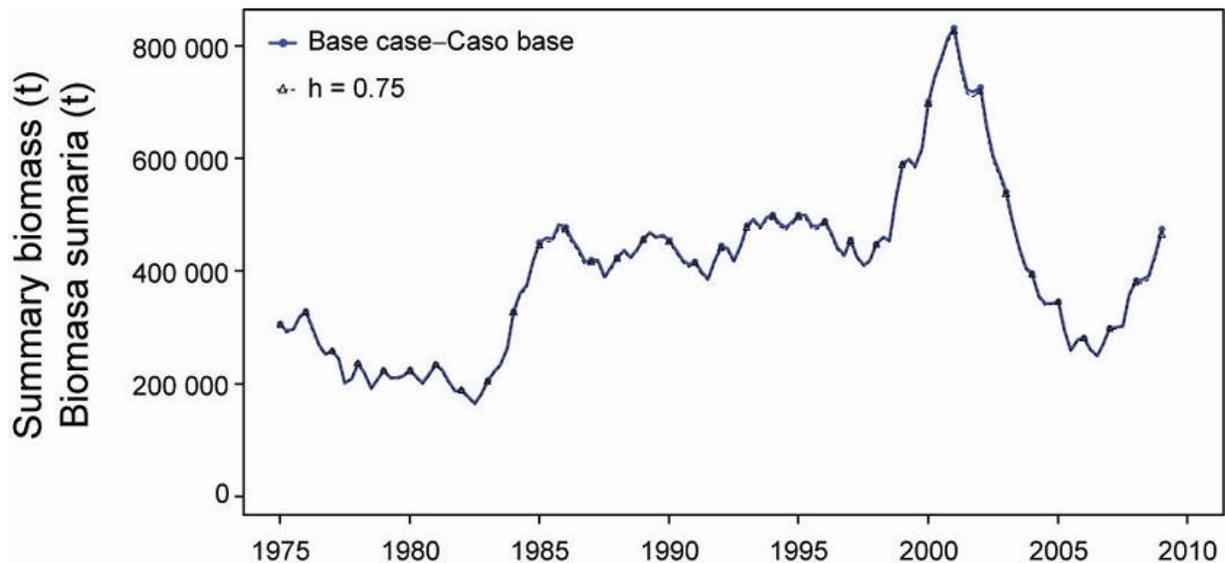
FIGURE A.1. Comparison of the estimates of biomass of yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).
FIGURA A.1. Comparación de las estimaciones de la biomasa de atún aleta amarilla del análisis sin relación población-reclutamiento (caso base) y con relación población-reclutamiento (inclinación = 0,75).
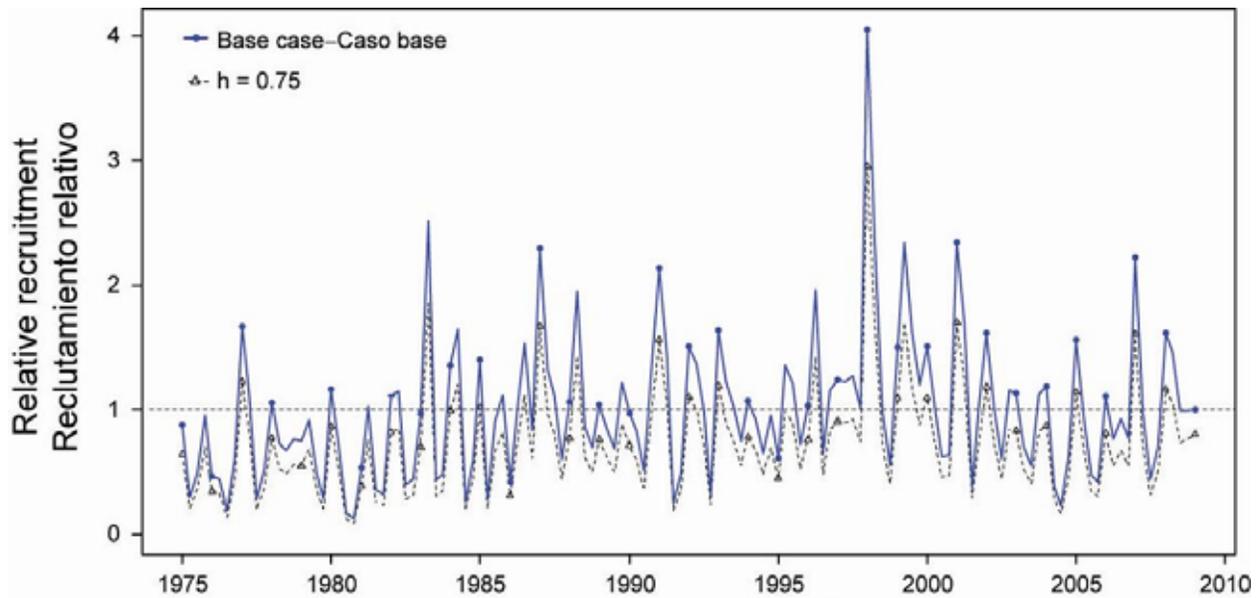
FIGURE A.2. Comparison of estimates of recruitment of yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).
FIGURA A.2. Comparación de las estimaciones de reclutamiento de atún aleta amarilla del análisis sin relación población-reclutamiento (caso base) y con relación población-reclutamiento (inclinación = 0,75).
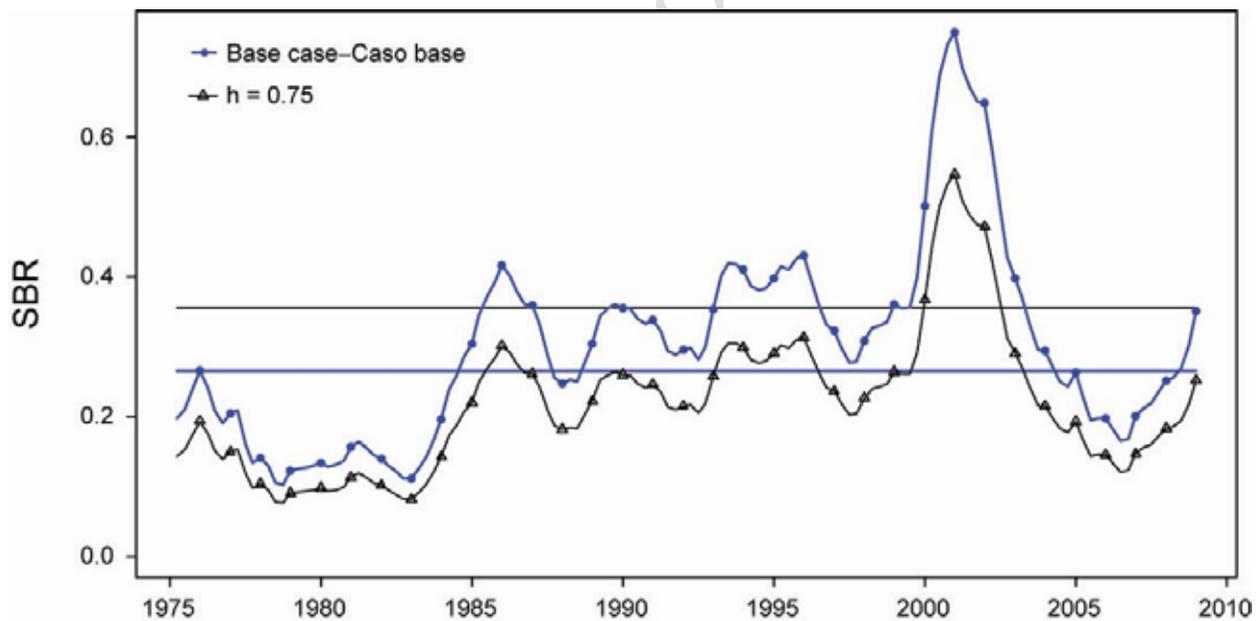
FIGURE A.3a. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). The horizontal lines represent the SBRs associated with MSY for the two scenarios.
FIGURA A.3a. 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 el SBR asociado con el RMS para los dos escenarios.
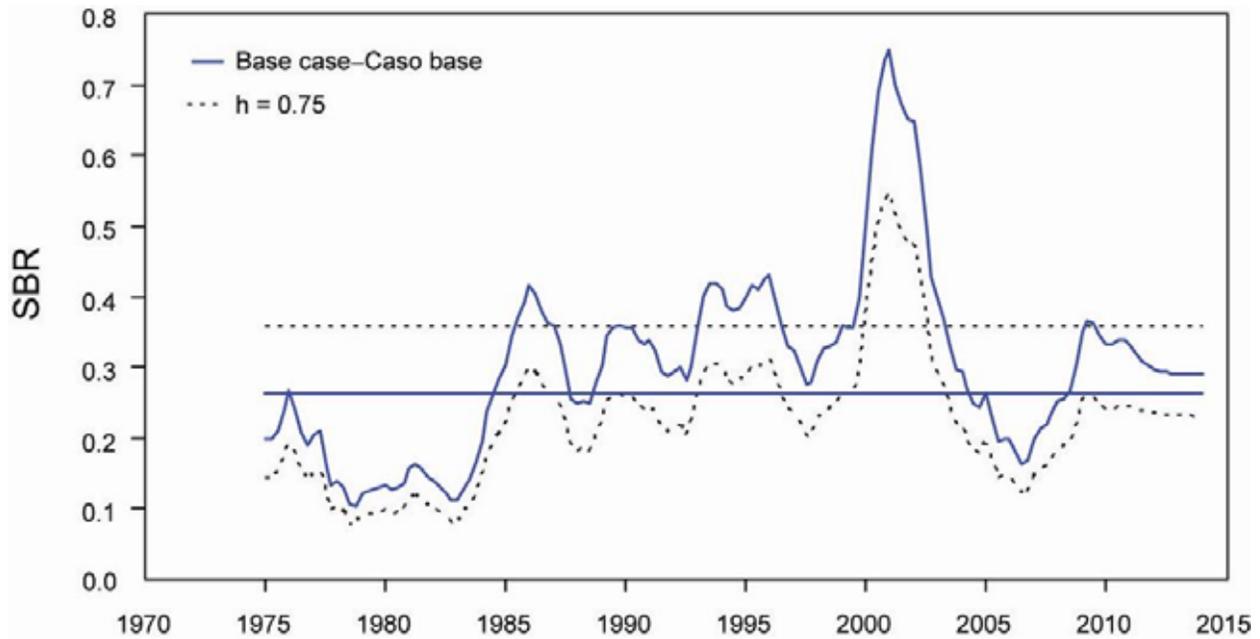
FIGURE A.3b. Comparison of estimates of the spawning biomass ratios (SBRs) projected during 2009-2013 for yellowfin tuna from the analysis without (base case) and with (steepness = 0.75) a stock-recruitment relationship. The horizontal lines represent the SBRs associated with MSY for the two scenarios.

FIGURA A.3b. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún aleta amarilla durante 2008-2013 del análisis sin (caso base) y con (inclinación = 0,75) una relación población-reclutamiento. Las líneas horizontales representan el SBR asociado con el RMS para los dos escenarios.
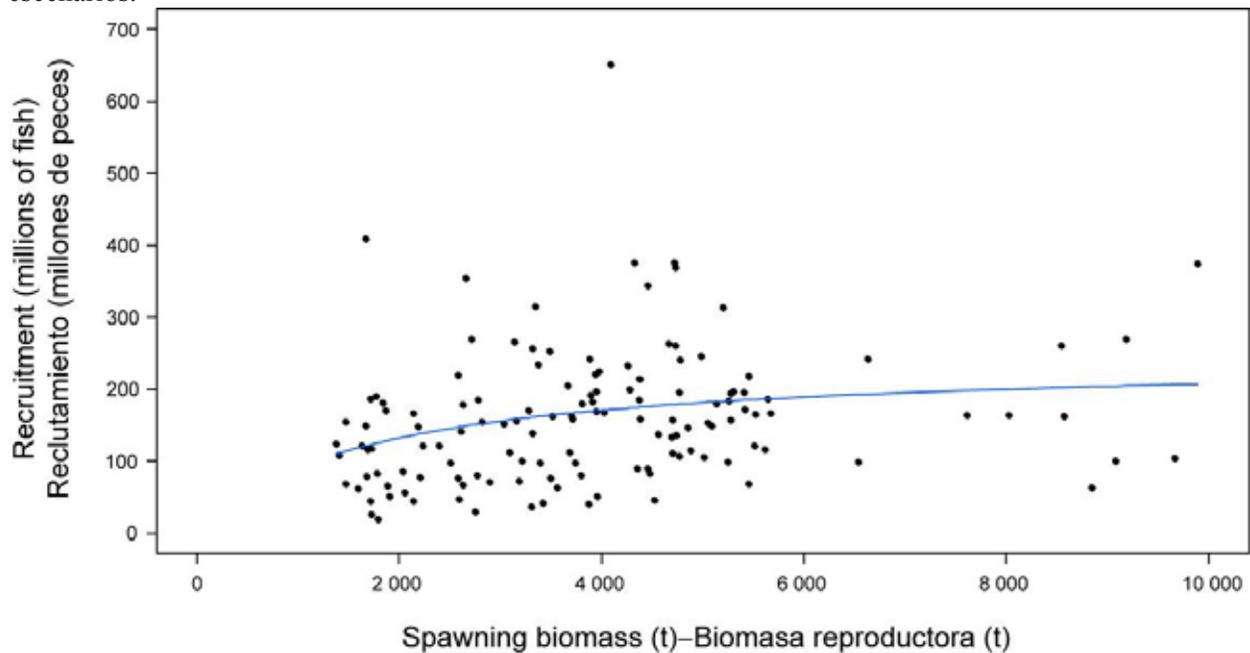
FIGURE A.5. Recruitment plotted against spawning biomass of yellowfin tuna when the analysis has a stock-recruitment relationship (steepness = 0.75).

FIGURA A.5. Reclutamiento graficado contra biomasa reproductora de atún aleta amarilla cuando el análisis incluye una relación población-reclutamiento (inclinación = 0,75).

APPENDIX B: SENSITIVITY ANALYSIS FOR ALL DATA
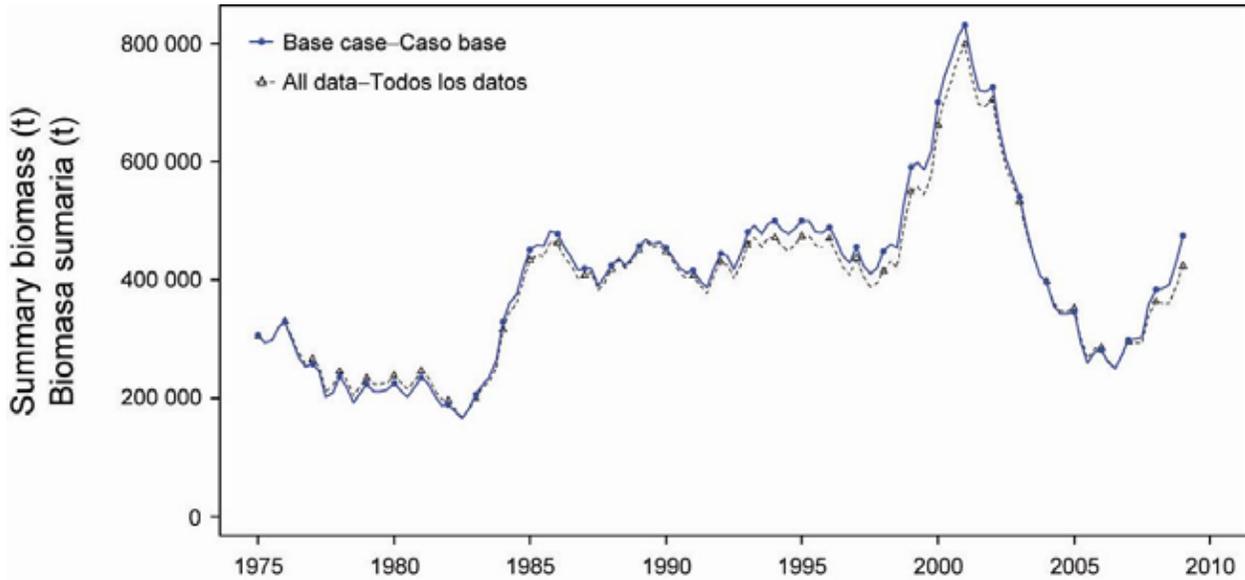
**FIGURE B.1.** Comparison of the estimates of biomass of yellowfin tuna from the base case with the sensitivity analysis that includes all the data.
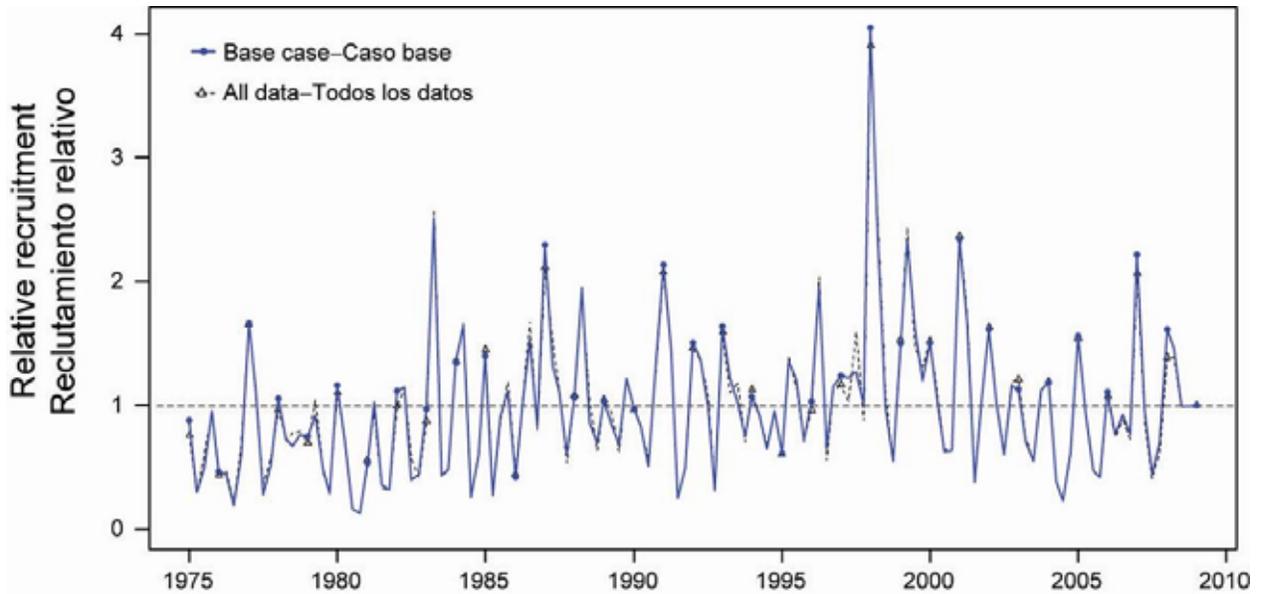
**FIGURE B.2.** Comparison of estimates of recruitment of yellowfin tuna from the base case with the sensitivity analysis that includes all the data.
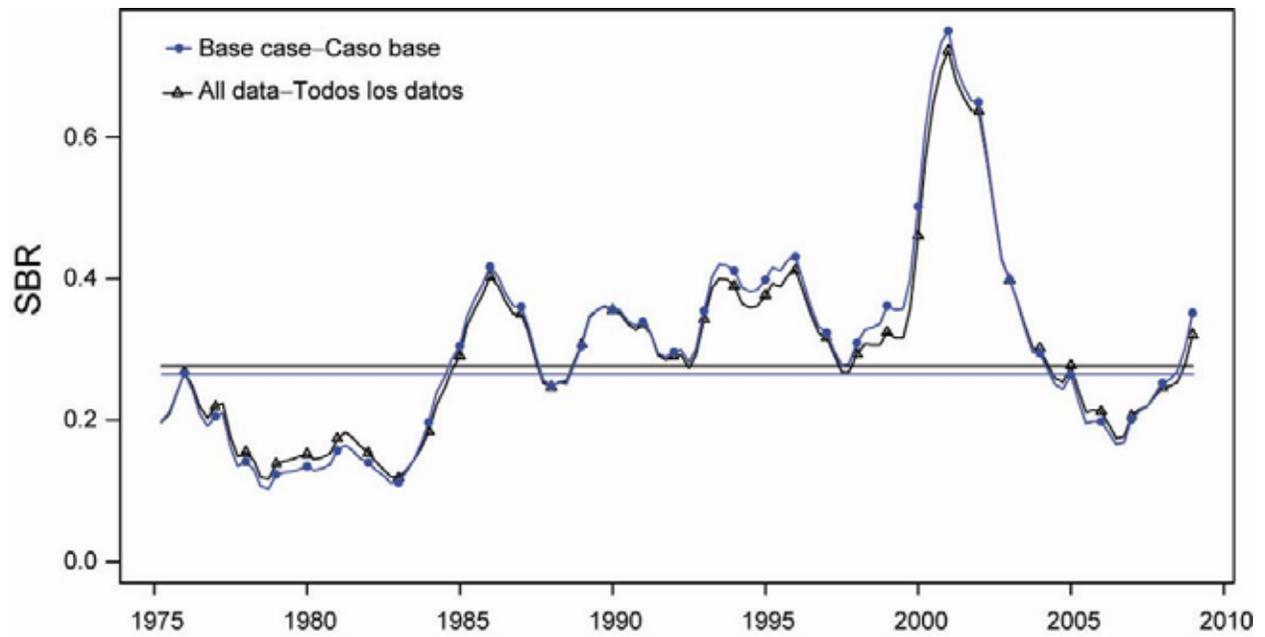
FIGURE B.3a. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the base case with the sensitivity analysis that includes all the data. The horizontal lines represent the SBRs associated with MSY for the two scenarios.
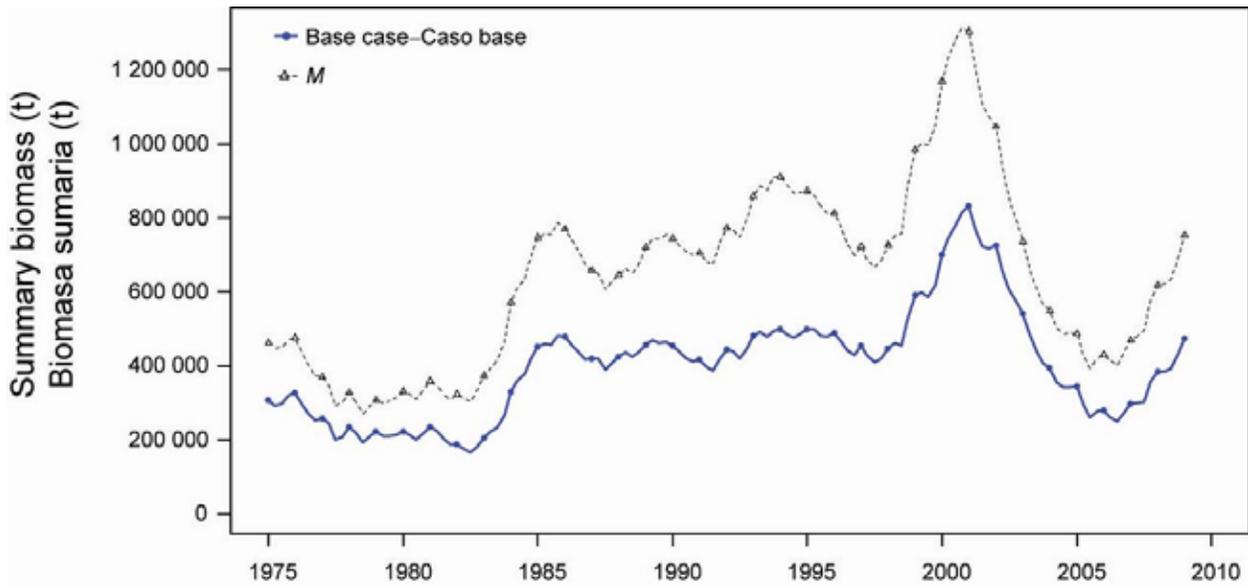
FIGURE C.1. Comparison of the estimates of biomass of yellowfin tuna from the base case with the sensitivity analysis that estimates natural mortality for adult females and males.
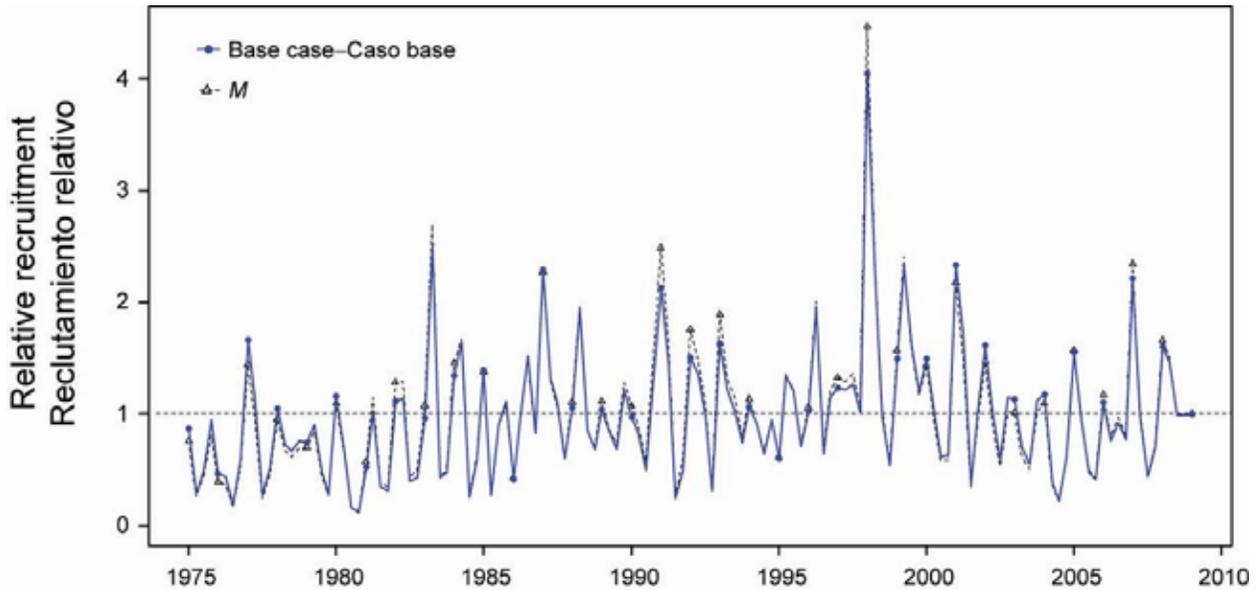

FIGURE C.2. Comparison of estimates of recruitment of yellowfin tuna from the base case with the sensitivity analysis that estimates natural mortality for adult females and males.
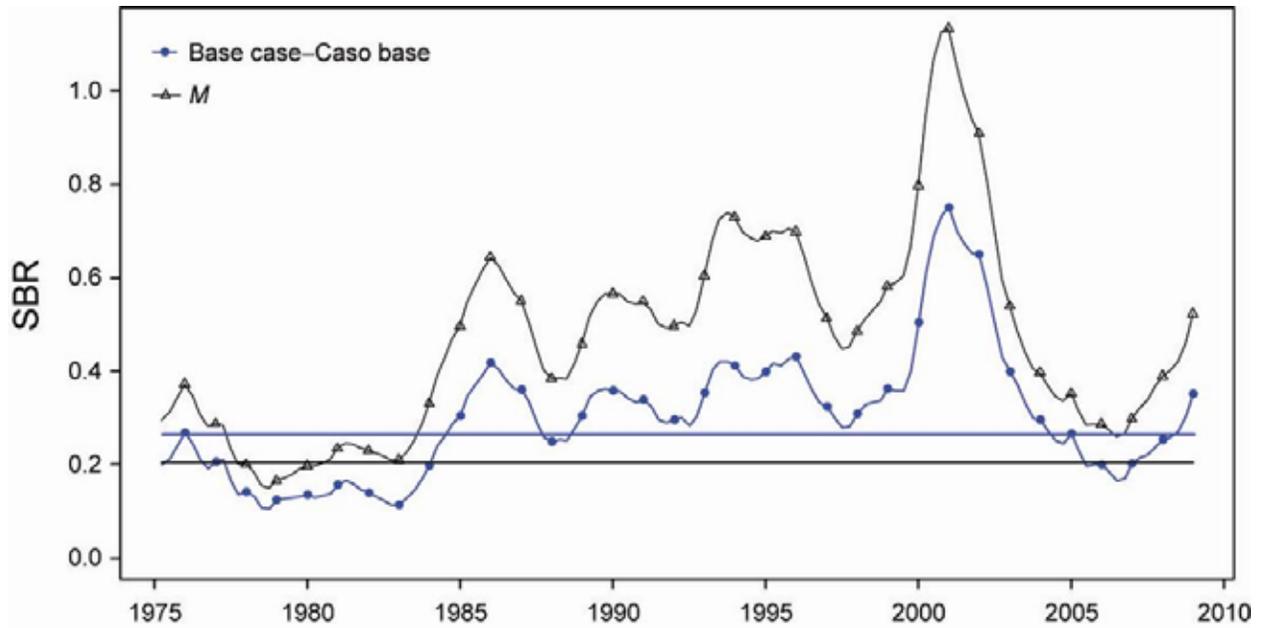
FIGURE C.3. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the base case with the sensitivity analysis that estimates natural mortality for adult females and males. The horizontal lines represent the SBRs associated with MSY for the two scenarios.

FIGURE C.4. Estimated natural mortality for females and males from the sensitivity analysis that estimates natural mortality.
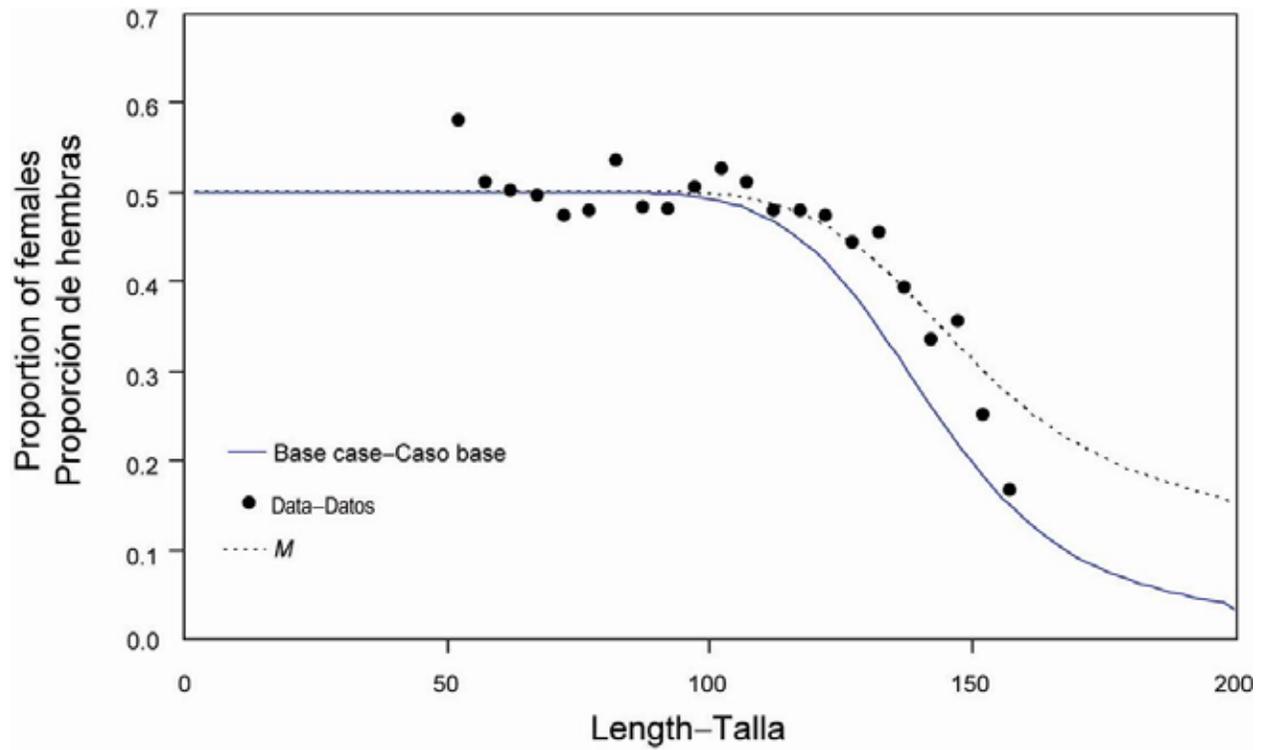
FIGURE C.5. Fit to the sex ratio information for the base case and the sensitivity analysis that estimates natural mortality.

APPENDIX D: SENSITIVITY ANALYSIS FOR SELECTIVITY
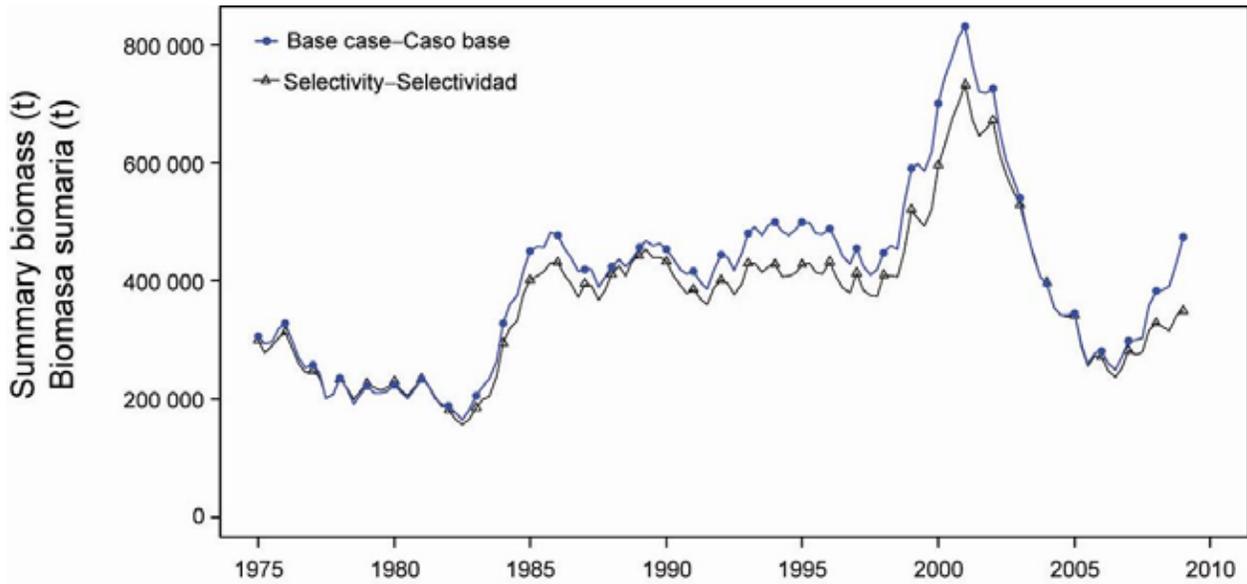
FIGURE D.1. Comparison of the estimates of biomass of yellowfin tuna from the base case with the sensitivity analysis that estimates age specific selectivity.
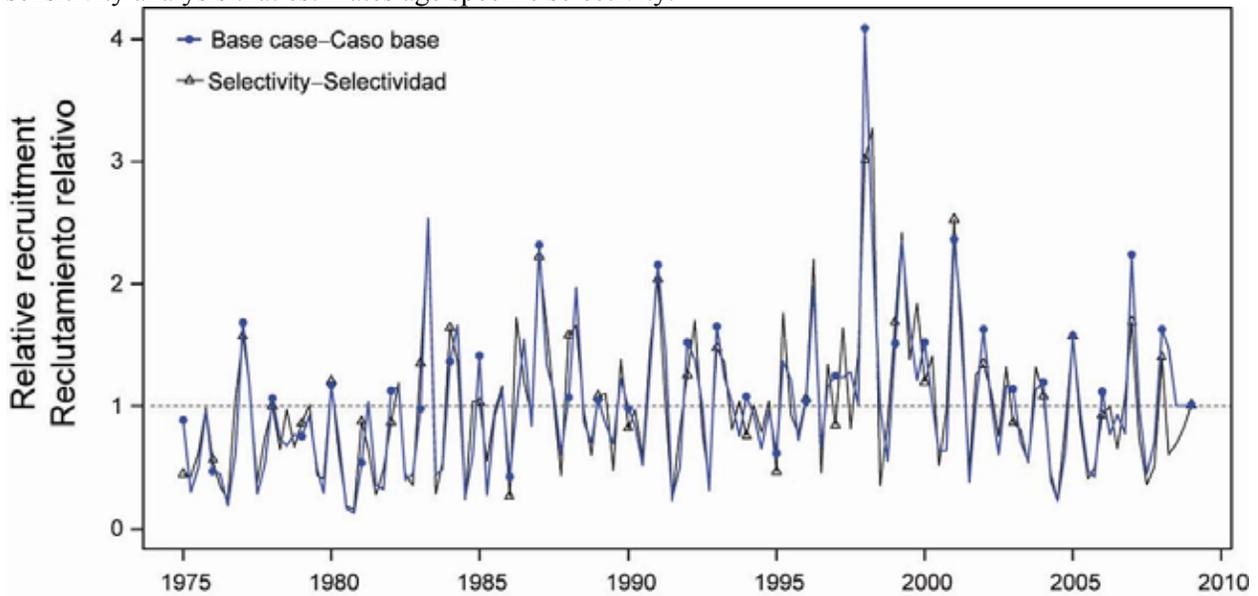
FIGURE D.2. Comparison of estimates of recruitment of yellowfin tuna from the base case with the sensitivity analysis that estimates age specific selectivity.
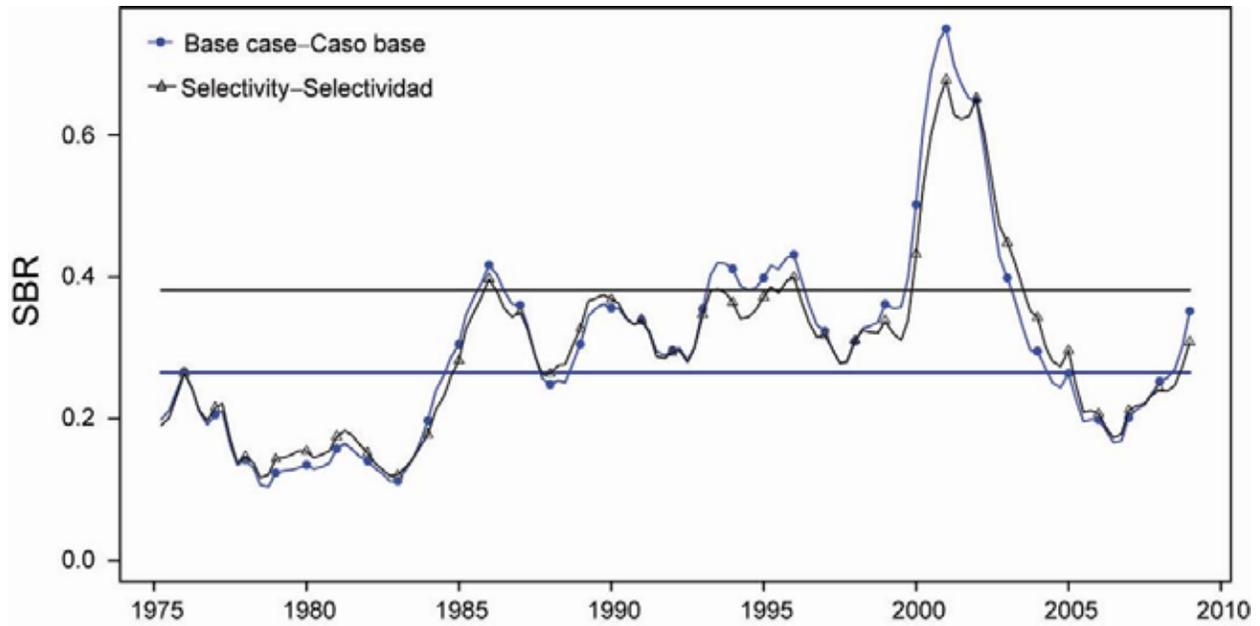
FIGURE D.3. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the base case with the sensitivity analysis that estimates age specific selectivity. The horizontal lines represent the SBRs associated with MSY for the two scenarios.
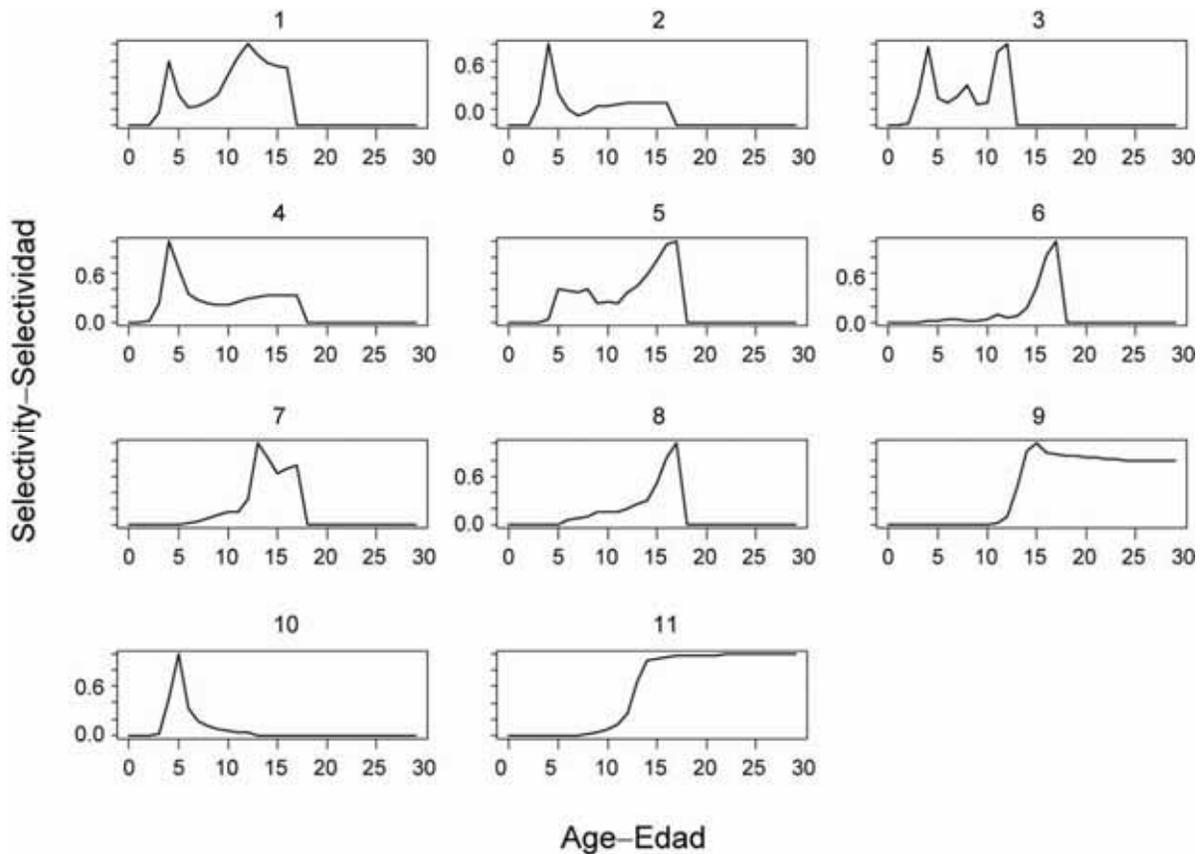

FIGURE D.4. Estimated age-specific selectivity curves for the sensitivity analysis that estimates selectivity.

APPENDIX E: SENSITIVITY ANALYSIS FOR GROWTH
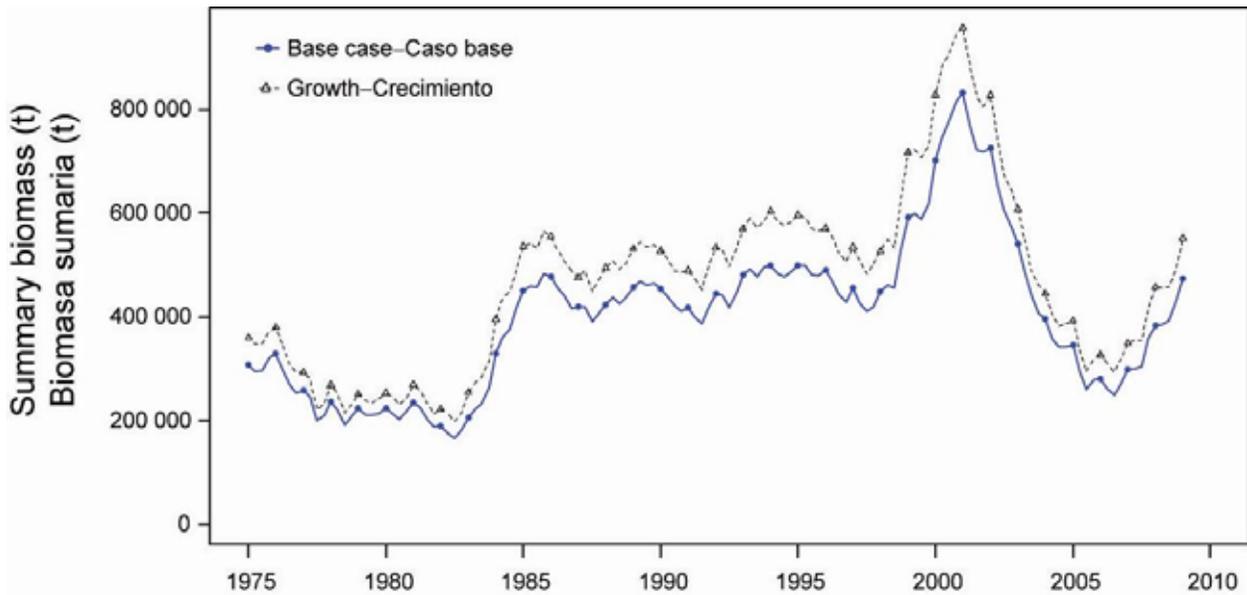
FIGURE E.1. Comparison of the estimates of biomass of yellowfin tuna from the base case with the sensitivity analysis that fixes the length at the maximum age at 175 cm and estimates the remaining parameters of the Richards growth equation.
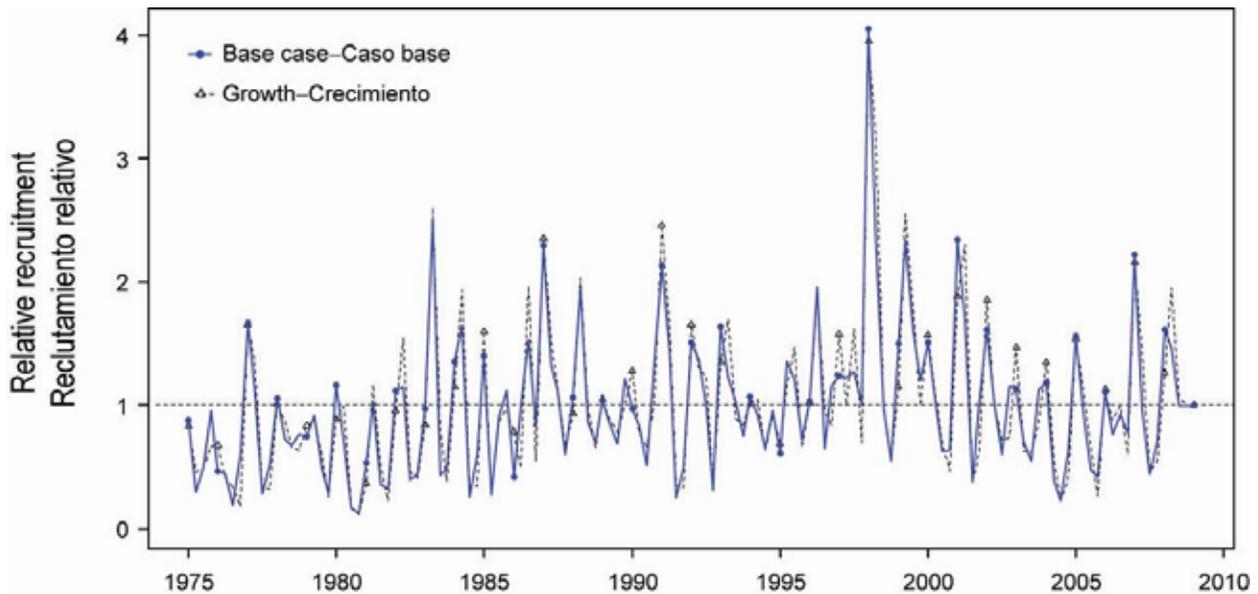

FIGURE E.2. Comparison of estimates of recruitment of yellowfin tuna from the base case with the sensitivity analysis that fixes the length at the maximum age at 175 cm and estimates the remaining parameters of the Richards growth equation.
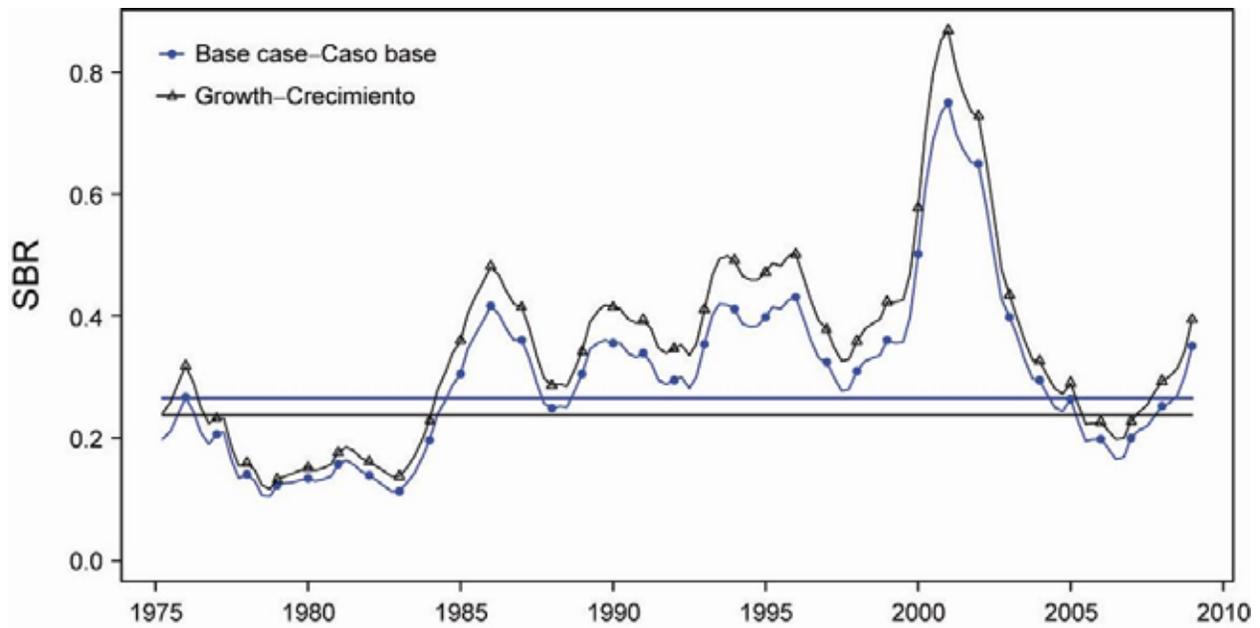
FIGURE E.3. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the base case with the sensitivity analysis that fixes the length at the maximum age at 175 cm and estimates the remaining parameters of the Richards growth equation. The horizontal lines represent the SBRs associated with MSY for the two scenarios.
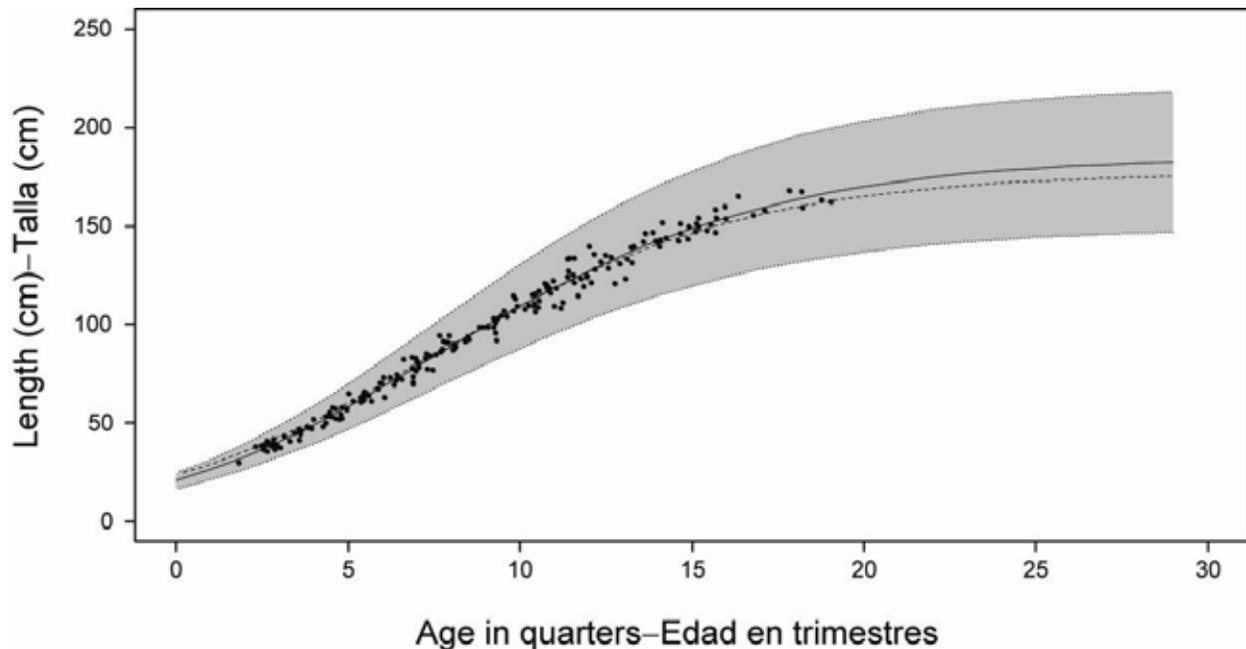

FIGURE E.4. Fit to the otolith age-at-length data for the base case and the sensitivity analysis that fixes the length at the maximum age at 175 cm.

APPENDIX F: SENSITIVITY ANALYSIS FOR EXCLUSION OF FLOATING-OBJECT SIZE COMPOSITION DATA
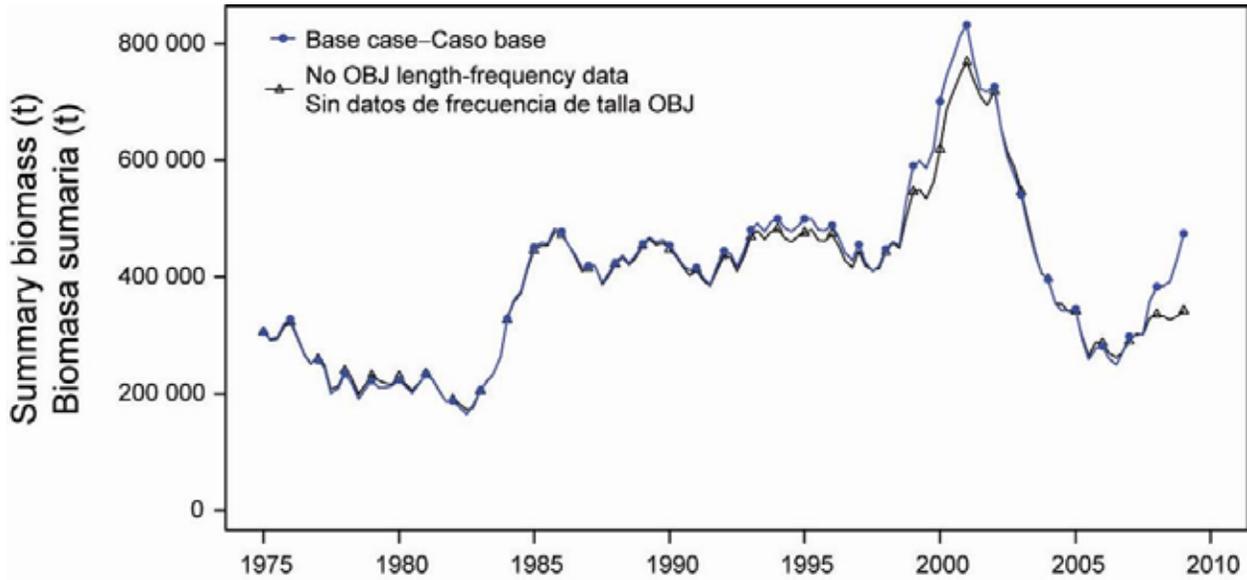

FIGURE F.1. Comparison of the estimates of biomass of yellowfin tuna from the base case with the sensitivity analysis that excludes the floating-object size composition data.
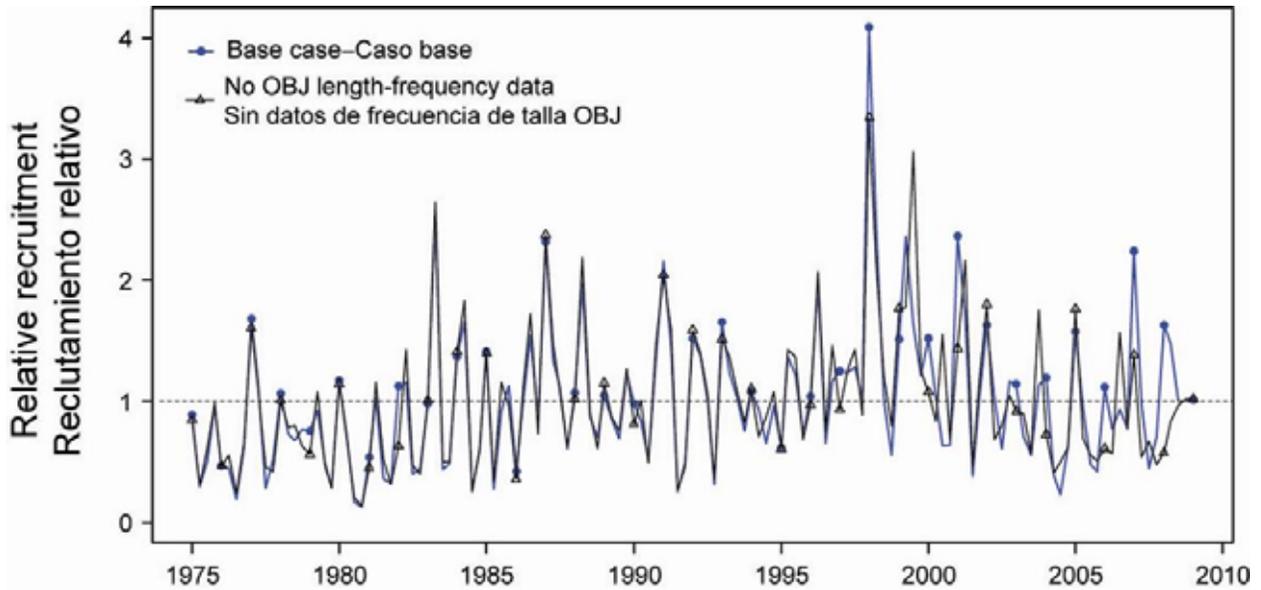

FIGURE F.2. Comparison of estimates of recruitment of yellowfin tuna from the base case with the sensitivity analysis that excludes the floating-object size composition data.
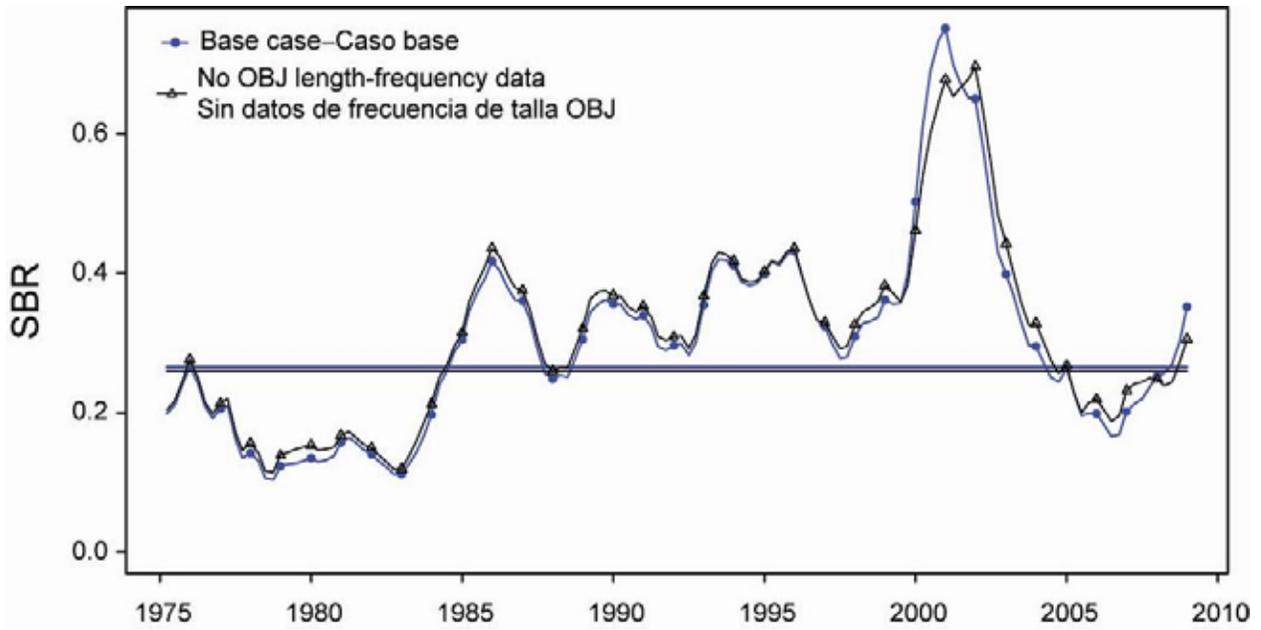
FIGURE F.3. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the base case with the sensitivity analysis that that excludes the floating-object size composition data. The horizontal lines represent the SBRs associated with MSY for the two scenarios.
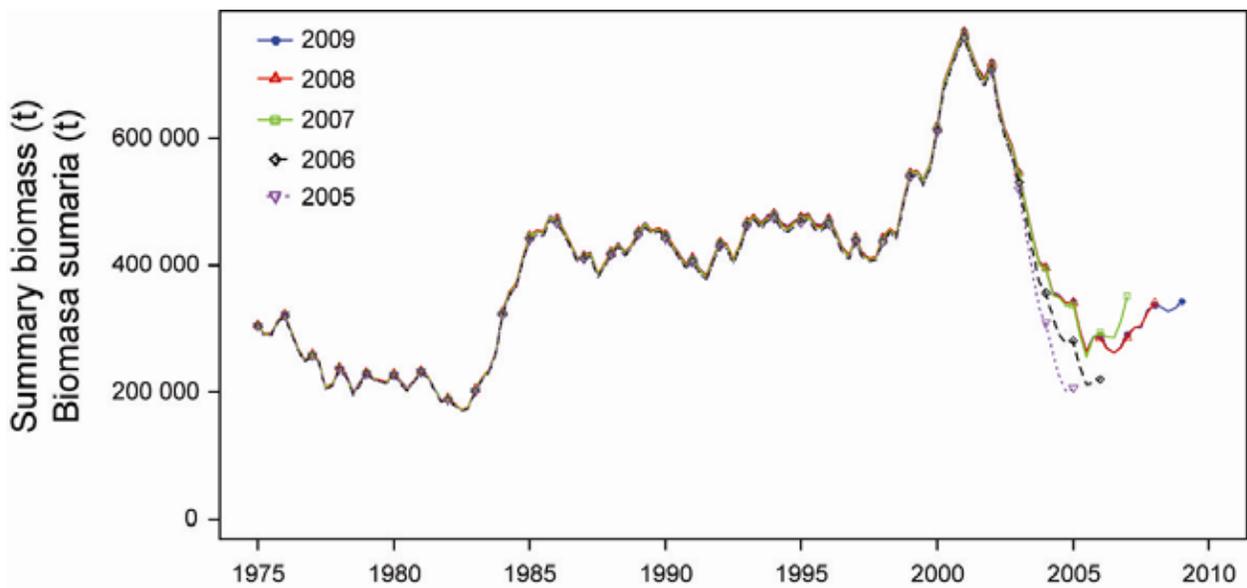
FIGURE F.4. Retrospective analysis of biomass from the sensitivity analysis that excludes the floating-object size composition data.
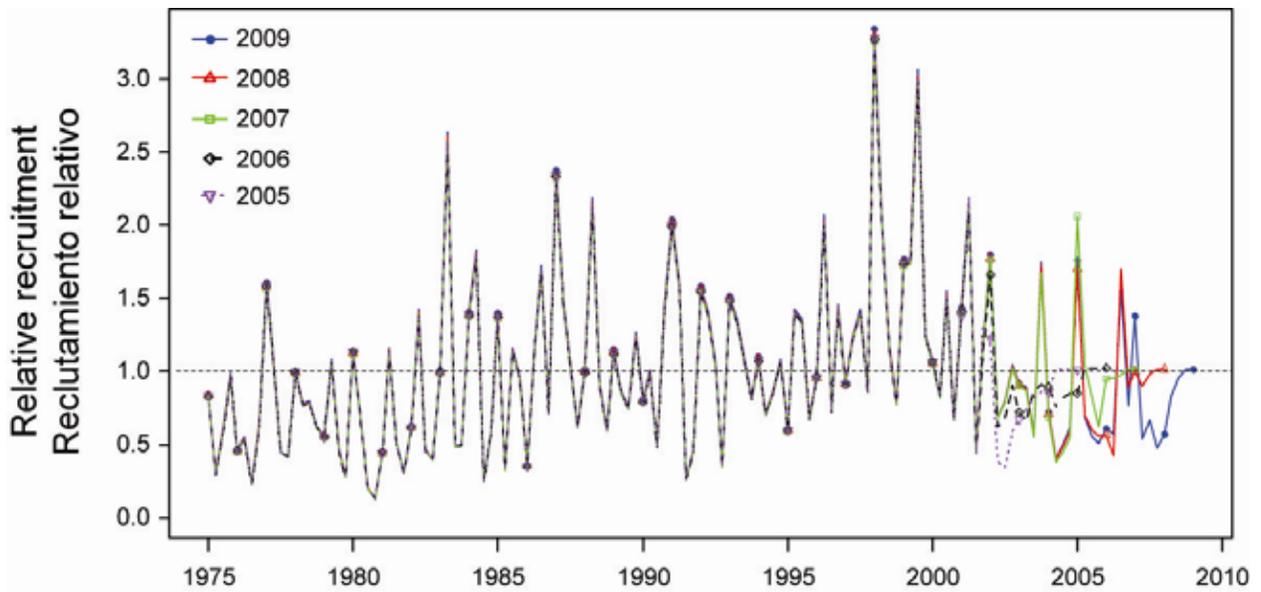
FIGURE F.5. Retrospective analysis of recruitment from the sensitivity analysis that excludes the floating-object size composition data.
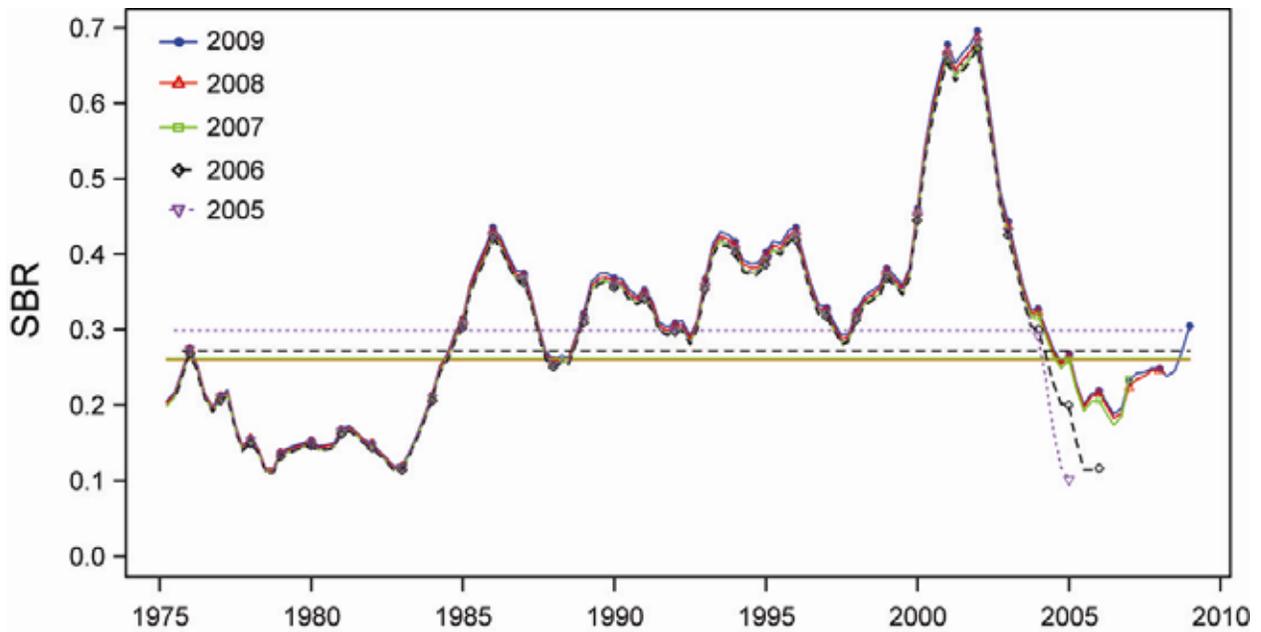
FIGURE F.6. Retrospective analysis of spawning biomass ratio from the sensitivity analysis that excludes the floating-object size composition data.
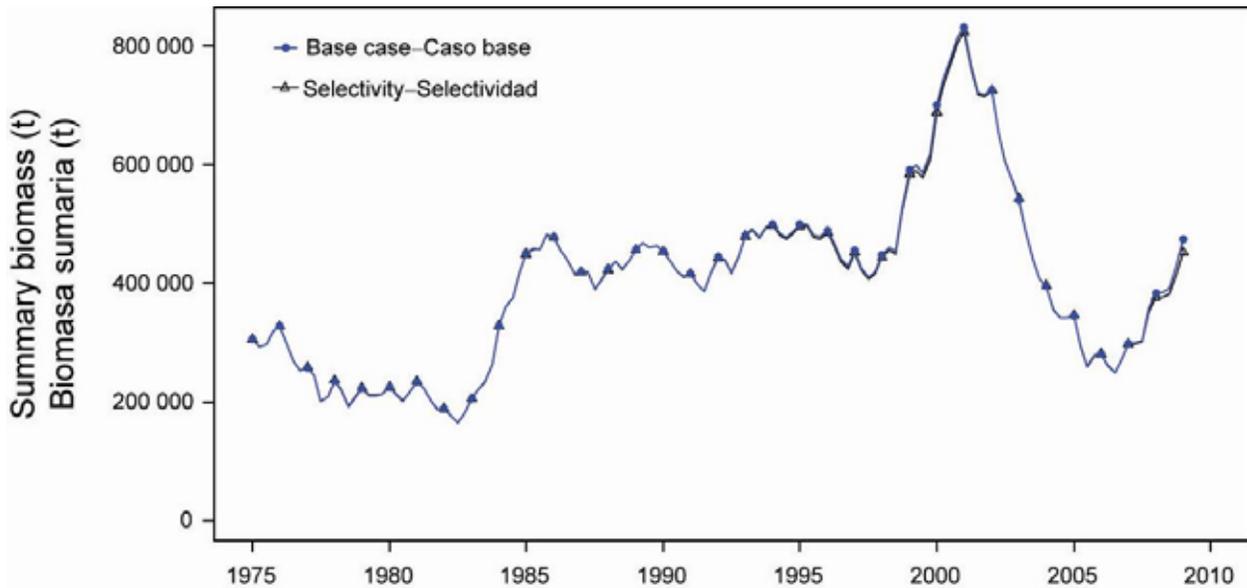
FIGURE G.1. Comparison of the estimates of biomass of yellowfin tuna from the base case with the sensitivity analysis that has a change in selectivivity for the floating-object fisheries.
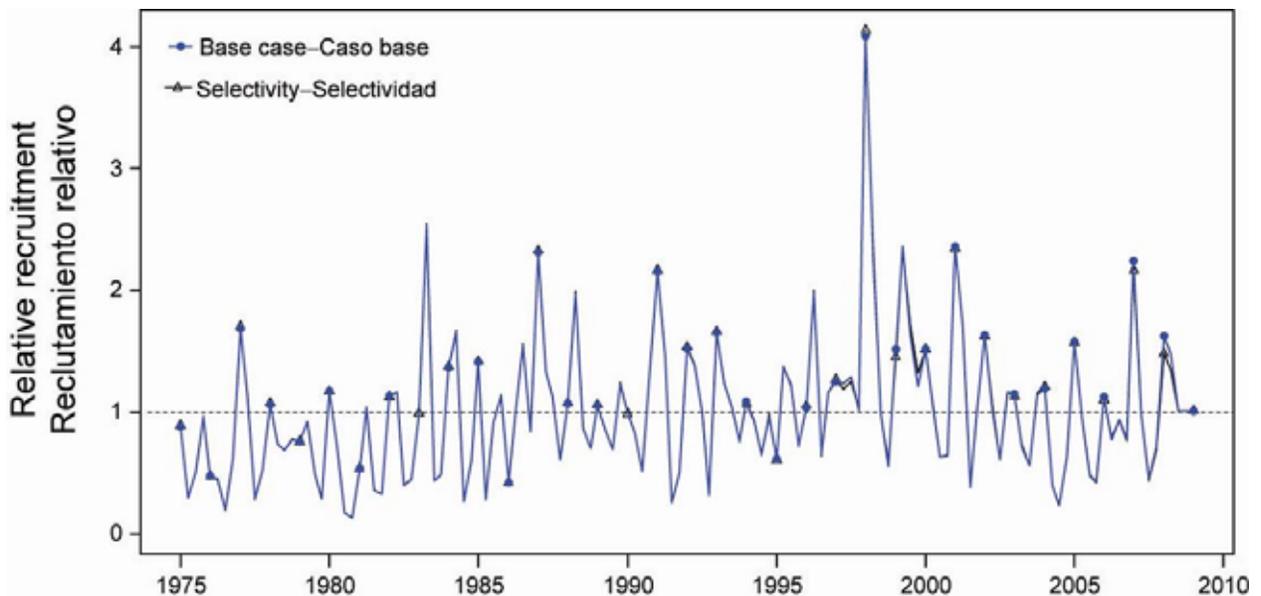
FIGURE G.2. Comparison of estimates of recruitment of yellowfin tuna from the base case with the sensitivity analysis that has a change in selectivivity for the floating-object fisheries.
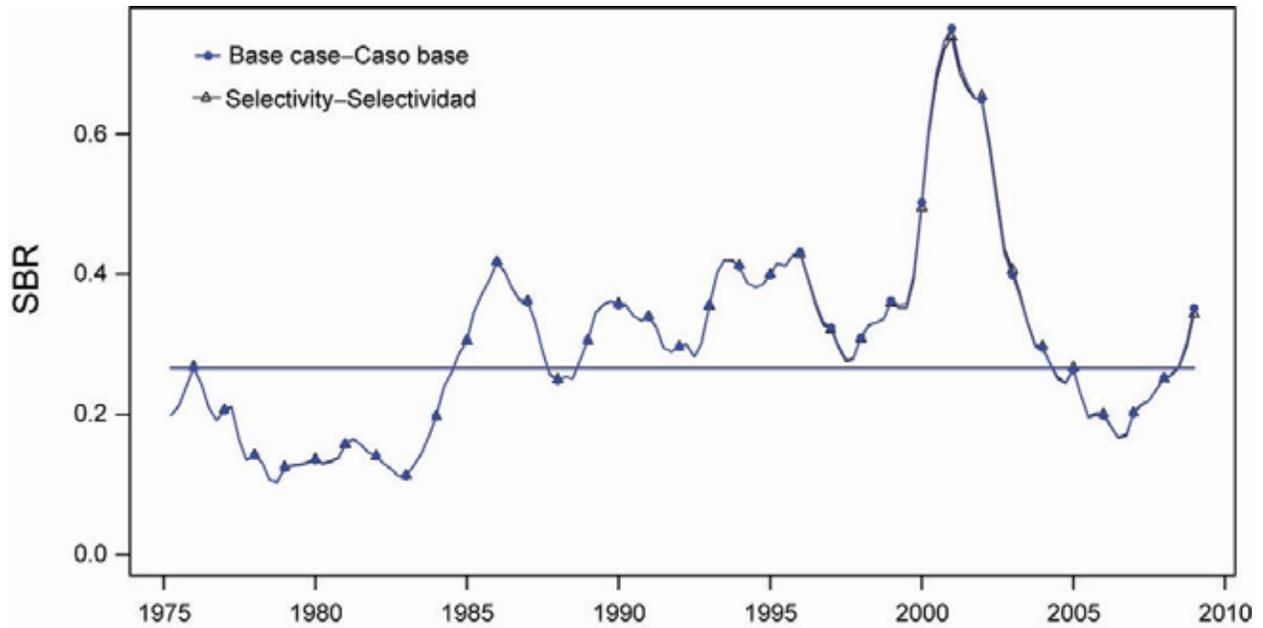
FIGURE G.3. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the base case with the sensitivity analysis that that has a change in selectivity for the floating object fisheries. The horizontal lines, which overlap, represent the SBRs associated with MSY for the two scenarios.
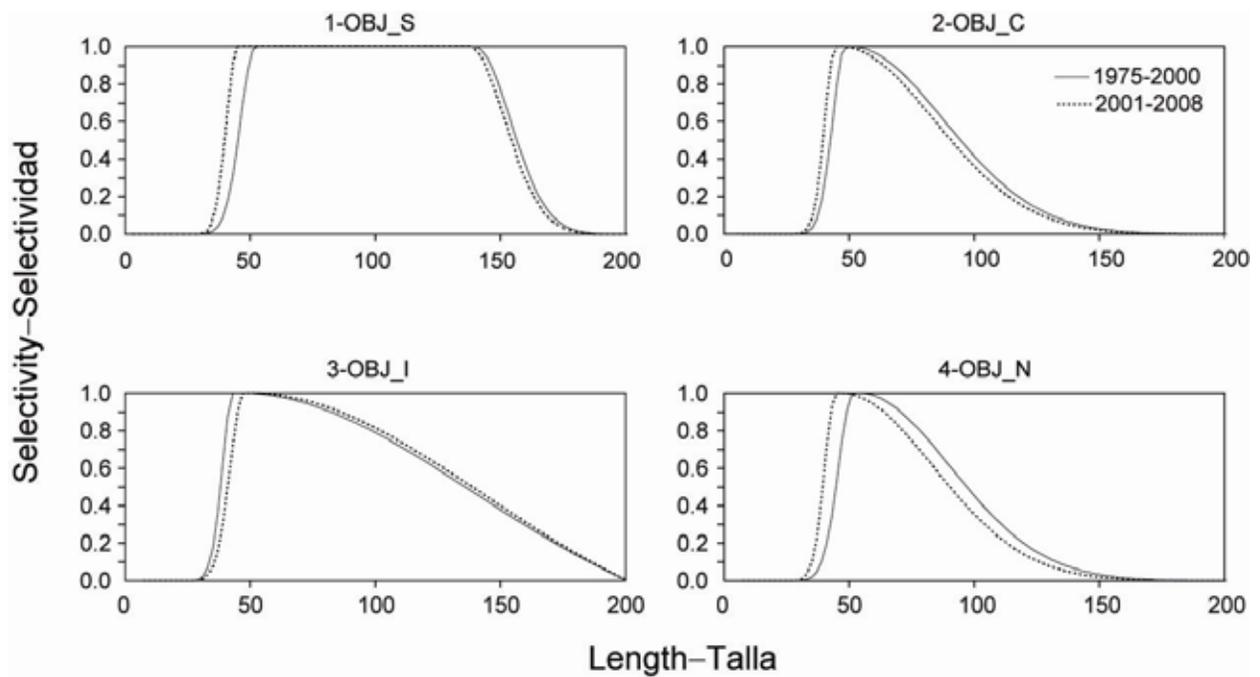
FIGURE G.4. Selectivity estimates for the floating-object fisheries from the sensitivity analysis that has a change in selectivity for the floating-object fisheries.

# APPENDIX H: ADDITIONAL RESULTS FROM THE BASE CASE ASSESSMENT

This appendix contains additional results from the base case assessment of yellowfin tuna in the EPO. These results are annual summaries of the age-specific estimates of abundance and total fishing mortality rates. This appendix was prepared in response to requests received during the second meeting of the Scientific Working Group.

ANEXO H: RESULTADOS ADICIONALES DE LA EVALUACION DEL CASO BASE

Este anexo contiene resultados adicionales de la evaluación de caso base del atún aleta amarilla en el OPO: resúmenes anuales de las estimaciones por edad de la abundancia y las tasas de mortalidad por pesca total. Fue preparado en respuesta a solicitudes expresadas durante la segunda reunión del Grupo de Trabajo Científico.

TABLE H.1. Average annual fishing mortality rates for yellowfin tuna in the EPO.
TABLA H.1. Tasas de mortalidad por pesca anual media del atún aleta amarilla en el OPO.

Year Año	Age in quarters—Edad en trimestres						
	2-5	6-9	10-13	14-17	18-21	22-25	26+
1975	0.1689	0.6454	1.2983	1.3742	1.0340	0.8540	0.7847
1976	0.2485	0.7194	1.4502	1.6443	1.3597	1.2040	1.1440
1977	0.2479	0.8166	1.5497	1.7942	1.5715	1.4335	1.3766
1978	0.3594	0.9499	1.5175	1.6569	1.4123	1.2673	1.2076
1979	0.3236	0.9986	1.6636	1.8341	1.5705	1.4074	1.3387
1980	0.2694	0.8051	1.4041	1.5205	1.2263	1.0631	0.9988
1981	0.2924	0.8782	1.4158	1.5259	1.2710	1.1231	1.0626
1982	0.2667	0.7338	1.2520	1.3938	1.1808	1.0540	1.0018
1983	0.1461	0.4211	0.7901	0.9238	0.8154	0.7507	0.7248
1984	0.0920	0.3880	0.7147	0.7821	0.6444	0.5628	0.5291
1985	0.0759	0.4384	0.7979	0.8470	0.6851	0.5831	0.5393
1986	0.1379	0.5085	0.9915	1.0280	0.7625	0.6193	0.5632
1987	0.1559	0.6711	1.1739	1.2128	0.9504	0.7948	0.7294
1988	0.1802	0.7083	1.2707	1.3361	1.0515	0.8924	0.8287
1989	0.1413	0.5948	1.1328	1.2058	0.9453	0.7964	0.7358
1990	0.1561	0.5599	1.1991	1.3299	1.0575	0.9090	0.8515
1991	0.1396	0.5727	1.1117	1.2306	1.0181	0.8908	0.8380
1992	0.1058	0.5515	1.0580	1.1156	0.8671	0.7234	0.6644
1993	0.1770	0.5055	0.7646	0.8165	0.7034	0.6320	0.6011
1994	0.1385	0.4302	0.7903	0.8986	0.7795	0.7054	0.6744
1995	0.1426	0.4230	0.7368	0.7886	0.6383	0.5525	0.5178
1996	0.2018	0.5717	0.8349	0.8332	0.6610	0.5594	0.5163
1997	0.1802	0.5826	1.1670	1.2571	0.9679	0.8140	0.7548
1998	0.1774	0.5935	1.0002	1.0469	0.8343	0.7119	0.6616
1999	0.1769	0.5462	0.8481	0.8615	0.6763	0.5713	0.5283
2000	0.1128	0.3088	0.5718	0.6422	0.5425	0.4830	0.4586
2001	0.1661	0.4536	0.7381	0.7849	0.6476	0.5672	0.5338
2002	0.1443	0.5957	1.0630	1.1176	0.8867	0.7488	0.6911
2003	0.1892	0.7658	1.5996	1.7889	1.4561	1.2643	1.1872
2004	0.1920	0.6750	1.5187	1.8376	1.6236	1.4883	1.4329
2005	0.2268	0.8642	1.6662	1.8454	1.5222	1.3329	1.2555
2006	0.1809	0.6598	1.1639	1.2820	1.0833	0.9595	0.9068
2007	0.1616	0.5716	1.0214	1.1405	0.9762	0.8728	0.8288
2008	0.1395	0.4590	0.8377	0.8909	0.6995	0.5914	0.5479

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