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STATUS OF YELLOWFIN TUNA IN THE EASTERN PACIFIC OCEAN IN 2010 AND OUTLOOK FOR THE FUTURE

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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 3.20b) was used in the assessment, which is based on the assumption that there is a single stock of yellowfin in the EPO. Yellowfin are distributed across the Pacific Ocean, and 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. The bulk of the catches of yellowfin is made in the eastern and western regions, although the purse-seine catches are relatively low in the vicinity of the western boundary of the EPO at 150°W. The movements of tagged yellowfin generally cover hundreds, rather than thousands, of kilometers, and exchange of fish 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. 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 (F), and stock structure. The catch data for the surface fisheries have been updated, and new data added for 2010. New or updated longline catch data are available for French Polynesia (2008), Japan (2008-2010), Korea (2009), and the United States (2008-2009). Surface fishery CPUE data were

updated, and new CPUE data added for 2010. New or updated CPUE data are available for the Japanese longline fleet (2008-2010). New surface fishery size-composition data for 2010 were added. New or updated length-frequency data are available for the Japanese longline fleet (2007-2009).

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 2003-2010). The productivity regimes correspond to regimes in biomass, with 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 this is probably an artifact of the apparent regime shifts. A recent sharp decline in the levels of spawning biomass since 2009 follows a series of below-average recruitments from the second quarter of 2007 through the last quarter of 2008.

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 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. The dolphin-associated and unassociated purse-seine fisheries have the greatest impact on the spawning biomass of yellowfin, followed by the floating-object fisheries. The impact of the longline and discard fisheries is much less.

There is a large retrospective pattern of overestimating recent recruitment. This pattern, in combination with the wide confidence intervals of the estimates of recent recruitment, indicate that these estimates and those of recent biomass are uncertain.

Historically, the spawning biomass ratio (the ratio of the spawning biomass to that of the unfished population; SBR) of yellowfin in the EPO was below the level corresponding to the maximum sustainable yield (MSY) during 1975-1983, coinciding with the low productivity regime, but above that level during most of the following years, except for the recent period (2004-2007 and 2010). 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 2011 was estimated to be at 0.18, below the level corresponding to the MSY (0.25). 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), and recent catches are below 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. Therefore, changes in the long-term levels of effort will change the long-term catches only marginally, while changing the biomass considerably. Reducing fishing mortality below the level at MSY would result in only a marginal decrease in the long-term average yield, with the benefit of a relatively large increase in the spawning biomass. In addition, if management is based on the base case assessment (which assumes that there is no stock-recruitment relationship), when in fact there is such a relationship, there would be a greater loss in yield than if management is based on assuming a stock-recruitment relationship when in fact there is no relationship.

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 (1975-2010), 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.

If a stock-recruitment relationship is assumed, the outlook is more pessimistic, and current effort is estimated to be above the level corresponding to the MSY. The status of the stock is also sensitive to the value assumed for the average size of the oldest fish. If the CPUE of the northern dolphin-associated fishery, rather than that of the southern longline fishery, is assumed to be the most reliable index of abundance, the current spawning stock biomass is estimated to be at about the level corresponding to MSY.

Under current levels of fishing mortality (2008-2010), the spawning biomass is predicted to rebuild, and remain above the level corresponding to MSY. However, the confidence intervals are wide, a retrospective pattern exists in recent recruitment, and there is a moderate probability that the SBR will be substantially above or below this level. 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. There is uncertainty about recent and future levels of recruitment and biomass, and there are retrospective patterns of overestimating recent recruitment.
2. The recent fishing mortality rates are lower than those corresponding to the MSY.
3. The recent levels of spawning biomass are below those corresponding to the MSY.
4. Increasing the average weight of the yellowfin caught could increase the MSY.
5. There have been two, and possibly three, different productivity regimes, and the levels of MSY and the biomasses corresponding to the MSY may differ among the regimes. The population may have recently switched from a high to an intermediate productivity regime.
6. The results are more pessimistic if a stock-recruitment relationship is assumed.
7. The results are sensitive to the average size assumed for the oldest fish.

2. DATA

Catch, indices of abundance, and size-composition data for January 1975-December 2010, plus biological data, were used to conduct the stock assessment of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean (EPO). The data for 2010, which are preliminary, include records that had been entered into the IATTC databases by 15 April 2011. 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. They 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. Catches

To conduct the stock assessment of yellowfin tuna, the catch and effort data in the IATTC databases are stratified in accordance with 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, and “retained catch” is the catch that is taken in a given year and not discarded at sea. “Catch” is used for either total catch (discards plus retained catch) or retained catch; the context determines the appropriate definition.

All three 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 (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 (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 2010 and updated data for earlier years are used for the surface fisheries.

The species-composition method (Tomlinson 2002) was used to estimate the 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 data 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. Updated 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 French Polynesia (2008), Japan (2008-2010), Korea (2009) and the United States (2008-2009).

A substantial proportion of the longline catch data for 2010 was not available, so catches for the longline fisheries in the recent years for which the data were not available were set equal, by flag, 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 2010 are shown in Figures 2.2a and 2.2b. It should be noted that there were substantial surface and longline fisheries for yellowfin prior to 1975 (Shimada and Schaefer 1956; Schaefer 1957; Matsumoto and Bayliff 2008). The majority of the catch has been taken in 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, most of the longline catches of yellowfin in the stock assessment were expressed in numbers of fish.

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 are 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 annual discards as proportions of the total (retained plus discarded) catches for the surface fisheries that catch yellowfin in association with floating-objects are presented in Figure 2.3. The figure shows a reduction in bycatch rates beginning around 2001, possibly as a consequence of a series of resolutions adopted by the IATTC during 2001-2007 which prohibited discarding catches of small tunas. No such resolution was 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 2010 and updated for earlier years. New or updated catch and effort data are available for the Japanese longline fisheries (2008-2010). 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 2.4, which does not include the pole-and-line and four discard fisheries.

The catch per unit of effort (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 estimated 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 CPUE (1975-2010) were obtained for the longline fisheries (Fisheries 11 and 12), using a delta-lognormal general linear model (Hoyle and Maunder 2006) in which the explanatory variables were latitude, longitude, and hooks per basket.

The CPUE time series for the different fisheries are presented in Figure 2.5. The indices of abundance that were considered appropriate for use in the assessment were those from Fisheries 5 and 6 (purse-seine sets on unassociated 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 fishing effort or 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

New purse-seine length-frequency data were included for 2010. New or updated longline length-frequency data for 2007-2009 for the Japanese fleet were included. Size composition data for the other longline fleets are not used in the assessment.

The fisheries of the EPO catch yellowfin of various sizes, as described by Maunder and Watters (2001). In general, floating-object, unassociated, and pole-and-line fisheries catch smaller yellowfin, while dolphin-associated and longline fisheries catch larger ones. The temporal variation of the catch from each fishery defined in Table 2.1 is shown in Figures 2.6a-2.6e.

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 and variability of the length-at-age. Wild’s data consists 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.

3. ASSUMPTIONS AND PARAMETERS

3.1. Biological and demographic information

3.1.1. Growth

In this assessment, the Richards growth curve is used to model growth (Figure 3.1). The parameters of the model are taken from Maunder and Aires-da-Silva (2009), and are based on the fit to the 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.

The coefficient of variation in length-at-age is assumed constant, and is taken from Maunder and Aires-da-Silva (2009).

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 including this alternative data set in the stock assessment model gives essentially identical results.

3.1.2. Natural mortality

For this 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 this assessment, and M differs between males and females. The values of quarterly M used in this assessment are plotted in Figure 3.2. 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.

3.1.3. Recruitment and reproduction

The Stock Synthesis software 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. As in the previous assessments, the base case assessment assumes that there is no relationship between stock size and recruitment. 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 assessment 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. 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 3.3.

3.1.4. Movement

The evidence of yellowfin movement within the EPO is summarized by Maunder and Watters (2001), and the results of more recent research are given by Schaefer *et al.* (2007). They 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 is expected to be very low. This result is consistent with the results of various tagging studies, using conventional and archival tags, 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 this assessment, it is assumed that movement does not affect the results. However, given the results of Schaefer *et al*. (2007), investigation of finer spatial scale or separate sub-stocks should be considered.

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 there is limited mixing of fish between the EPO and the areas to the west of it. Therefore, for the purposes of this 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 the 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 (2002a) 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 software (Methot 2005, 2009) is used 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, and 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 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 age, they become more vulnerable to Fisheries 6, 9, 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 on floating objects (Fisheries 1-4), associated with dolphins in the south (Fishery 9), the pole-and-line fishery (Fishery 10), the northern longline fishery (Fishery 11), and fisheries whose catch is composed of the discards from sorting (Fisheries 13-16) provide relatively little information about biomass levels, either because they do not direct their effort at yellowfin or because 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 the fishery associated with dolphins in the south (Fishery 9) are considered too variable, so its selectivity curve is assumed to be equal to that of Fishery 12, and its size-composition data are not fitted 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 of the year from the first quarter of 1975 through the first quarter of 2011 (average recruitment and quarterly recruitment deviates);
2. Catchability coefficients for the five CPUE time series that are used as indices of abundance (Fisheries 5-8 and 12);
3. Coefficients of variation (CVs) for four of the CPUE indices used as indices of abundance (Fisheries 5-8). Following a recommendation by an external review of the IATTC staff's assessment of bigeye tuna, the CV of one CPUE index was fixed rather than estimated, in this case the CV of the southern longline fishery (Fishery 12), assumed as the most reliable index of abundance.
4. Selectivity curves for 11 of the 16 fisheries (Fishery 9 mirrors the selectivity of Fishery 12, and Fisheries 13-16 have assumed selectivity curves);
5. 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 assessment of yellowfin in the EPO:

1. Mean length at age (Section 3.1.1, Figure 3.1);

2. Parameters of a linear model relating the coefficient of variation of length at age to age.
3. Sex- and age-specific natural mortality (Figure 3.2);
4. Fecundity of females at age (Figure 3.3);
5. Selectivity curves for the discard fisheries (Fisheries 13-16);
6. The steepness of the stock-recruitment relationship (steepness = 1 for the base case assessment).

The estimates of management quantities and future projections were computed based on 3-year average fishing mortality rates (*F*), by gear, for 2008-2010. The sensitivity of estimates of key management quantities to including the most recent year (2010) in the 3-year average estimate of *F* was tested. For this purpose, a 2-year (2008-2009) average *F* was used in the calculations.

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

The following summarizes the important aspects of the base case assessment (1) and the three sensitivity analyses:

Base case assessment:

1. **Steepness of the stock-recruitment relationship = 1** (no relationship between stock and recruitment); growth parameters are fixed to the estimates obtained in an earlier assessment (Maunder and Aires-da-Silva 2009); fitted to CPUE time series for purse-seine Fisheries 5-8 and longline Fishery 12; mirrors selectivity curves of Fisheries 9 and 12, assumed to be asymptotic; selectivity curves of all other fisheries assumed to be dome-shaped.
2. **Sensitivity to the steepness of the stock-recruitment relationship**: The base case assessment included an assumption that recruitment was independent of stock size, and a Beverton-Holt stock-recruitment relationship with a steepness of 0.75 was used for the sensitivity analysis. In addition, a likelihood profile for steepness was computed (steepness ranging from 0.6 to 1, with 0.1 increments).
3. **Sensitivity to the average size of the older fish** (L_2 parameter of the Richards growth function). L_2 is fixed at 182.3 cm in the base case model, an estimate was obtained in an earlier assessment (Maunder and Aires-da-Silva 2009). Two alternative fixed values of L_2 were considered for the sensitivity analysis, a lower and a higher value of 170 cm and 190 cm, respectively.
4. **Sensitivity to fitting to the CPUE of the northern dolphin-associated fishery** (Fishery 9) as the main index of abundance, rather than the CPUE of the southern longline fishery (Fishery 12). For this purpose, the CV of Fishery 9 was fixed at 0.2, and the CVs of other fisheries are estimated.

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 (*F*) exerted by the fisheries that catch yellowfin in the EPO (Figure 4.1). Fishing mortality changes with age (Figure 4.2a), being greatest for middle-aged fish. There is a peak at around ages of 14-15 quarters (Figures 4.2a and 4.2b), which corresponds to peaks in the selectivity curves for fisheries on unassociated and dolphin-associated yellowfin (Figure 4.3). 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 (Figures 4.1 and 4.2a).

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 2.3 (also see Figure 2.4).

Selectivity curves are estimated for 11 of the 16 fisheries defined in the assessment of yellowfin (Figure 2.1) and are shown in Figure 4.3. Purse-seine sets on floating objects (Fisheries 1-4) tend to select smaller yellowfin, except in the southern and inshore fisheries, which catch larger fish (Figure 4.3). 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 4.3, Fishery 5). Purse-seine sets on unassociated schools of yellowfin in the south and on yellowfin associated with dolphins select larger yellowfin (Figure 4.3, Fisheries 6-8). The selectivity curve for the pole-and-line fishery selects mainly smaller yellowfin (Figure 4.3, Fishery 10). The longline fisheries for yellowfin also select mainly larger individuals, particularly in the southern fishery (Figure 4.3, Fisheries 11 and 12). Since it became difficult to estimate the selectivity curve of the southern dolphin-associated fishery (Fishery 9), this curve was not estimated, and mirrored Fishery 12, which catches similar size fish (Figure 4.3). In the future, it may be necessary to allow for time-varying selectivity to better estimate the selectivity curve of this fishery.

Discards resulting from sorting purse-seine catches of yellowfin taken in association with floating objects are assumed to be composed only of fish of ages 2-4 quarters (Fisheries 13-16).

4.1.2. Recruitment

Over the range of estimated spawning biomasses shown in Figure 4.7, the abundance of yellowfin recruits appears to be related to the relative potential egg production at the time of spawning (Figure 4.4). The apparent relationship between spawning 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 spawning biomass. Therefore, in the long term, above-average recruitment is related to above-average spawning biomass, and below-average recruitment to below-average spawning 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 at least as plausible as an effect of population size on recruitment. The results when a stock-recruitment relationship is included are described in Section 4.4.

The estimated time series of yellowfin recruitment is shown in Figure 4.5, 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 1975-2010 period. A sustained period of high recruitment was estimated from 1999 until the start of 2002. A large recruitment was estimated for the first quarter of 2007, followed by a series of continuous below-average recruitments through the last quarter of 2008. The recruitment estimate for the first quarter of 2010 is particularly high; however, it is very uncertain and should be regarded with caution, due to the fact that recently-recruited yellowfin are represented in only a few length-frequency samples, and there is a retrospective pattern (see section 4.3.2).

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, and produced a similar change in biomass (Figure 4.6). There is an indication that the recruitments from 2003-2009 were at low levels, similar to those prior to 1983, perhaps indicating a lower productivity regime (Figure 4.5).

The confidence intervals for recruitment are relatively narrow, indicating that the estimates are fairly precise, except for that of the most recent year (Figure 4.5). The estimates of uncertainty are surprisingly small, considering the inability of the model to fit modes in the length-frequency data (Figure 4.11). 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 old or more. The trends in the biomass of yellowfin in the EPO are shown in Figure 4.6, 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, remained relatively constant during 1986-1999, then increased rapidly again, peaking in 2001, but by 2005 had declined to levels similar to those prior to 1984. The biomass in recent years has remained at levels below those of 1985-1998.

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 4.7, and estimates of the SBR (defined in Section 3.1.3) at the beginning of each year are shown 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. The recent sharp decline of the spawning biomass observed since 2009 is partially attributed to a series of continuous below-average recruitments from the second quarter of 2007 through the last quarter of 2008.

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 4.8b. The large difference in the two trajectories indicates that fishing has a major impact on the spawning biomass of yellowfin in the EPO (Figure 4.8a). 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 4.5), 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 4.8b. The estimates of the index of spawning biomass in the absence of fishing were computed as above, and then the biomass trajectory was estimated by setting the catch for each fisheries group, in turn, to zero (Wang *et al.* 2010). 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. The fishery associated with dolphins and unassociated purse-seine fisheries have the greatest impact on the spawning biomass of yellowfin, followed by the floating-object fisheries. The impact of the longline and discard fisheries is much smaller.

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 1975-2010 period, but have differed considerably among fisheries (Figure 4.9). The average weight was high during 1975-1977, 1985-1992, 2001-2004, and 2008-2010, when the catches of the dolphin-associated fisheries were greater (Figure 2.2). The average weight of yellowfin caught by the different gears varies widely, but remains fairly consistent over time within each fishery (Figure 4.9). The lowest average weights occur in the floating-object and pole-and-line fisheries, followed by the unassociated fisheries, then the dolphin-associated, and finally the longline fisheries. The average weight caught also varies within these fisheries groups, as indicated by the selectivity curves (Figure 4.3).

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.

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 4.10. The model fits the CPUE observations for the dolphin-associated purse-seine and southern longline fisheries reasonably well (Figures 4.10c and 4.10d, respectively). However, the peak in 2001 is predicted too early in the former and too late in the latter. Also, the model fits less well to the early CPUE of the southern longline fishery (Figure 4.10.d). The fits to the CPUE data series for the unassociated purse-seine fisheries are less satisfactory (Figure 4.10.b). The model is not fitted explicitly to the CPUE of the floating-object fisheries; however, it corresponds well to the CPUE of these fisheries in the late period (post-1995), but poorly in the early period (pre-1995) of highly variable CPUEs (Figure 4.10a). The fit to the CPUE data, as measured by the mean square error, indicates that the best fits are to the CPUEs of the southern longline fishery (CV = 0.36) and the dolphin-associated purse-seine fisheries (CVs of 0.39 and 0.38 for Fisheries 7 and 8, respectively) (Table 4.3).

Pearson residual plots are presented for the model fits to the length-composition data (Figures 4.11a-4.11d). The grey and black circles represent observations that are less and greater, respectively, than the model predictions. The areas of the circles are proportional to the absolute values of the residuals. There are several notable characteristics of the residuals. The model underestimates (black circles) the proportions of large and small fish for the floating-object fisheries; conversely, it underestimates medium-sized fish for the southern longline fishery. There is a substantial residual pattern for the southern dolphin-associated purse-seine fishery (Fishery 9), but this is expected, because the selectivity curve is mirrored with another fishery (southern longline, Fishery 12) and so the model is not fitted to the catch-at-length data of Fishery 9. There is also a noticeable residual pattern for both unassociated fisheries, consisting of an early period of about 5 years (1975-1980) with positive residuals (black circles) mainly for smaller fish, unlike in subsequent years.

For all fisheries, the model fits the length-frequency data better (as indicated by the estimated effective sample size) than the assumed sample size used in the model (Table 4.4). The average fits to the observed size compositions of the catches taken by each fishery are shown in Figure 4.11e. The model fits to the size-compositions of the recent catches of yellowfin are also shown for different fisheries (Figures 4.11f-i).

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

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 reveal inadequacies in the method. Retrospective analyses are usually carried out by repeatedly eliminating one year of data from the analysis while using the same assessment method and assumptions. This allows the change in estimated quantities to be determined 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 indicate only 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 the strengths of recent recruitment (Figure 4.13), and consequently to overestimate recent levels of summary biomass (fish 3+ quarters old), which includes the most recent cohorts (Figures 4.12). However, the recent levels of the SBR (defined in section 3.1.3) are apparently not subject to the same retrospective pattern, since they are less affected by recent recruitment estimates. A sensitivity analysis conducted on an early assessment (Maunder and Aires-da-Silva 2010) suggests that removing the size-composition data of the floating-object fisheries from the analyses removes this retrospective pattern. This indicates that the size-composition data for these fisheries are inconsistent with the size-composition data for the other fisheries at greater ages. Resolution C-00-08, adopted in 2000, prohibited the discarding of yellowfin tuna due to size, which changed the selectivity curves of the floating-object fisheries in 2001 and could potentially cause the retrospective pattern. However, another sensitivity analysis incorporating this into the stock assessment did not remove the retrospective pattern (Maunder and Aires-da-Silva 2010).

4.4. Sensitivity to assumptions

Three sensitivity analyses were carried out to investigate the incorporation of a Beverton-Holt (1957) stock-recruitment relationship (Appendix A), average size of the older fish (Appendix B), and fitting to the CPUE data of the northern dolphin-associated fishery (Fishery 9) as the main index of abundance (Appendix C). Here we describe differences in model fit and model prediction, and defer our discussion of differences in stock status to Section 5. A comparison of the likelihoods for the base case and sensitivity analyses is provided in Table 4.5.

1. The base case assessment 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 that from an unexploited population. As in previous assessments, the analysis with a stock-recruitment relationship fits the data better than the analysis without the stock-recruitment relationship. However, as stated previously, 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 those of the base case assessment. A likelihood profile on steepness confirms that the model fits better at lower fixed values for this parameter, with its maximum likelihood apparently occurring at about 0.7.

2. The base case model assumes a Richards (1959) growth function. The choice of the average size of the older fish – the L_2 parameter – is somewhat arbitrary, since otolith readings are not available for larger (older) fish. In the base case, L_2 is fixed at 182.3 cm, a value estimated in a previous assessment (Maunder and Aires-da-Silva 2009). A sensitivity analysis was done to study the effect of fixing L_2 at different values (a lower and a higher value, 170 and 190 cm, respectively) (Figure B.1). The estimated biomass and recruitment time series are very sensitive to the assumed value of L_2 (Figures B.2 and B.3), they are greater for a lesser value of the parameter.

3. The base case model assumes the CPUE of the southern longline fishery (Fishery 12) to be the most reliable index of abundance (CV = 0.2). However, this fishery mainly targets bigeye tuna, not yellowfin. If instead the model is fitted more closely to the northern dolphin-associated fishery

(Fishery 9, CV = 0.2), the biomass and recruitment trajectories are still very similar to those from the base case (Figures C1 and C2, respectively). This suggests that there is consistency in the information provided by the two CPUE indices. However, the recent decline in biomass levels estimated by the base case is not so strong in the sensitivity analysis, particularly for spawning biomass (Figure C.3). This result is mainly due to the model fitting more closely to the recent CPUE trends of the northern dolphin-associated fishery (C.4a), rather than the southern longline fishery (Figure C.4b). The model fit to the CPUE of the northern dolphin-associated fishery is not so indicative of the pronounced recent decline as indicated by the base case model which fits more closely to the CPUE of the southern longline fishery (Figure 4.10c and 4.10d).

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 estimate the catch of the surface fishery, and a different size of the selectivity smoothness penalties (if set at realistic values), yielded similar results (Maunder and Harley 2004). The results were not sensitive to the link function used in the general linear model (GLM) standardization of the longline effort data (Hoyle and Maunder 2007).

Other sensitivity analyses conducted in early assessments include: fitting to all the data (size composition and CPUE data for all fisheries except the discard fisheries and pole and line fishery); estimating natural mortality for mature fish while fitting to sex ratio data; excluding the size-composition data for the floating-object fisheries from the analysis; and including a change in selectivity for the floating-object fisheries starting in 2001 due to the Resolution C-00-08. The results of these sensitivity analyses are described in Maunder and Aires-da-Silva (2010).

4.5. Comparison to previous assessment

The estimates of biomass (Figure 4.15) and the index of spawning biomass (Figure 4.16) from this assessment are very similar to those of the previous assessment. The estimates of recruitment are also very similar, except in 2009, the last year of the previous assessment, for which recruitment is estimated to be very high (Figures 4.17a and b). This is not surprising, considering the retrospective tendency to overestimate recent recruitment strengths, described in Section 4.3.2. As updated data for 2009 and new data for 2010 became available, the 2009 recruitment estimated in the current assessment became much smaller. The historic estimates of the SBR (defined in Section 3.1.3) are also very similar to those of the previous assessment (Figure 4.18).

4.6. 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 indicate that the yellowfin population has experienced two, or possibly three, different recruitment productivity regimes (1975-1982, 1983-2002, and 2003-2010). The productivity regimes correspond to regimes in biomass, higher-productivity regimes producing higher 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. The recently observed sharp decline in the levels of spawning biomass since 2009 follows a series of below-average recruitments from the second quarter of 2007 through the last quarter of 2008.

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 and dolphin-associated purse-seine fisheries and the longline fisheries. The longline fisheries and the dolphin-associated purse seine fishery in the southern region capture older, larger yellowfin than do the northern and coastal dolphin-associated purse-seine fisheries.

Significant levels of fishing mortality have been estimated for the yellowfin fishery in the EPO. These levels are highest for middle-aged yellowfin. The fisheries associated with dolphins and unassociated purse-seine fisheries have the greatest impact on the spawning biomass of yellowfin, followed by the floating-object fisheries. The impact of the longline and discard fisheries is much smaller (Figure 4.8).

There is a large retrospective pattern of overestimating recent recruitment in the yellowfin stock assessment. A previous assessment (Maunder and Aires-da-Silva 2010) indicated that this pattern is due to the size composition data for the floating object fishery. These, in combination with the wide confidence intervals for estimates of recent recruitment, indicate that estimates of recent recruitment and recent biomass are uncertain. The estimated biomasses and recruitments are very similar to those produced in the latest stock assessment (Maunder and Aires-da-Silva 2011).

5. STOCK STATUS

The status of the stock of yellowfin in the EPO is assessed from calculations based on the spawning biomass, yield per recruit, and the maximum sustainable yield (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 and with the current distribution of types of gear and how these gears are deployed.

Maintaining tuna stocks at levels that will permit the MSY is the management objective specified by the IATTC Convention. The IATTC has not adopted any target of limit reference points for the stocks that it manages, but some possible reference points are described in the following sections.

5.1. Assessment of stock status based on spawning biomass

The SBR, defined in Section 3.1.3, 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 2011). Estimates of the index of spawning biomass during the period of harvest (S_t) are discussed in Section 4.1.3 and presented in Figure 4.7. 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 0.25. This is lower than estimated in the previous assessment (0.27), due mainly to the use of different selectivity curves.

The spawning biomass of yellowfin in the EPO has declined since 2009, when it peaked at 0.35. The estimate of SBR at the beginning of 2011 was about 0.18, with lower and upper 95% confidence limits of 0.15 and 0.22, respectively (Figure 5.1). 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 0.25 in Figure 5.1. For most of the early period (1975-1984), 2005-2007, and during the most recent year (2010), however, the spawning biomass was estimated to be less than S_{MSY}. The spawning biomass at the start of 2011 is estimated to be at 0.18, 28% below than the level corresponding to MSY.

5.2. Assessment of stock status based on MSY

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 2008-2010.

At the beginning of 2011, the biomass of yellowfin in the EPO appears to have been below 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 4.2) are maintained, the current (average of 2008-2010) level of fishing effort is less than that estimated to produce the MSY. The effort at MSY is 113% of the current level of effort. Due to reduced fishing mortality in 2008, repeating the calculations based on a fishing mortality averaged over 2008-2009 indicates that effort at MSY is 129% of the current level. 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 result in 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 that 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 analysis of sensitivity to a stock-recruitment relationship when recruitment is, in fact, independent of spawning biomass (Figure 5.2).

The historical time series of exploitation rates, spawning biomass, and summary biomasses relative to the MSY reference points are shown in Figure 5.3a. The fishing mortality has generally been below that corresponding to the MSY, except for the period before 1982 and during 2004-2007 (Figure 5.4a). The spawning biomass has generally been above the level corresponding to MSY, except during the low-productivity regime prior to 1984, and the years since 2004 except for 2008 and 2009. According to the base case assessment, the most recent estimate indicates that the yellowfin stock in the EPO is overfished ($S<S_{\mathrm{MSY}}$), but that overfishing is not taking place ($F>F_{\mathrm{MSY}}$). The high precision of this most recent estimate, as indicated by its narrow approximate confidence intervals (Figure 5.3a), does not allow for other interpretations of stock status under the base case assumptions. However, the stock status interpretation is sensitive to the assumptions made about the steepness parameter of the stock-recruitment relationship and the average size of the older fish (Table 5.1).

5.3. Comparisons with previous assessments

Estimates of management quantities are compared to estimates from previous assessments in Figure 5.4b. 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, because of the mix of fishing effort by gear and the total changes over time, because recruitment changes over time, and because the assumptions used in the assessments can differ from year to year as the understanding of the stock dynamics improves. The estimates of MSY and the SBR corresponding to MSY (Figure 5.4b) are similar to those produced in the previous assessment. The estimates of the F multiplier and the recent level of SBR with respect to that of the MSY are lower than those from the previous assessment.

5.4. Impact of fishing methods

The estimation of 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 purse-seine fisheries, the unassociated fisheries, and finally the floating-object fisheries (Table 5.2). If an additional management objective is to maximize S_{MSY}, the order is similar, but with dolphin-associated purse-seine 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 MSY.

MSY and S_{MSY} have been very stable during the model 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.

6. Impact of environmental conditions

The apparent regime shift in productivity that began in 1984 and the recent lower level of productivity suggest alternative approaches to estimating MSY, as different regimes will give rise to different values for 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 during 1985-2010 was used instead of during the whole time period, MSY and the spawning biomass corresponding to MSY would be increased. This would mean that greater yields would be possible, but the fishery would be overexploited (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 4.8a). This approach takes the fluctuations of recruitment into consideration.

6.1. 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. Fixing the mean size of the oldest age class to a lower value than that assumed in the base case (*e.g*., 170 cm) produces more optimistic results, with the spawning biomass being at about the level corresponding to MSY and current effort being substantially below that level, but the level of MSY that can be obtained is about the same. In contrast, fixing the mean size of the oldest age class to a higher value than that assumed in the base case (*e.g*.,190 cm) produces more pessimistic results, with the spawning biomass being below that corresponding to MSY and current effort dropping below the level corresponding to MSY, but the level of MSY that can be obtained changes little. The sensitivity analyses showed that fitting more closely to the CPUE data of the northern dolphin-associated fishery (CV fixed at 0.2), rather than taking the CPUE of the southern longline fishery as the main index of abundance, produces a more optimistic assessment of the status of the stock. While the recent spawning biomass is estimated to be about the level corresponding to MSY, the recent levels of fishing effort are estimated to be well below those corresponding to MSY.

6.2. Summary of stock status

The SBR of yellowfin in the EPO was below the level corresponding to MSY during the lower productivity regime of 1975-1983), but above that level for most of the following years, except for the recent period (2004-2007 and 2010). The 1984 increase in the SBR is attributed to the regime change, and the recent decrease may be a reversion to an lower productivity regime. The two different productivity regimes may support two different MSY levels and associated SBR levels. The SBR at the start of 2011 was estimated to be at 0.18, below the level corresponding to MSY (0.25).. The effort levels are estimated to be less than those that would support MSY (based on the current distribution of effort among the different fisheries), and 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.

If a stock-recruitment relationship is assumed, the outlook is more pessimistic, and current effort is estimated to be above the level corresponding to MSY. The status of the stock is also sensitive to the value assumed for the average size of the oldest fish. If the CPUE of the northern dolphin-associated fishery is assumed to be the most reliable index of abundance, instead of the CPUE of the southern longline fishery, the current spawning stock biomass is estimated to be at about the level corresponding to MSY.

7. SIMULATED EFFECTS OF FUTURE FISHING OPERATIONS

A simulation study was conducted to gain further understanding of 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.

7.1. Assumptions about fishing operations

7.1.1. Fishing effort

Future projection studies were carried out to investigate the influence of different levels of fishing effort on biomass and catch. The projected fishing mortality was based on the averages during 2008-2010.

The scenarios investigated were:

1. Quarterly fishing mortality for each year in the future equal to the average for 2008-2010;
2. Quarterly fishing mortality for each year in the future set to that corresponding to MSY.

7.2. Results of the simulation

The simulations were used to predict future levels of the SBR, total biomass, and the total catch taken by the surface (purse-seine) fisheries. There is probably more uncertainty in the future levels of these outcome variables than is suggested by the results presented in Figures 6.1-6.3. 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 of variation in catchability.

These simulations were carried out using the average recruitment during 1975-2010. If they had been carried out using the average recruitment during 1984-2001, the projected trend in SBR and catches would have been more positive. Conversely, if they had been carried out with the average recruitment during 2002-2010, the projected trend in SBR and catches would have been more negative.

7.2.1. Current effort levels

Under current levels of fishing mortality (2008-2010), the spawning biomass is predicted to rebuild, and 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 greater over the near term than in 2010, but will decline slightly in the future (Figure 6.3).

7.2.2. Fishing at F_{MSY}

Fishing at F_{msy} is predicted to reduce the spawning biomass slightly from that with current effort (Figure 6.2) and produces slightly greater catches (Figure 6.3).

7.3. Summary of the simulation results

Under current levels of fishing mortality (2008-2010), the spawning biomass is predicted to rebuild and remain above the level corresponding to MSY. However, the confidence intervals are wide, and there is a moderate probability that the SBR will be substantially above or below this level. Fishing at F_{msy} is predicted to reduce the spawning biomass slightly from that under current effort and produces slightly higher catches, particularly for the longline fishery.

8. FUTURE DIRECTIONS

8.1. 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.

8.2. Refinements to the assessment model and methods

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

1. Determine appropriate weighting of the different data sets;
2. Explore alternative assumptions on stock structure (spatial analysis);
3. Time-variant selectivity for the floating-object purse-seine fisheries.
4. More robust selectivity curves.

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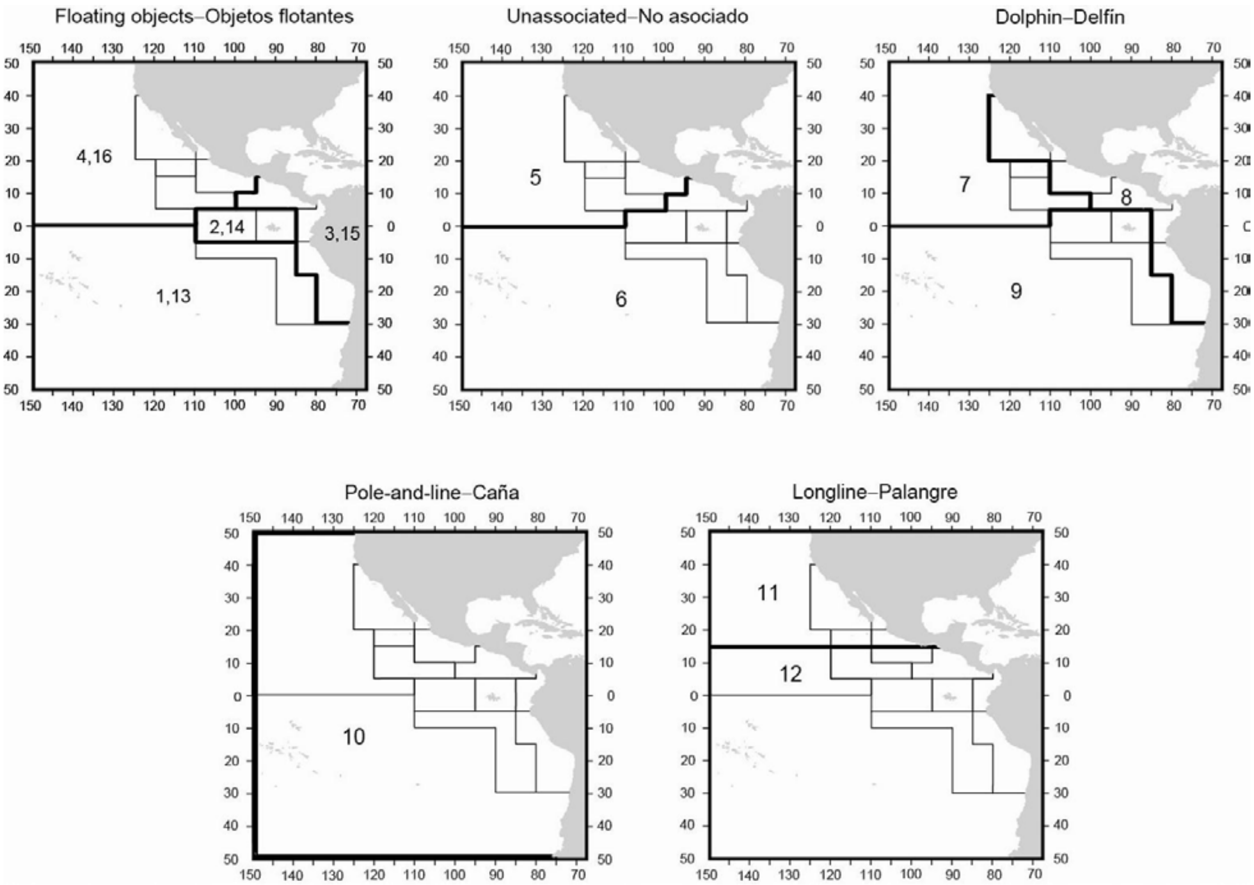

FIGURE 2.1. Spatial extents of the fisheries defined by the IATTC staff for the stock assessment of yellowfin tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the bold numbers 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 de la población, y los números en negritas las pesquerías correspondientes a estos últimos límites. En la Tabla 2.1 se describen las pesquerías.

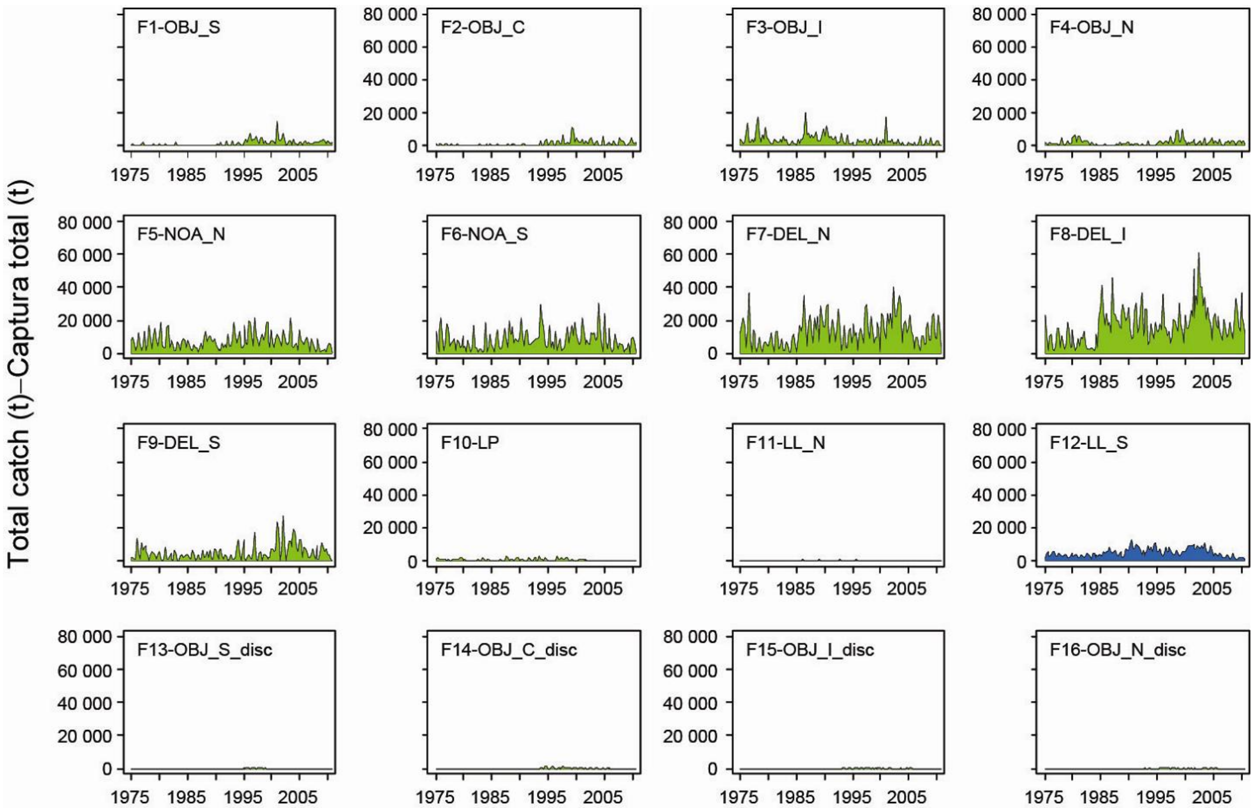

FIGURE 2.2a. Quarterly catches by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were analyzed on a quarterly basis, there are four observations of catch for each year. Although all the catches are displayed as weights, the stock assessment model uses catches in numbers of fish for Fisheries 11 and 12. Catches in weight for Fisheries 11 and 12 are estimated internally by Stock Synthesis by multiplying the catches in numbers of fish by estimates of the average weights.

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. Las capturas en peso de las Pesquerías 11 y 12 son estimadas internamente por *Stock Synthesis*, multiplicando las capturas en número de peces por estimaciones del peso promedio.

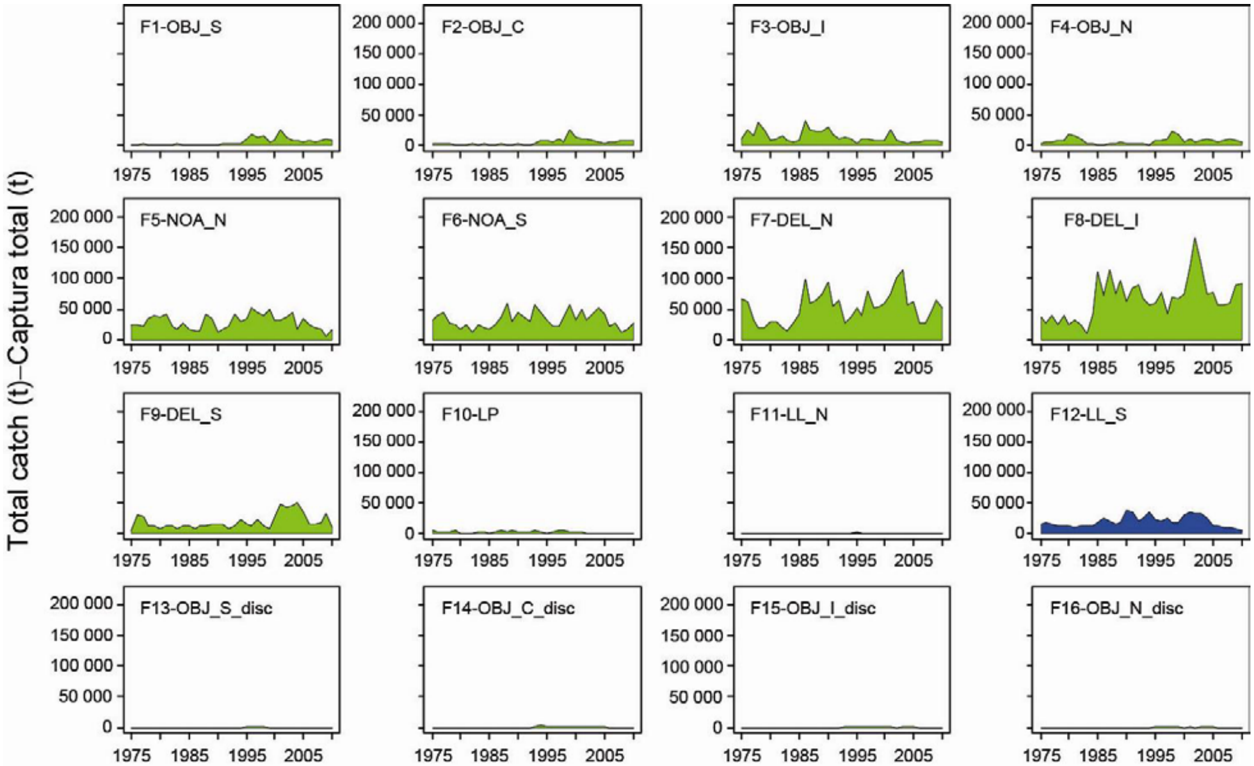

FIGURE 2.2b. Annual catches by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Although all the catches are displayed as weights, the stock assessment model uses catches in numbers of fish for Fisheries 11 and 12. Catches in weight for Fisheries 11 and 12 are estimated internally by Stock Synthesis by multiplying the catches in numbers of fish by estimates of the average weights.

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. Las capturas en peso de las Pesquerías 11 y 12 son estimadas internamente por *Stock Synthesis*, multiplicando las capturas en número de peces por estimaciones del peso promedio.

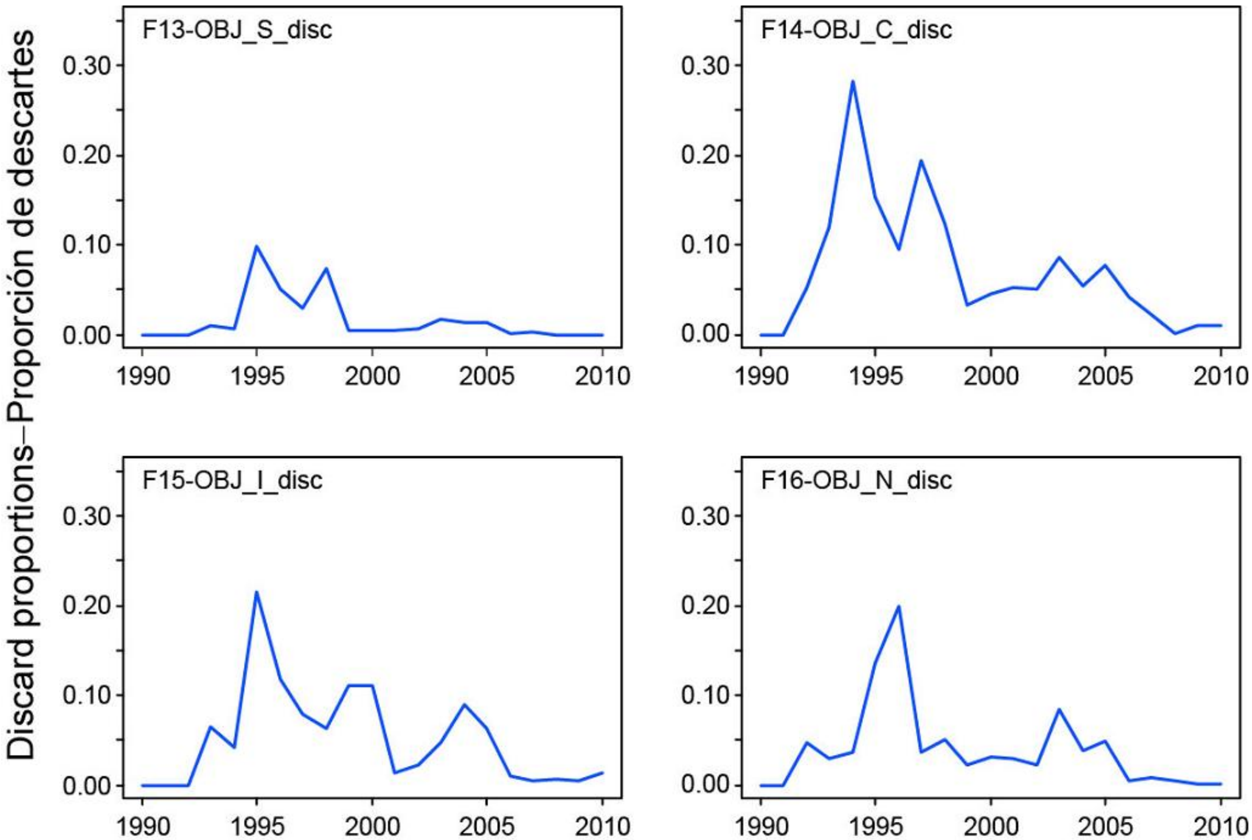

FIGURE 2.3. Weights of discarded yellowfin tuna as proportions of the total (retained plus discarded) annual catches for the four floating-object fisheries. Fisheries 1-4 are the 'real' fisheries, and Fisheries 13-16 are the corresponding discard fisheries. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 2.3. Pesos de atún aleta amarilla descartado como proporciones de las capturas anuales totales (retenidas más descartadas) de las cuatro pesquerías sobre objetos flotantes. Las Pesquerías 1-4 son las pesquerías 'reales', y las Pesquerías 13-16 son las pesquerías de descarte correspondientes. Los números en los paneles corresponden a los números que designan las pesquerías en la Tabla 2.1.

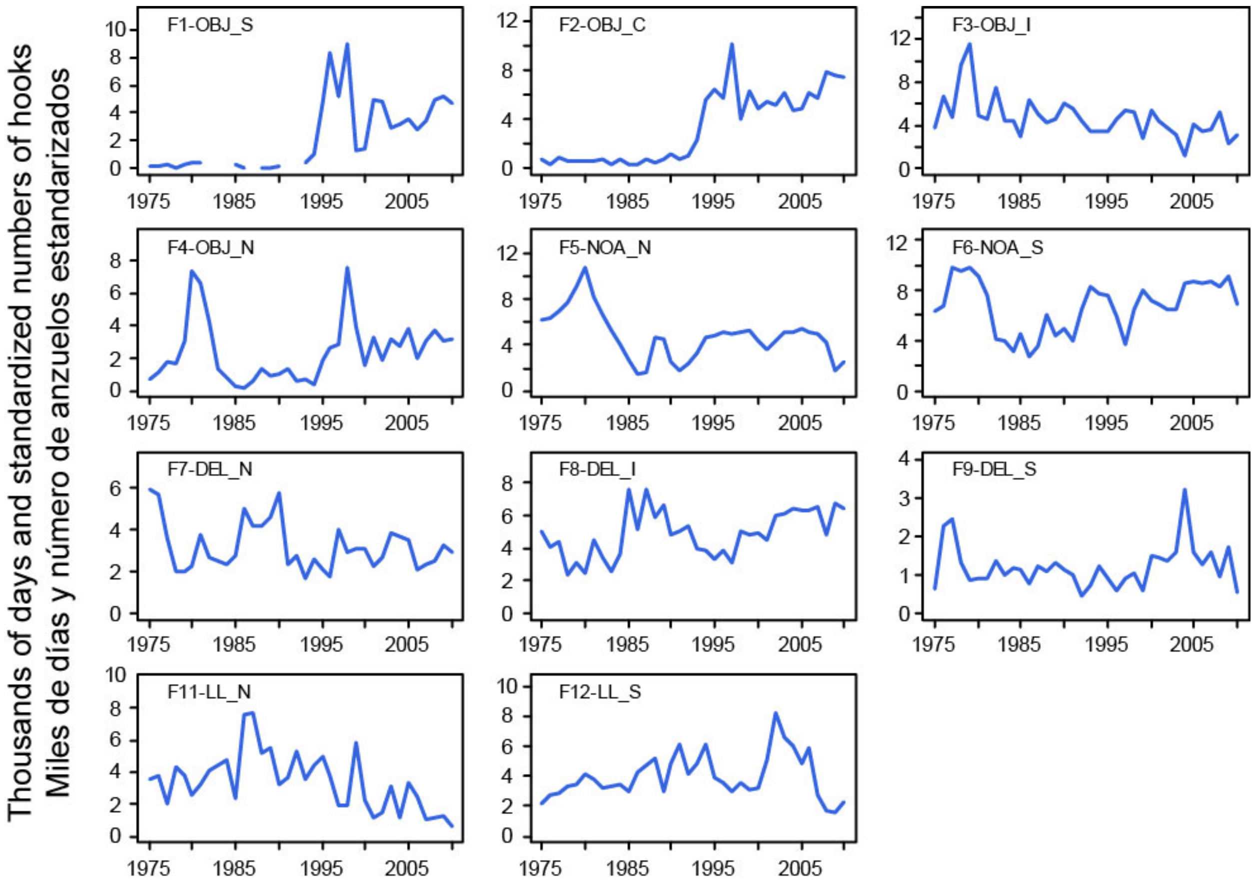

FIGURE 2.4. Annual fishing effort exerted by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). The effort for Fisheries 1-10 and 13-16 is in days fished, and that for Fisheries 11 and 12 is in standardized numbers of hooks. Fishing effort for the discard fisheries (13-16) is that of their corresponding 'real' fisheries' (1-4). Note that the vertical scales of the panels are different. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 2.4. 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 de anzuelos estandarizados. Nótese que las escalas verticales de los recuadros son diferentes. Los números de los paneles corresponde a los números que designan las pesquerías en la Tabla 2.1.

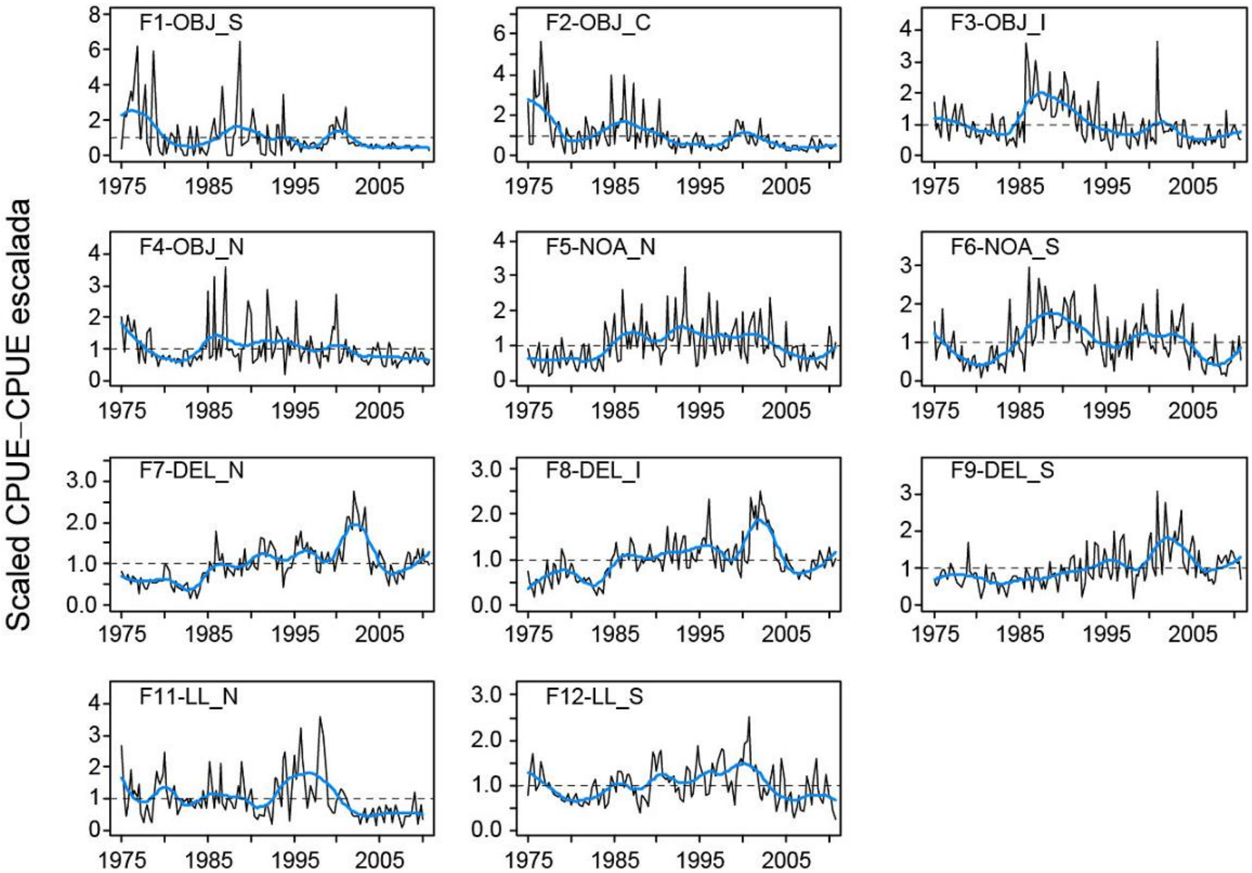

FIGURE 2.5. Quarterly CPUEs for the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of CPUE for each year. The CPUEs for Fisheries 1-9 are in tons per day fished, and those for Fisheries 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 2.5. 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 toneladas 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.

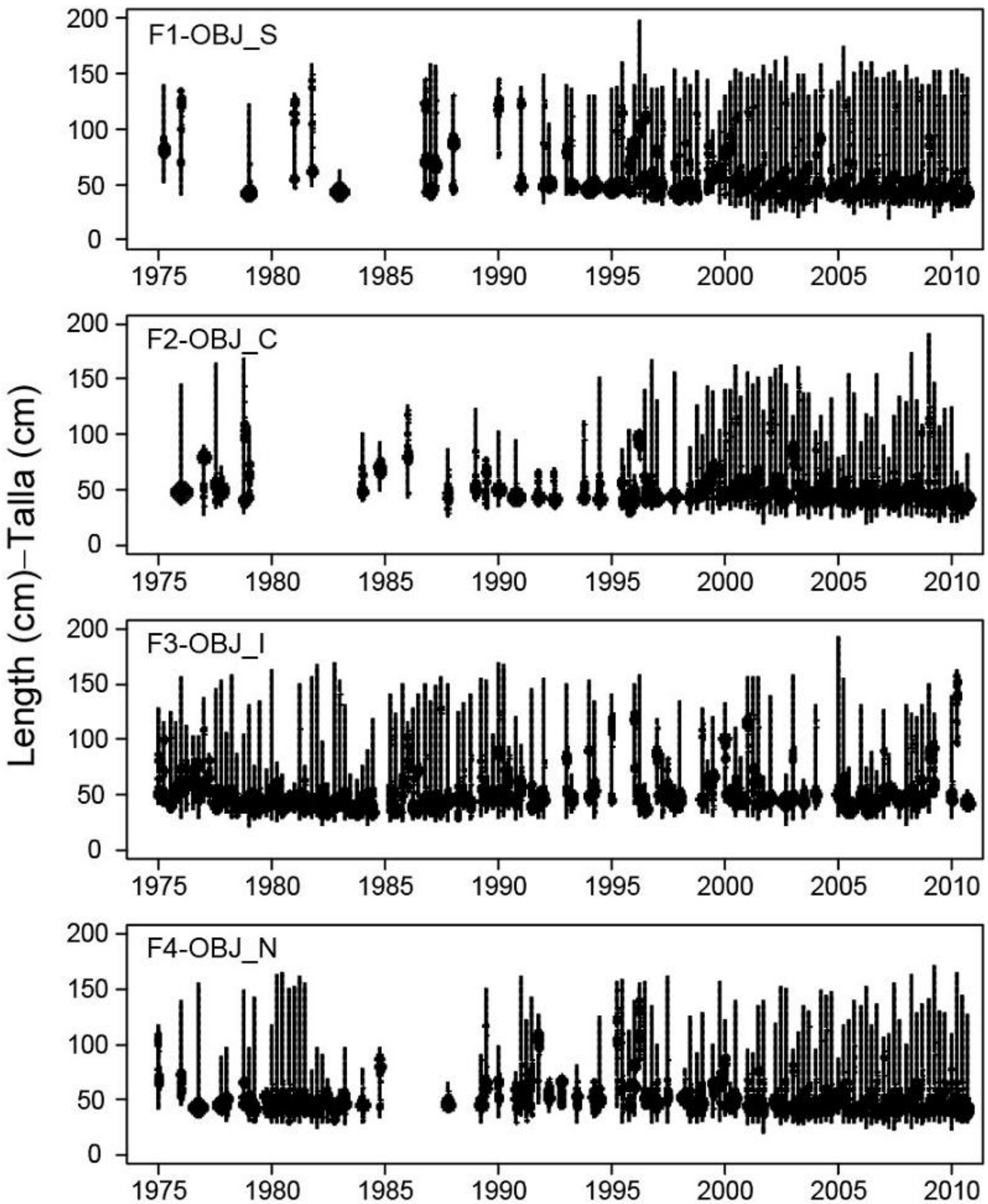

FIGURE 2.6a. Observed length compositions of the catches of yellowfin tuna taken by the floating-object fisheries, by quarter. The areas of the circles are proportional to the catches.
FIGURA 2.6a. Composición por talla observada de las capturas de atún aleta amarilla por las pesquerías sobre objetos flotantes, por trimestre. El tamaño de los círculos es proporcional a las capturas.

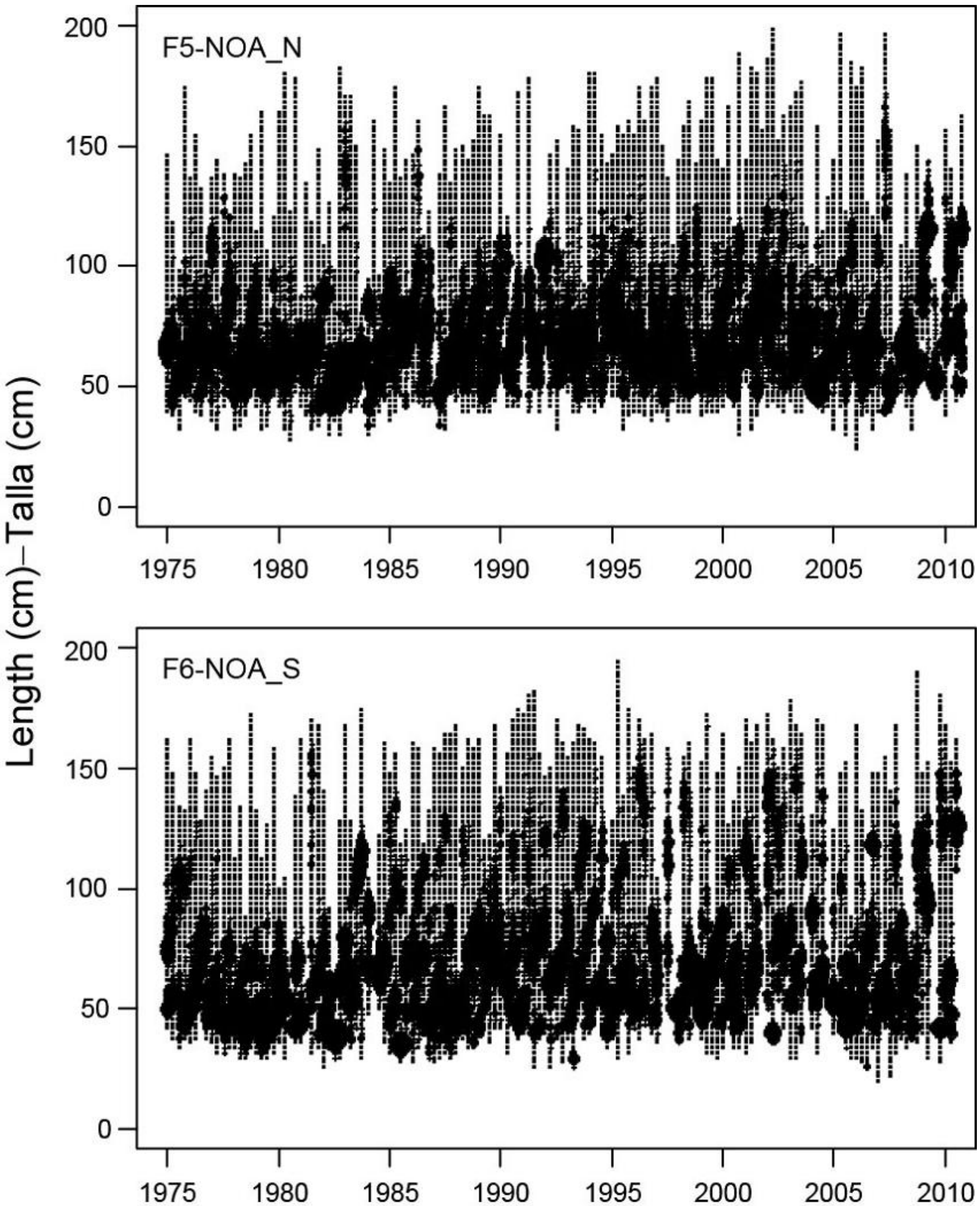

FIGURE 2.6b. Observed length compositions of the catches of yellowfin tuna taken by the unassociated fisheries, by quarter. The areas of the circles are proportional to the catches.
FIGURA 2.6b. Composición por talla observada de las capturas de atún aleta amarilla por las pesquerías no asociadas, por trimestre. El tamaño de los círculos es proporcional a las capturas.

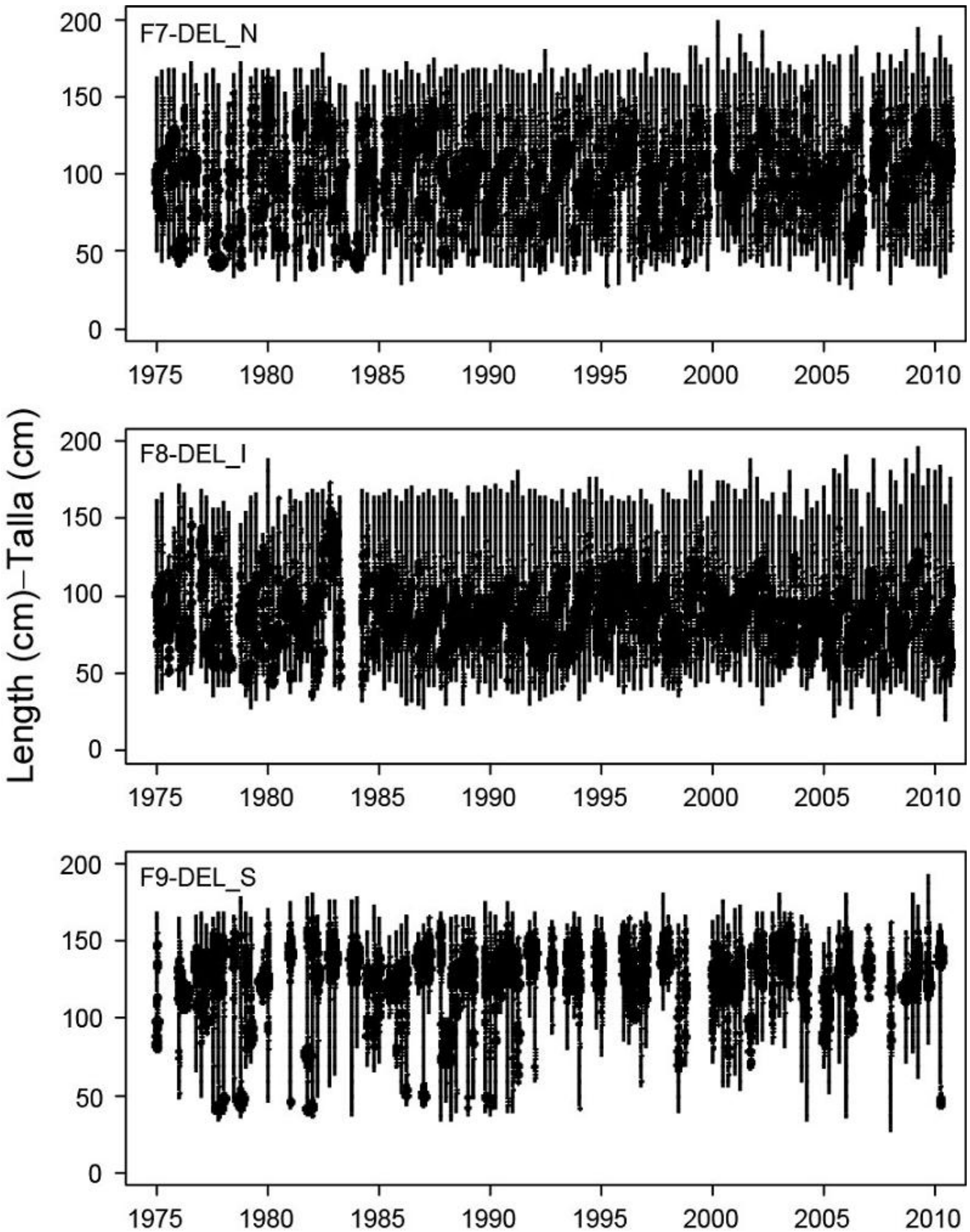

FIGURE 2.6c. Observed length compositions of the catches of yellowfin tuna taken by the dolphin-associated purse-seine fisheries, by quarter. The areas of the circles are proportional to the catches.
FIGURA 2.6c. Composición por talla observada de las capturas de atún aleta amarilla por las pesquerías de cerco asociadas con delfines, por trimestre. El tamaño de los círculos es proporcional a las capturas.

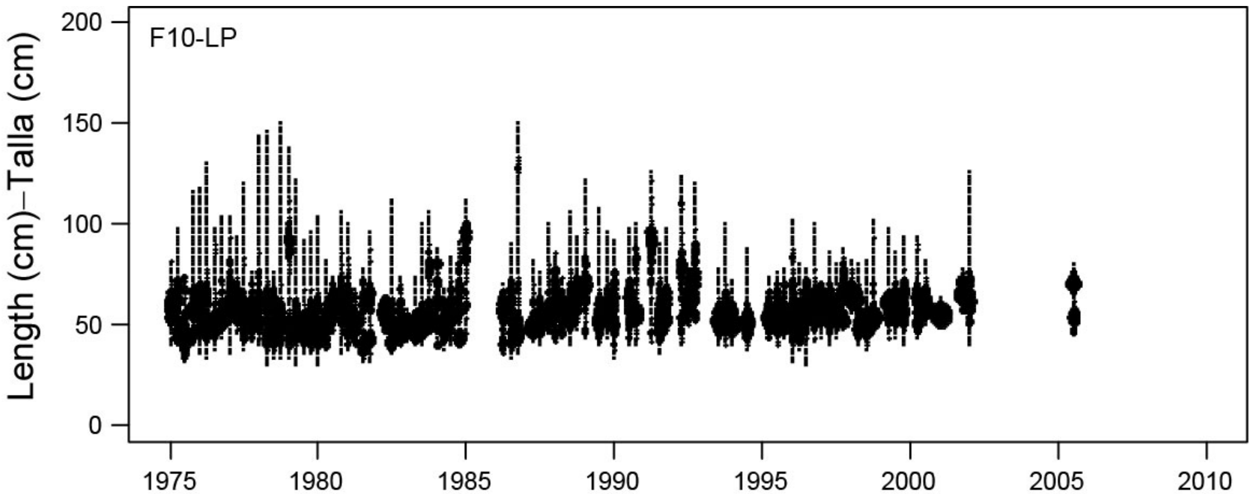

FIGURE 2.6d. Observed length compositions of the catches of yellowfin tuna taken by the pole-and-line fishery, by quarter. The areas of the circles are proportional to the catches.
FIGURA 2.6d. Composición por talla observada de las capturas de atún aleta amarilla por la pesquería cañera, por trimestre. El tamaño de los círculos es proporcional a las capturas.

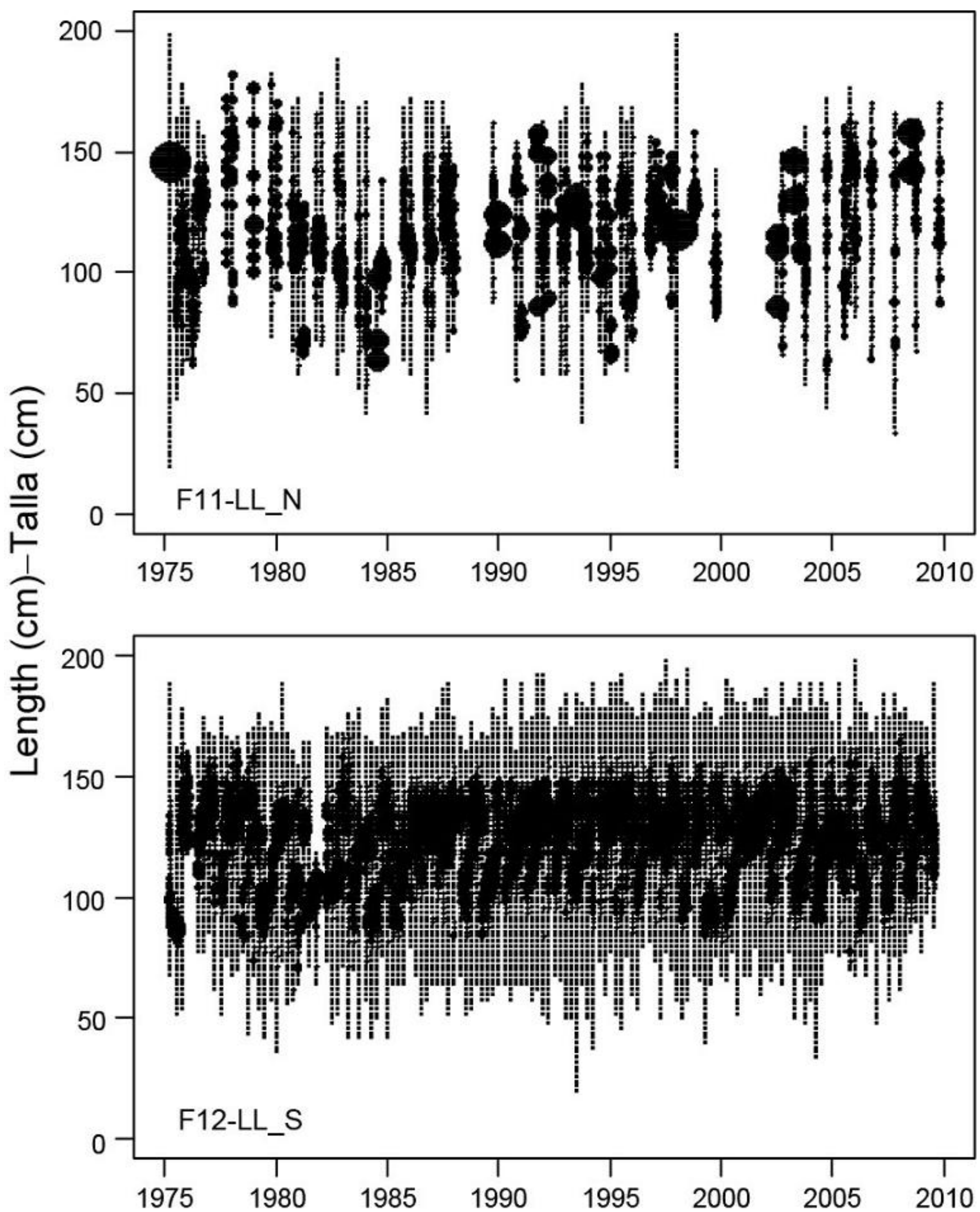

FIGURE 2.6e. Observed length compositions of the catches of yellowfin tuna taken by the longline fisheries, by quarter. The areas of the circles are proportional to the catches.

FIGURA 2.6e. 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.

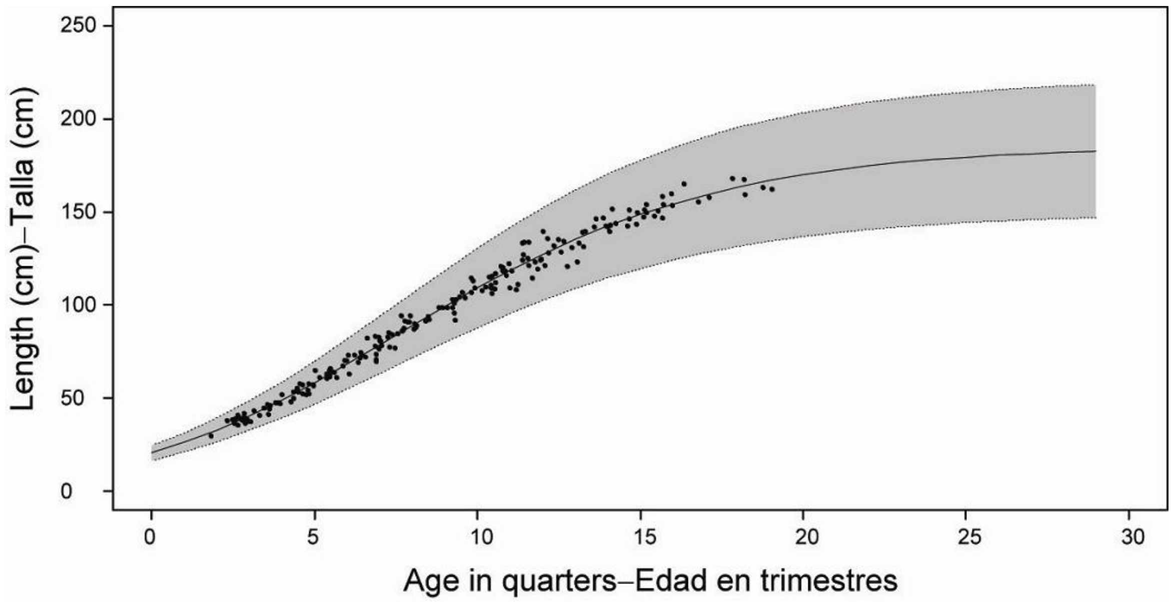

FIGURE 3.1. Growth curve estimated for the assessment of yellowfin tuna in the EPO. The points represent length-at-age data from otoliths (Wild 1986). The shaded region represents the assumed variation in length at age (± 2 standard deviations).
FIGURA 3.1. Curva de crecimiento estimada para la evaluación del atún aleta amarilla en el OPO. Los puntos representan los datos de talla por edad de otolitos (Wild 1986). La región sombreada representa la variación supuesta de la talla por edad (± 2 desviaciones estándar).

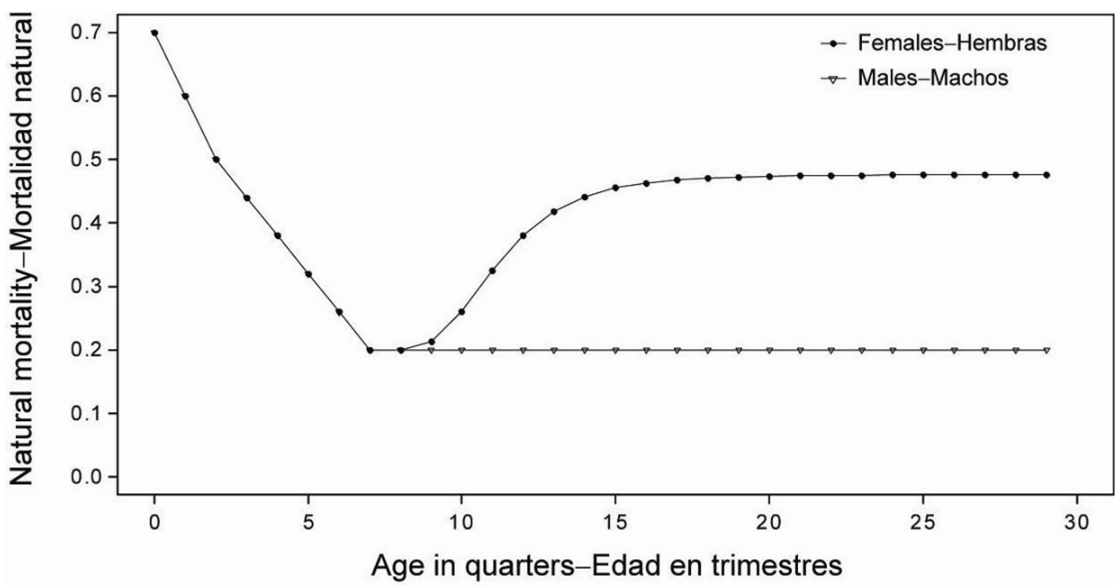

FIGURE 3.2. Rates of natural mortality (*M*) rates, at quarterly intervals, used for the assessment of yellowfin tuna in the EPO. Descriptions of the three phases of the mortality curve are provided in Section 3.1.2.
FIGURA 3.2. Tasas de mortalidad natural (*M*), por intervalo trimestral, usadas para la evaluación del atún aleta amarilla en el OPO. En la Sección 3.1.2 se describen las tres fases de la curva de mortalidad.

FIGURE 3.3. Relative fecundity-at-age curve (from Schaefer 1998) used to estimate the index of spawning biomass of yellowfin tuna in the EPO.
FIGURA 3.3. Curva de fecundidad relativa por edad (de Schaefer 1998) usada para estimar el índice de biomasa reproductora del atún aleta amarilla en el OPO.

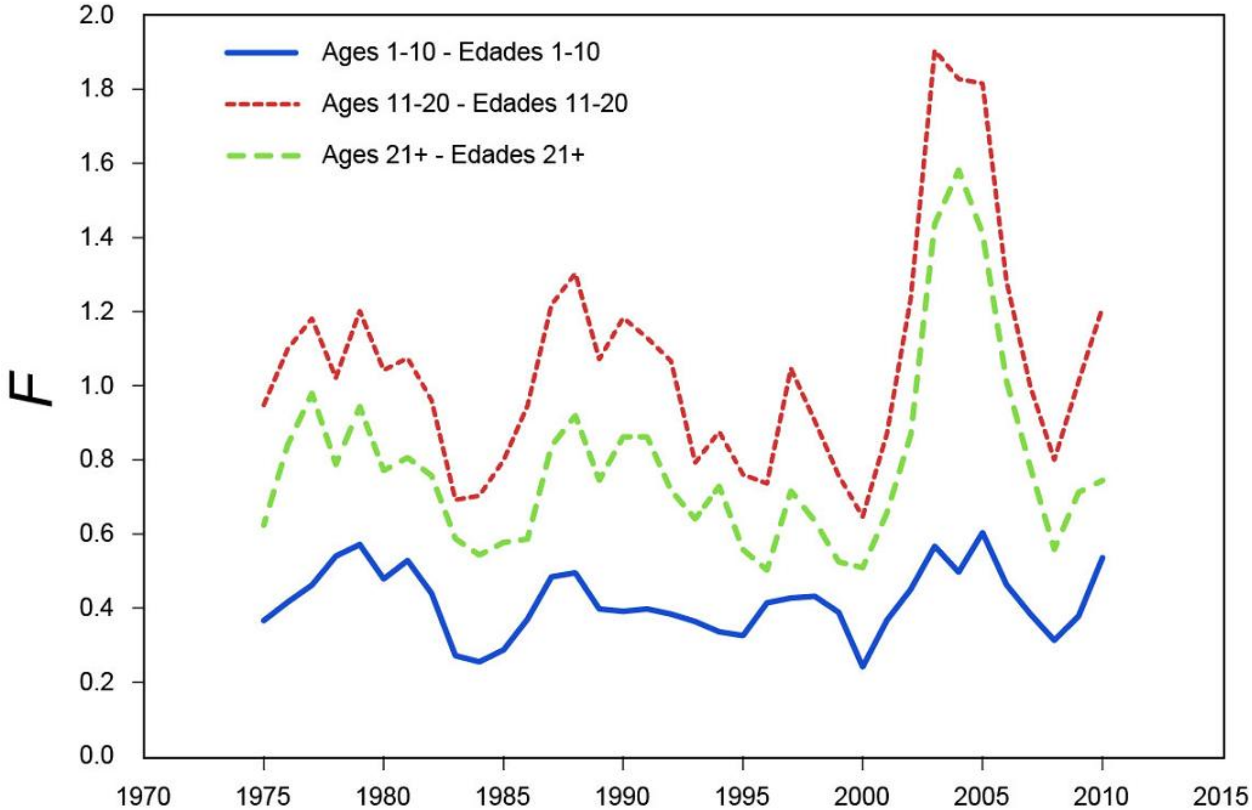

FIGURE 4.1. Average annual fishing mortality (*F*) by age groups, by all gears, of yellowfin tuna recruited to the fisheries of the EPO. The age groups are defined by age in quarters.

FIGURA 4.1. 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.

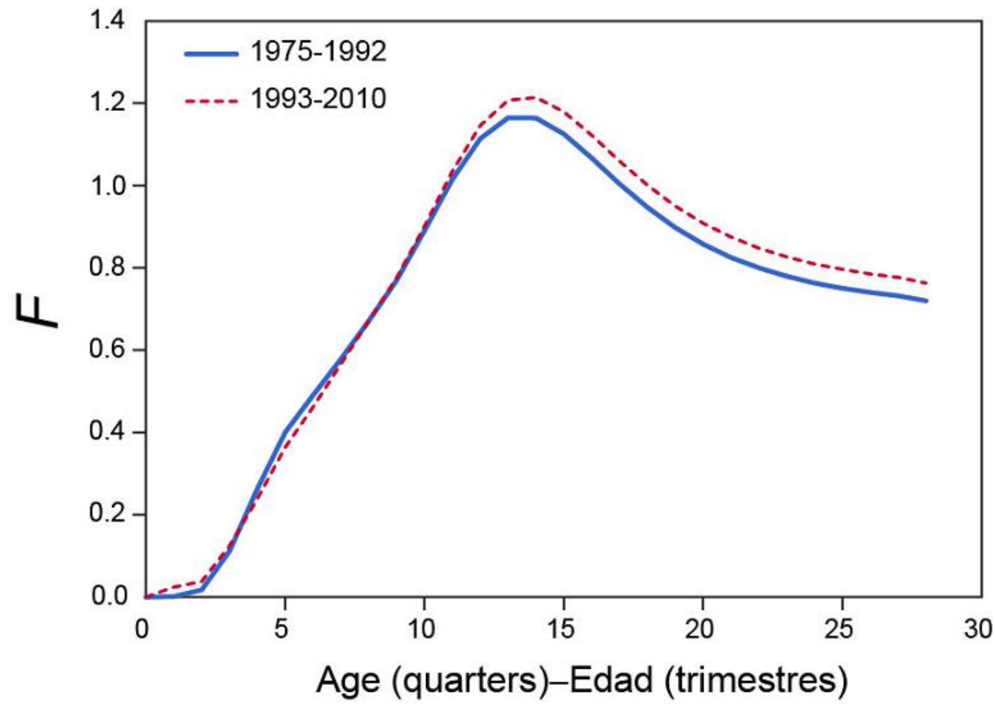

FIGURE 4.2a. Average annual fishing mortality (*F*) of yellowfin tuna by age in the EPO, by all gears. The estimates are presented for two periods, before and after the increase in effort associated with floating objects.

FIGURA 4.2a. 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.

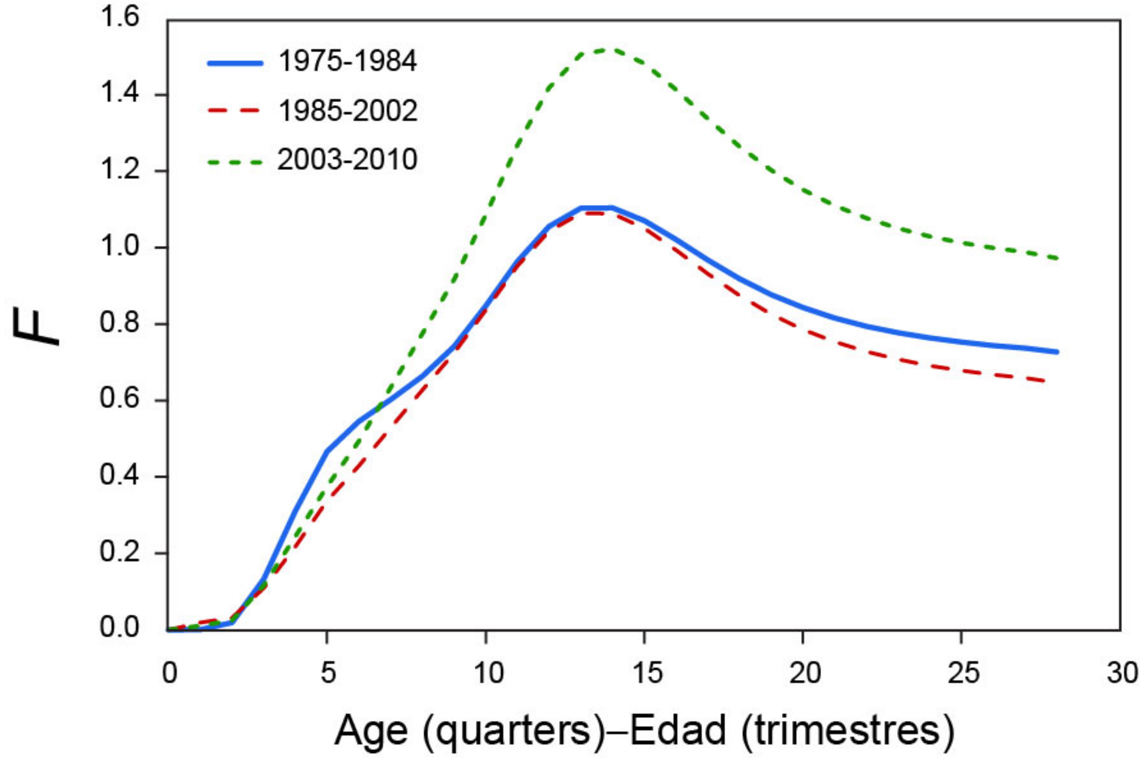

FIGURE 4.2b. Average annual fishing mortality (*F*) of yellowfin tuna by age in the EPO, by all gears. The estimates are presented for three periods corresponding to possible productivity regimes.
FIGURA 4.2b. Mortalidad por pesca (*F*) anual media de atún aleta amarilla por edad en el OPO, por todas las artes. Se presentan estimaciones para tres períodos correspondientes a posibles regímenes de productividad.

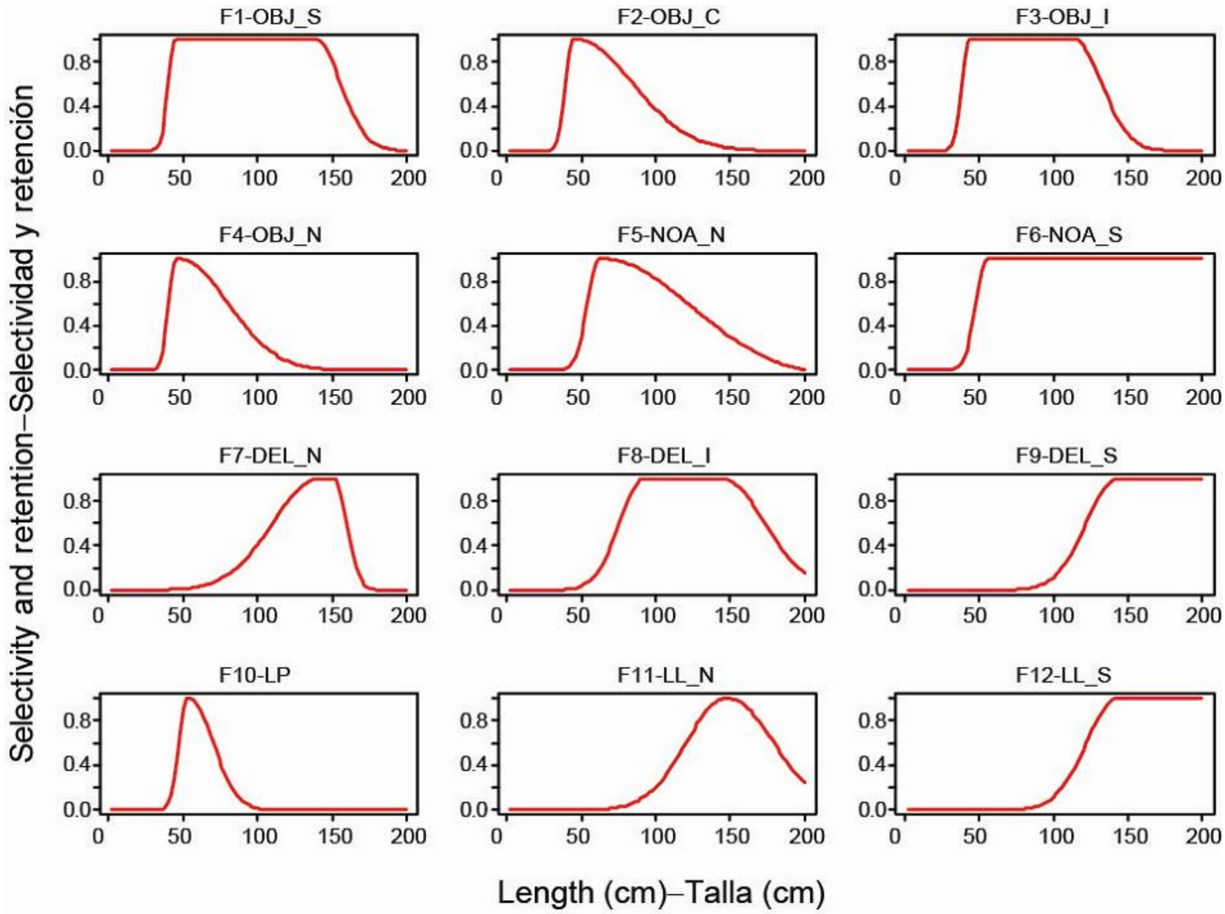

FIGURE 4.3. Selectivity curves for 12 of the 16 fisheries that catch yellowfin tuna in the EPO. The selectivity curves for the discard fisheries (Fisheries 13-16) are fixed at assumed values.

FIGURA 4.3. 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.

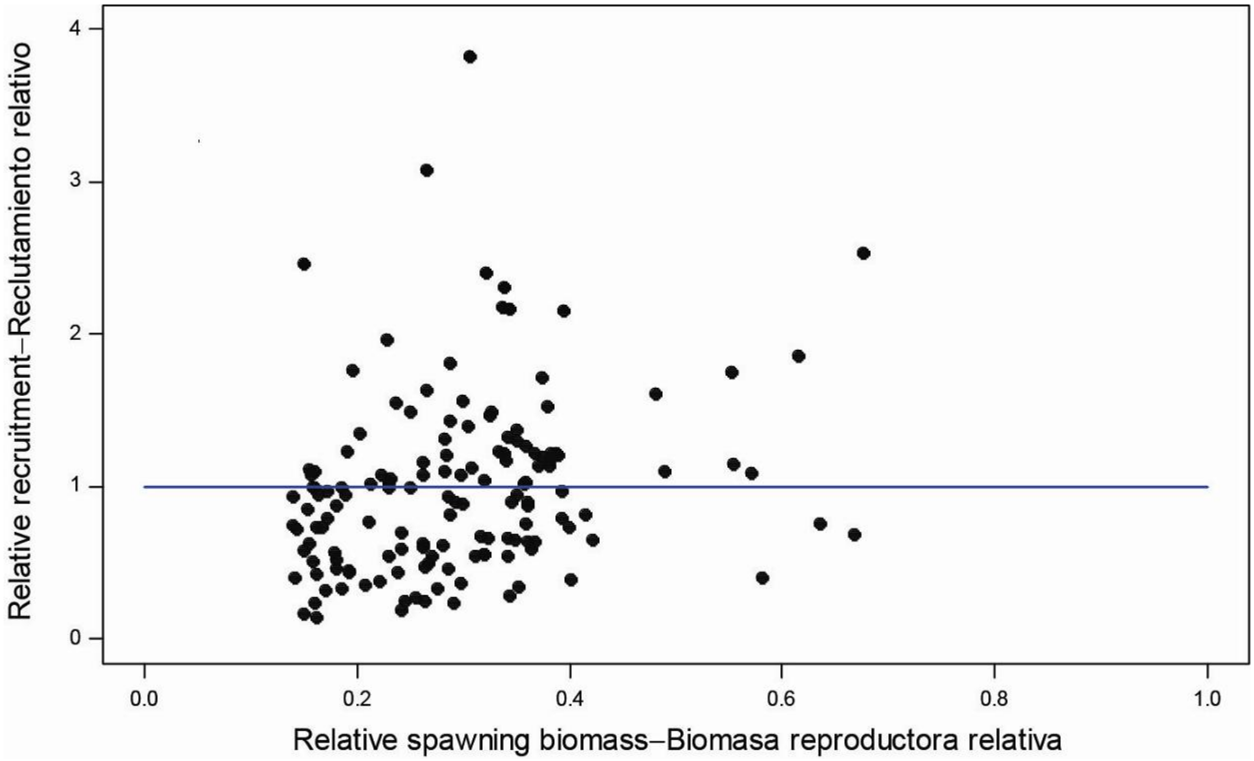

FIGURE 4.4. Estimated relationship between recruitment and spawning biomass of yellowfin tuna. The recruitment is scaled so that the average recruitment is equal to 1.0. The spawning biomass is scaled so that the average unexploited spawning biomass is equal to 1.0.

FIGURA 4.4. 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.

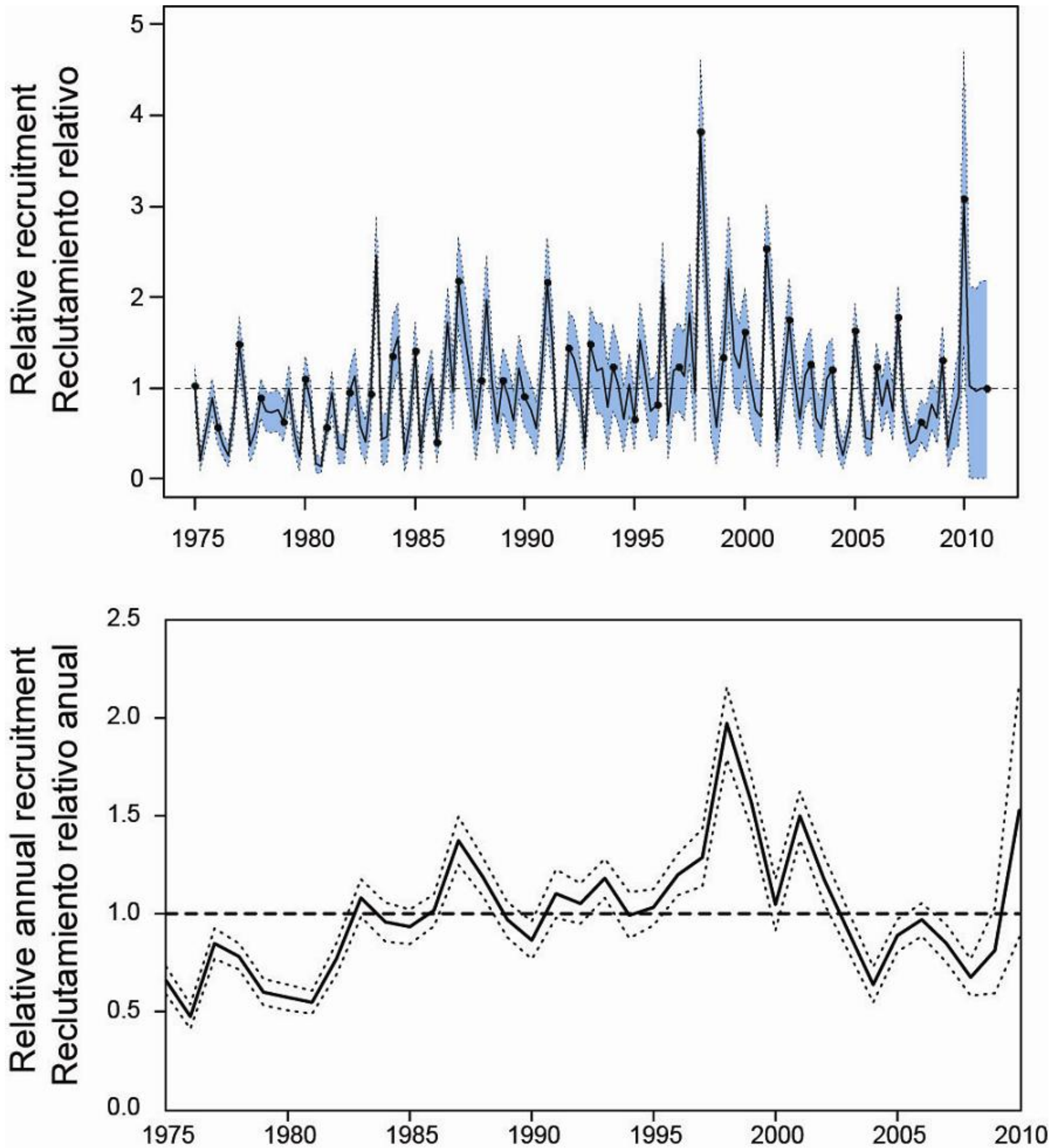

FIGURE 4.5. Estimated recruitment of yellowfin tuna to the fisheries of the EPO: a) quarterly recruitment; b) annual recruitment. The estimates are scaled so that the average recruitment is equal to 1.0 (dashed horizontal line). The bold line illustrates the maximum likelihood estimates of recruitment, 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 in the quarterly recruitmet figure a).

FIGURA 4.5. Reclutamiento (a) trimestral y (b) anual 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.

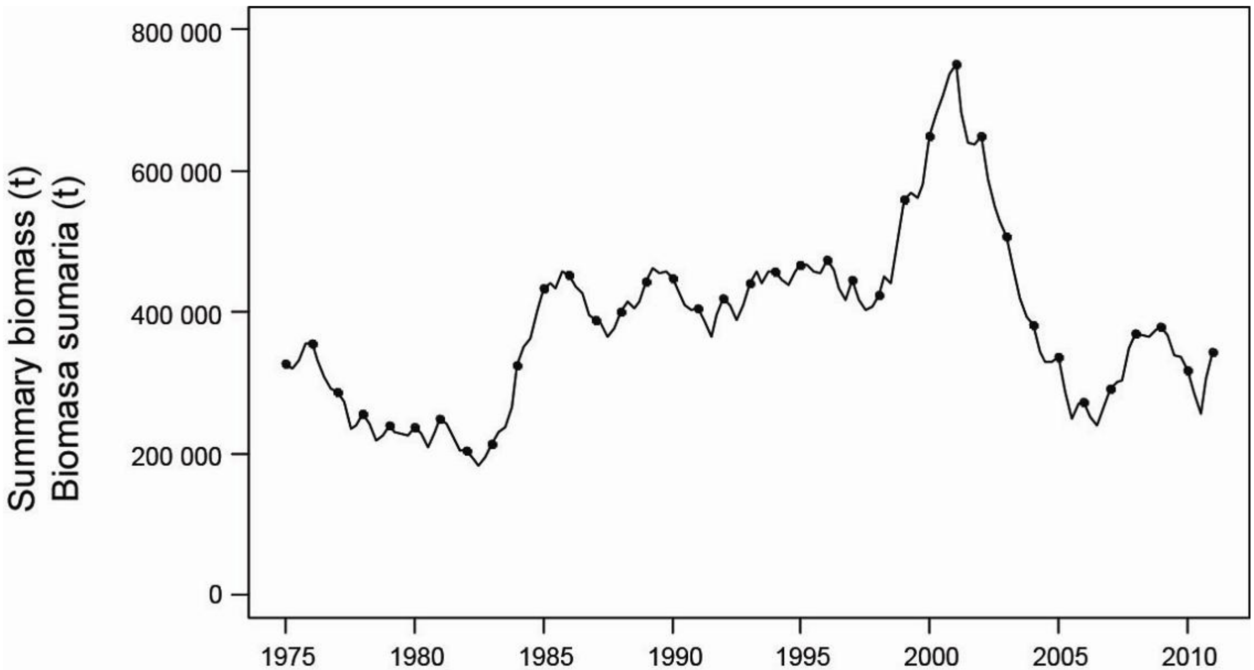

FIGURE 4.6. Estimated biomass of yellowfin tuna aged three quarters and older in the EPO. The line illustrates the maximum likelihood estimates of the biomass. Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year.

FIGURA 4.6. 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.

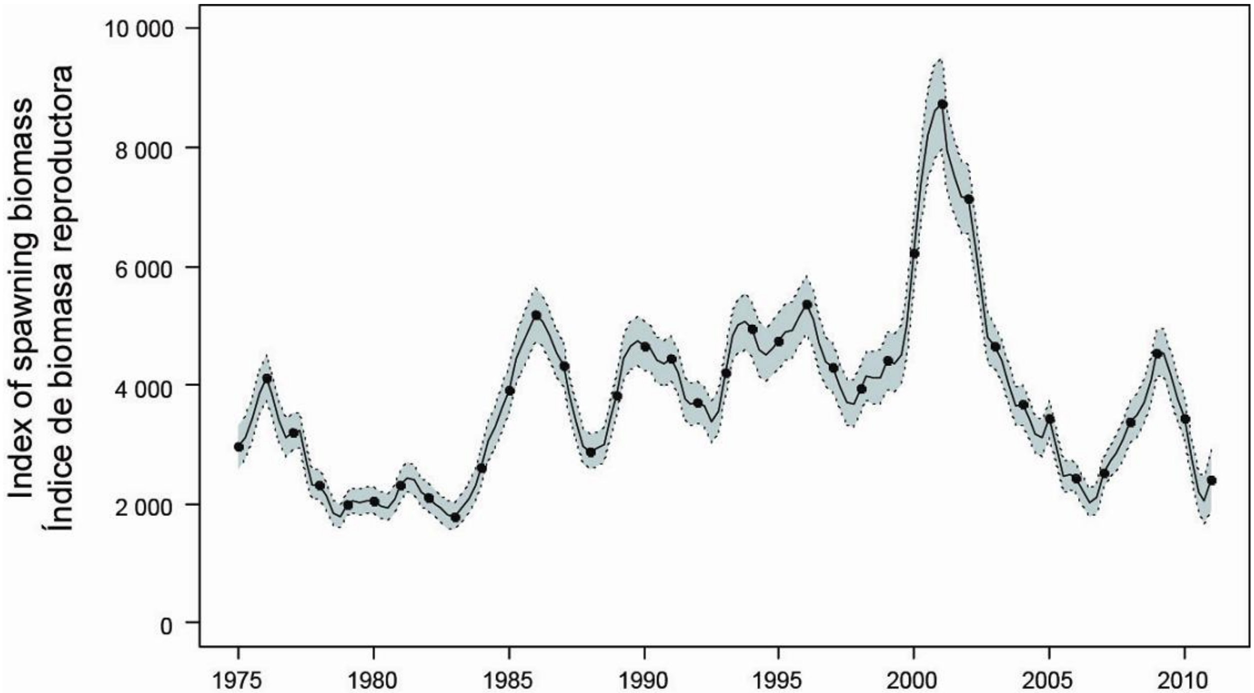

FIGURE 4.7. Estimated index of spawning biomass of yellowfin tuna in the EPO. The solid line illustrates the maximum likelihood estimates of the biomass, and the dashed lines the approximate 95% confidence intervals around those estimates. Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year.

FIGURA 4.7. 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 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.

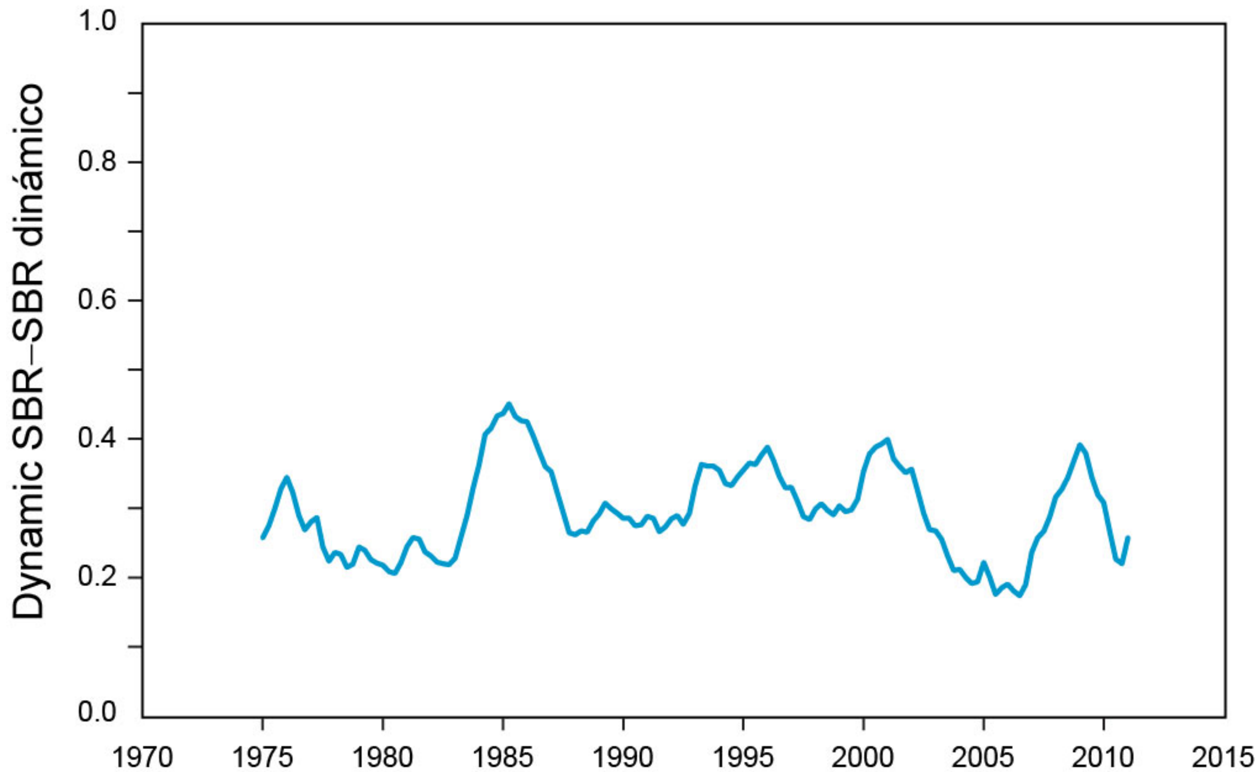

FIGURE 4.8a. Spawning biomass as a ratio of the trajectory of spawning biomass simulated from a population of yellowfin tuna that was never exploited. Dynamic SBR is the spawning biomass as a ratio of the unfished spawning biomass calculated by modeling the population over time in the absence of fishing.

FIGURA 4.8a. 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 a lo largo del tiempo en la ausencia de pesca.

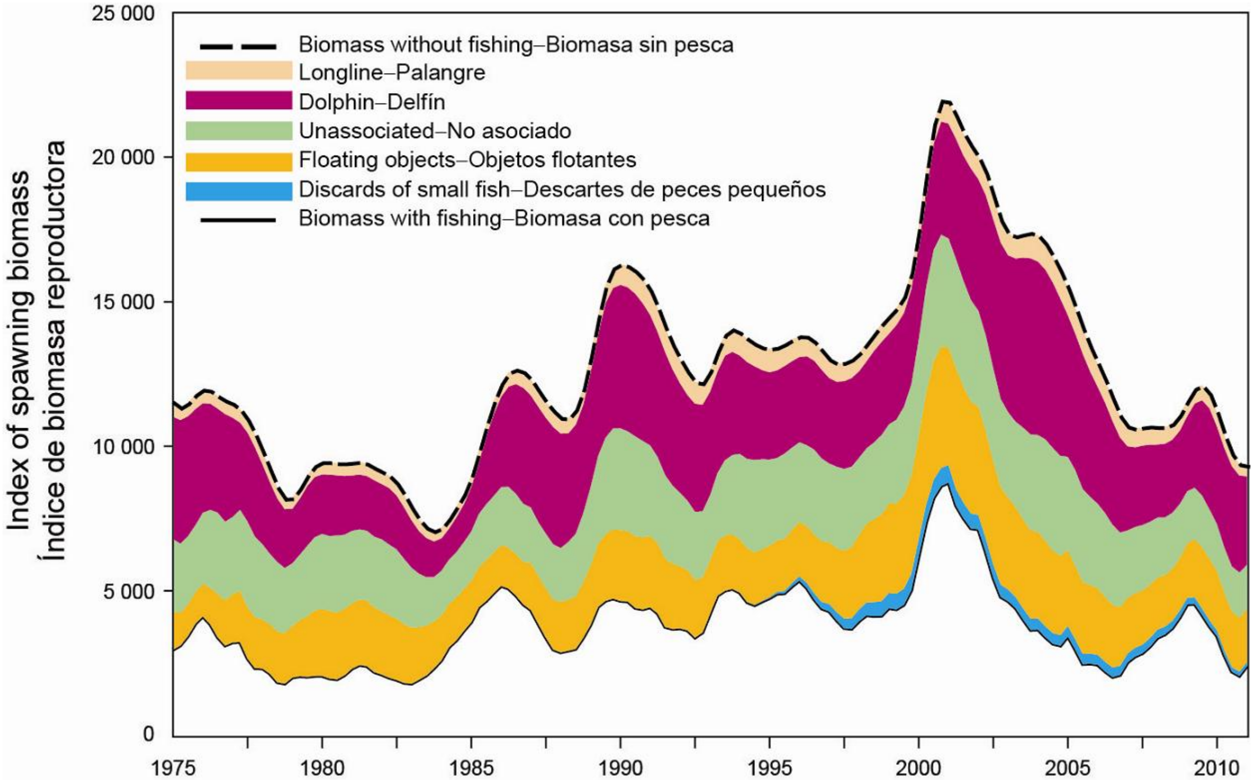

FIGURE 4.8b. Biomass trajectory of a simulated population of yellowfin tuna that was never exploited (dashed line) and that predicted by the stock assessment model (solid line). The shaded areas between the two lines show the portions of the fishery impact attributed to each fishing method.

FIGURA 4.8b. 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 (línea sólida). Las áreas sombreadas entre las dos líneas representan la porción del impacto de la pesca atribuida a cada método de pesca.

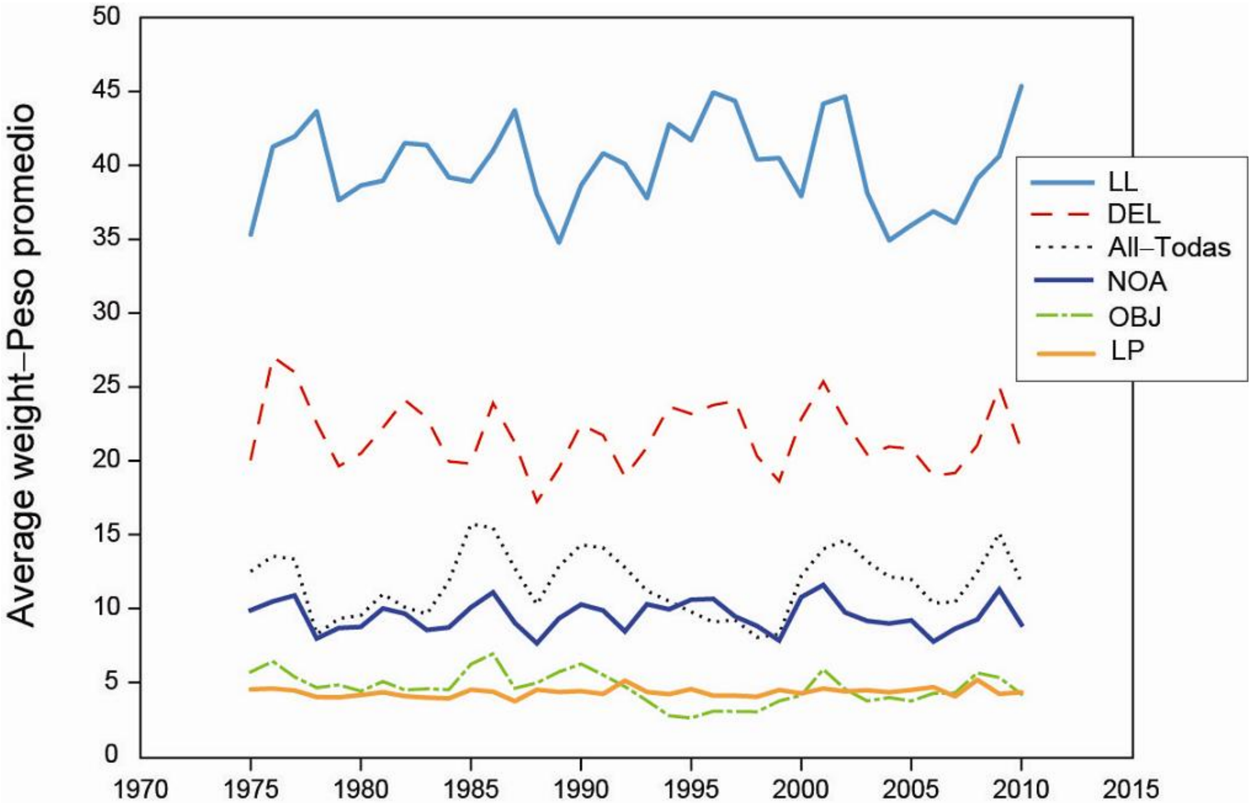

FIGURE 4.9. Estimated average weights of yellowfin tuna caught by the fisheries of the EPO (OBJ = purse-seine sets on floating objects; NOA = purse-seine sets on unassociated schools; DEL = purse-seine sets on schools associated with dolphins; LL = longline; All = all fisheries combined).

FIGURA 4.9. 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).

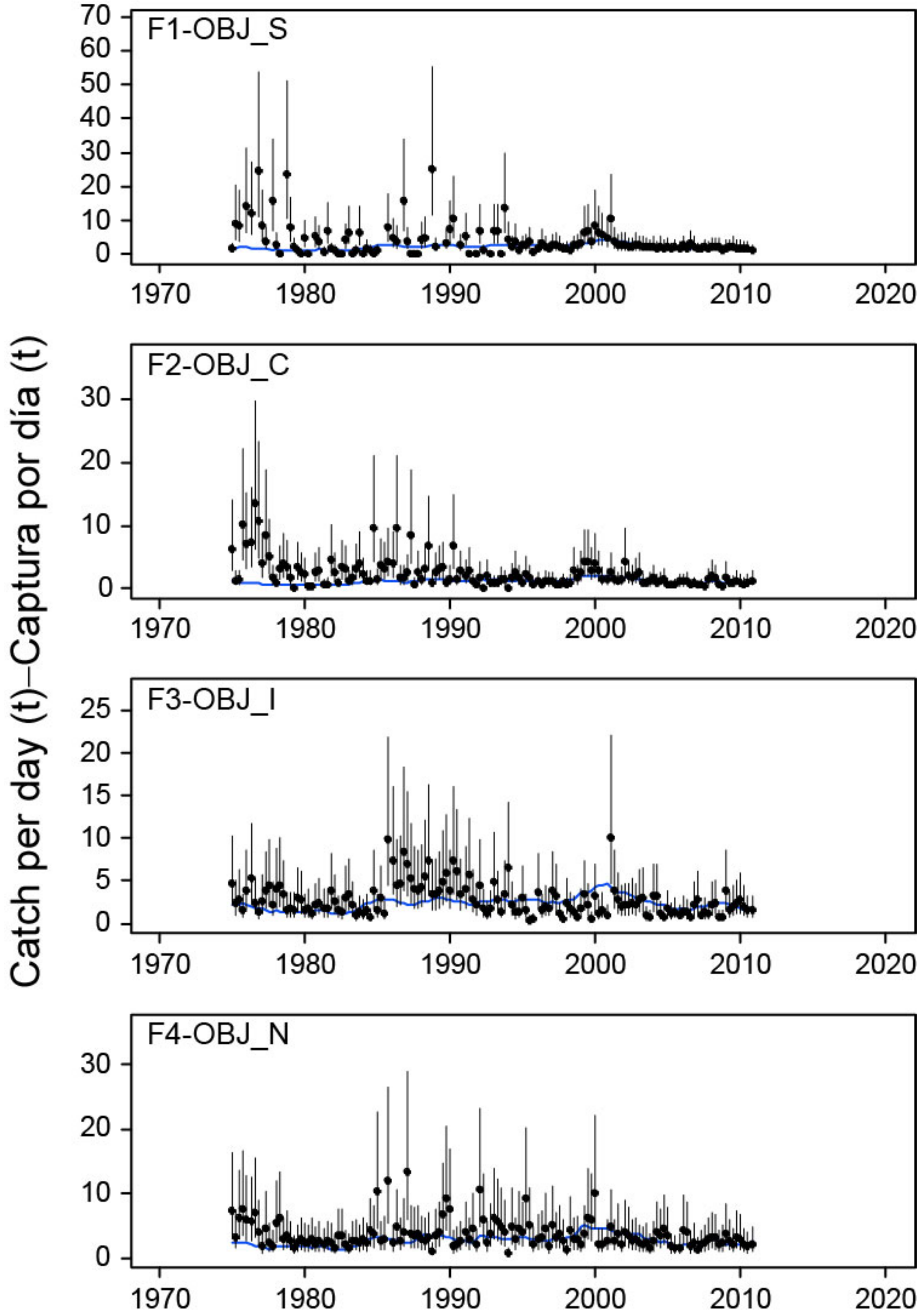

FIGURE 4.10a. Model fits to the CPUE-based indices of abundance for the floating-object fisheries. The vertical lines are the 95% confidence intervals for the observed data based on the internally-estimated standard deviations for the lognormal-based likelihood function.

FIGURA 4.10a. Ajustes a los índices de abundancia basados en CPUE correspondientes a las pesquerías sobre objetos flotantes. 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.

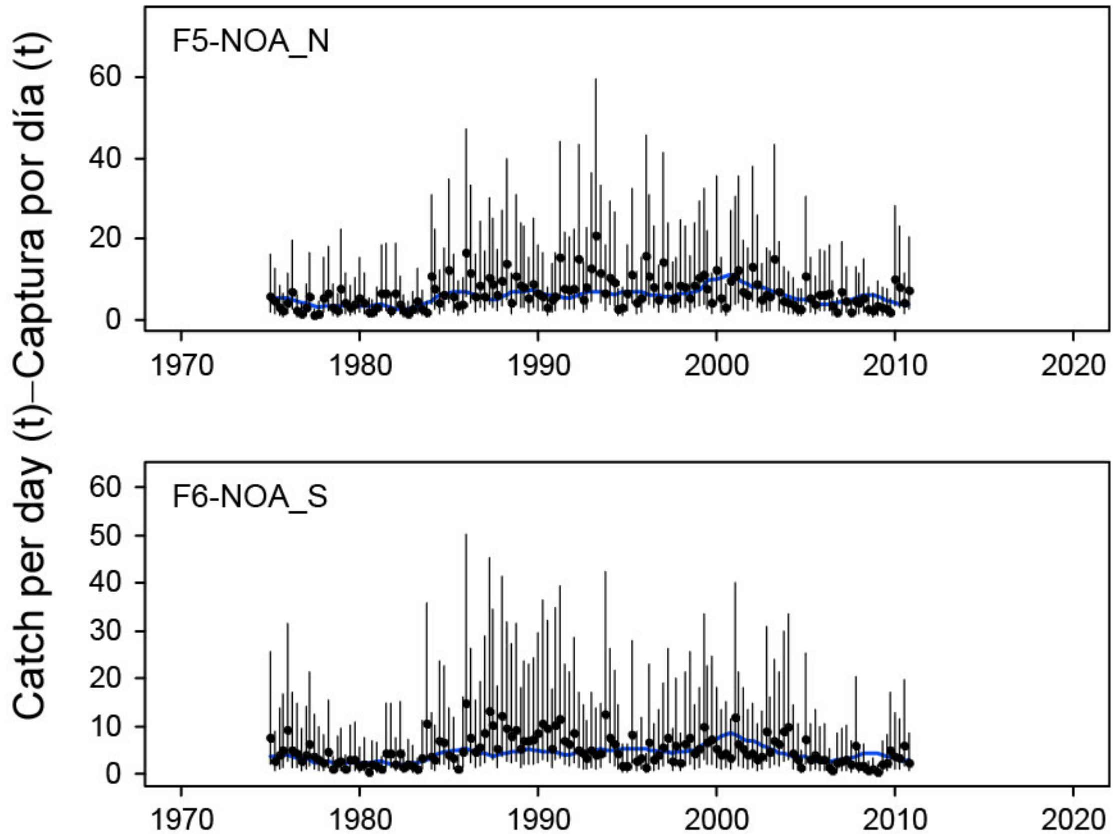

FIGURE 4.10b. Model fits to the CPUE based indices of abundance for the unassociated fisheries. The vertical lines are the 95% confidence intervals for the observed data based on the internally-estimated standard deviations for the lognormal-based likelihood function.

FIGURA 4.10b. Ajustes a los índices de abundancia basados en CPUE correspondientes a las pesquerías no asociadas. 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.

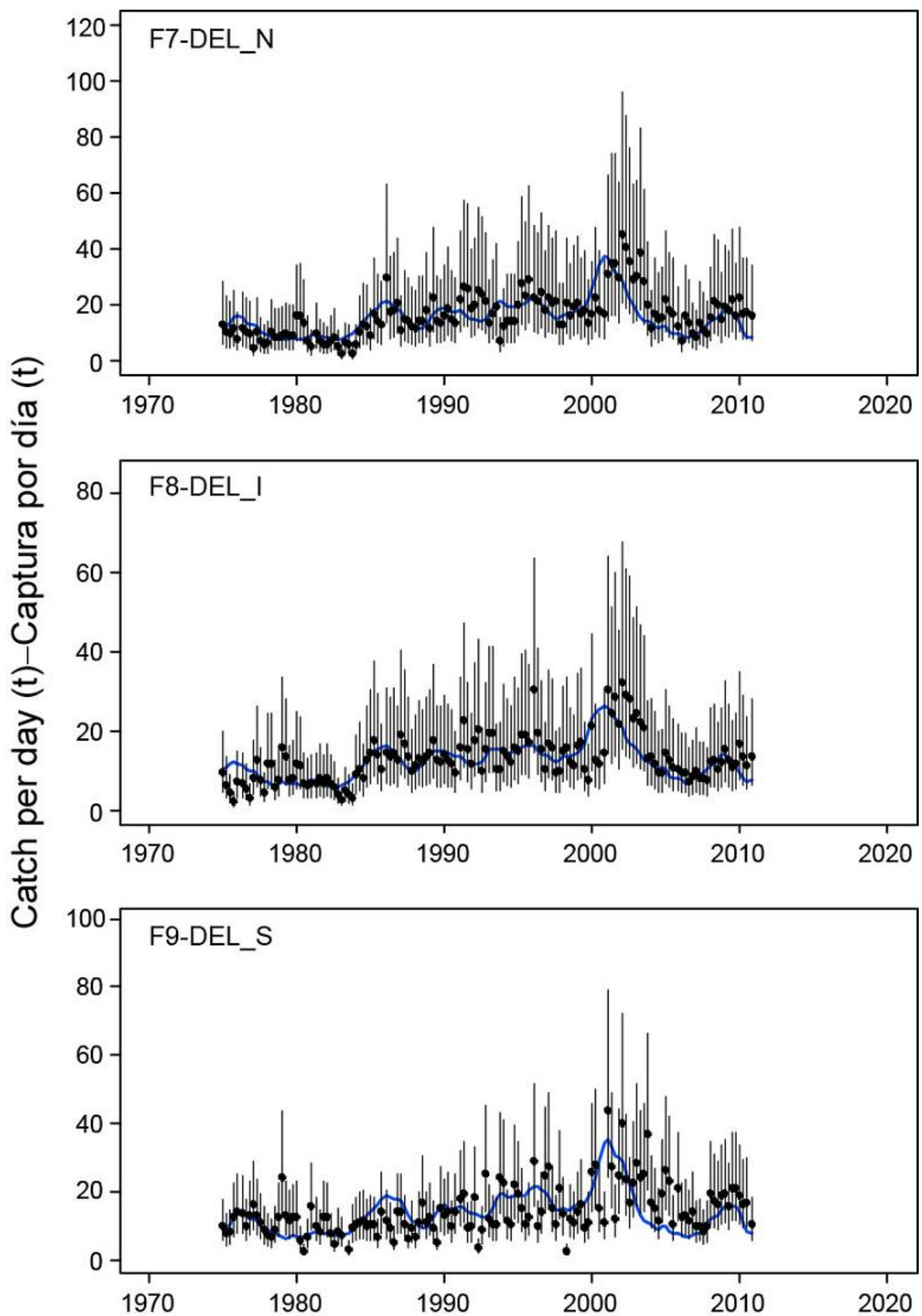

FIGURE 4.10c. Model fits to the CPUE based indices of abundance for the dolphin fisheries. The vertical lines are the 95% confidence intervals for the observed data based on the internally-estimated standard deviations for the lognormal-based likelihood function.

FIGURA 4.10c. Ajustes a los índices de abundancia basados en CPUE correspondientes a las pesquerías sobre delfines. 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.

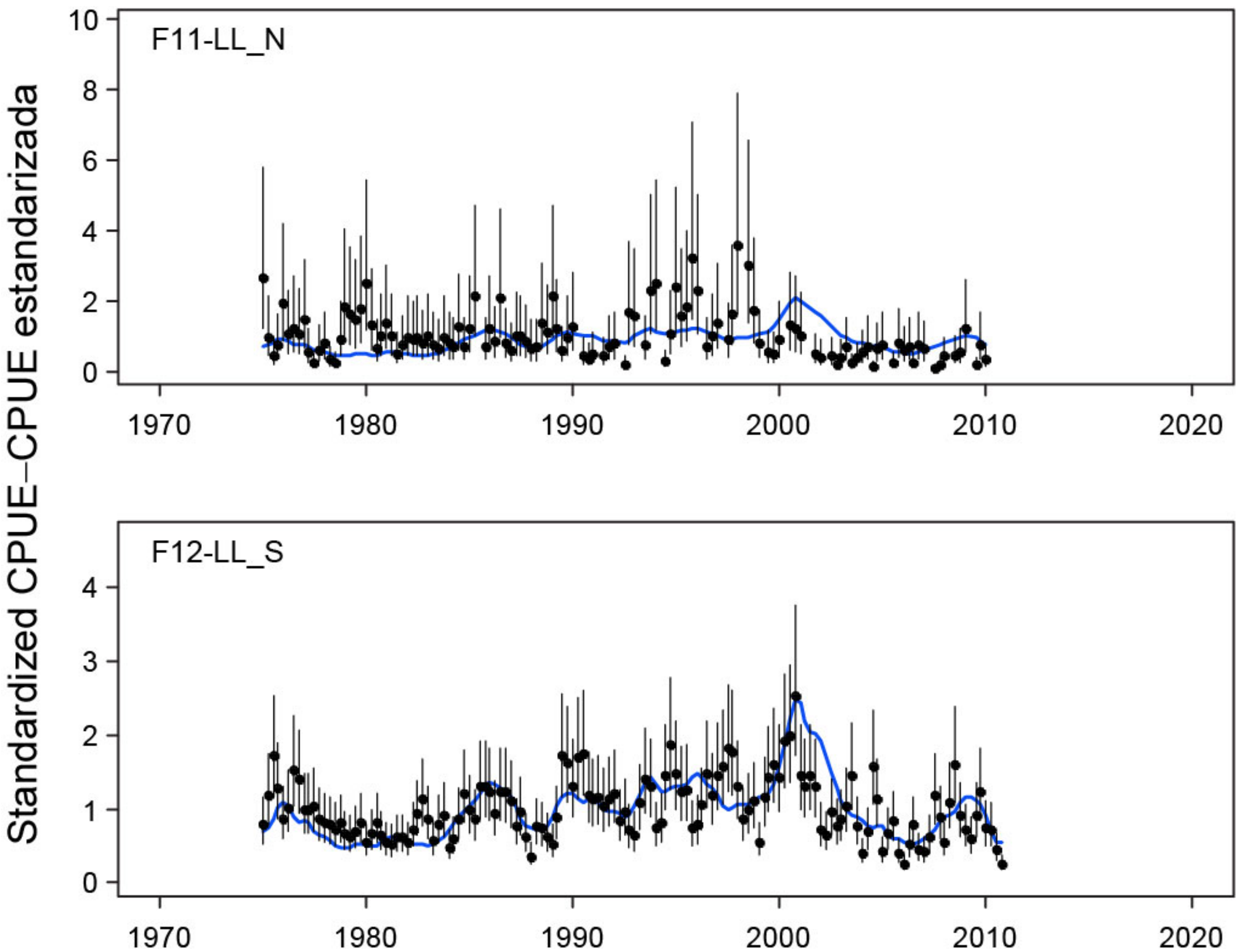

FIGURE 4.10d. Model fits to the CPUE based indices of abundance for the longline fisheries. The vertical lines are the 95% confidence intervals for the observed data based on the internally-estimated standard deviations for the lognormal-based likelihood function.
FIGURA 4.10d. Ajustes a los índices de abundancia basados en CPUE correspondientes a las pesquerías de palangre. 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.

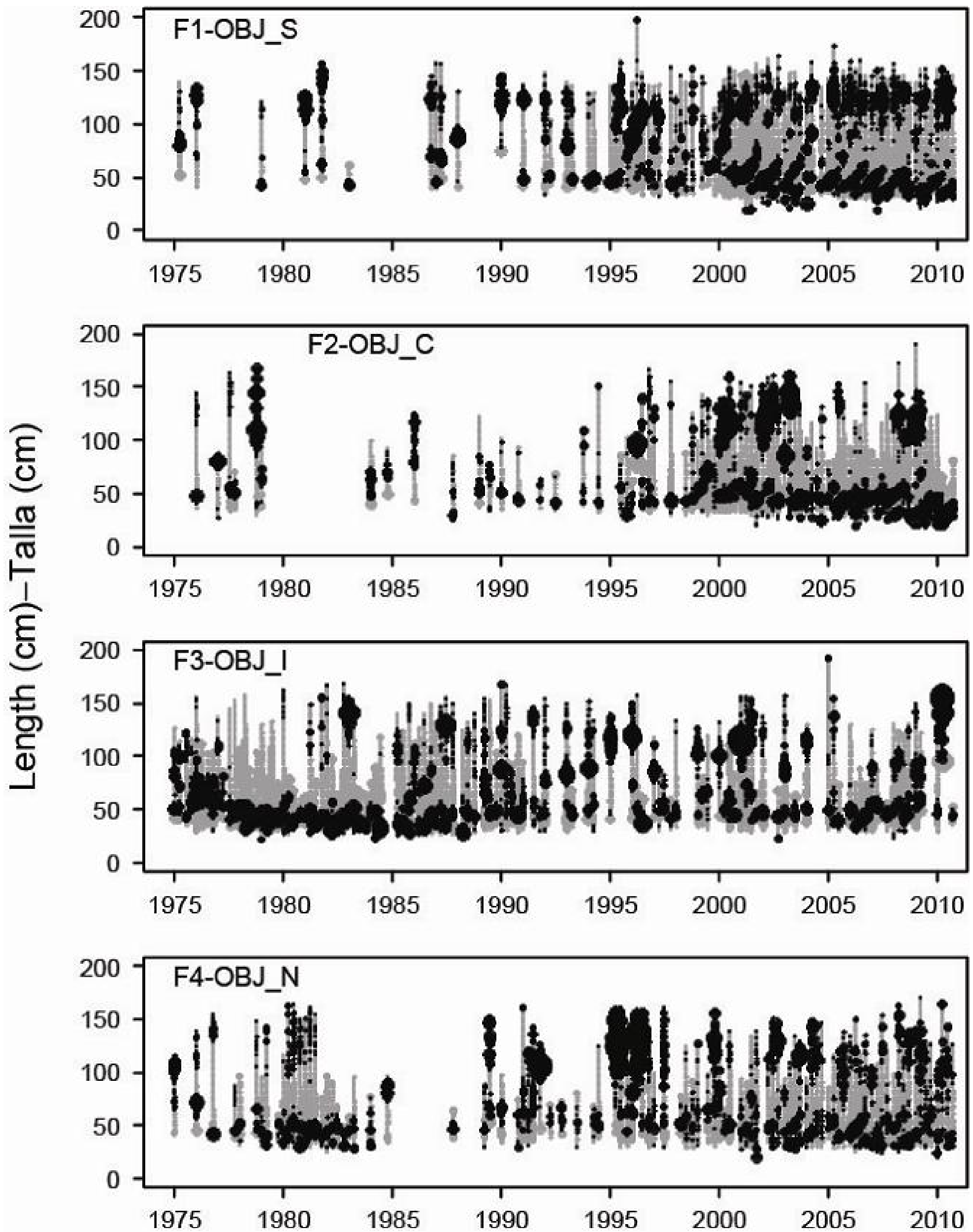

FIGURE 4.11a. Pearson residual plots for the model fits to the length-composition data for the floating-object fisheries. The black and grey circles represent observations that are higher and lower, respectively, than the model predictions. The areas of the circles are proportional to the absolute values of the residuals.

FIGURA 4.11a. 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.

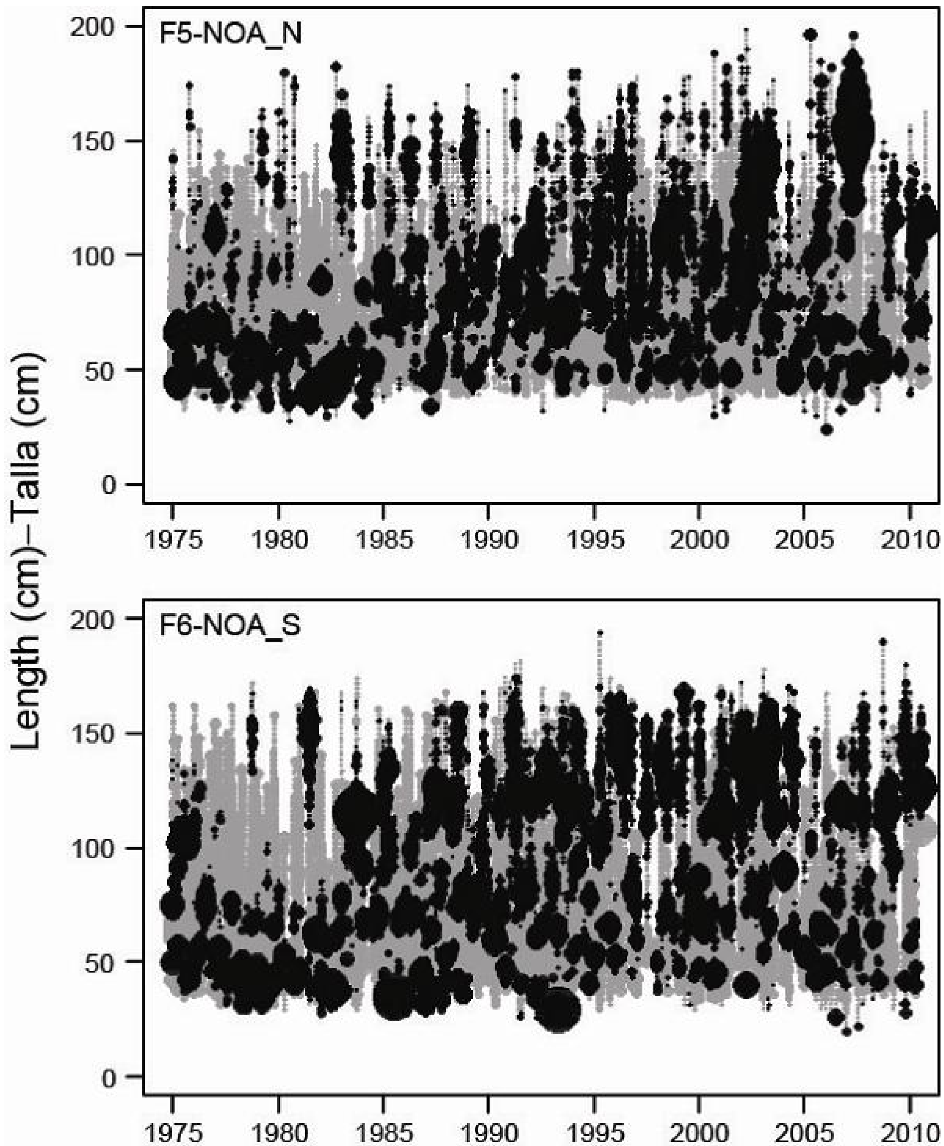

FIGURE 4.11b. Pearson residual plots for the model fits to the length-composition data for the unassociated fisheries. The black and grey circles represent observations that are higher and lower, respectively, than the model predictions. The areas of the circles are proportional to the absolute values of the residuals.

FIGURA 4.11b. 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.

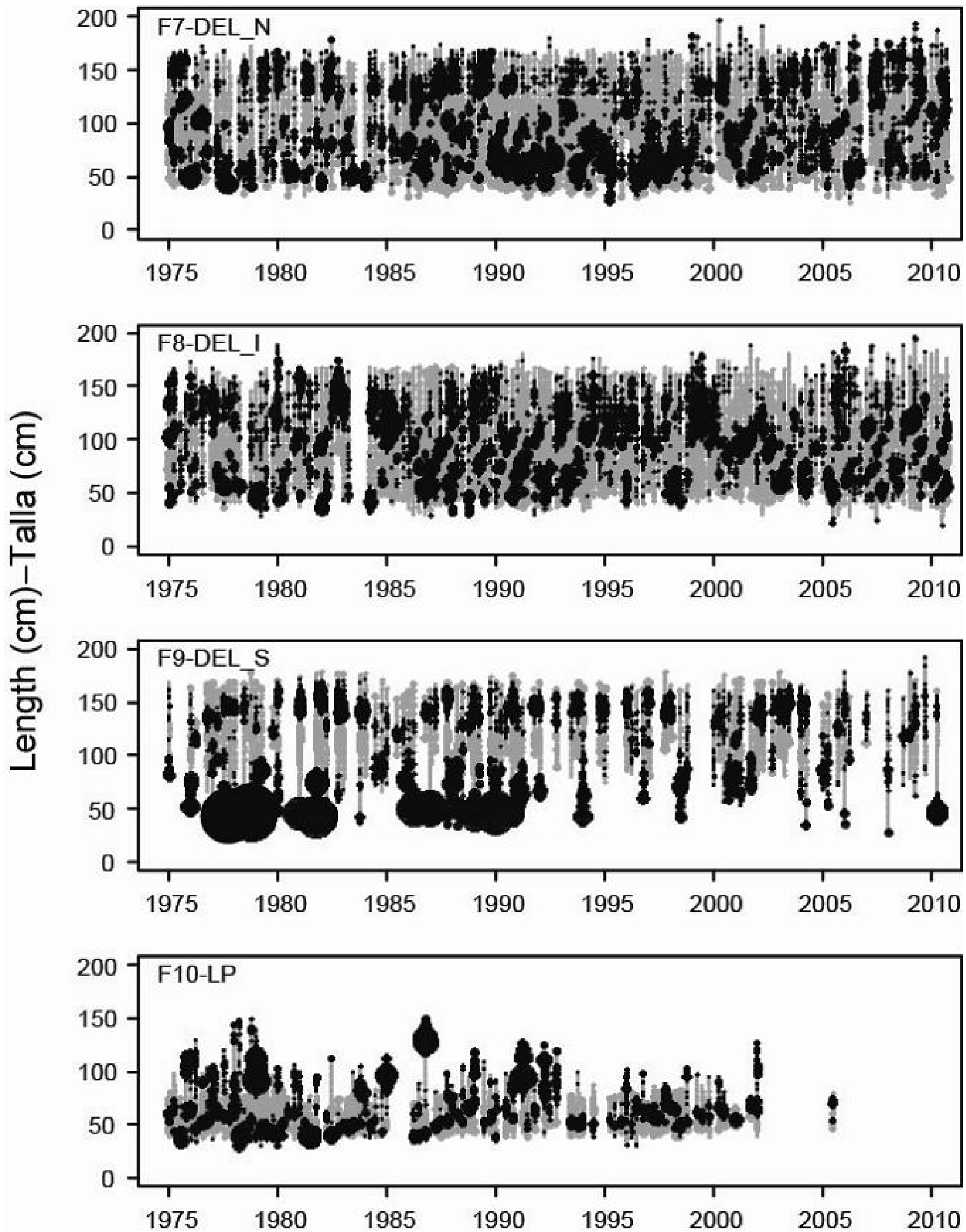

FIGURE 4.11c. Pearson residual plots for the model fits to the length-composition data for the dolphin-associated purse-seine fisheries and the pole-and-line fishery. The black and grey circles represent observations that are higher and lower, respectively, than the model predictions. The areas of the circles are proportional to the absolute values of the residuals.

FIGURA 4.11c. 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.

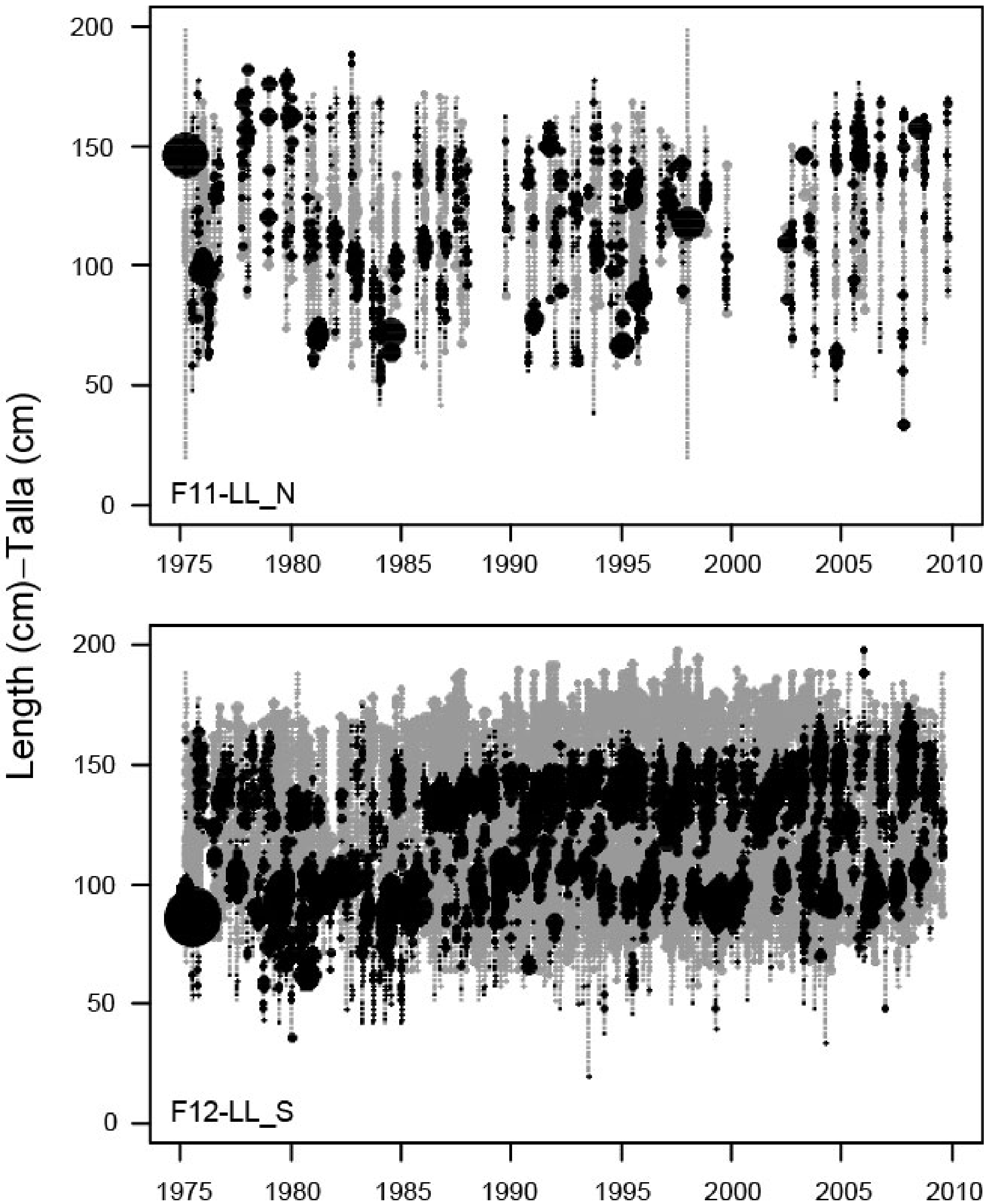

FIGURE 4.11d. Pearson residual plots for the model fits to the length-composition data for the longline fisheries. The black and grey circles represent observations that are higher and lower, respectively, than the model predictions. The areas of the circles are proportional to the absolute values of the residuals.

FIGURA 4.11d. 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.

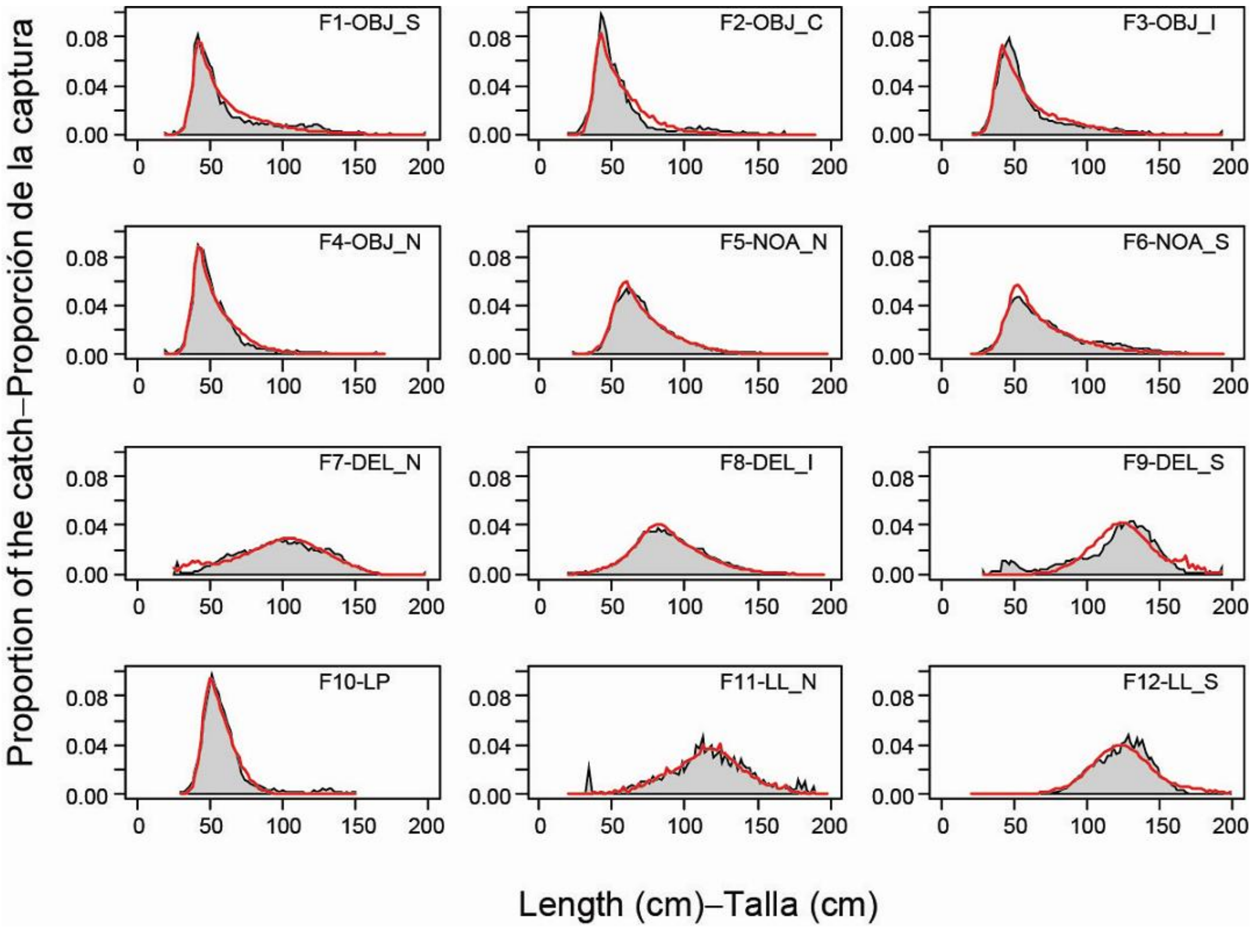

FIGURE 4.11e. Average observed (shaded area) and predicted (curves) length compositions of the catches taken by the fisheries defined for the stock assessment of yellowfin tuna in the EPO.

FIGURA 4.11e. Composición por talla 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.

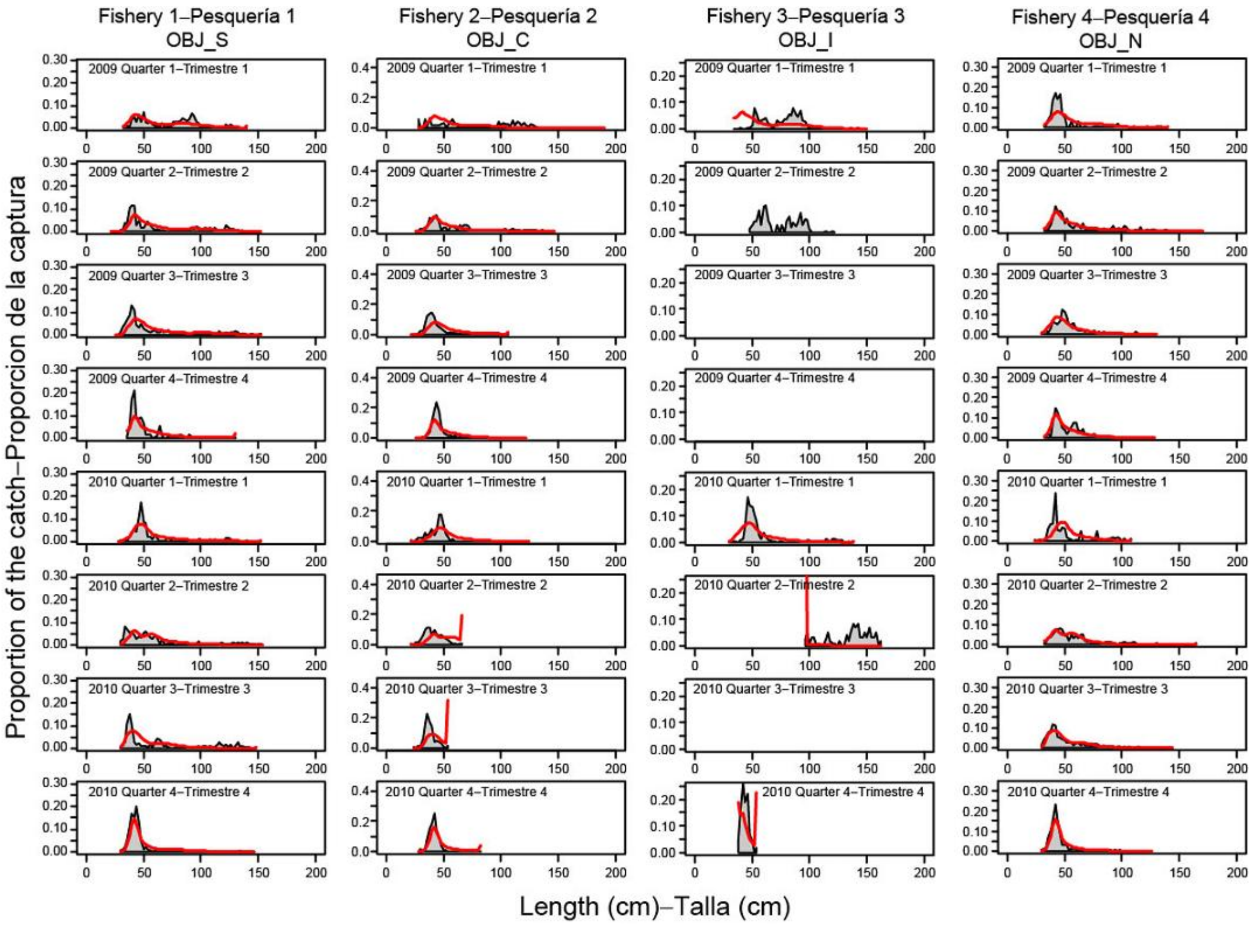

FIGURE 4.11f. Observed (shaded area) and predicted (curves) length compositions of the recent catches of yellowfin by the fisheries that take tunas in association with floating objects (Fisheries 1-4).

FIGURA 4.11f. 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).

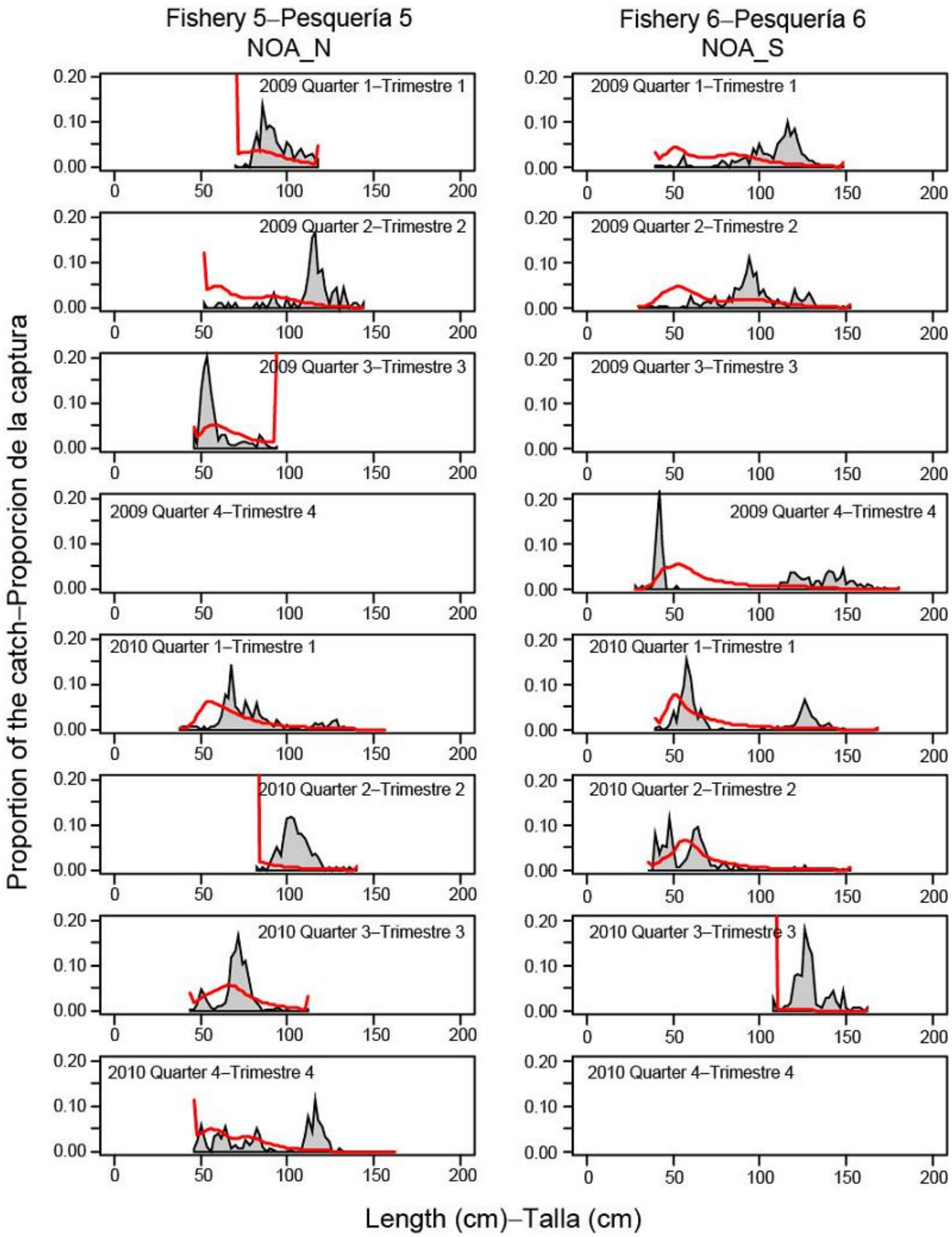

FIGURE 4.11g. Observed (shaded area) and predicted (curves) length compositions of the recent catches of yellowfin by the fisheries that take tunas in unassociated schools (Fisheries 5 and 6).

FIGURA 4.11g. Composición por talla observada (puntos) y predicha (curvas) de las capturas recientes de aleta amarilla por las pesquerías que capturan atún en cardúmenes no asociados (Pesquerías 5 y 6).

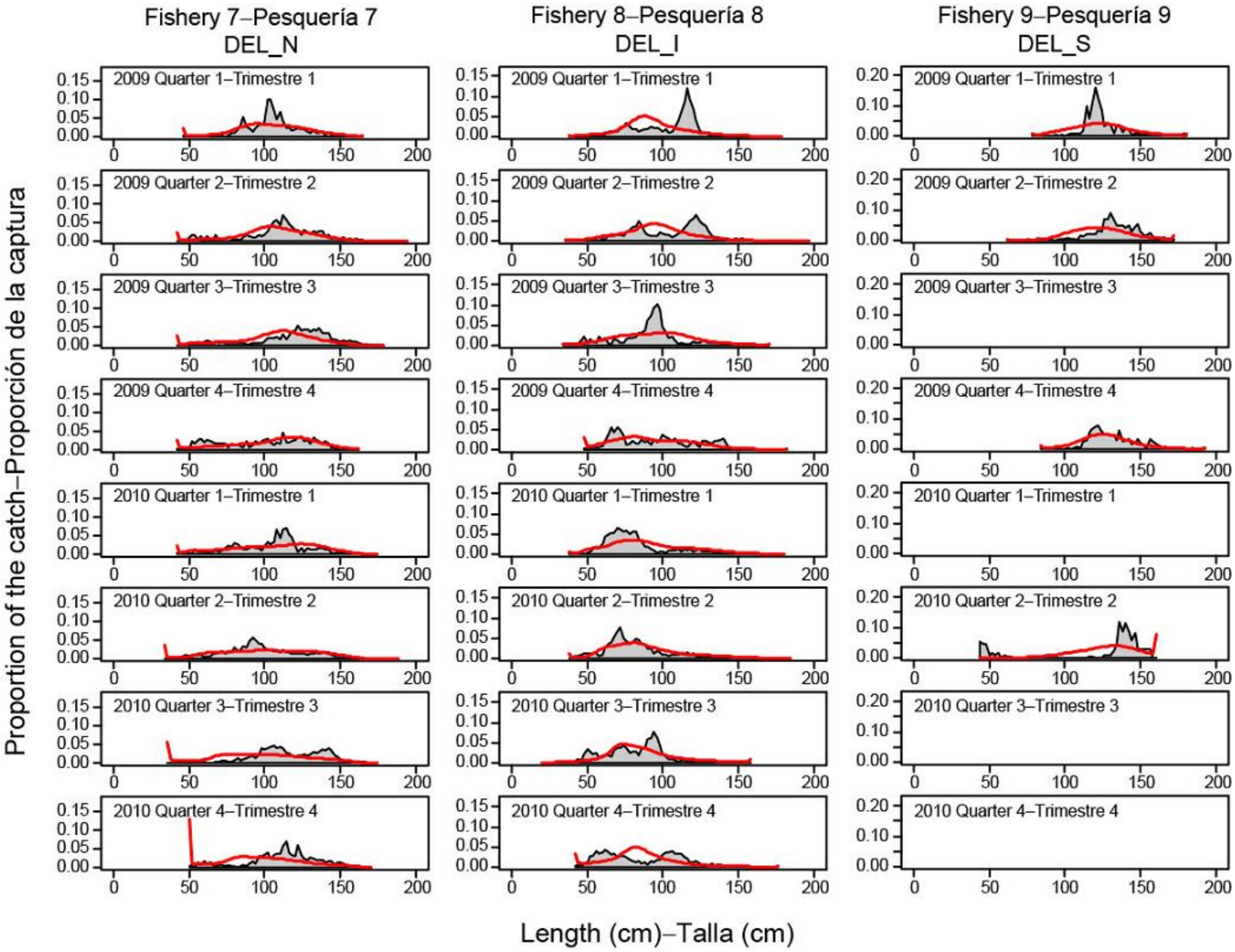

FIGURE 4.11h. Observed (shaded area) and predicted (curves) length compositions of the recent catches of yellowfin tuna by the fisheries that take tunas in association with dolphins (Fisheries 7-9).

FIGURA 4.11h. 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).

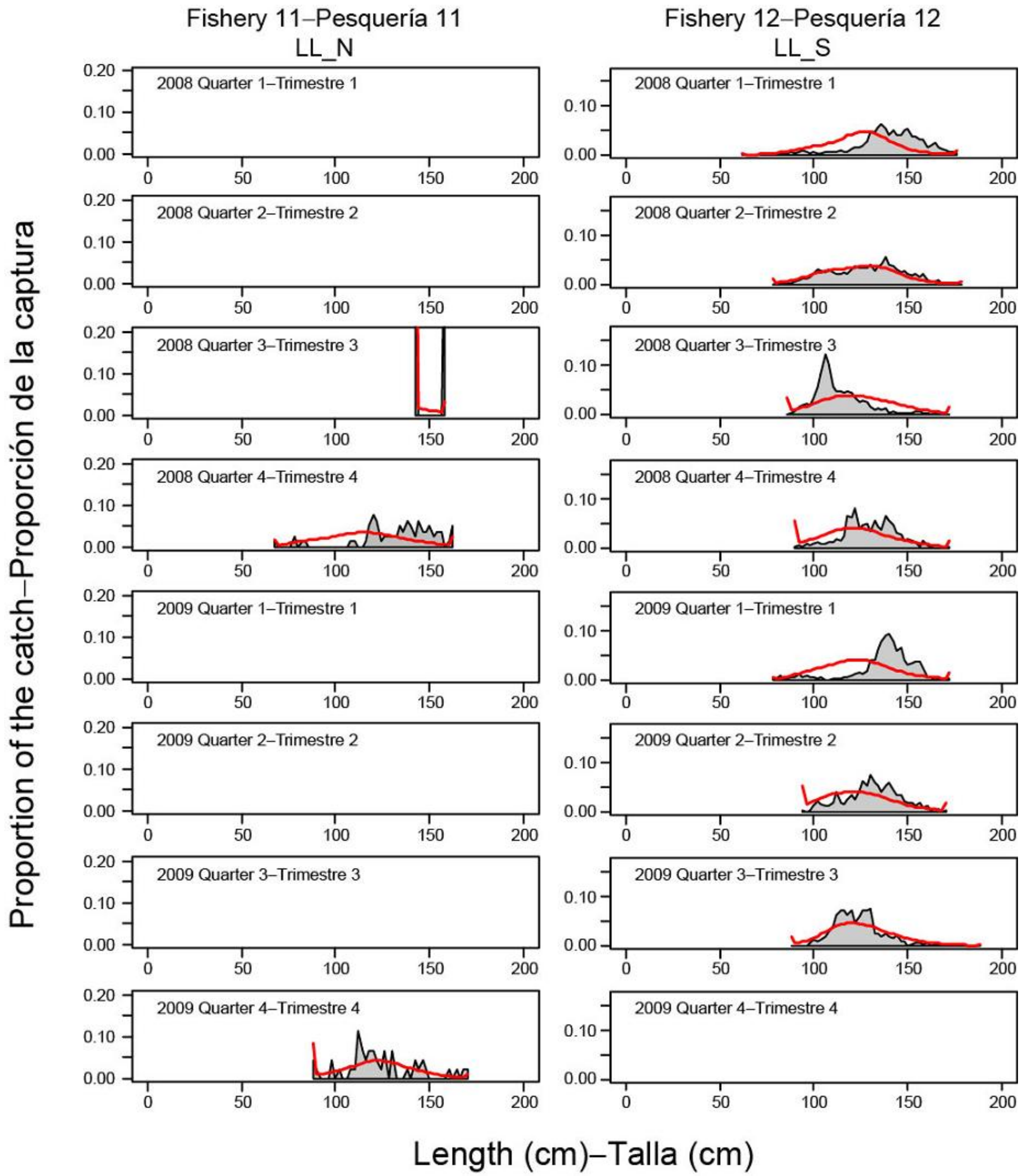

FIGURE 4.11i. Observed (shaded area) and predicted (curves) length compositions of the recent catches of yellowfin tuna by the southern longline fishery (Fishery 12). There are no recent size composition data for the northern longline fishery.

FIGURA 4.11i. 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.

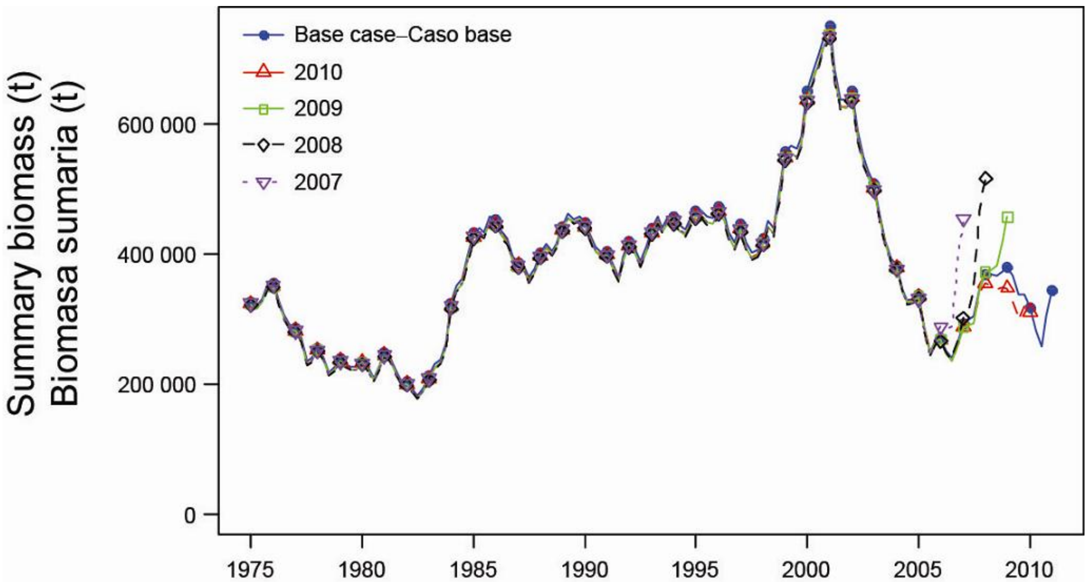

FIGURE 4.12. Comparison of estimated biomasses of yellowfin tuna aged three quarters and older in the EPO from the current assessment and from retrospective analyses that remove recent data.
FIGURA 4.14a. Comparación de las biomasas estimadas de atunes aleta amarilla de tres trimestres y más de edad en el OPO de la evaluación actual y de los análisis retrospectivos que eliminan los datos recientes.

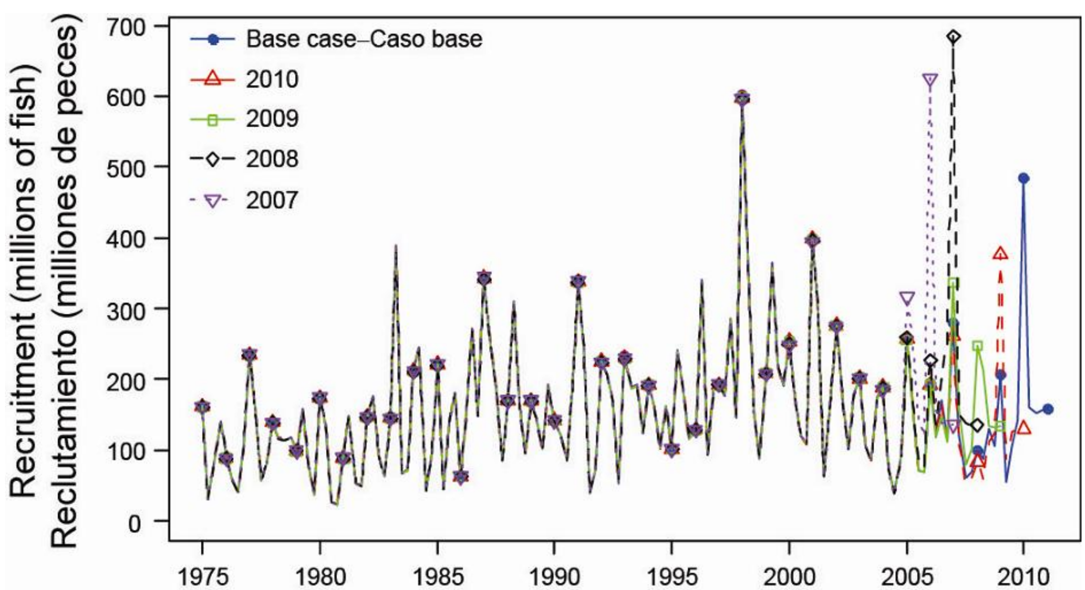

FIGURE 4.13. Comparison of estimated recruitment of yellowfin tuna in the EPO from the current assessment and from retrospective analyses that remove recent data
FIGURA 4.13. Comparación del reclutamiento estimado de atún aleta amarilla en el OPO de la evaluación actual y de los análisis retrospectivos que eliminan los datos recientes.

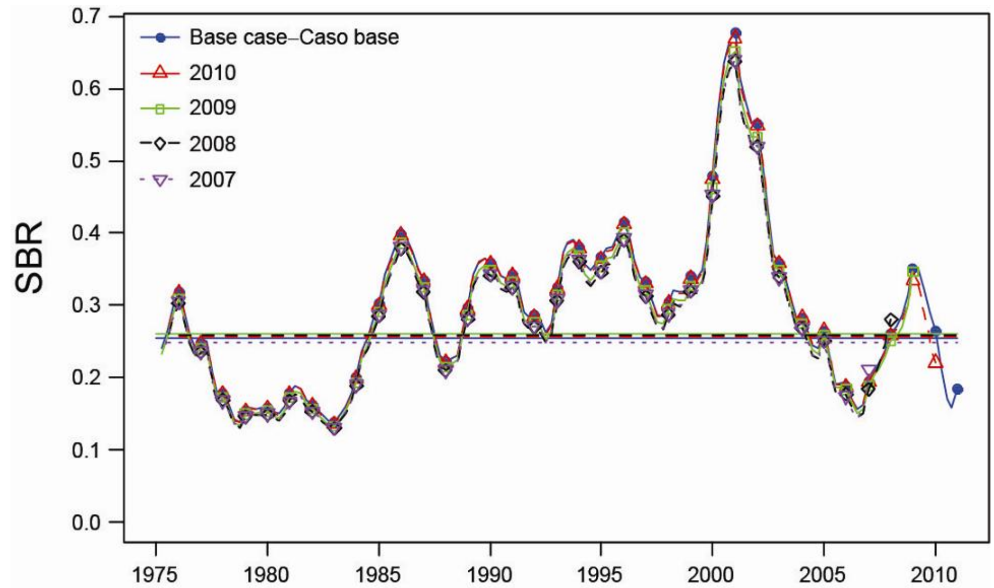

FIGURE 4.14. Comparison of estimated spawning biomass ratio (SBR) of yellowfin tuna in the EPO from the current assessment and from retrospective analyses that remove recent data. The horizontal line represents the SBR that corresponds to MSY estimated in the current assessment.
FIGURA 4.14. Comparación del cociente de biomasa reproductora (SBR) estimado del atún aleta amarilla en el OPO de la evaluación actual y de los análisis retrospectivos que eliminan los datos recientes. La línea horizontal representa el SBR que corresponde al RMS estimado en la evaluación actual.

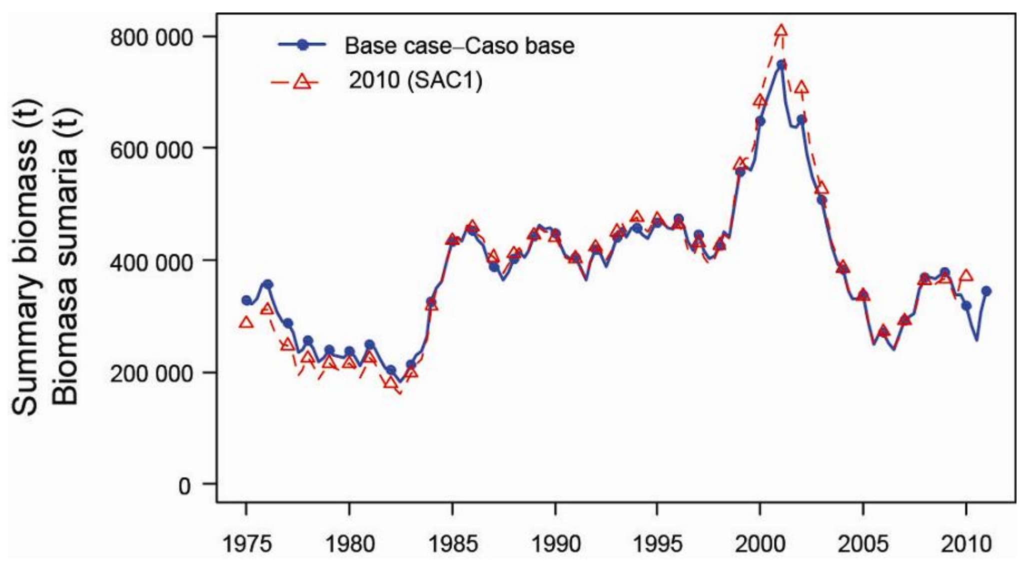

FIGURE 4.15. Comparison of estimated biomasses of yellowfin tuna aged three quarters and older in the EPO from the most recent previous assessment (dashed line) and from the current assessment (solid line).
FIGURA 4.15. Comparación de la biomasa estimada de atún aleta amarilla de tres trimestres y más de edad en el OPO de la evaluación previa más reciente y de la evaluación actual.

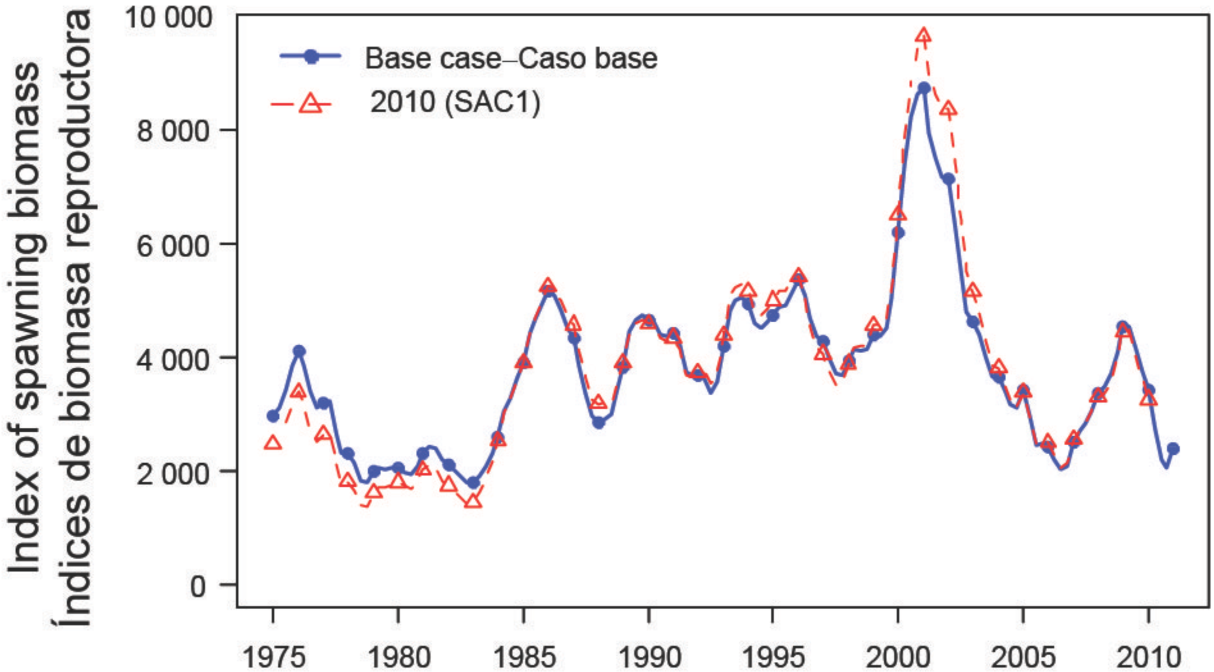

FIGURE 4.16. Comparison of estimated indices of spawning biomass of yellowfin tuna in the EPO from the most recent previous assessment (dashed line) and from the current assessment (solid line).
FIGURA 4.16. Comparación de los índices estimados de biomasa reproductora del atún aleta amarilla en el OPO de la evaluación previa más reciente (línea de trazos) y de la evaluación actual (línea sólida).

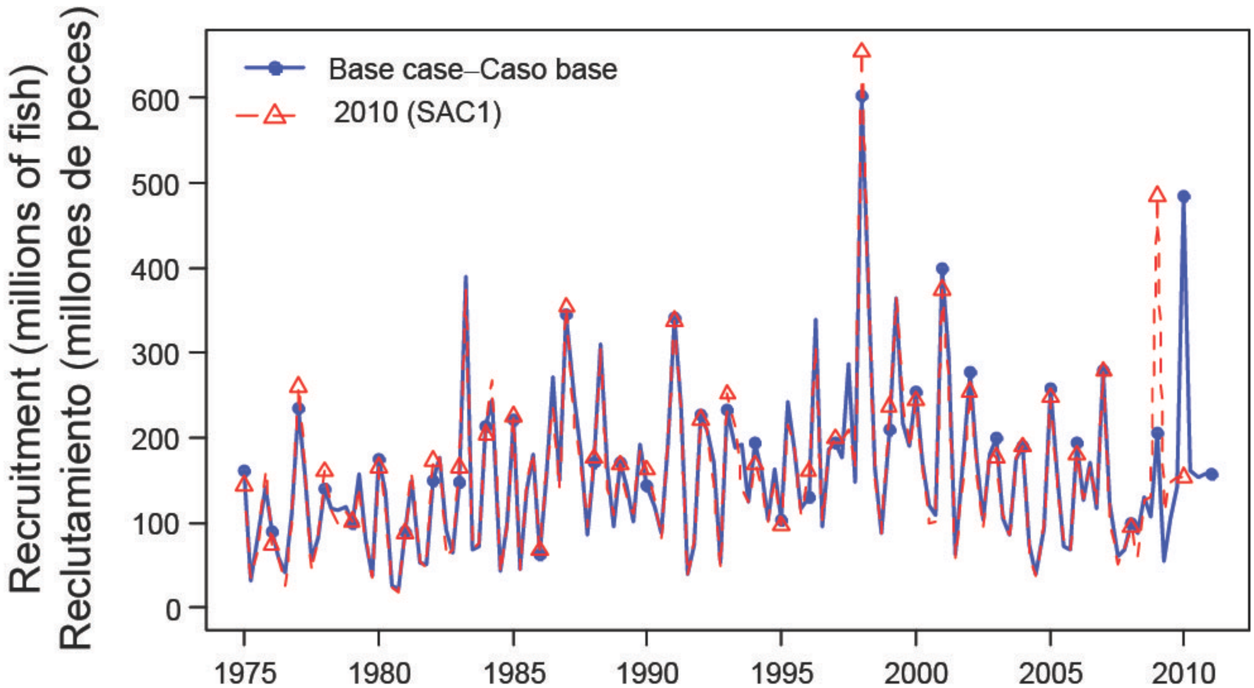

FIGURE 4.17a. Comparison of estimated recruitment of yellowfin in the EPO from the most recent previous assessment (dashed line) and from the current assessment (solid line).
FIGURA 4.17a. Comparación del reclutamiento estimado de aleta amarilla en el OPO de la evaluación previa más reciente (línea de trazos) y de la evaluación actual (línea sólida).

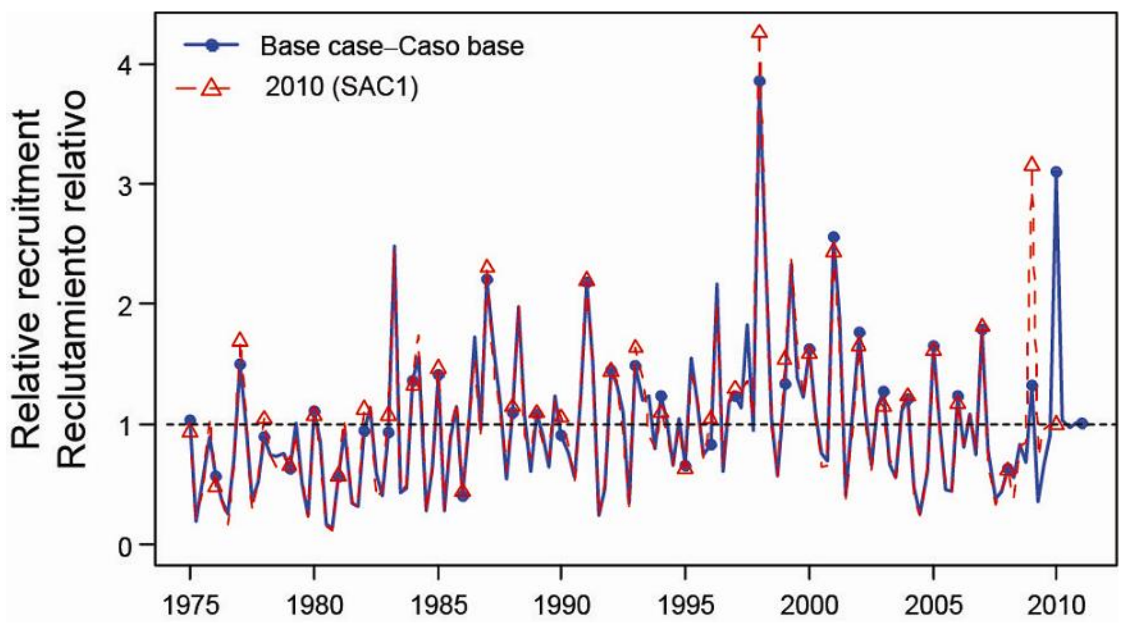

FIGURE 4.17b. Comparison of estimated relative recruitment of yellowfin in the EPO from the most recent previous assessment (dashed line) and from the current assessment (solid line).
FIGURA 4.17b. Comparación del reclutamiento relativo estimado de aleta amarilla en el OPO de la evaluación previa más reciente (línea de trazos) y de la evaluación actual (línea sólida).

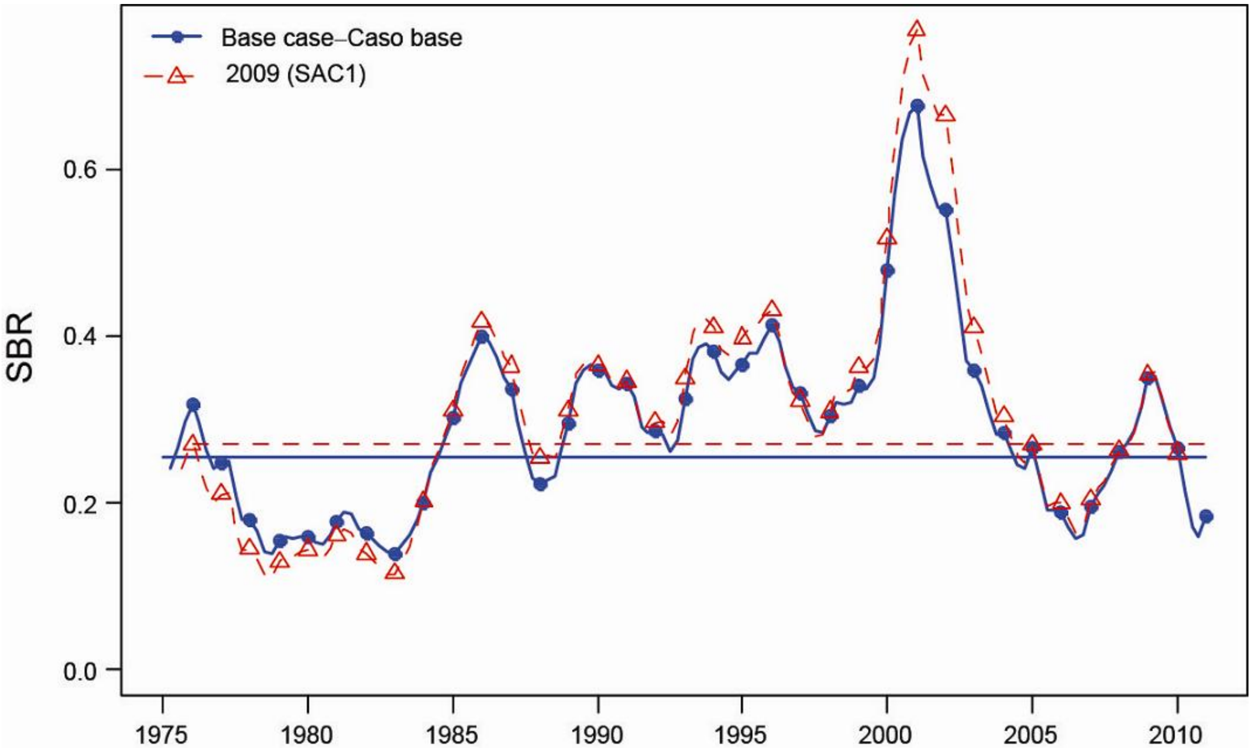

FIGURE 4.18. Comparison of estimated spawning biomass ratios (SBRs) of yellowfin tuna from the current assessment (solid line) and from the most recent previous assessment (dashed line). The horizontal lines identify the SBRs at MSY.

FIGURA 4.18. 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 los SBR en RMS.

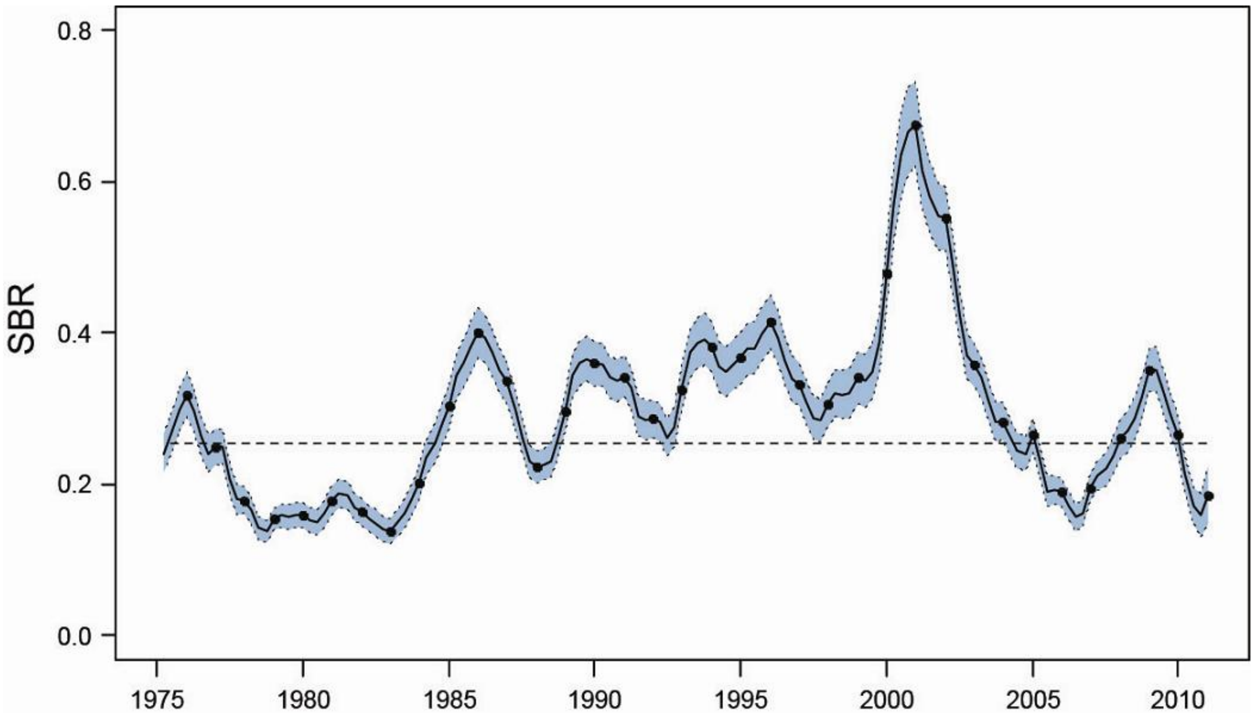

FIGURE 5.1. Estimated spawning biomass ratios (SBRs) for yellowfin tuna in the EPO. The thin dashed lines represent approximate 95% confidence intervals. The dashed horizontal line identifies the SBR at MSY.

FIGURA 5.1. 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.

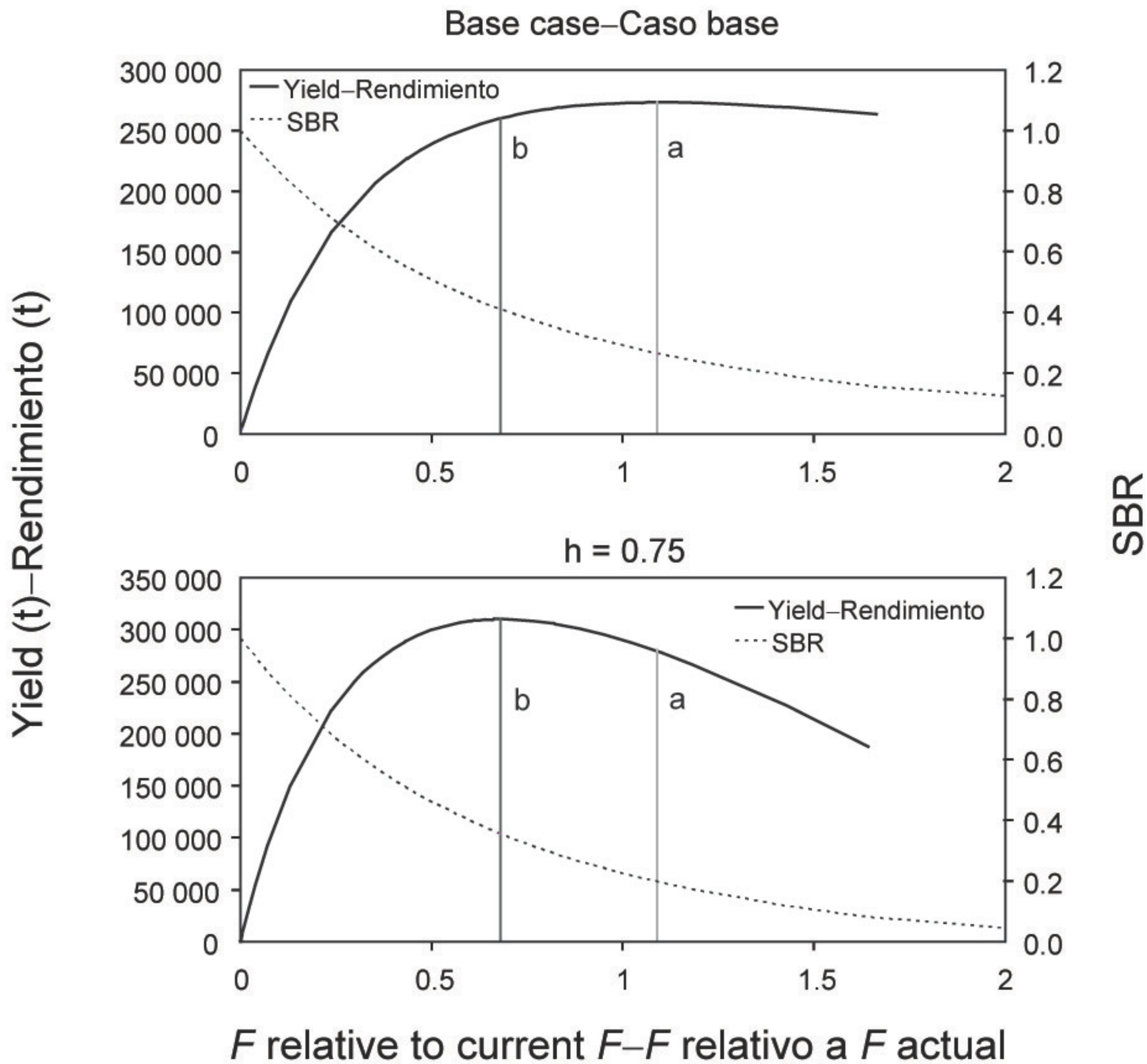

FIGURE 5.2. Yield and spawning biomass ratio (SBR) as a function of fishing mortality relative to the current fishing mortality. The vertical lines represent the fishing mortality corresponding to MSY for the base case and the sensitivity analysis that uses a stock-recruitment relationship (h = 0.75).
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 del análisis de sensibilidad que usa una relación población-reclutamiento (h = 0.75).

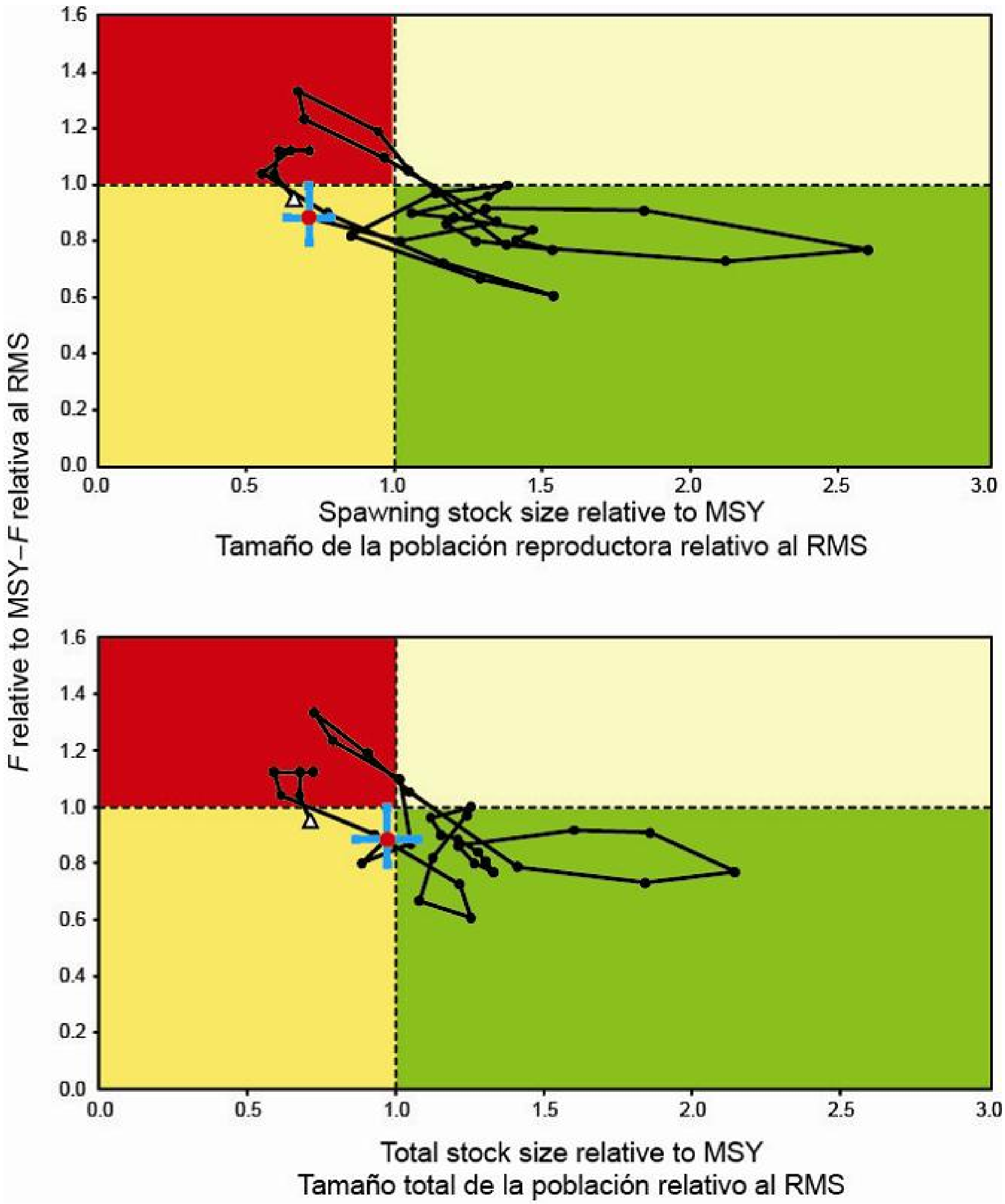

FIGURE 5.3. Phase (Kobe) plot of the time series of estimates for stock size (top: spawning biomass; bottom: total biomass) and fishing mortality relative to their MSY reference points. Each dot is based on the average exploitation rate over three years; the large triangle and the red dot indicate the earliest and most recent estimates, respectively. The squares represent approximate 95% confidence intervals around the most recent estimate.

FIGURA 5.3. Gráfica de fase (Kobe) de la serie de tiempo de las estimaciones del tamaño de la población (arriba: biomasa reproductora; abajo: biomasa total) 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 triángulo grande y el punto rojo indican las estimaciones más antiguas y más recientes, respectivamente. Los cuadrados representan los intervalos de confianza de 95% aproximados.

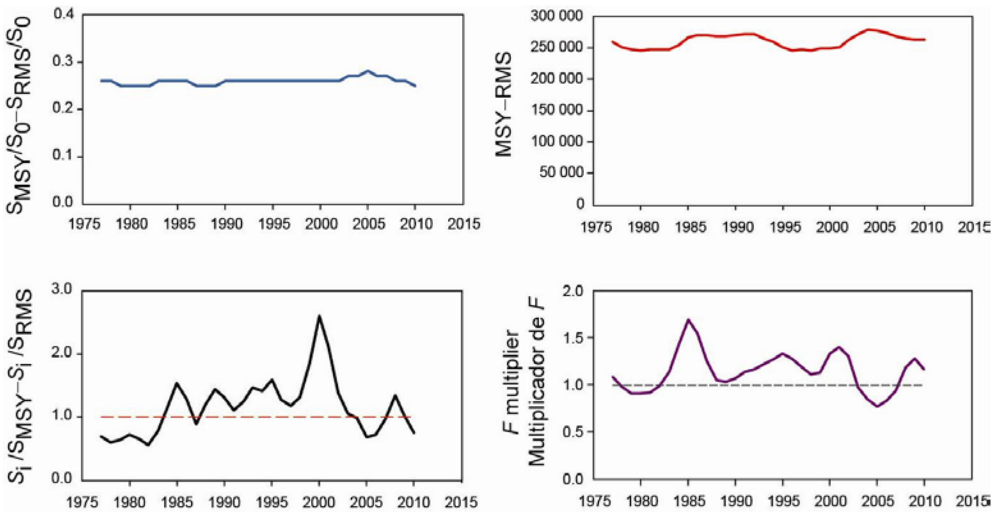

FIGURE 5.4a. Estimates of MSY-related quantities calculated using the three-year average age-specific fishing mortality for each year on the x-axis, including its two previous years. (S_i is the index of spawning biomass at the start of the year on the x-axis.) See the text for definitions.
FIGURA 5.4a. Estimaciones de cantidades relacionadas con el RMS calculadas a partir de la mortalidad por pesca media por edad para cada año en el eje x, incluyendo los dos años previos. (S_i es el índice de la biomasa reproductora al principio del año en el eje x.) Ver definiciones en el texto.

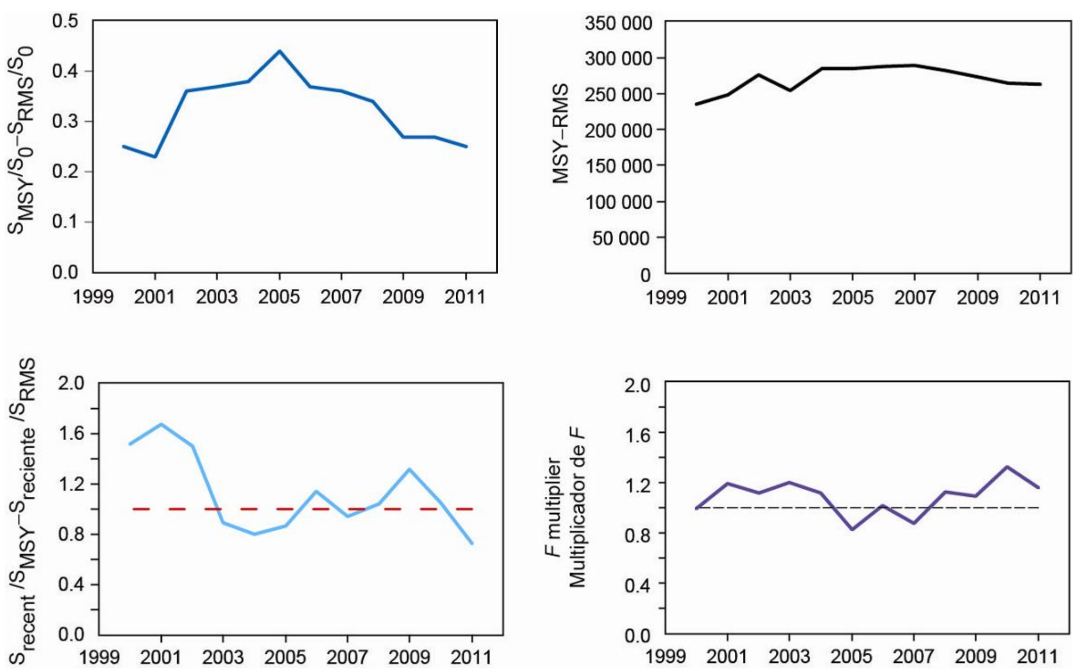

FIGURE 5.4b. Estimates of MSY-related quantities from the current assessment compared to those estimated in previous assessments. (S_{recent} is the index of spawning biomass at the latest year in the assessment). See the text for definitions.
FIGURA 5.4b. Estimaciones de cantidades relacionadas con el RMS de la evaluación actual comparadas con aquéllas estimadas en evaluaciones previas. ($S_{reciente}$ es el índice de la biomasa reproductora en el último año en la evaluación). Ver definiciones en el texto.

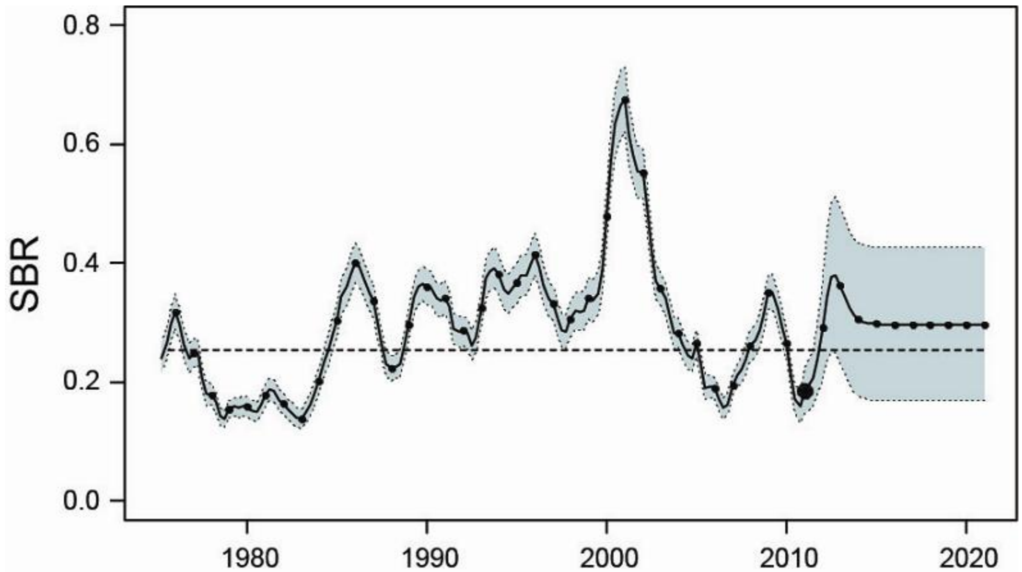

FIGURE 6.1. Spawning biomass ratios (SBRs) for 1975-2010 and SBRs projected during 2011-2020 for yellowfin tuna in the EPO. The dashed horizontal line identifies SBR_{MSY} (Section 5.1), and the thin dashed lines represent the 95% confidence intervals of the estimates. The estimates after 2010 indicate 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 10 years.
FIGURA 6.1. Cocientes de biomasa reproductora **(**SBR) de 1975-2010 y SBR proyectados durante 2011-2020 para el atún aleta amarilla en el OPO. La línea de trazos horizontal identifica el SBR_{RMS} (Sección 5.1), y las líneas delgadas de trazos representan los intervalos de confianza de 95% de las estimaciones. Las estimaciones a partir de 2010 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.

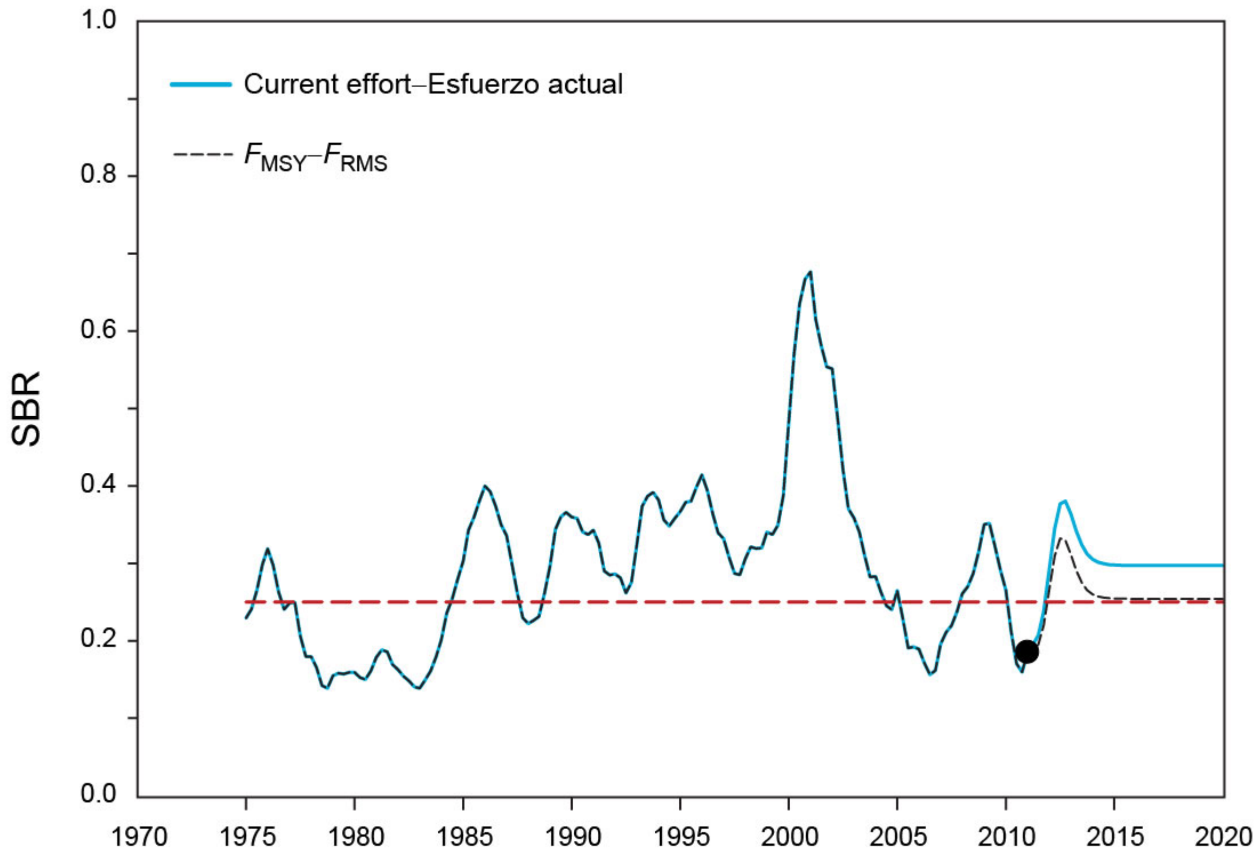

FIGURE 6.2. Spawning biomass ratios (SBRs) projected for yellowfin tuna in the EPO during 2011-2020 under current effort and under effort corresponding to MSY. The horizontal line (at 0.25) identifies SBR_{MSY} (Section 5.1).

FIGURA 6.2. Cocientes de biomasa reproductora (SBR) de atún aleta amarilla en el OPO proyectados durante 2011-2020, con el esfuerzo actual y con el esfuerzo correspondiente al RMS. La línea horizontal (en 0.25) identifica SBR_{RMS} (Sección 5.1).

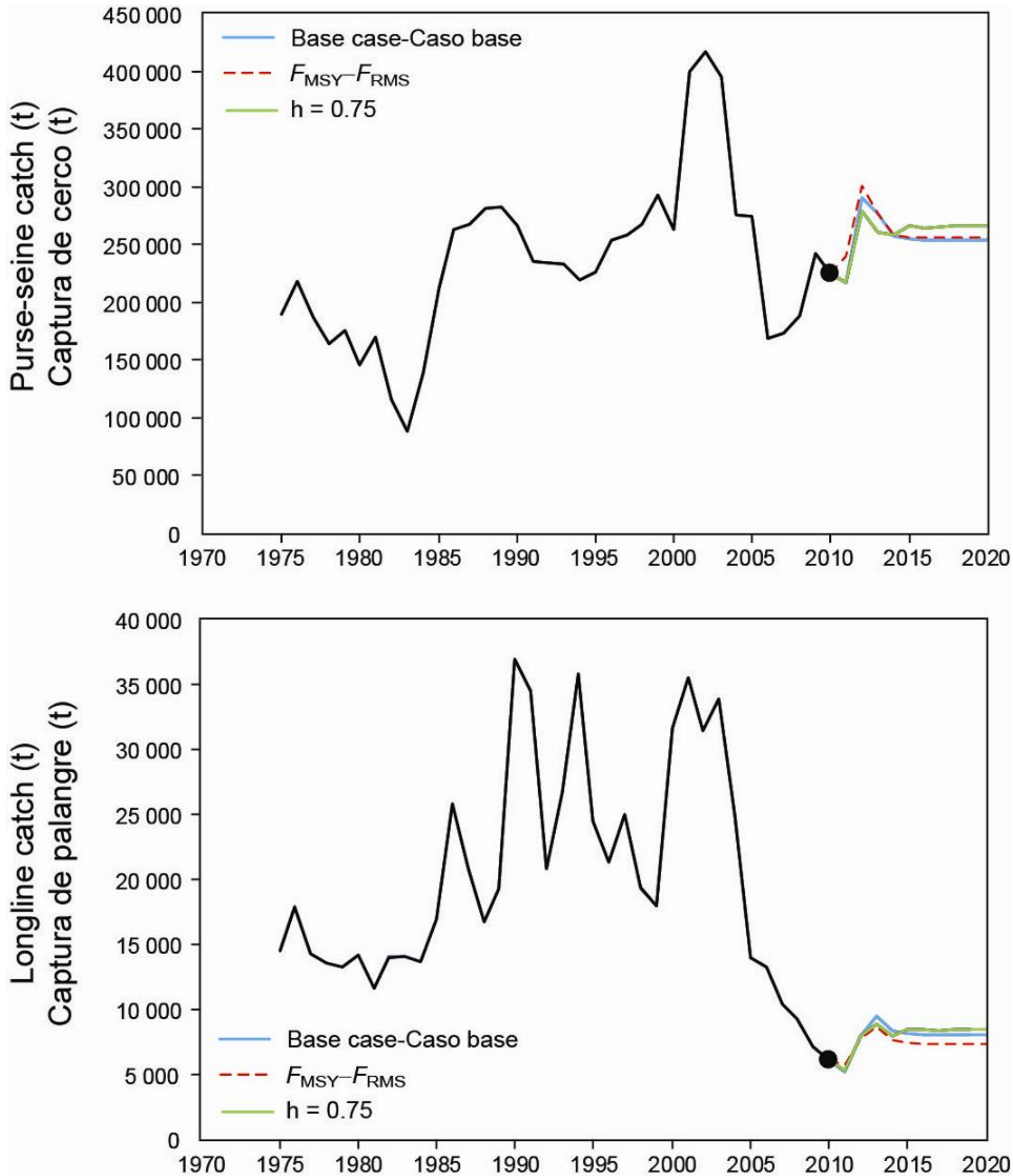

FIGURE 6.3. Historic and projected purse-seine and longline catch from the base case while fishing with the current effort, the base case while fishing at the fishing mortality corresponding to MSY (F_{MSY}), and the analysis of sensitivity to steepness of the stock-recruitment relationship (*h*) while 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 (*h*) al pescar con el esfuerzo actual.

TABLE 2.1. Fisheries defined 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 2.1, and the discards are described in Section 2.2.1.

TABLA 2.1. Pesquerías definidas para la evaluación de la población de atún aleta amarilla en el OPO. PS = red de cerco; LP = caña; LL = palangre; OBJ = lances sobre objetos flotantes; NOA = lances sobre atunes no asociados; DEL = lances sobre atunes asociados con delfines. En la Figura 2.1 se ilustran las zonas de muestreo, y en la Sección 2.2.1 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	1975-2010	11-12	retained catch + discards from inefficiencies in fishing process–captura retenida + descartes por ineficacias en el proceso de pesca
2	PS	OBJ	1975-2010	7, 9	
3	PS	OBJ	1975-2010	5-6, 13	
4	PS	OBJ	1975-2010	1-4, 8, 10	
5	PS	NOA	1975-2010	1-4, 8, 10	retained catch + discards–captura retenida + descartes
6	PS	NOA	1975-2010	5-7, 9, 11-13	
7	PS	DEL	1975-2010	2-3, 10	
8	PS	DEL	1975-2010	1, 4-6, 8, 13	
9	PS	DEL	1975-2010	7, 9, 11-12	
10	LP		1975-2010	1-13	retained catch only (in numbers)— captura retenida solamente (en número)
11	LL		1975-2010	N of-de 15°N	
12	LL		1975-2010	S of-de 15°N	
13	PS	OBJ	1993-2010	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	1993-2010	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	1993-2010	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	1993-2010	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 (SBR) of yellowfin tuna in the EPO at the beginning of the year. 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 (SBR) 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+	SBR
1975	412,283	327,929	0.23
1976	296,433	355,987	0.32
1977	529,966	286,818	0.25
1978	488,572	256,642	0.18
1979	374,687	239,564	0.15
1980	357,419	236,638	0.16
1981	342,036	248,880	0.18
1982	481,308	204,445	0.16
1983	675,799	213,116	0.14
1984	598,555	325,181	0.20
1985	583,703	433,989	0.30
1986	636,024	452,537	0.40
1987	858,688	387,864	0.34
1988	742,582	401,717	0.22
1989	606,005	442,857	0.30
1990	540,831	448,359	0.36
1991	689,146	404,739	0.34
1992	657,546	420,047	0.29
1993	738,519	440,724	0.32
1994	620,151	458,514	0.38
1995	645,929	467,751	0.37
1996	750,099	474,309	0.41
1997	804,810	446,297	0.33
1998	1,234,582	425,355	0.31
1999	981,989	558,744	0.34
2000	654,466	650,190	0.48
2001	938,097	750,325	0.68
2002	733,082	650,417	0.55
2003	565,763	508,006	0.36
2004	398,717	382,538	0.28
2005	555,754	337,682	0.27
2006	606,024	272,015	0.19
2007	530,555	292,794	0.20
2008	421,575	369,409	0.26
2009	508,284	379,526	0.35
2010	956,492	318,930	0.27
2011		344,999	0.19

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)	Average length (cm)	Average weight (kg)	Age (quarters)	Average length (cm)	Average weight (kg)
Edad (trimestres)	**Talla media (cm)**	**Peso medio (kg)**	**Edad (trimestres)**	**Talla media (cm)**	**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 4.3. Measure of the goodness of fit (root mean square error, RMSE) to the CPUE data of different fisheries.
TABLA 4.3. Medida de la bondad del ajuste (raíz del error cuadrado medio, RECM) a los datos de CPUE de distintas pesquerías.

Fishery	RMSE	Used
Pesquería	**RECM**	**Usado**
F1-OBJ_S	0.35	No
F2-OBJ_C	0.41	No
F3-OBJ_I	0.69	No
F4-OBJ_N	0.41	No
F5-NOA_N	0.54	Yes/Sí
F6-NOA_S	0.62	Yes/Sí
F7-DEL_N	0.39	Yes/Sí
F8-DEL_I	0.38	Yes/Sí
F9-DEL_S	0.51	No
F10-BB	N/A	No
F11-LL_N	0.75	No
F12-LL_S	0.36	Yes/Sí

TABLE 4.4. Mean input and effective sample sizes of the size composition of different fisheries.
TABLA 4.4. Tamaño de muestra medio de insumo y efectivo de la composición por talla de distintas pesquerías.

Fishery	Mean input sample size	Mean effective sample size	Used
Pesquería	**Tamaño de muestra medio de insumo**	**Tamaño de muestra medio efectivo**	**Usado**
F1-OBJ_S	14	33	Yes/Sí
F2-OBJ_C	14	28	Yes/Sí
F3-OBJ_I	13	23	Yes/Sí
F4-OBJ_N	11	57	Yes/Sí
F5-NOA_N	23	56	Yes/Sí
F6-NOA_S	21	34	Yes/Sí
F7-DEL_N	32	120	Yes/Sí
F8-DEL_I	30	129	Yes/Sí
F9-DEL_S	9	53	No
F10-LP	12	36	Yes/Sí
F11-LL_N	2	31	Yes/Sí
F12-LL_S	30	104	Yes/Sí

TABLE 4.5. Likelihood components obtained for the base case and sensitivity analyes.
TABLA 4.5. Componentes de verosimilitud obtenidos para el caso base y los análisis de sensibilidad.

<table>
<tr><th></th><th></th><th></th><th colspan="2">L_2</th><th></th></tr>
<tr><th>Data</th><th>Base case</th><th rowspan="2">h = 0.75</th><th rowspan="2">170 cm</th><th rowspan="2">190 cm</th><th rowspan="2">CPUE DEL-N</th></tr>
<tr><th>Datos</th><th>Caso base</th></tr>
<tr><td>CPUE</td><td>-140.54</td><td>-140.23</td><td>-143.58</td><td>-138.48</td><td>-177.80</td></tr>
<tr><td>Size compositions –
Composiciones por talla</td><td>8300.04</td><td>8299.45</td><td>8260.65</td><td>8336.89</td><td>8272.20</td></tr>
<tr><td>Age at length – Talla por edad</td><td>100.87</td><td>100.99</td><td>122.68</td><td>107.05</td><td>104.76</td></tr>
<tr><td>Recruitment - Reclutamiento</td><td>-2.37</td><td>-7.39</td><td>0.53</td><td>-5.36</td><td>-0.74</td></tr>
<tr><td>Total</td><td>8257.99</td><td>8252.83</td><td>8240.27</td><td>8300.10</td><td>8198.41</td></tr>
</table>

TABLE 5.1. Estimates of the MSY and its associated quantities for yellowfin tuna for the base case assessment and the sensitivity analyses. All analyses are based on average fishing mortality during 2008-2010. B_{recent} and B_{MSY} are defined as the biomass of fish 3+ quarters old (in metric tons) at the beginning of 2011 and at MSY, respectively. S_{recent} and S_{MSY} are in metric tons. C_{recent} is the estimated total catch in 2010. The *F* multiplier indicates how many times effort would have to be effectively increased to achieve the MSY in relation to the average fishing mortality during 2008-2010.
TABLA 5.1. Estimaciones del RMS y sus cantidades asociadas para el atún patudo para la evaluación del caso base y los análisis de sensibilidad. Todos los análisis se basan en la mortalidad por pesca promedio de 2008-2010. Se definen B_{recent} y B_{RMS} como la biomasa de peces de 3+ trimestres de edad (en toneladas métricas) al principio de 2011 y en RMS, respectivamente. Se expresan S_{recent} y S_{MSY} en toneladas métricas. C_{recent} es la captura total estimada en 2010. El multiplicador de *F* indica cuántas veces se tendría que incrementar el esfuerzo para lograr el RMS en relación con la mortalidad por pesca media durante 2008-2010.

Data – Datos	**Base case Caso base**	***F* (avg.-prom. 2008-2009)**	***h* = 0.75**	***L*$_2$**		**CPUE DEL-N**
				170 cm	**190 cm**	
MSY-RMS	262,857	263,310	291,790	275,310	264,704	266,470
B_{MSY}- B_{RMS}	354,958	360,024	559,967	370,334	359,144	362,808
S_{MSY}- S_{RMS}	3,305	3,407	5,993	3,777	3,169	3,413
B_{MSY}/B_0- B_{RMS}/B_0	0.31	0.32	0.37	0.31	0.31	0.32
S_{MSY}/S_0- S_{RMS}/S_0	0.26	0.27	0.35	0.24	0.27	0.26
C_{recent}/MSY- C_{recent}/RMS	0.88	0.88	0.79	0.84	0.87	0.87
B_{recent}/B_{MSY}- B_{recent}/B_{RMS}	0.96	0.95	0.61	1.20	0.85	1.23
S_{recent}/S_{MSY}-S_{recent}/S_{RMS}	0.71	0.69	0.39	1.03	0.59	0.98
F multiplier-Multiplicador de *F*	1.13	1.29	0.71	1.65	0.94	1.29

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.

Data -Datos	All - Todas	OBJ	NOA	DEL	LL
MSY-RMS	262,857	166,349	221,759	307,523	407,748
B_{MSY}- B_{RMS}	354,958	208,259	295,992	363,447	380,574
S_{MSY}- S_{RMS}	3,305	1,607	2,485	3,139	3,137
B_{MSY}/B_0- B_{RMS}/B_0	0.31	0.18	0.26	0.32	0.33
S_{MSY}/S_0- S_{RMS}/S_0	0.26	0.13	0.19	0.24	0.24
C_{recent}/MSY- C_{recent}/RMS	0.88	1.39	1.04	0.75	0.57
$B_{\mathrm{recent}}/B_{\mathrm{MSY}}$- $B_{\mathrm{recent}}/B_{\mathrm{RMS}}$	0.96	1.64	1.15	0.94	0.89
$S_{\mathrm{recent}}/S_{\mathrm{MSY}}$-$S_{\mathrm{recent}}/S_{\mathrm{RMS}}$	0.71	1.47	0.95	0.75	0.75
F multiplier-Multiplicador de *F*	1.13	8.11	7.79	2.20	138.30

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

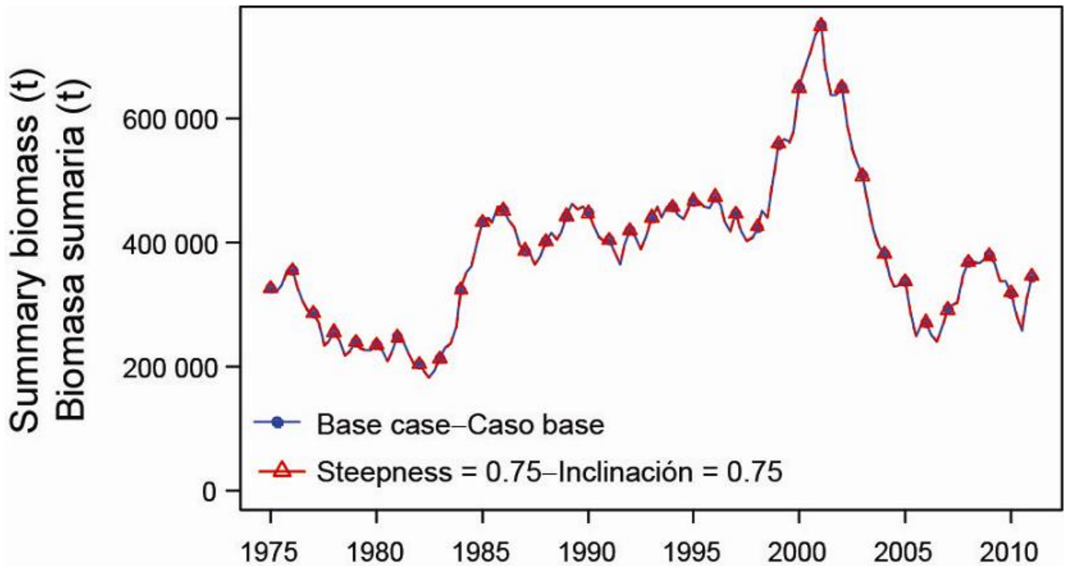

FIGURE A.1. Comparison of the estimates of biomass of yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).
FIGURA A.1. Comparación de las estimaciones de la biomasa de atún aleta amarilla del análisis sin relación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

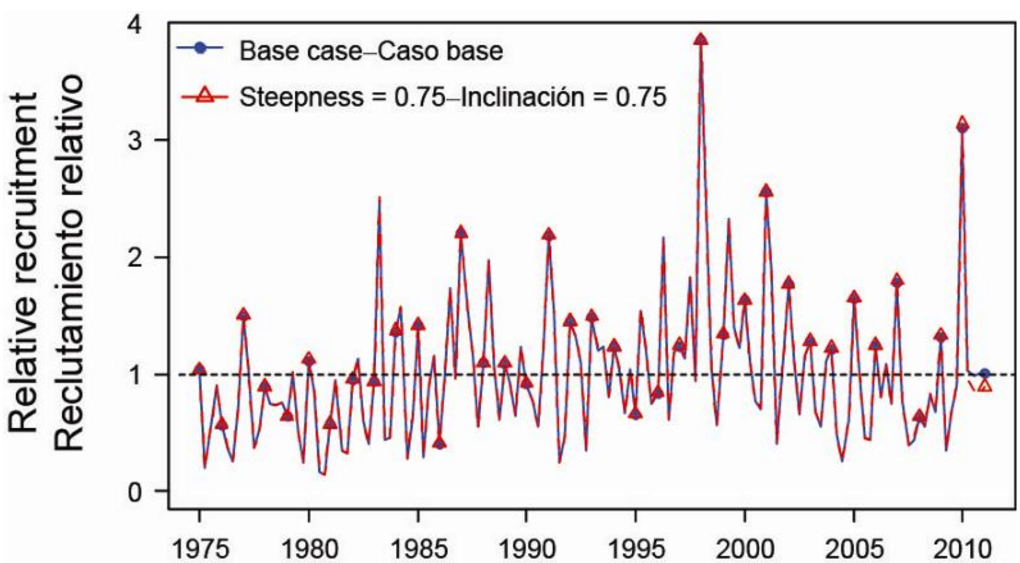

FIGURE A.2. Comparison of estimates of recruitment of yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).
FIGURA A.2. Comparación de las estimaciones de reclutamiento de atún aleta amarilla del análisis sin relación población-reclutamiento (caso base) y con relación población-reclutamiento (inclinación = 0,75).

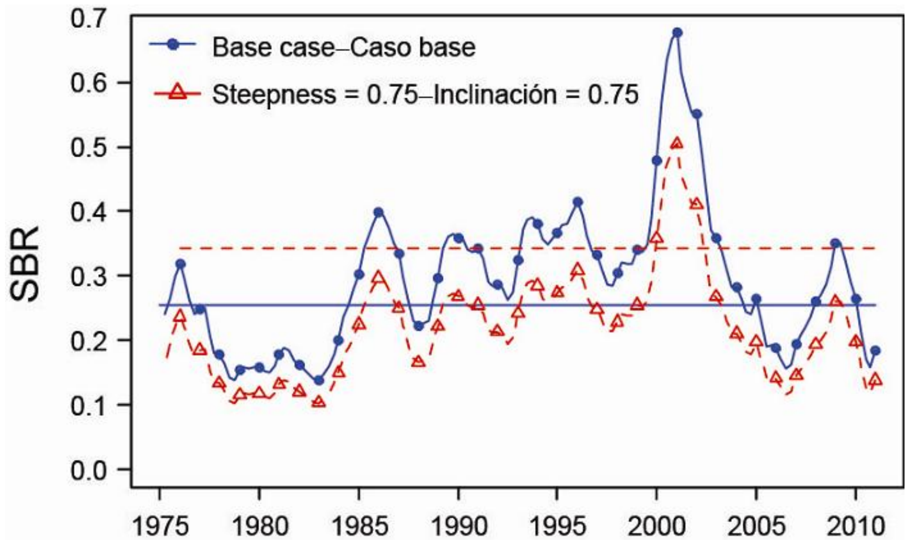

FIGURE A.3a. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). The horizontal lines represent the SBRs associated with MSY for the two scenarios.

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 los SBR asociados con el RMS para los dos escenarios.

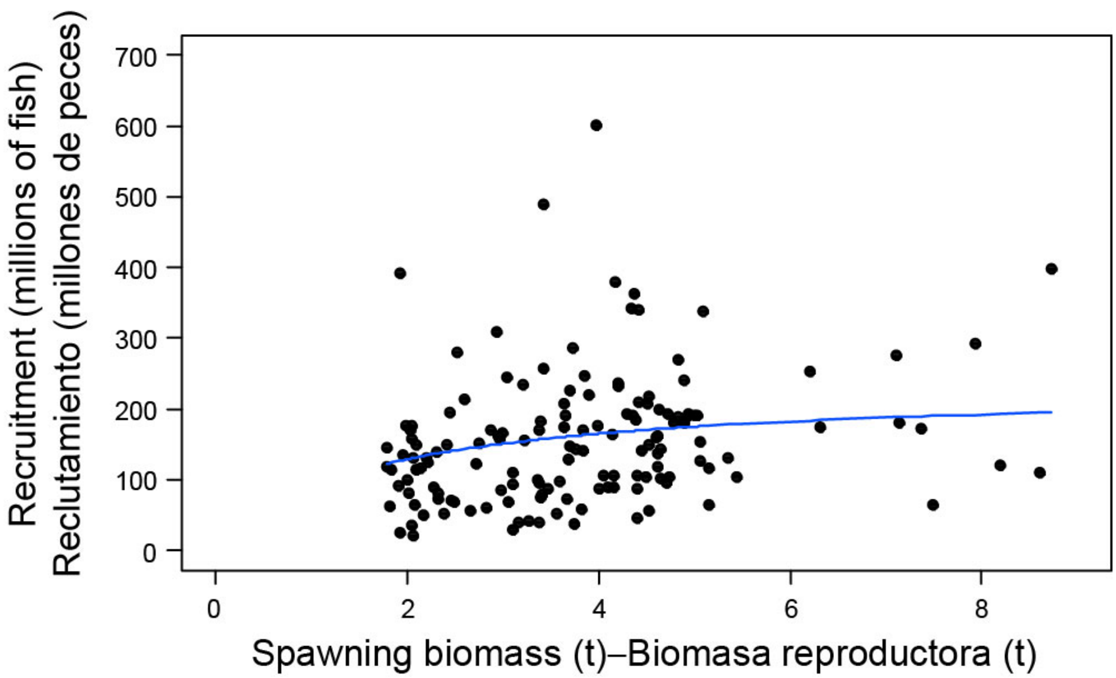

FIGURE A.4. Recruitment plotted against the index of spawning biomass of yellowfin tuna when the analysis has a stock-recruitment relationship (steepness = 0.75).

FIGURA A.4. Reclutamiento graficado como función de la biomasa reproductora de atún aleta amarilla cuando el análisis incluye una relación población-reclutamiento (inclinación = 0,75).

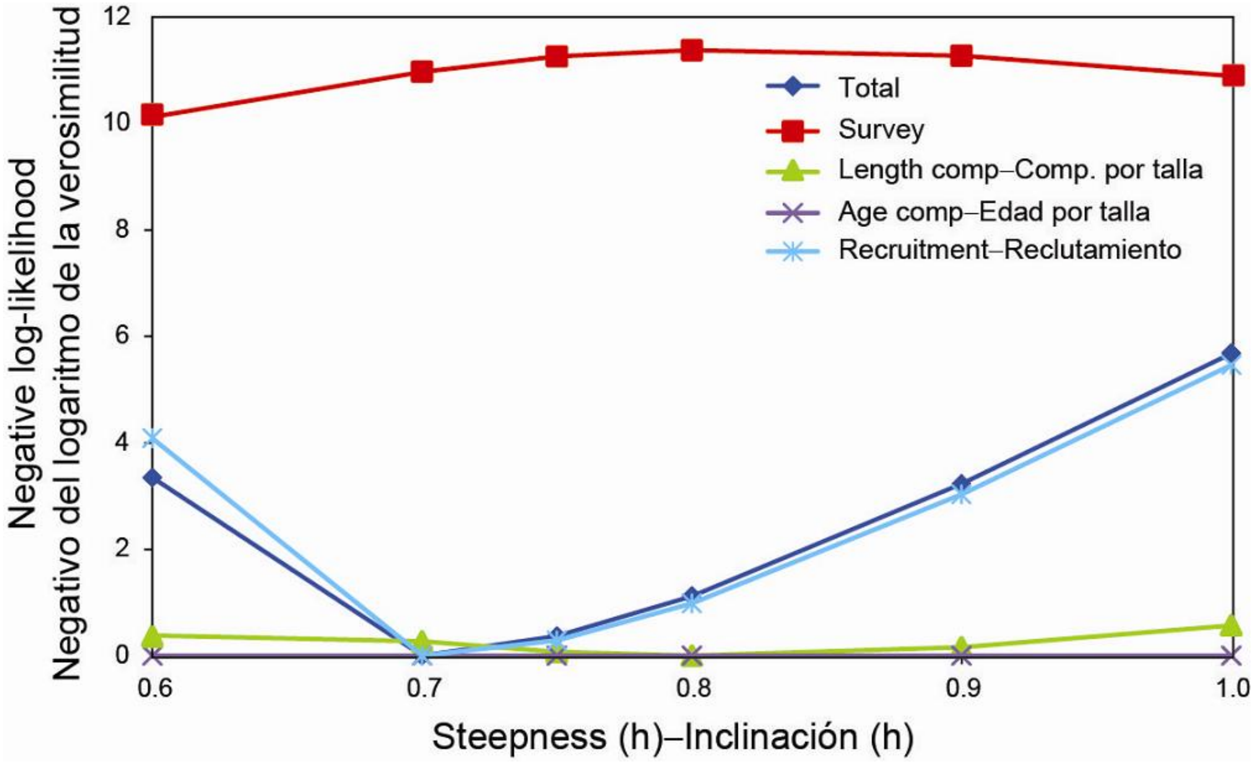

FIGURE A.5. Likelihood profile on steepness.
FIGURA A.5. Perfil de verosimilitud en inclinación.

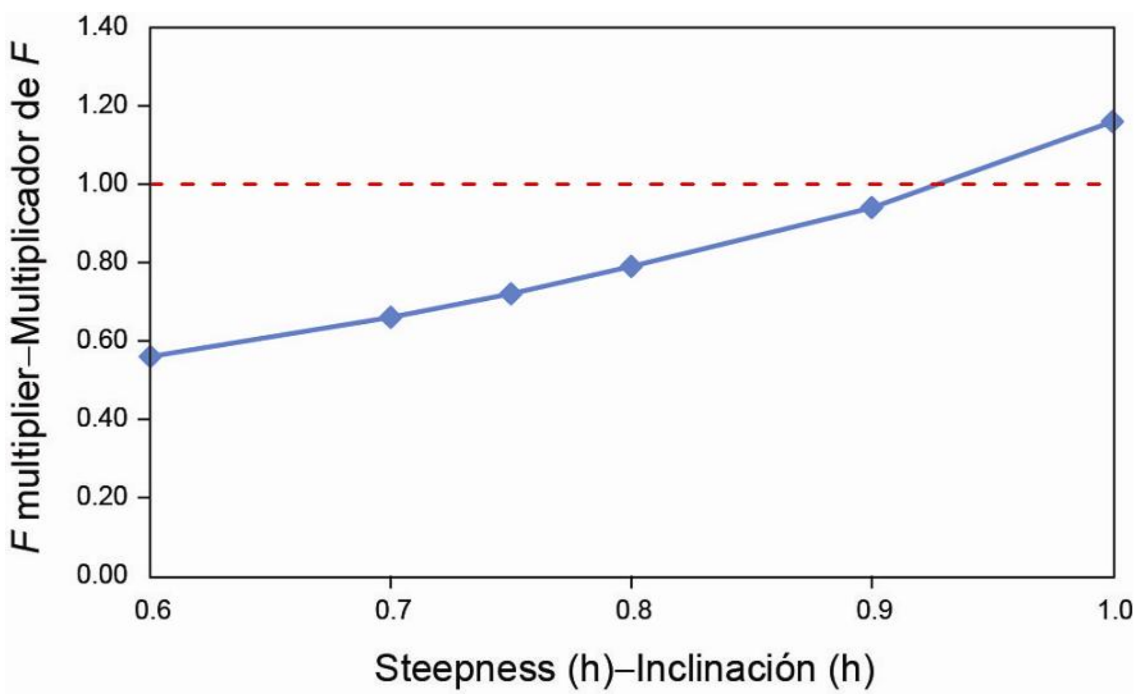

FIGURE A.6. *F* multiplier as a function of steepness.
FIGURA A.6. Multiplicador de *F* como función de la inclinación.

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

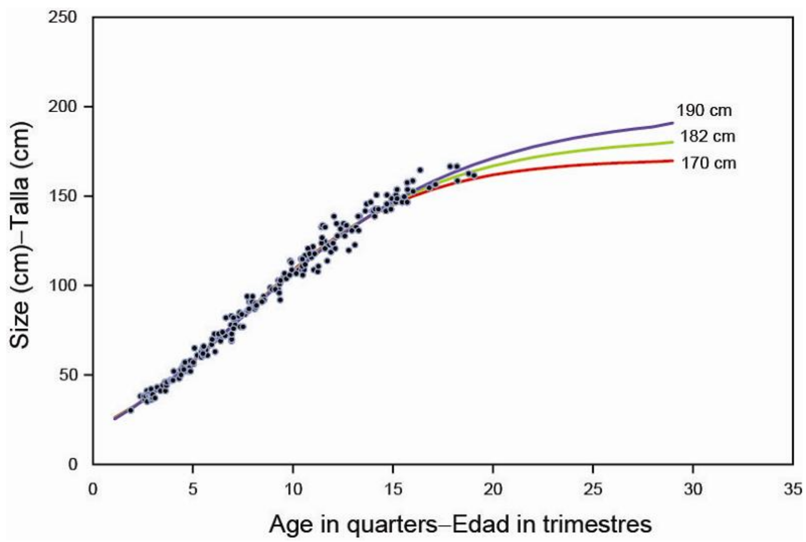

FIGURE B.1. Comparison of the Richards growth curves (sensitivity) for yellowfin tuna, assuming different fixed values for the average size of the oldest fish (L_2) parameter.
FIGURA B.1. Comparación de las curvas de crecimiento de Richards (sensibilidad) del atún alleta amarilla, con diferentes supuestos de valor fijo del parámetro de talla media de los peces de mayor edad (L_2).

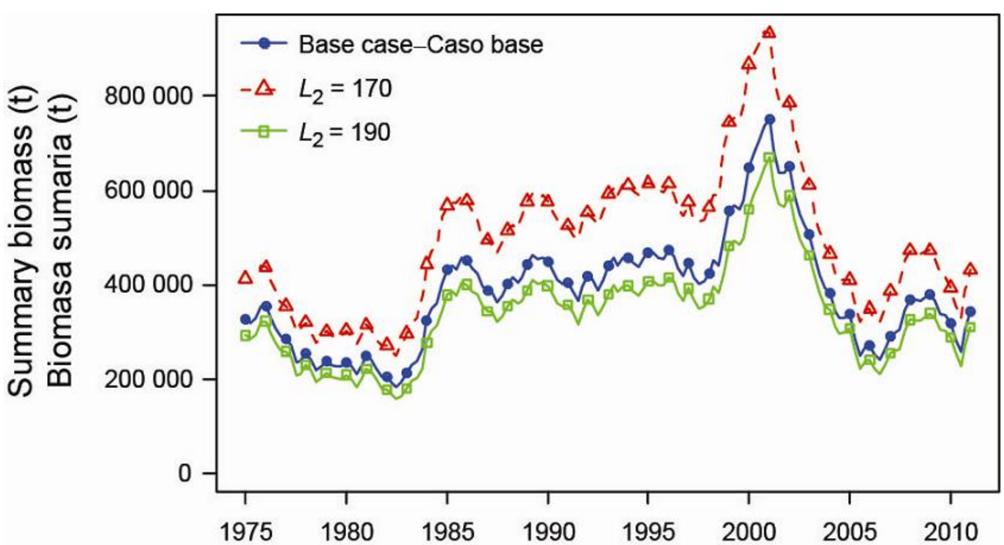

FIGURE B.2. Comparison of estimates of biomass of yellowfin tuna from the base case analysis using a Richards growth curve with the average size of the oldest fish (L_2) fixed at 182 cm, and two alternative models with L_2 fixed at a lower (170 cm) and a higher value (190 cm). t = metric tons.
FIGURA B.2. Comparación de las estimaciones de biomasa de atún alleta amarilla del análisis del caso base que usa una curva de crecimiento de Richards con el tamaño promedio de los peces de mayor edad (L_2) fijado en 182 cm, y dos modelos alternativos con L_2 fijado en valores menor (170 cm) y mayor (190 cm). t = toneladas métricas.

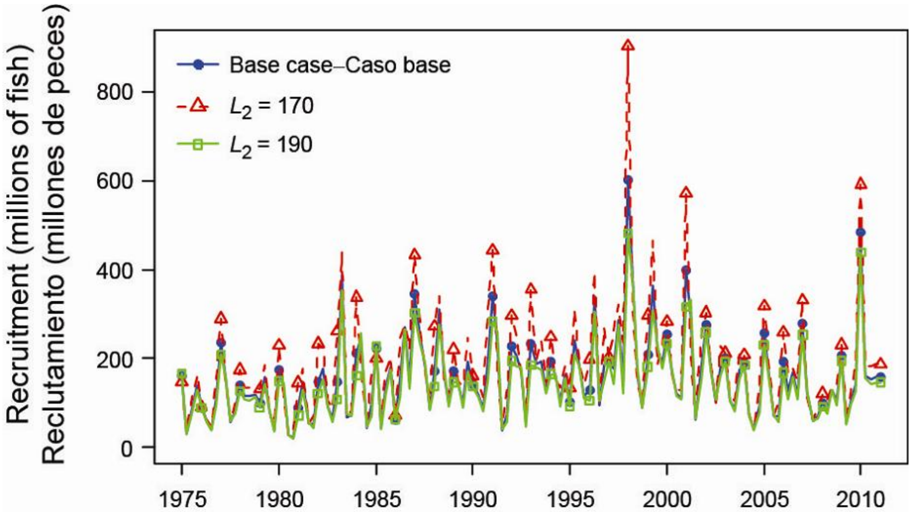

FIGURE B.3a. Comparison of estimates of absolute recruitment (in millions of fish) for yellowfin tuna from the base case analysis using a Richards growth curve with the average size of the oldest fish (L_2) fixed at 182 cm, and two alternative models with L_2 fixed at a lower (170 cm) and a higher value (190 cm).

FIGURA B.3a. Comparación de las estimaciones de reclutamiento absoluto (en millones de peces) de atún alleta amarilla del análisis del caso base que usa una curva de crecimiento de Richards con la talla promedio de los peces de mayor edad (L_2) fijado en 182 cm, y dos modelos alternativos con L_2 fijado en valores menor (170 cm) y mayor (190 cm).

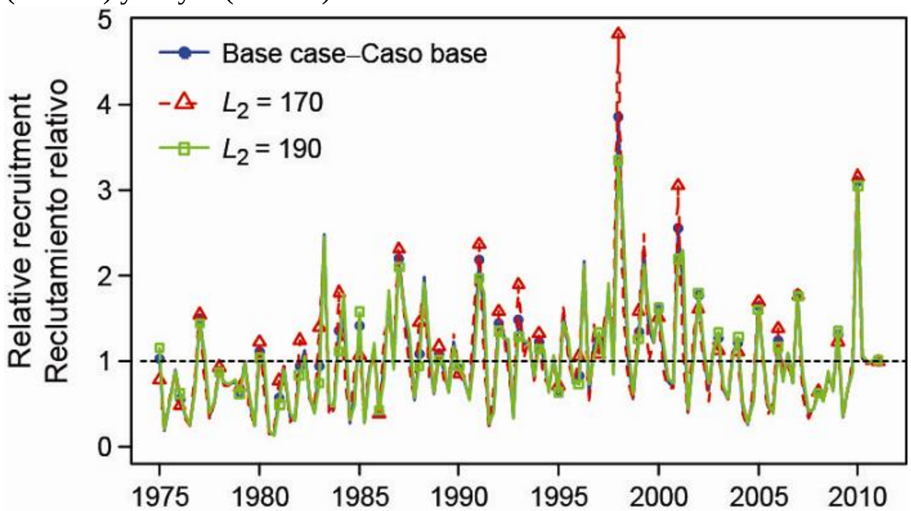

FIGURE B.3b. Comparison of estimates of relative recruitment for yellowfin tuna from the base case analysis using a Richards growth curve with the average size of the oldest fish (L_2) fixed at 182 cm, and two alternative models with L_2 fixed at a lower (170 cm) and a higher value (190 cm). The estimates are scaled so that the estimate of average recruitment is equal to 1.0 (dashed horizontal line).

FIGURA B.3b. Comparación de las estimaciones de reclutamiento relativo de atún alleta amarilla del análisis del caso base que usa una curva de crecimiento de Richards con el tamaño promedio de los peces de mayor edad (L_2) fijado en 182 cm, y dos modelos alternativos con L_2 fijado en valores menor (170 cm) y mayor (190 cm). Se escalan las estimaciones para que la estimación de reclutamiento medio equivalga a 1,0 (línea de trazos horizontal).

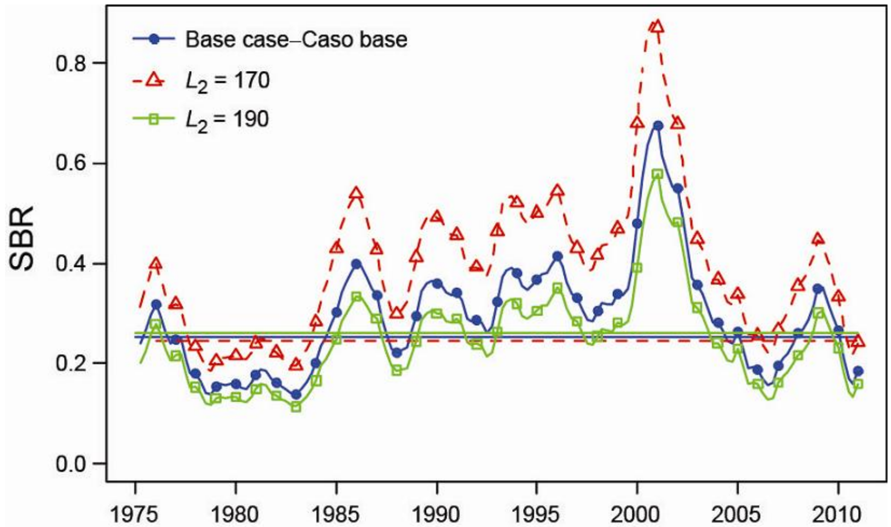

FIGURE B.4. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the base case analysis using a Richards growth curve with the average size of oldest fish (L_2) fixed at 182 cm, and two alternative models with L_2 fixed at a lower (170 cm) and a higher value (190 cm). The horizontal lines represent the SBRs associated with MSY under the two scenarios.

FIGURA B.4. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún aleta amarilla del análisis del caso base que usa una curva de crecimiento de Richards con el tamaño promedio de los peces de mayor edad (L_2) fijado en 182 cm, y dos modelos alternativos con L_2 fijado en valores menor (170 cm) y mayor (190 cm). Las líneas horizontales representan los SBR asociados con el RMS en los dos escenarios.

APPENDIX C: SENSITIVITY ANALYSIS TO FITTING THE CPUE OF THE NORTHERN DOLPHIN ASSOCIATED FISHERY AS THE MAIN INDEX OF ABUNDANCE
ANEXO C: ANÁLISIS DE SENSIBILIDAD AL AJUSTE DE LA CPUE DE LA PESQUERÍA ASOCIADA CON DELFINES DEL NORTE COMO ÍNDICE PRINCIPAL DE LA ABUNDANCIA

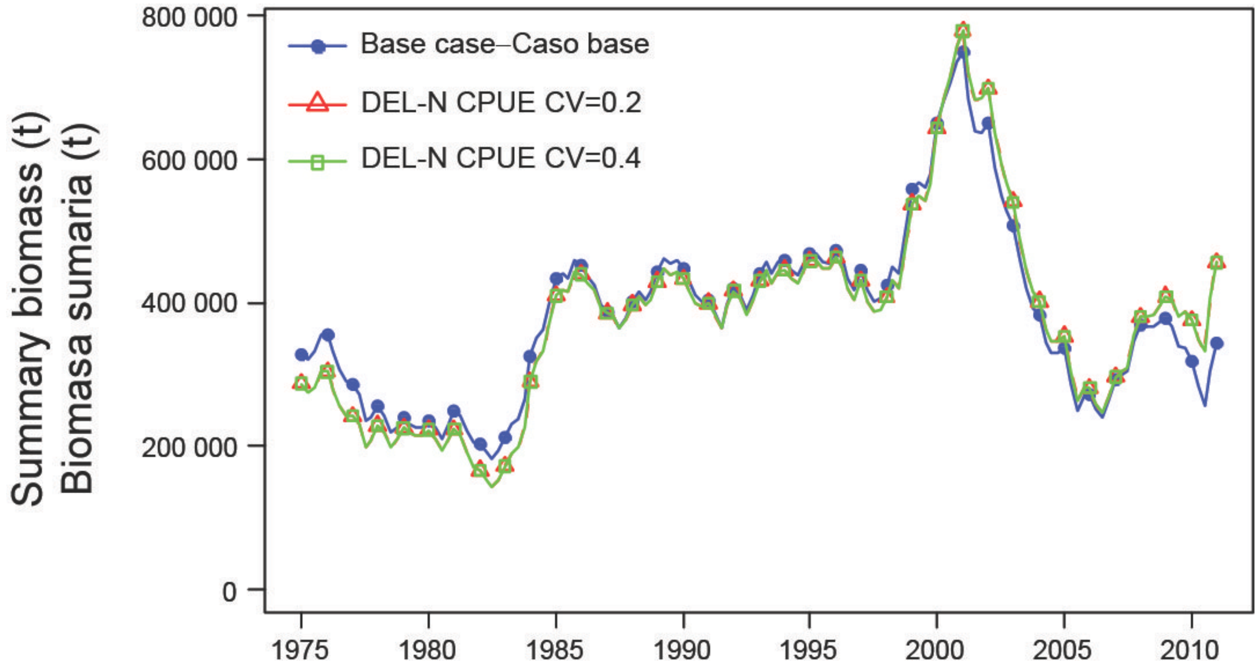

FIGURE C.1. Comparison of the estimates of biomass of yellowfin tuna from the model fitting more closely to the CPUE of the southern longline fishery (base case) and the model fitting more closely to the CPUE of the northern dolphin fishery.
FIGURA C.1. Comparación de las estimaciones del reclutamiento de atún aleta amarilla del modelo que se ajusta más estrechamente a la CPUE de la pesquería de palangre del sur (caso base) y el modelo que se ajusta más estrechamente a la CPUE de la pesquería sobre delfines del norte.

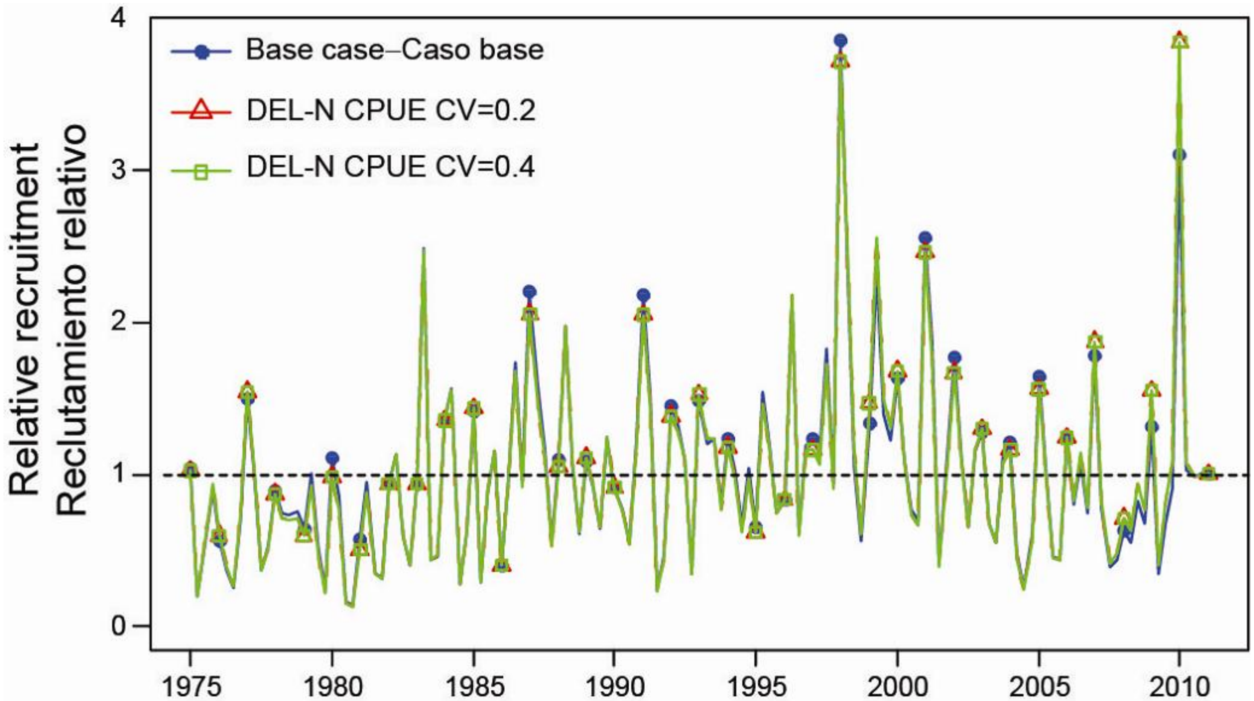

FIGURE C.2. Comparison of estimates of recruitment of yellowfin tuna from the model fitting more closely to the CPUE of the southern longline fishery (base case) and the model fitting more closely to the CPUE of the northern dolphin fishery.
FIGURA C.2. Comparación de las estimaciones del reclutamiento de atún aleta amarilla del modelo que se ajusta más estrechamente a la CPUE de la pesquería de palangre del sur (caso base) y el modelo que se ajusta más estrechamente a la CPUE de la pesquería sobre delfines del norte.

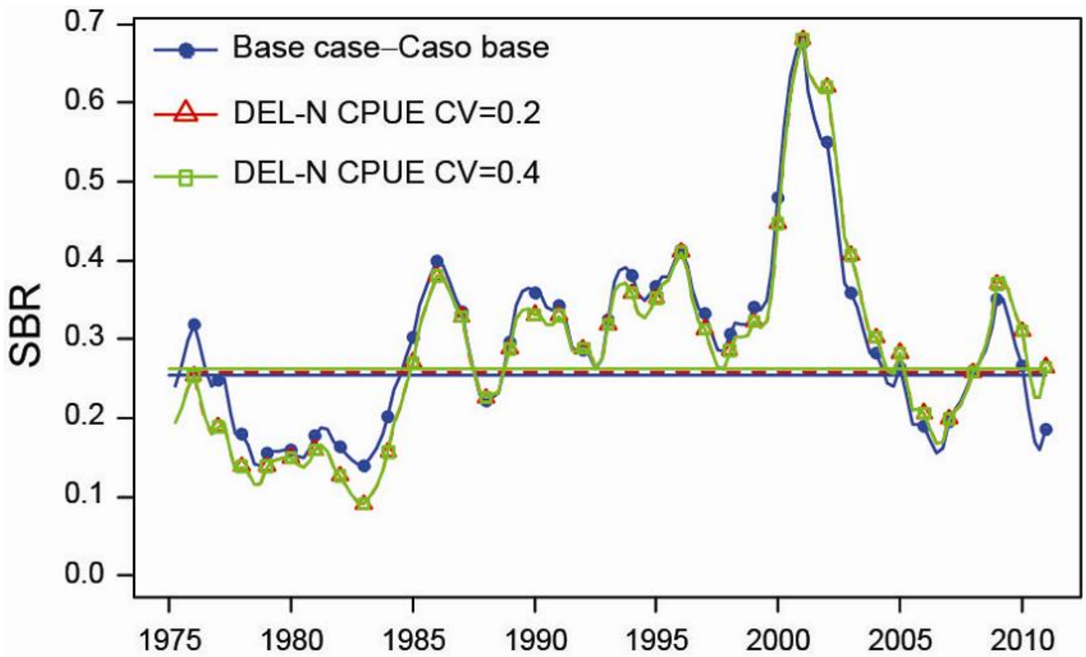

FIGURE C.3. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the model fitting more closely to the CPUE of the southern longline fishery (base case) and the model fitting more closely to the CPUE of the northern dolphin fishery. The horizontal lines represent the SBRs associated with MSY for the two scenarios.

FIGURA C.3. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún aleta amarilla del modelo que se ajusta más estrechamente a la CPUE de la pesquería de palangre del sur (caso base) y el modelo que se ajusta más estrechamente a la CPUE de la pesquería sobre delfines del norte. Las líneas horizontales representan los SBR asociados con el RMS correspondiente a cada escenarios.

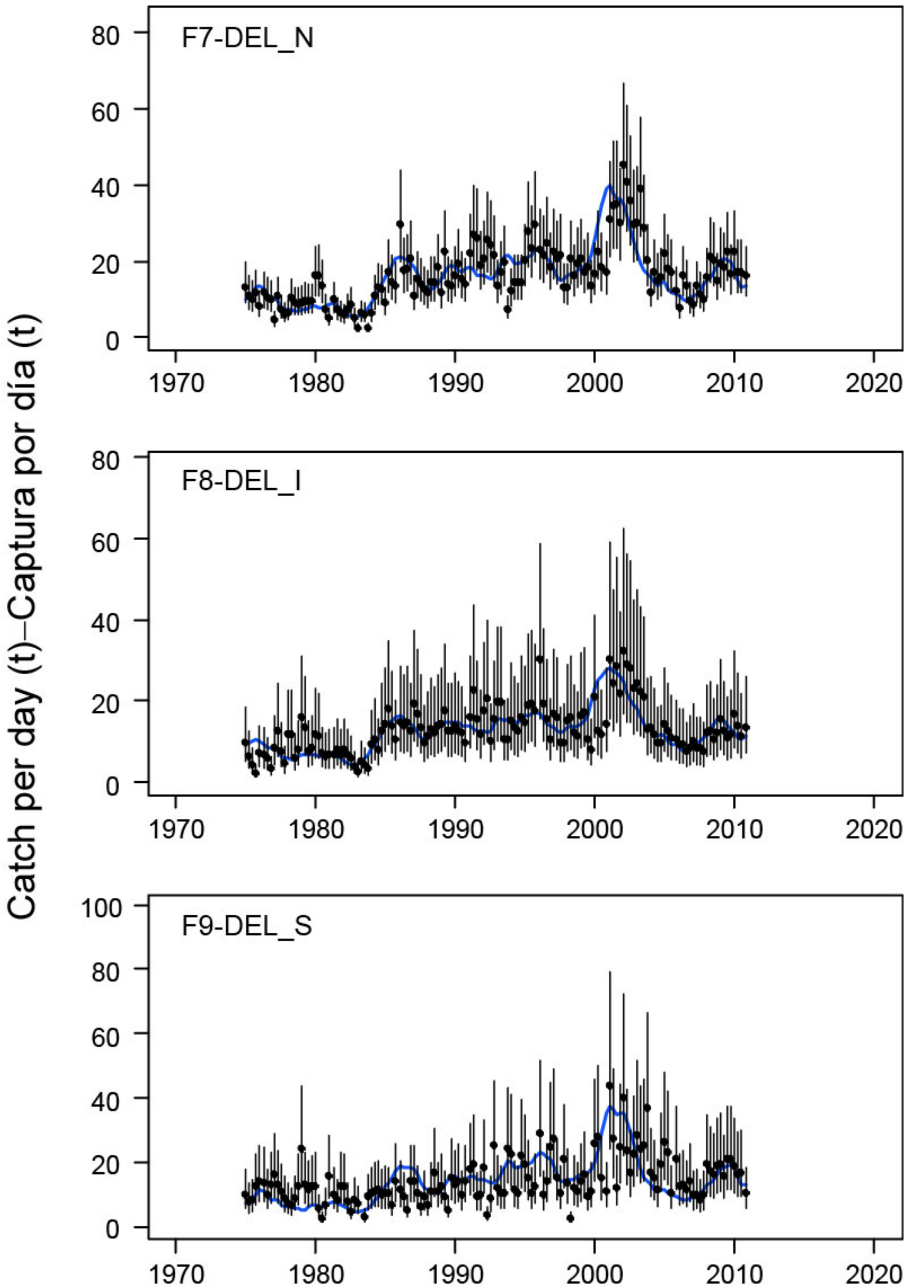

FIGURE C.4a. Model fits to the CPUE-based indices of abundance for the dolphin-associated fisheries, from the model fitting more closely to the CPUE of the northern dolphin fishery. The vertical lines represent the 95% confidence intervals for the observed data based on the internally-estimated standard deviations for the lognormal-based likelihood function.

FIGURA C.4a. Ajustes del modelo a los índices de abundancia basados en CPUE correspondientes a las pesquerías asociadas con delfines del modelo que se ajusta más estrechamente a la CPUE del pesquería sobre delfines del norte. 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.

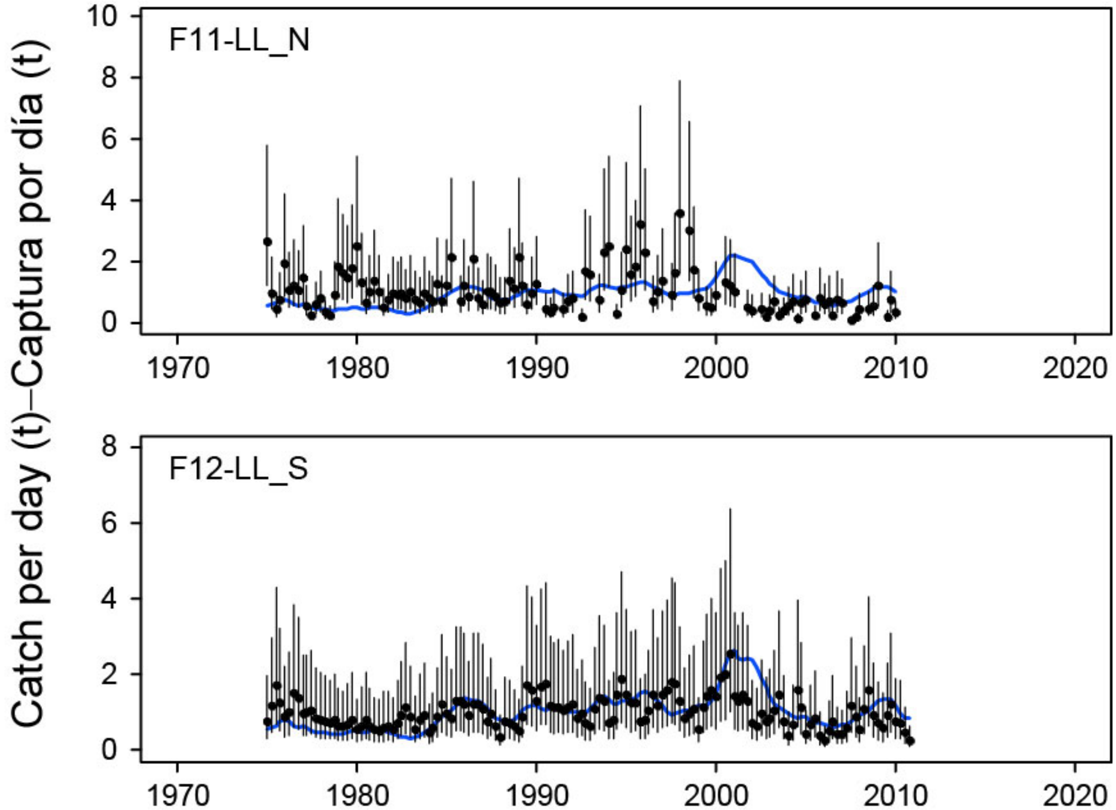

FIGURE C.4b. Model fits to the CPUE-based indices of abundance for the longline fisheries, from the model fitting more closely to the CPUE of the northern dolphin fishery. The vertical lines are the 95% confidence intervals for the observed data based on the internally-estimated standard deviations for the lognormal-based likelihood function.

FIGURA C.4b. Ajustes del modelo a los índices de abundancia basados en CPUE correspondientes a las pesquerías de palangre del modelo que se ajusta más estrechamente a la CPUE del pesquería sobre delfines del norte. 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.

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.

	Age in quarters - Edad en trimestres		
	1-10	**11-20**	**21+**
1975	0.37	0.95	0.62
1976	0.42	1.10	0.84
1977	0.46	1.18	0.98
1978	0.54	1.02	0.79
1979	0.57	1.20	0.94
1980	0.48	1.04	0.77
1981	0.53	1.07	0.81
1982	0.44	0.96	0.76
1983	0.27	0.69	0.59
1984	0.26	0.70	0.54
1985	0.29	0.80	0.58
1986	0.37	0.95	0.59
1987	0.48	1.22	0.84
1988	0.50	1.30	0.92
1989	0.40	1.07	0.74
1990	0.39	1.18	0.86
1991	0.40	1.13	0.86
1992	0.38	1.07	0.72
1993	0.36	0.79	0.64
1994	0.34	0.88	0.73
1995	0.33	0.76	0.56
1996	0.41	0.74	0.50
1997	0.43	1.05	0.72
1998	0.43	0.90	0.64
1999	0.39	0.76	0.52
2000	0.24	0.65	0.51
2001	0.37	0.87	0.66
2002	0.45	1.24	0.87
2003	0.57	1.90	1.44
2004	0.50	1.83	1.58
2005	0.60	1.82	1.41
2006	0.46	1.28	1.01
2007	0.38	1.00	0.78
2008	0.31	0.80	0.56
2009	0.38	1.01	0.71
2010	0.54	1.21	0.74

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