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STATUS OF YELLOWFIN TUNA IN THE EASTERN PACIFIC OCEAN IN 2007 AND OUTLOOK FOR THE FUTURE

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CONTENTS

1. EXECUTIVE SUMMARY

This report presents the most current stock assessment of yellowfin tuna (*Thunnus albacares*) in the eastern Pacific Ocean (EPO). An age-structured, catch-at-length analysis (A-SCALA) 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, but the bulk of the catch is made in the eastern and western regions. The purse-seine catches of yellowfin are relatively low in the vicinity of the western boundary of the EPO. The movements of tagged yellowfin are generally over hundreds, rather than thousands, of kilometers, and exchange between the eastern and western Pacific Ocean appears to be limited. This is consistent with the fact that longline catch-per-unit-of-effort (CPUE) trends differ among areas. It is likely that there is a continuous stock throughout the Pacific Ocean, with exchange of individuals at a local level, although there is some genetic evidence for local isolation. Movement rates between the EPO and the western Pacific cannot be estimated with currently-available tagging data.

The stock assessment requires substantial amounts of information, including data on retained catches, discards, fishing effort, and the size compositions of the catches of the various fisheries. Assumptions have been made about processes such as growth, recruitment, movement, natural mortality, fishing mortality, and stock structure. The assessment for 2008 differs from that of 2007 in the following ways. The catch and length-frequency data for the surface fisheries have been updated to include new data for 2007 (except the first quarter) and revised data for 2000-2006 and the first quarter of 2007. New or updated longline catch data are available for Chinese Taipei (2004-2006) and Japan (2003-2006).

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 productivity regimes (1975-1982, 1983-2001, and 2002-2006) corresponding to low, high, and intermediate levels of recruitment. The productivity regimes correspond to regimes in biomass, higher-productivity regimes producing greater biomasses. 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 analysis indicates that strong cohorts entered the fishery during 1998-2001, and that these cohorts increased the biomass during 1999-2001. However, these cohorts have now moved through the population, so the biomass decreased during 2002-2007. The biomass in 2005-2008 was at levels similar to those prior to 1985.

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, unassociated, and pole-and-line fisheries capture younger, smaller yellowfin than do the dolphin-associated and longline fisheries. The longline fisheries and the dolphin-associated fishery in the southern region capture older, larger yellowfin than do the northern and coastal dolphin-associated fisheries.

Significant levels of fishing mortality have been estimated for the yellowfin fishery in the EPO. These levels are highest for middle-aged yellowfin. Most of the yellowfin catch is taken in sets associated with dolphins, and, accordingly, this method has the greatest impact on the yellowfin population, although it has almost the least impact per unit of weight captured of all fishing methods.

Historically, the spawning biomass ratio (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 the lower productivity regime of 1975-1983, but above that level for most of the following years, except for the recent period (2003-2007). The increase in the SBR in 1984 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 2008 is estimated to be above the level corresponding to the MSY. The effort levels are estimated to be less than those that would support the MSY (based on the current distribution of effort among the different fisheries), but recent catches are substantially below the MSY.

If a stock-recruitment relationship is assumed, the outlook is more pessimistic, and current biomass is estimated to be below the level corresponding to the MSY.

The current average weight of yellowfin in the catch is much less than the critical weight. 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 MSY multiplier.

Under current levels of fishing mortality, it is predicted that the biomass will increase and then decrease but remain above the current level, and that the SBR will follow a similar trend, remaining above the level corresponding to the MSY. A comparison of the biomass and SBR predicted with and without the restrictions from Resolutions C-04-09 and C-06-02 suggests that, without the restrictions, they would be at lower levels than at present, and would decline to about the level corresponding to the MSY.

These simulations were carried out, using the average recruitment for the 1975-2007 period. If they had been carried out using the average recruitment for the 1983-2001 period, the projected trend in SBR and catches would have been more positive. Conversely, if they had been carried out using the average recruitment for the 2002-2006 period, the projected trend in SBR and catches would have been more negative.

Summary

1. The results are similar to the previous assessments, except that the current effort is less than that corresponding to MSY.

2. There is uncertainty about recent and future recruitment and biomass levels.

3. The recent fishing mortality rates are close to 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 between the regimes. The population may have recently switched from the high to an intermediate productivity regime.

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

2. DATA

Catch, effort, and size-composition data for January 1975-December 2007, plus biological data, were used to conduct the stock assessment of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean (EPO). The data for 2007, which are preliminary, include records that had been entered into the IATTC databases by 15 April 2007. All data are summarized and analyzed on a quarterly basis.

2.1. Definitions of the fisheries

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

In general, fisheries are defined so that, over time, there is little change in the size composition of the catch. Fishery definitions for purse-seine sets on floating objects are also stratified to provide a rough

distinction between sets made mostly on fish-aggregating devices (FADs) (Fisheries 1-2, 4, 13-14, and 16), and sets made on mixtures of flotsam and FADs (Fisheries 3 and 15).

2.2. Catch and effort data

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

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

New and updated catch and effort data for the surface fisheries (Fisheries 1-10 and 13-16) have been incorporated into the current assessment. New catch and effort data for 2007 (except the first quarter, which was used in the previous assessment) and updated data for earlier years are used for the surface fisheries.

The species-composition method (Tomlinson 2002) was used to estimate catches of the surface fisheries. Comparisons of catch estimates from different sources show consistent differences between cannery and unloading data and the results of species composition sampling. Comparing the two sets of results is complex, as the cannery and unloading data are collected at the trip level, while the species-composition samples are collected at the well level, and represent only a small subset of the data. Differences in catch estimates could be due to the proportions of small tunas in the catch, differences in identification of the fish at the cannery, or even biases introduced in the species-composition algorithm in determining the species composition in strata for which no species-composition samples are available. In this assessment we calculated average quarterly and fishery-specific scaling factors for 2000-2005 and applied these to the cannery and unloading estimates for 1975-1999. Harley and Maunder (2005) compared estimates of the catches of bigeye obtained by sampling catches with estimates of the catches obtained from cannery data. Maunder and Watters (2001) provide a brief description of the method that is used to estimate fishing effort by surface gear (purse seine and pole-and-line).

Updates and new catch and effort data for the longline fisheries (Fisheries 11 and 12) have also been incorporated into the current assessment. New or updated catch data were available for Chinese Taipei (2004-2006) and Japan (2003-2006).

The amount of longlining effort was estimated by dividing standardized estimates of the catch per unit of effort (CPUE) from the Japanese longline fleet into the total longline landings. Estimates of standardized CPUE were obtained using a delta-lognormal generalized linear model (Stefansson 1996) that took into account latitude, longitude, and numbers of hooks between floats (Hoyle and Maunder 2006b).

2.2.1. Catch

A substantial proportion of the longline catch data for 2007 were not available, so effort data were assumed (see Section 2.2.2), and the catch was estimated by the stock assessment model. Therefore, the total 2007 longline catch is a function of the assumed 2007 longline effort, the estimated number of yellowfin of catchable size in the EPO in 2007, and the estimated selectivities and catchabilities for the longline fisheries. Catches for the longline fisheries for the recent years for which the data were not available were set equal 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 March 2007 are shown in Figure 2.2. It should be noted that there were substantial surface and longline fisheries for yellowfin prior to 1975 (Shimada and Schaefer 1956; Schaefer 1957; Okamoto and Bayliff 2003). The majority of the catch has been taken by purse-seine sets on yellowfin associated with dolphins and in unassociated schools. One main characteristic of the catch trends is the increase in catch taken since about 1993 by purse-seine sets on fish associated with floating objects, especially FADs in Fisheries 1 and 2. However, this is a relatively small part of the total catch.

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

2.2.2. Effort

New effort data for 2007 (except the first quarter, which was used in the previous assessment) and updated data for earlier years are used for the surface fisheries.

A complex algorithm, described by Maunder and Watters (2001), was used to estimate the amount of fishing effort, in days fished, exerted by purse-seine vessels. The longline effort data for yellowfin have been estimated from standardized CPUE data, as follows. Detailed data on catch, effort, and hooks between floats by latitude and longitude from the Japanese longline fleet, provided by Mr. Adam Langley of the Secretariat of the Pacific Community, were used in a generalized linear model with a delta lognormal link function to produce an index of standardized CPUE (E.J. Dick, NOAA Santa Cruz, personal communication); see Stefansson (1996) for a description of the method and Hoyle and Maunder (2006b) for more detailed information. The Japanese effort data were scaled by the ratio of the Japanese catch to the total catch to compensate for the inclusion of catch data from the other nations into the assessment. This allows inclusion of all the longline catch data into the assessment, while using only the Japanese effort data to provide information on relative abundance.

Effort information from the Japanese longlining operations conducted in the EPO during 2007 was not available for this assessment. The longline effort exerted during each quarter of 2007 was assumed to be equal to the estimated effort exerted during the corresponding quarter of 2006. No longline catch data were input for 2007 (see above).

Trends in the amount of fishing effort exerted by the 16 fisheries defined for the stock assessment of yellowfin in the EPO are plotted in Figure 2.3. Fishing effort for surface gears (Fisheries 1-10 and 13-16) is in days fishing. The fishing effort in Fisheries 13-16 is equal to that in Fisheries 1-4 (Figure 2.3) because the catches taken by Fisheries 13-16 are derived from those taken by Fisheries 1-4 (see Section 2.2.3). Fishing effort for longliners (Fisheries 11 and 12) is in standardized units.

2.2.3. 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. In the present assessment the discard rates are not smoothed over time, which should allow for a better representation of recruitment in the model.

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 (see Figure 4.5). Maunder and Watters (2001) provide a rationale for treating such discards as separate fisheries. The discard rate prior to 1993 is assumed to be the average rate observed in each fishery after this time. Estimates of the amounts of fish discarded during sorting are made only for fisheries that take yellowfin associated with floating objects (Fisheries 2-5) because sorting is infrequent in the other purse-seine fisheries.

Time series of discards as proportions of the retained catches for the surface fisheries that catch yellowfin in association with floating-objects are presented in Figure 2.4. It is assumed that yellowfin are not discarded from longline fisheries (Fisheries 11 and 12).

2.3. Size-composition data

The fisheries of the EPO catch yellowfin of various sizes. The average size composition of the catch from each fishery defined in Table 2.1 is shown in Figure 4.2. Maunder and Watters (2001) describe the sizes of yellowfin caught by each fishery. In general, floating-object, unassociated, and pole-and-line fisheries catch smaller yellowfin, while dolphin-associated and longline fisheries catch larger ones. New purse-seine length-frequency data were included for the last three quarters of 2007, and revised data for 2000-2005 and the first quarter of 2007.

New longline length-frequency data for 2005 for the Japanese fleet, and updated data for that fleet for 2002-2004, were included. Size composition data for the other longline fleets are not used in the assessment.

The length frequencies of the catches during 2007 from the four floating-object fisheries were similar to those observed over the entire modeling period (compare Figures 4.2 and 4.8a). The appearance, disappearance, and subsequent reappearance of strong cohorts in the length-frequency data is a common phenomenon for yellowfin in the EPO. This may indicate spatial movement of cohorts or fishing effort, limitations in the length-frequency sampling, or fluctuations in the catchability of the fish. Bayliff (1971) observed that groups of tagged fish have also disappeared and then reappeared in this fishery, which he attributed to fluctuations in catchability.

2.4. Auxiliary data

Age-at-length estimates (Wild 1986) calculated from otolith data were integrated into the stock assessment model in 2005 (Hoyle and Maunder 2006a) to provide information on mean length at age and variation in length at age. His data consisted of ages, based on counts of daily increments in otoliths, and lengths for 196 fish collected between 1977 and 1979. The sampling design involved collection of 15 yellowfin in each 10-cm interval in the length range of 30 to 170 cm. The model has been altered to take this sampling scheme into account (see Section 3.1.1).

3. ASSUMPTIONS AND PARAMETERS

3.1. Biological and demographic information

3.1.1. Growth

The growth model is structured so that individual growth increments (between successive ages) can be estimated as free parameters. These growth increments for all ages were highly constrained to be similar to a Richards growth curve. The Richards growth equation, $L_t = L_\infty \left(1 - \frac{\exp\left(-K\left(t - t_0\right)\right)}{b} \right)^b$, fitted to

data from Wild (1986) was used as the prior (Figure 3.1) (L_∞ = 185.7 cm, annual K= 0.761, t_0 = 1.853 years, b = -1.917). The growth increments are also constrained so that the mean length is a monotonically increasing function of age. The size at which fish are first recruited to the fishery must be specified, and it is assumed that yellowfin are recruited to the discard fisheries (Fisheries 13-16) when they are 30 cm long and two quarters old.

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

An important component of growth used in age-structured statistical catch-at-length models is the variation in length at age. Age-length information contains information about variation of length at age, in addition to information about mean length at age. Unfortunately, as in the case of the data collected by Wild (1986), sampling is usually aimed at getting fish of a wide range of lengths. Therefore, this sample may represent the population in variation of age at length, but not variation of length at age. However, by applying conditional probability the appropriate likelihood can be developed.

This assessment used the approach first employed by Hoyle and Maunder (2006a) to estimate variation in length at age from the data. Both the sampling scheme and the fisheries and time periods in which data were collected were taken into account. The mean lengths of older yellowfin were assumed to be close to those indicated by the growth curve of Wild (1986).

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

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

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

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

3.1.2. Recruitment and reproduction

The A-SCALA method allows a Beverton-Holt (1957) stock-recruitment relationship to be specified. The Beverton-Holt curve is parameterized so that the relationship between spawning biomass and recruitment is determined by estimating the average recruitment produced by an unexploited population (virgin recruitment) and a parameter called steepness. Steepness is defined as the fraction of virgin recruitment that is produced if the spawning stock size is reduced to 20% of its unexploited level, and it controls how quickly recruitment decreases when the size of the spawning stock is reduced. Steepness can vary between 0.2 (in which case recruitment is a linear function of spawning stock size) and 1.0 (in which case recruitment is independent of spawning stock size). In practice, it is often difficult to estimate steepness because of lack of contrast in spawning stock size, high inter-annual (and inter-quarter) variation in recruitment, and confounding with long-term changes in recruitment, due to environmental effects not included in the model that affect spawning stock size. The base case assessment assumes that there is no relationship between stock size and recruitment. This assumption is the same as that used in the previous assessments. The influence of a Beverton-Holt stock-recruitment relationship is investigated in a sensitivity analysis.

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

An assumption is made about the way that recruitment can vary around its expected level, as determined from the stock-recruitment relationship. This assumption is used to penalize the temporal recruitment

deviates. It is assumed that the logarithm of the quarterly recruitment deviates is normally distributed with a standard deviation of 0.6.

Yellowfin are assumed to be recruited to the discard fisheries in the EPO at about 33 cm (about 2 quarters old) (Section 3.1.1). At this size (age), the fish are vulnerable to capture by fisheries that catch fish in association with floating objects (*i.e.* they are recruited to Fisheries 13-16).

The spawning potential of the population is estimated from the numbers of fish, proportion of females, percentage of females that are mature, batch fecundity, and spawning frequency (Schaefer 1998). These quantities (except numbers) are estimated for each age class, based on the mean length at age given by the Richards growth equation fitted to the otolith data of Wild (1986). Maunder and Watters (2002) describe the method, but using the von Bertalanffy growth curve. These quantities were re-estimated when investigating sensitivity to different growth curves. 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 and the sex ratio at age are shown in Figures 3.2 and 3.3, respectively.

3.1.3. Movement

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

3.1.4. Natural mortality

For the current stock assessment, it is assumed that, as yellowfin grow older, the natural mortality rate (*M*) changes. This assumption is similar to that made in previous assessments, for which the natural mortality rate was assumed to increase for females after they reached the age of 30 months (*e.g.* Anonymous 1999: 38). Males and females are not treated separately in the current stock assessment, and *M* is treated as a rate for males and females combined. The values of quarterly *M* used in the current stock assessment are plotted in Figure 3.4. These values were estimated by making the assumptions described above, fitting to sex ratio at length data (Schaefer 1998), and comparing the values with those estimated for yellowfin in the western and central Pacific Ocean (Hampton 2000; Hampton and Fournier 2001). Maunder and Watters (2001) describe in detail how the age-specific natural mortality schedule for yellowfin in the EPO is estimated.

3.1.5. Stock structure

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

3.2. Environmental influences

Recruitment of yellowfin in the EPO has tended to be greater after El Niño events (Joseph and Miller 1989). Previous stock assessments have included the assumption that oceanographic conditions might influence recruitment of yellowfin in the EPO (Maunder and Watters 2001, 2002; see Maunder and

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

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

4. STOCK ASSESSMENT

A-SCALA, an age-structured statistical catch-at-length analysis model (Maunder and Watters 2003a), and information contained in catch, effort, size-composition, and biological data are used to assess the status of yellowfin in the EPO. The A-SCALA model is based on the method described by Fournier *et al.* (1998). The term "statistical" indicates that the model implicitly recognizes the fact that data collected from fisheries do not perfectly represent the population; there is uncertainty in our knowledge about the dynamics of the system and about how the observed data relate to the real population. The model uses quarterly time steps to describe the population dynamics. The parameters of the model are estimated by comparing the predicted catches and size compositions to data collected from the fishery. After these parameters have been estimated, the model is used to estimate quantities that are useful for managing the stock.

The A-SCALA method was first used to assess yellowfin in the EPO in 2000 (Maunder and Watters, 2001), and was modified and used for subsequent assessments. The following parameters have been estimated for the current stock assessment of yellowfin in the EPO:

1. recruitment to the fishery in every quarter from the first quarter of 1975 through the first quarter of 2008;
2. quarterly catchability coefficients for the 16 fisheries that take yellowfin from the EPO;
3. selectivity curves for 12 of the 16 fisheries (Fisheries 13-16 have an assumed selectivity curve);
4. initial population size and age-structure;
5. mean length at age (Figure 3.1);
6. parameters of a linear model relating the standard deviations in length at age to the mean lengths at age.

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

1. fecundity of females at age (Figure 3.2);
2. sex ratio at age (Figure 3.3);
3. natural mortality at age (Figure 3.4);

4. selectivity curves for the discard fisheries (Fisheries 13-16);
5. steepness of the stock-recruitment relationship (steepness = 1 for the base case assessment).

Yield and catchability estimates for estimations of the average maximum sustainable yield (MSY) or future projections were based on estimates of quarterly fishing mortality for 2005 to 2007. Sensitivity of estimates of key management quantities to this assumption was tested.

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

4.1. Indices of abundance

CPUEs have been used as indices of abundance in previous assessments of yellowfin in the EPO (*e.g.* Anonymous 1999). It is important to note, however, that trends in the CPUE will not always follow trends in the biomass or abundance. There are many reasons why this could be the case. For example, if, due to changes in technology or targeting, a fishery became more or less efficient at catching yellowfin while the biomass was not changing, the CPUEs would increase or decrease despite the lack of trend in biomass. Fisheries may also show hyper- or hypo-stability, in which the relationship between CPUE and abundance is non-linear (Hilborn and Walters 1992; Maunder and Punt 2004). The CPUEs of the 16 fisheries defined for the current assessment of yellowfin in the EPO are shown in Figure 4.1. Trends in longline CPUE are based only on the Japanese data. As mentioned in Section 2.2.2, CPUE for the longline fisheries was standardized using general linear modeling. Discussions of historical catch rates can be found in Maunder and Watters (2001, 2002), Maunder (2002a), Maunder and Harley (2004, 2005), and Hoyle and Maunder (2006a), but trends in CPUE should be interpreted with caution. Trends in estimated biomass are discussed in Section 4.2.3.

4.2. Assessment results

Below we describe important aspects of the base case assessment (1 below) and changes for the sensitivity analyses (2 below):

1. Base case assessment: steepness of the stock-recruitment relationship equals 1 (no relationship between stock and recruitment), species-composition estimates of surface fishery catches scaled back to 1975, delta-lognormal general linear model standardized CPUE, and assumed sample sizes for the length-frequency data.

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.

The results of the base case assessment are described in the text, and the stock-recruitment relationship sensitivity analysis is described in the text, with figures and tables presented in Appendix A1.

The A-SCALA method provides a reasonably good fit to the catch and size-composition data for the 16 fisheries that catch yellowfin in the EPO. The assessment model is constrained to fit the time series of catches made by each fishery almost perfectly. The 16 predicted time series of yellowfin catches are almost identical to those plotted in Figure 2.2. It is important to predict the catch data closely, because it is difficult to estimate biomass if reliable estimates of the total amount of fish removed from the stock are not available.

It is also important to predict the size-composition data as accurately as possible, but, in practice, it is more difficult to predict the size composition than to predict the total catch. Accurately predicting the size composition of the catch is important because these data contain most of the information necessary for modeling recruitment and growth, and thus for estimating the impact of fishing on the stock. A description of the size distribution of the catch for each fishery is given in Section 2.3. Predictions of the size compositions of yellowfin caught by Fisheries 1-12 are summarized in Figure 4.2, which simultaneously illustrates the average observed and predicted size compositions of the catches for these 12 fisheries. (Size-composition data are not available for discarded fish, so Fisheries 13-16 are not included in this discussion.) The predicted size compositions for all of the fisheries with size-composition data are good, although the predicted size compositions for some fisheries have lower peaks than the observed size compositions (Figure 4.2). The model also tends to over-predict larger yellowfin in some fisheries. However, the fit to the length-frequency data for individual time periods shows much more variation (Figure 4.8).

The results presented in the following section 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 estimates of the biomass and recruitment in recent years.

4.2.1. Fishing mortality

There is variation in fishing mortality exerted by the fisheries that catch yellowfin in the EPO, with fishing mortality being higher before 1984, during the lower productivity regime (Figure 4.3a), and since 2003. Fishing mortality changes with age (Figure 4.3b). The fishing mortalities for younger and older yellowfin are low. There is a peak at around ages of 14-15 quarters, which corresponds to peaks in the selectivity curves for fisheries on unassociated and dolphin-associated yellowfin (Figures 4.3b and 4.4). The fishing mortality of young fish has not greatly increased in spite of the increase in effort associated with floating objects that has occurred since 1993 (Figure 4.3b).

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

Selectivity curves estimated for the 16 fisheries defined in the stock assessment of yellowfin are shown in Figure 4.4. Purse-seine sets on floating objects select mostly yellowfin that are about 4 to 14 quarters old (Figure 4.4, Fisheries 1-4). Purse-seine sets on unassociated schools of yellowfin select fish similar in size to those caught by sets on floating objects (about 5 to 15 quarters old, Figure 4.4, Fisheries 5 and 6), but these catches contain greater proportions of fish from the upper portion of this range. Purse-seine sets on yellowfin associated with dolphins in the northern and coastal regions select mainly fish 7 to 15 quarters old (Figure 4.4, Fisheries 7 and 8). The dolphin-associated fishery in the south selects mainly yellowfin 12 or more quarters old (Figure 4.4, Fishery 9). Longline fisheries for yellowfin also select mainly older individuals about 12 or more quarters old (Figure 4.4, Fisheries 11 and 12). Pole-and-line gear selects yellowfin about 4 to 8 quarters old (Figure 4.4, Fishery 10).

Discards resulting from sorting purse-seine catches of yellowfin taken in association with floating objects are assumed to be composed only of fish recruited to the fishery for three quarters or less (age 2-4 quarters, Figure 4.4, Fisheries 13-16). (Additional information regarding the treatment of discards is given in Section 2.2.3.)

The ability of purse-seine vessels to capture yellowfin in association with floating objects has generally declined over time (Figure 4.5a, Fisheries 1-4). These fisheries have also shown high temporal variation in catchability. Changes in fishing technology and behavior of the fishermen may have decreased the

catchability of yellowfin during this time.

The ability of purse-seine vessels to capture yellowfin in unassociated schools has also been highly variable over time (Figure 4.5a, Fisheries 5 and 6).

The ability of purse-seine vessels to capture yellowfin in dolphin-associated sets has been less variable in the northern and coastal areas than in the other fisheries (Figure 4.5a, Fisheries 7 and 8). The catchability in the southern fishery (Fishery 9) is more variable. All three dolphin-associated fisheries have had greater-than-average catchability during most of 2001-2005. However, catchability was estimated to decrease during 2006 and 2007.

The ability of pole-and-line gear to capture yellowfin has been highly variable over time (Figure 4.5a, Fishery 10). There have been multiple periods of high and low catchability.

The ability of longline vessels to capture yellowfin has been more variable in the northern fishery (Fishery 11), which catches fewer yellowfin, than in the southern fishery (Fishery 12). Catchability in the northern fishery has been very low since the late 1990s.

The catchabilities of small yellowfin by the discard fisheries (Fisheries 13-16) are shown in Figure 4.5b.

In previous assessments catchability for the southern longline fishery has shown a highly significant correlation with SST (Maunder and Watters 2002). Despite its significance, the correlation between SST and catchability in that fishery did not appear to be a good predictor of catchability (Maunder and Watters 2002), and therefore it is not included in this assessment.

4.2.2. Recruitment

In a previous assessment, the abundance of yellowfin recruited to fisheries in the EPO appeared to be correlated to SST anomalies at the time that these fish were hatched (Maunder and Watters 2001). However, inclusion of a seasonal component in recruitment explained most of the variation that could be explained by SST (Maunder and Watters 2002). No environmental time series was investigated for this assessment.

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

A sensitivity analysis was carried out, fixing the Beverton-Holt (1957) steepness parameter at 0.75 (Appendix A). This means that recruitment is 75% of the recruitment from an unexploited population when the population is reduced to 20% of its unexploited level. Given the information currently available, the hypothesis of two regimes in recruitment is as plausible as an effect of population size on recruitment. The results when a stock-recruitment relationship is used are described in Section 4.5.

The estimated time series of yellowfin recruitment is shown in Figure 4.7, and the estimated annual total recruitment in Table 4.1. The large recruitment that entered the discard fisheries in the third quarter of 1998 (6 months old) was estimated to be the strongest cohort of the 1975-2003 period. A sustained period of high recruitment was estimated for mid-1999 until the end of 2000. A large recruitment is estimated for 2007, but there is considerable uncertainty in the estimate. The assessment model has shown a tendency to overestimate recent recruitment strengths in the last few assessments.

Another characteristic of the recruitment, which was also apparent in previous assessments, is the regime change in the recruitment levels, starting during the second quarter of 1983. The recruitment was, on average, consistently greater after 1983 than before. This change in recruitment levels produces a similar change in biomass (Figure 4.9a). There is an indication that the recruitments in five recent years (2002-

2006) were at low levels, similar to those prior to 1983, perhaps indicating a change back to a low productivity regime.

The confidence intervals for recruitment are relatively narrow, indicating that the estimates are fairly precise, except for that of the most recent year (Figure 4.7). The standard deviation of the estimated recruitment deviations (on the logarithmic scale) is 0.60, which is equal to the 0.6 assumed in the penalty applied to the recruitment deviates. The estimates of uncertainty are surprisingly small, considering the inability of the model to fit modes in the length-frequency data (Figure 4.8). These modes often appear, disappear, and then reappear.

The estimates of the most recent recruitments are highly uncertain, as can be seen from the large confidence intervals (Figure 4.7). In addition, the floating-object fisheries, which catch the youngest fish, account for only a small portion of the total catch of yellowfin.

4.2.3. Biomass

Biomass is defined as the total weight of yellowfin that are 1.5 or more years old. The trends in the biomass of yellowfin in the EPO are shown in Figure 4.9a, and estimates of the biomass at the beginning of each year in Table 4.1. Between 1975 and 1983 the biomass of yellowfin declined to about 250,000 metric tons (t); it then increased rapidly during 1983-1986, and reached about 540,000 t in 1986. During 1986-1999 it remained relatively constant at about 450,000-550,000 t; it then peaked in 2001 and subsequently declined to levels similar to those prior to 1984. The confidence intervals for the biomass estimates are relatively narrow, indicating that the biomass is well estimated.

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

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

The impact of each major type of fishery on the yellowfin stock is shown in Figures 4.10b and 4.10c. The estimates of biomass in the absence of fishing were computed as above, and then the biomass trajectory was estimated by setting the effort for each fisheries group, in turn, to zero. The biomass impact for each fishery group at each time step is derived as this biomass trajectory minus the 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. These impacts are plotted as a proportion of unfished biomass (Figure 4.10b) and in absolute biomass (Figure 4.10c).

4.2.4. 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 12 to 22 kg for most of the 1975-2007 period, but have differed considerably among fisheries (Figures 4.11). The average weight was high during the 1985-1992 period, when the effort for the floating-object and unassociated fisheries was less (Figure 2.3). The average weight was also high in

1975-1977 and in 2001-2004. The average weight of yellowfin caught by the different gears varies widely, but remains fairly consistent over time within each fishery (Figure 4.11). The lowest average weights (about 1 kg) are produced by the discard fisheries, followed by the pole-and-line fishery (about 4-5 kg), the floating-object fisheries (about 5-10 kg for Fishery 3, 10 kg for Fisheries 2 and 4, and 10-15 kg for Fishery 1), the unassociated fisheries (about 15 kg), the northern and coastal dolphin-associated fisheries (about 20-30 kg), and the southern dolphin-associated fishery and the longline fisheries (each about 40-50 kg).

4.3. Comparisons to external data sources

No external data were used as a comparison in the current assessment.

4.4. Diagnostics

We present diagnostics in three sections: (1) residual plots, (2) parameter correlations, and (3) retrospective analysis.

4.4.1. Residual plots

Residual plots show the differences between the observations and the model predictions. The residuals should show characteristics similar to the assumptions used in the model. For example, if the likelihood function is based on a normal distribution and assumes a standard deviation of 0.2, the residuals should be normally distributed with a standard deviation of about 0.2.

The estimated annual effort deviations, which are one type of residual in the assessment and represent temporal changes in catchability, are shown plotted against time in Figure 4.5a. These residuals are assumed to be normally distributed (the residual is exponentiated before multiplying by the effort so the distribution is actually lognormal) with a mean of zero and a given standard deviation. A trend in the residuals indicates that the assumption that CPUE is proportional to abundance is violated. The assessment assumes that the southern longline fishery (Fishery 12) provides the most reasonable information about abundance (standard deviation (sd) = 0.2) while the dolphin-associated and unassociated fisheries have less information (sd = 0.3), the floating-object, the pole-and-line fisheries, and the northern longline fishery have the least information (sd = 0.4), and the discard fisheries have no information (sd = 2). Therefore, a trend is less likely in the southern longline fishery (Fishery 12) than in the other fisheries. The trends in effort deviations are estimates of the trends in catchability (see Section 4.2.1). Figure 4.5a shows no overall trend in the southern longline fishery effort deviations, but there are some consecutive residuals that are all above or all below the average. The standard deviations of the residuals are greater than those assumed. These results indicate that the assessment gives more weight to the CPUE information than it should. The effort residuals for the floating-object fisheries have a declining trend over time, while the effort residuals for the northern and coastal dolphin-associated fisheries have slight increasing trends over time. These trends may be related to true trends in catchability.

The observed proportion of fish caught in a length class is assumed to be normally distributed around the predicted proportion, with the standard deviation equal to the binomial variance, based on the observed proportions, divided by the square of the sample size (Maunder and Watters 2003a). Previous analyses have indicated that the length-frequency residuals appear to be less than the assumed standard deviation .

4.4.2. Parameter correlation

Often quantities, such as recent estimates of recruitment deviates and fishing mortality, can be highly correlated. This information indicates a flat solution surface, which implies that alternative states of nature had similar likelihoods.

There is negative correlation between the current estimated effort deviates for each fishery and estimated recruitment deviates lagged to represent cohorts entering each fishery. The negative correlation is most obvious for the discard fisheries. Earlier effort deviates are positively correlated with these recruitment deviates.

Current spawning biomass is positively correlated with recruitment deviates lagged to represent cohorts entering the spawning biomass population. This correlation is greater than for earlier spawning biomass estimates. Similar correlations are seen for recruitment and spawning biomass.

4.4.3. Retrospective analysis

Retrospective analysis is a useful method to determine how consistent a stock assessment method is from one year to the next. Inconsistencies can often highlight inadequacies in the stock assessment method. The estimated biomass and SBR (defined in Section 3.1.2) from the previous assessment and the current assessment are shown in Figure 4.12a and 4.12b. However, data differ between these assessments, so differences may be expected (see Section 4.6). Retrospective analyses are usually carried out by repeatedly eliminating one year of data from the analysis while using the same stock assessment method and assumptions. This allows the analyst to determine the change in estimated quantities as more data are included in the model. Estimates for the most recent years are often uncertain and biased. Retrospective analysis and the assumption that more data improves the estimates can be used to determine if there are consistent biases in the estimates. Retrospective analysis carried out by Maunder and Harley (2004) suggested that the peak in biomass in 2001 had been consistently underestimated, but the 2005 assessment estimated a slightly lower peak in 2001. The assessment model has shown a tendency to overestimate recent recruitment strengths in the last few assessments, indicating a possible retrospective pattern in recruitment estimates.

4.5. Sensitivity to assumptions

Sensitivity analyses were carried out to investigate the incorporation of a Beverton-Holt (1957) stock-recruitment relationship (Appendix A1).

The base case analysis assumed no stock-recruitment relationship, and an alternative analysis was carried out with the steepness of the Beverton-Holt stock-recruitment relationship fixed at 0.75. This implies that when the population is reduced to 20% of its unexploited level, the expected recruitment is 75% of the recruitment from an unexploited population. As in previous assessments, (Maunder and Watters 2002, Hoyle and Maunder 2006a) the analysis with a stock-recruitment relationship fits the data better than the analysis without the stock-recruitment relationship. However, the regime shift could also explain the result, since the period of high recruitment is associated with high spawning biomass, and vice versa. When a Beverton-Holt stock-recruitment relationship (steepness = 0.75) is included, the estimated biomass (Figure A1.1) and recruitment (Figure A1.2) are almost identical to those of the base case assessment.

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

4.6. Comparison to previous assessments

The estimated biomass and SBR trajectories are similar to those from the previous assessment presented by Maunder (2007) (Figure 4.12). These results are also similar to those obtained using cohort analysis (Maunder 2002b). This indicates that estimates of absolute biomass are robust to the assumptions that have been changed as the assessment procedure has been updated. The estimate of the recent biomass is lower in the current assessment.

4.7. Summary of the results from the assessment model

In general, the recruitment of yellowfin to the fisheries in the EPO is variable, with a seasonal component. This analysis and previous analyses have indicated that the yellowfin population has experienced two, or possibly three, different productivity regimes (1975-1983, 1984-2000, and 2001-2006). The productivity regimes correspond to regimes in biomass, higher-productivity regimes producing greater biomass levels. A stock-recruitment relationship is also supported by the data from these regimes, but the evidence is weak, and is probably an artifact of the apparent regime shifts. The analysis indicates that strong cohorts entered the fishery during 1998-2000, and that these cohorts increased the biomass during 1999-2000. However, these cohorts have now moved through the population, so the biomass decreased during 2001-2007. The biomass in 2005-2008 was at levels similar to those prior to 1985.

The average weights of yellowfin taken from the fishery have been fairly consistent over time, but vary substantially among the different fisheries (Figure 4.11). In general, the floating-object (Fisheries 1-4), unassociated (Fisheries 5 and 6), and pole-and-line (Fishery 10) fisheries capture younger, smaller yellowfin than do the dolphin-associated (Fisheries 7-9) and longline (Fisheries 11 and 12) fisheries. The longline fisheries and the dolphin-associated fishery in the southern region (Fishery 9) capture older, larger yellowfin than do the northern (Fishery 7) and coastal (Fishery 8) 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. Most of the yellowfin catch is taken in schools associated with dolphins, and, accordingly, this method has the greatest impact on the yellowfin population, although it has almost the least impact per unit of weight captured of all fishing methods.

5. STATUS OF THE STOCK

The status of the stock of yellowfin in the EPO is assessed by considering calculations based on the spawning biomass, yield per recruit, and MSY.

Precautionary reference points, as described in the FAO Code of Conduct for Responsible Fisheries and the United Nations Fish Stocks Agreement, are being widely developed as guides for fisheries management. The IATTC has not adopted any target or limit reference points for the stocks that it manages, but some possible reference points are described in the following subsections. Possible candidates for reference points are:

1. S_{MSY}, the spawning biomass corresponding to the MSY;

2. F_{MSY}, the fishing mortality corresponding to the MSY;

3. S_{min}, the minimum spawning biomass seen in the modeling period.

Maintaining tuna stocks at levels that will permit the MSY is the management objective specified by the IATTC Convention. The S_{min} reference point is based on the observation that the population has recovered from this population size in the past (*e.g.* the levels estimated in 1983). A technical meeting on reference points was held in La Jolla, California, USA, in October 2003. The outcome from this meeting was (1) a set of general recommendations on the use of reference points and research and (2) specific recommendations for the IATTC stock assessments. Several of the recommendations have been included in this assessment. Development of reference points that are consistent with the precautionary approach to fisheries management will continue.

5.1. Assessment of stock status based on spawning biomass

The spawning biomass ratio, SBR, defined in Section 3.1.2, is useful for assessing the status of a stock. The SBR has been used to define reference points in many fisheries. Various studies (*e.g.* Clark 1991, Francis 1993, Thompson 1993, Mace 1994) suggest that some fish populations can produce the MSY when the SBR is in the range of about 0.3 to 0.5, and that some fish populations are not able to produce the MSY if the spawning biomass during a period of exploitation is less than about 0.2. Unfortunately, the

types of population dynamics that characterize tuna populations have generally not been considered in these studies, and their conclusions are sensitive to assumptions about the relationship between adult biomass and recruitment, natural mortality, and growth rates. In the absence of simulation studies that are designed specifically to determine appropriate SBR-based reference points for tunas, estimates of SBR_t can be 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 second quarter of 2007). Estimates of the spawning biomass during the period of harvest (S_t) are discussed in Section 4.2.3 and presented in Figure 4.9b. The equilibrium 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 0.34.

At the beginning of 2008 the spawning biomass of yellowfin in the EPO had increased relative to 2006, which was probably its lowest level since 1983. The estimate of SBR at the beginning of 2008 was about 0.36, with lower and upper 95% confidence limits of 0.29 and 0.43, respectively (Figure 5.1a). The current assessment's estimate of SBR_{MSY} (0.34) is similar to the previous assessment (Figure 4.12b).

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 0.34 in Figure 5.1a. For most of the early period (1975-1984) and the most recent period (2005-2007), however, the spawning biomass was estimated to be less than S_{MSY}. The spawning biomass at the start of 2008 is estimated to be above the level corresponding to MSY.

5.2. Assessment of stock status based on MSY

MSY is defined as the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions. MSY calculations are described by Maunder and Watters (2001). The calculations differ from those of Maunder and Watters (2001) in that the present calculations include the Beverton-Holt (1957) stock-recruitment relationship when applicable. 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 2005-2007. The value Fscale uses the fishing mortality in the year of interest. Therefore, Fscale for the most recent year may not be the same as the F multiplier.

At the beginning of 2008, the biomass of yellowfin in the EPO appears to have been above the level corresponding to the MSY, and the recent catches have been substantially below the MSY level (Table 5.1).

If the fishing mortality is proportional to the fishing effort, and the current patterns of age-specific selectivity (Figure 4.4) are maintained, the current (average of 2005-2007) level of fishing effort is below that estimated to produce the MSY. The effort at MSY is 113% of the current level of effort. Due to reduced fishing mortality in 2007, repeating the calculations based on a fishing mortality averaged over 2005-2006 indicates that current effort would have to be increased by 6% to reach effort at MSY. It is important to note that the curve relating the average sustainable yield to the long-term fishing mortality (Figure 5.2, upper panel) is very flat around the MSY level. Therefore, changes in the long-term levels of effort will only marginally change the long-term catches, while considerably changing the biomass. The spawning stock biomass changes substantially with changes in the long-term fishing mortality (Figure 5.2, lower panel). Decreasing the effort would increase CPUE and thus might also reduce the cost of fishing. Reducing fishing mortality below the level at MSY would provide only a marginal decrease in the long-term average yield, with the benefit of a relatively large increase in the spawning biomass.

The apparent regime shift in productivity that began in 1984 suggests alternative approaches to estimating the MSY, as different regimes will give rise to different values for the MSY (Maunder and Watters 2001).

The estimation of the MSY, and its associated quantities, is sensitive to the age-specific pattern of selectivity that is used in the calculations. To illustrate how MSY might change if the effort is reallocated among the various fisheries (other than the discard fisheries) that catch yellowfin in the EPO, the previously-described calculations were repeated, using the age-specific selectivity pattern estimated for groups of fisheries. If the management objective is to maximize the MSY, the age-specific selectivity of the longline fisheries will perform the best, followed by that of the dolphin-associated fisheries, the unassociated fisheries, and finally the floating-object fisheries (Table 5.2a). If an additional management objective is to maximize the S_{MSY}, the order is the same. The age-specific selectivity of the purse-seine fisheries alone gives slightly less than the current MSY (Table 5.2c). 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 doubled to achieve the MSY.

If it is assumed that all fisheries but one are operating, and that each fishery maintains its current pattern of age-specific selectivity, the MSY would be increased by removing the floating-object or unassociated fisheries, and reduced by removing the dolphin-associated or longline fisheries (Table 5.2b). If it is assumed that all fisheries are operating, but either the purse-seine or the longline fisheries are adjusted to obtain MSY, the purse-seine fisheries would have to be increased by 7%, or the longline fisheries 37-fold. If it is also assumed that there is a stock-recruitment relationship, the MSY would be achieved with lower effort levels (Table 5.2c).

MSY and S_{MSY} have been very stable during the modeled period (Figure 4.12c). 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 Fscale.

The historical status of the population with respect to both the SBR and fishing mortality reference points is shown in Figure 5.1b. The fishing mortality has generally been below that corresponding to the MSY, except for the period before 1984 and during 2003-2005 (Figure 4.12c).

5.3. Summary of stock status

Historically, the SBR of yellowfin in the EPO was below the level corresponding to the MSY during the lower productivity regime of 1975-1983 (Section 4.2.1), but above that level for most of the following years, except for the recent period (2003-2007). The 1984 increase in the SBR is attributed to the regime change, and the recent decrease may be a reversion to an intermediate productivity regime. The two different productivity regimes may support two different MSY levels and associated SBR levels. The SBR at the start of 2008 is estimated to be above the level corresponding to the MSY. The effort levels are estimated to be less than those that would support the MSY (based on the current distribution of effort among the different fisheries), but recent catches are substantially below MSY.

If a stock-recruitment relationship is assumed, the outlook is more pessimistic, and current biomass is estimated to be below the level corresponding to the MSY.

The current average weight of yellowfin in the catch is much less than the critical weight. 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 MSY multiplier.

6. SIMULATED EFFECTS OF FUTURE FISHING OPERATIONS

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

of yellowfin in the EPO and the catches of yellowfin by the various fisheries. Several scenarios were constructed to define how the various fisheries that take yellowfin in the EPO would operate in the future, and also to define the future dynamics of the yellowfin stock. The assumptions that underlie these scenarios are outlined in Sections 6.1 and 6.2.

A method based on the normal approximation to the likelihood profile (Maunder *et al.* 2006) , which considers both parameter uncertainty and uncertainty about future recruitment, has been applied. A substantial part of the total uncertainty in predicting future events is caused by uncertainty in the estimates of the model parameters and current status, so this should be considered in any forward projections. Unfortunately, the appropriate methods are often not applicable to models as large and computationally-intense as the yellowfin stock assessment model. Therefore, we have used a normal approximation to the likelihood profile that allows for the inclusion of both parameter uncertainty and uncertainty about future recruitment. This method is implemented by extending the assessment model an additional 5 years with effort data equal to that assumed for the projection period (see below). No catch or length-frequency data are included for these years. The recruitments for the five years are estimated as in the assessment model with a lognormal penalty with a standard deviation of 0.6. Normal approximations to the likelihood profile are generated for SBR, surface catch, and longline catch.

6.1. Assumptions about fishing operations

6.1.1. Fishing effort

Several future projection studies were carried out to investigate the influence of different levels of fishing effort on the biomass and catch. The projected fishing mortality was based on the quarterly averages during 2005-2007.

The scenarios investigated were:

1. Quarterly fishing mortality for each year in the future equal to the quarterly average for 2005-2007, which reflects the reduced effort due to the conservation measures of Resolutions C-04-09 and C-06-02;

2. Quarterly fishing mortality for each year in the future and for 2004-2007 was set equal to the fishing mortality in scenario 1, adjusted for the effect of the conservation measures. For the adjustment, the fishing mortality for the purse-seine fishery in the fourth quarter was increased by 85%, and that for the southern longline fishery by 39%.

6.2. Results of the simulation

The simulations were used to predict future levels of the SBR, total biomass, the total catch taken by the primary surface fisheries, which would presumably continue to operate in the EPO (Fisheries 1-10), and the total catch taken by the longline fleet (Fisheries 11 and 12). There is probably more uncertainty in the future levels of these outcome variables than is suggested by the results presented in Figures 6.1-6.5. The amount of uncertainty is probably underestimated because the simulations were conducted under the assumption that the stock assessment model accurately describe the dynamics of the system, and because no account is taken for variation in catchability.

These simulations were carried out using the average recruitment for the 1975-2007 period. If they had been carried out using the average recruitment for the 1984-2001 period, the projected trend in SBR and catches would have been more positive. Conversely, if they had been carried out with the average recruitment for the 2002-2006 period, the projected trend in SBR and catches would have been more negative.

6.2.1. Current effort levels

Under current levels of fishing mortality (2005-2007), the biomass is predicted to increase and then decrease, but remain above the current level (Figure 6.1), and the SBR is predicted to follow a similar

trend. The SBR is predicted to remain above the level corresponding to the MSY (Figure 6.2). 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 surface catches will increase, while the longline catches will remain about the same (Figure 6.3).

6.2.2.   No management restrictions

Resolutions C-04-09 and C-06-02 called for restrictions on purse-seine effort and longline catches for 2004-2007: a 6-week closure during the third <u>or</u> fourth quarter of the year for purse-seine fisheries, and longline catches not to exceed 2001 levels. To assess the utility of these management actions, we projected the population forward five years, assuming that these conservation measures had not been implemented.

Comparison of the biomass and SBR predicted with and without the restrictions from the resolutions show some difference (Figures 6.4 and 6.5). The simulations suggest that, without the restrictions, biomass and SBR would have declined to slightly lower levels than seen at present, and would decline to about the level corresponding to MSY.

6.3. Summary of the simulation results

Under current levels of effort fishing mortality, the biomass is predicted to increase, and then decrease, but remain above the current level, and the SBR is predicted to follow a similar trend. The SBR is predicted to remain above the level corresponding to the MSY. A comparison of the biomass and SBR predicted with and without the restrictions from Resolutions C-04-09 and C-06-02 suggests that, without the restrictions, they would be at lower levels than those seen at present, and would decline to about the level corresponding to MSY.

These simulations were carried out using the average recruitment for the 1975-2007 period. If they had been carried out using the average recruitment for the 1983-2001 period, the projected trend in SBR and catches would have been more positive. Conversely, if they had been carried out using the average recruitment for the 2002-2006 period, the projected trend in SBR and catches would have been more negative.

7.   FUTURE DIRECTIONS

7.1. Collection of new and updated information

The IATTC staff intends to continue its collection of catch, effort, and size-composition data for the fisheries that catch yellowfin in the EPO. New and updated data will be incorporated into the next stock assessment.

7.2. Refinements to the assessment model and methods

The IATTC staff is considering changing to the *Stock Synthesis II* (SS2) general model (developed by Richard Methot at the U.S. National Marine Fisheries Service) for its stock assessments, based on the outcome of the workshop on stock assessment methods held in November 2005. Preliminary assessments for yellowfin and bigeye tuna were conducted in SS2 and presented at a workshop on management strategies held in November 2006. The current bigeye assessment was conducted using SS2, and the IATTC staff intends to conduct the next yellowfin assessment using SS2, once the growth curve in SS2 is made flexible enough to model the growth of yellowfin appropriately .
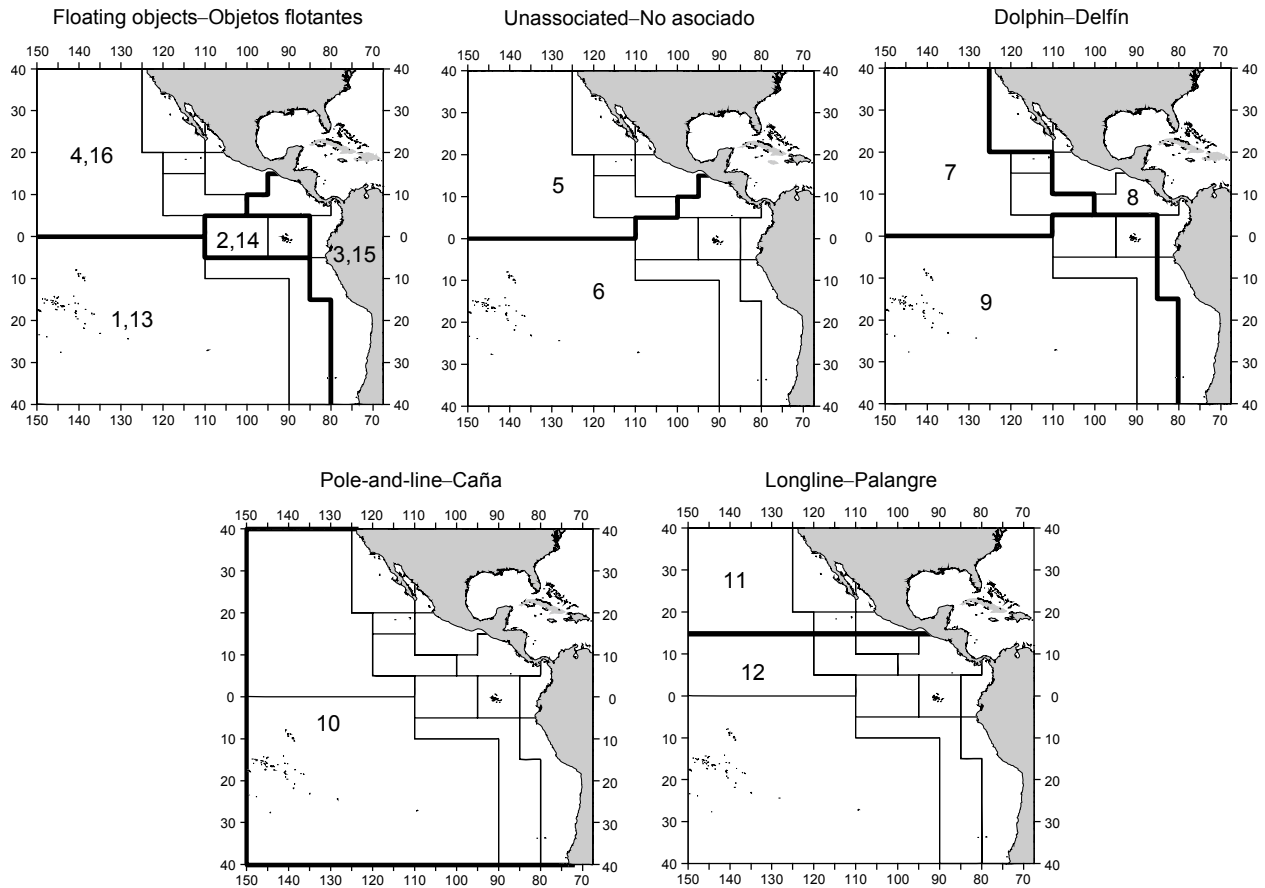
FIGURE 2.1. Spatial extents of the fisheries defined by the IATTC staff for the stock assessment of yellowfin tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the bold numbers the fisheries to which the latter boundaries apply. The fisheries are described in Table 2.1.

FIGURA 2.1. Extensión espacial de las pesquerías definidas por el personal de la CIAT para la evaluación del atún aleta amarilla en el OPO. Las líneas delgadas indican los límites de 13 zonas de muestreo de frecuencia de tallas, las líneas gruesas los límites de cada pesquería definida para la evaluación del stock, y los números en negritas las pesquerías correspondientes a estos últimos límites. En la Tabla 2.1 se describen las pesquerías.
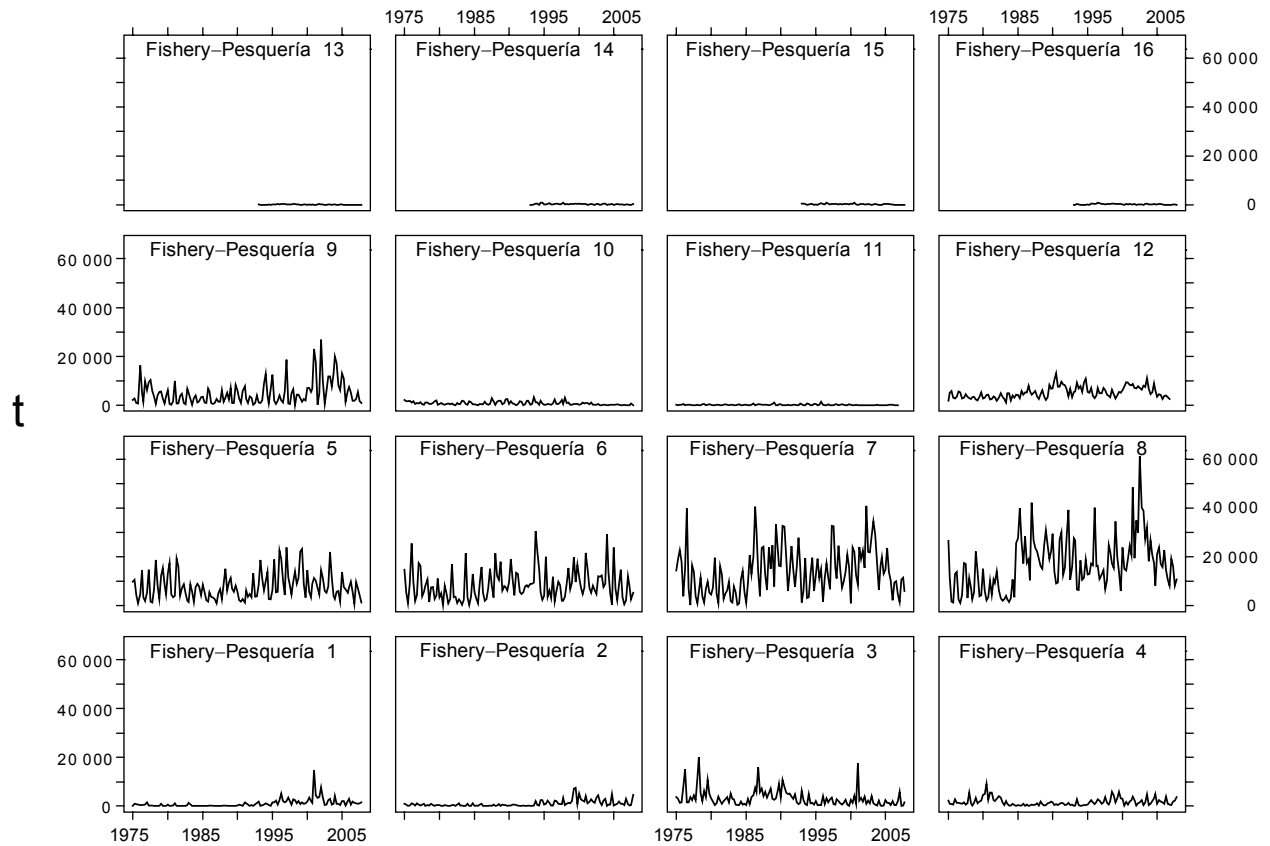
FIGURE 2.2. Catches by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were analyzed on a quarterly basis, there are four observations of catch for each year. Although all the catches are displayed as weights, the stock assessment model uses catches in numbers of fish for Fisheries 11 and 12. Catches in weight for Fisheries 11 and 12 are estimated by multiplying the catches in numbers of fish by estimates of the average weights. t = metric tons.

FIGURA 2.2. Capturas de las pesquerías definidas para la evaluación del stock de 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 del stock usa captura en número de peces para las Pesquerías 11 y 12. Se estiman las capturas de las Pesquerías 11 y 12 en peso multiplicando las capturas en número de peces por estimaciones del peso promedio. t = toneladas métricas.
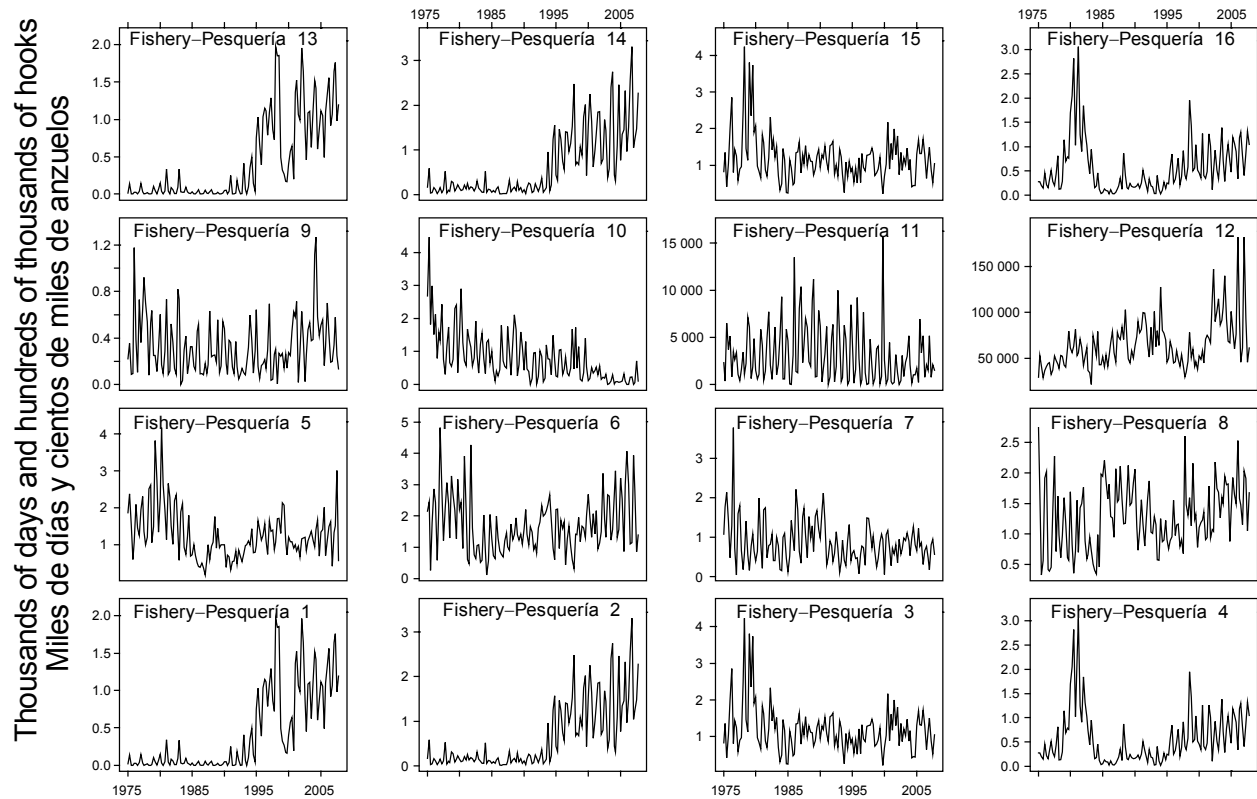
FIGURE 2.3. Fishing effort exerted by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of effort for each year. The effort for Fisheries 1-10 and 13-16 is in days fished, and that for Fisheries 11 and 12 is in standardized numbers of hooks. Note that the vertical scales of the panels are different.

FIGURA 2.3. Esfuerzo de pesca ejercido por las pesquerías definidas para la evaluación del stock de atún aleta amarilla en el OPO (Tabla 2.1). Ya que se analizaron los datos por trimestre, hay cuatro observaciones de esfuerzo para cada año. 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 estandarizado de anzuelos. Nótese que las escalas verticales de los recuadros son diferentes.
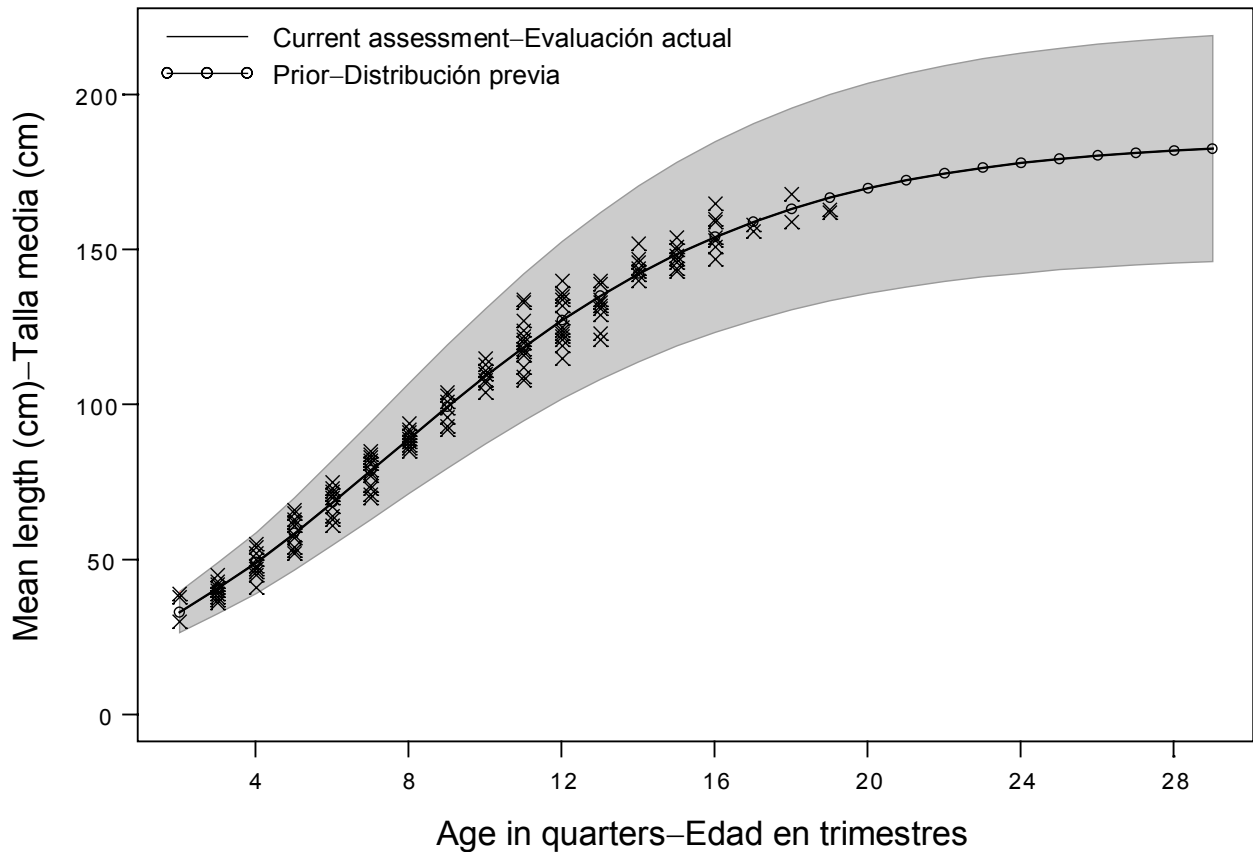
FIGURE 3.1. Growth curve estimated for the assessment of yellowfin tuna in the EPO (solid line). The connected points represent the mean length-at-age prior used in the assessment. The crosses represent length-at-age data from otoliths (Wild 1986). The shaded region represents the variation in length at age (± 2 standard deviations).

FIGURA 3.1. Curva de crecimiento usada para la evaluación del atún aleta amarilla en el OPO (línea sólida). Los puntos conectados representan la distribución previa (*prior*) de la talla por edad usada en la evaluación. Las cruces representan datos de otolitos de talla por edad (Wild 1986). La región sombreada representa la variación de la talla por edad (± 2 desviaciones estándar).
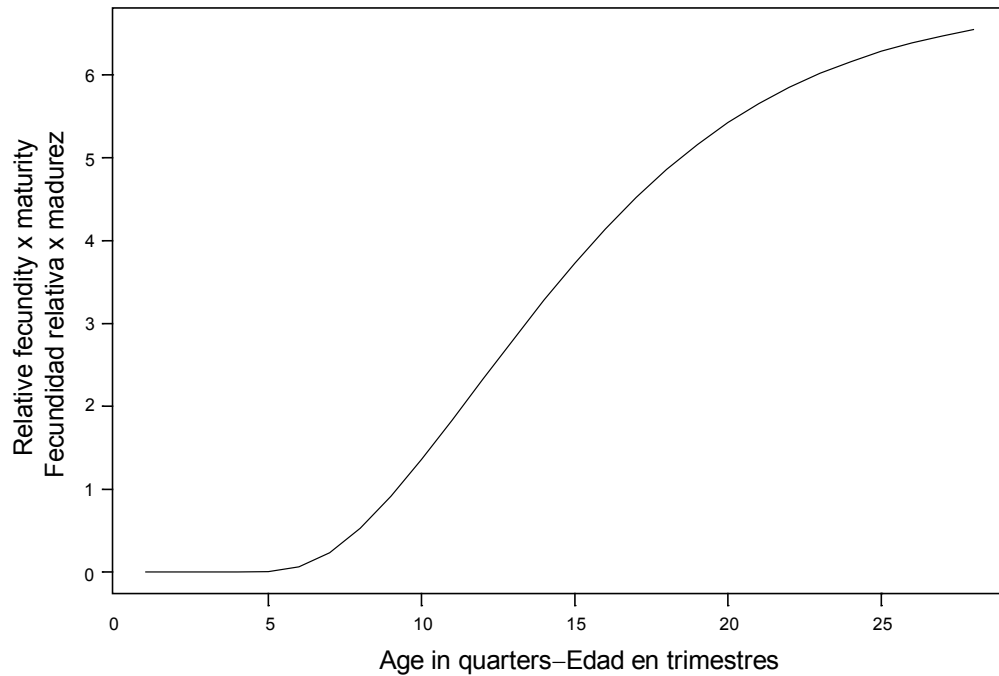
FIGURE 3.2. Relative fecundity-at-age curve (from Schaefer 1998) used to estimate the spawning biomass of yellowfin tuna in the EPO.
FIGURA 3.2. Curva de madurez relativa por edad (de Schaefer 1998) usada para estimar la biomasa reproductora del atún aleta amarilla en el OPO.
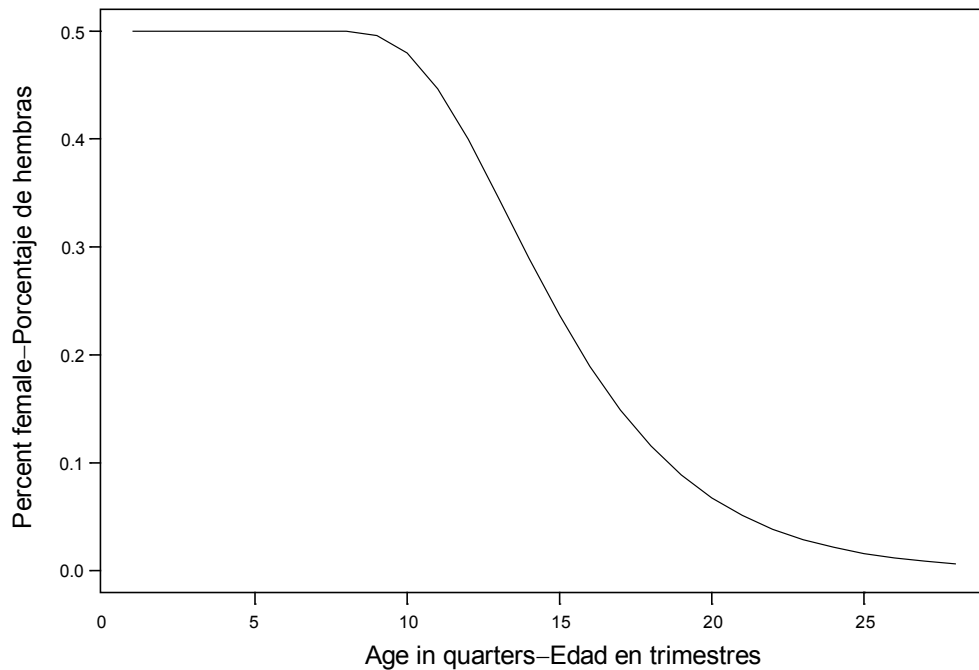
FIGURE 3.3. Sex ratio curve (from Schaefer 1998) used to estimate the spawning biomass of yellowfin tuna in the EPO.
FIGURA 3.3. Curva de proporciones de sexos (de Schaefer 1998) usada para estimar la biomasa reproductora de atún aleta amarilla en el OPO.
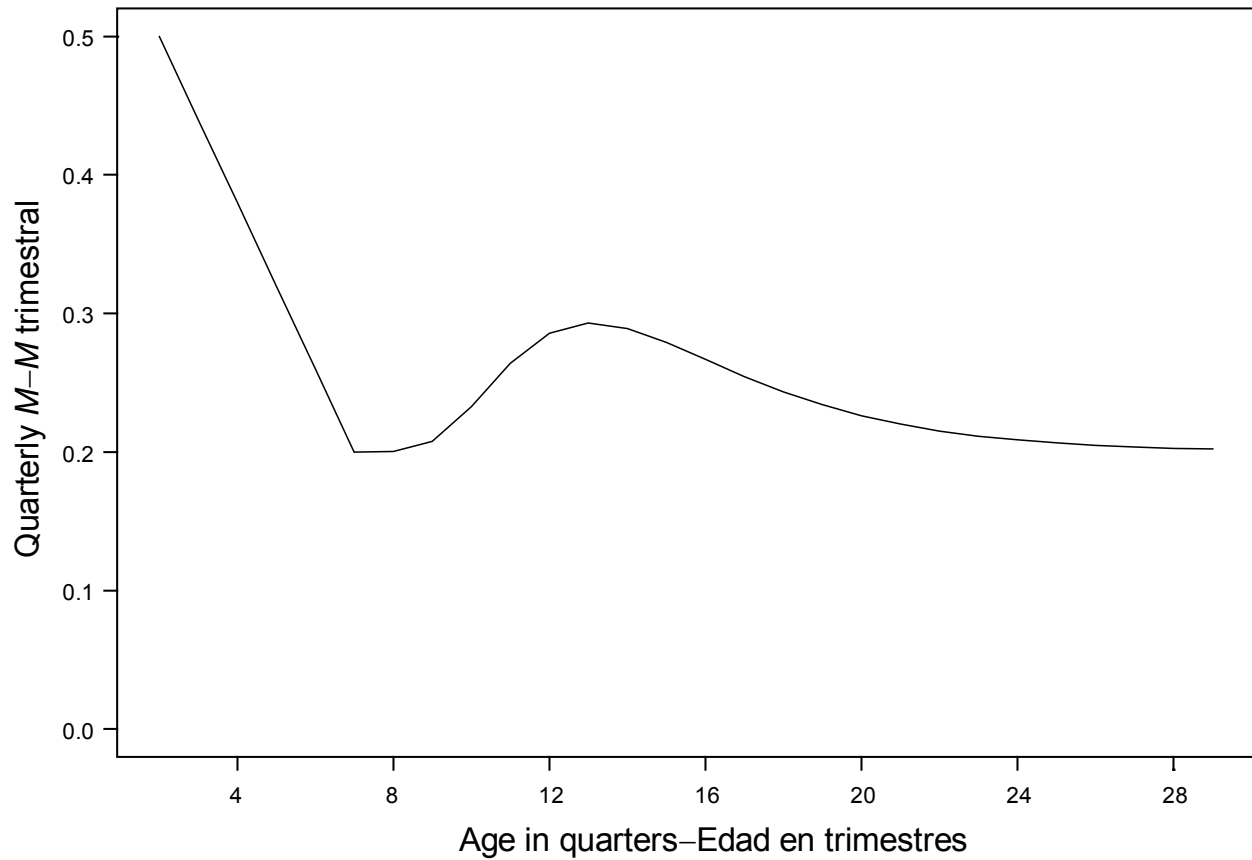
FIGURE 3.4. Natural mortality (*M*) rates, at quarterly intervals, used for the assessment of yellowfin tuna in the EPO. Descriptions of the three phases of the mortality curve are provided in Section 3.1.4.
FIGURA 3.4. Tasas de mortalidad natural (*M*), a intervalos trimestrales, usadas para la evaluación del atún aleta amarilla en el OPO. En la Sección 3.1.4 se describen las tres fases de la curva de mortalidad.
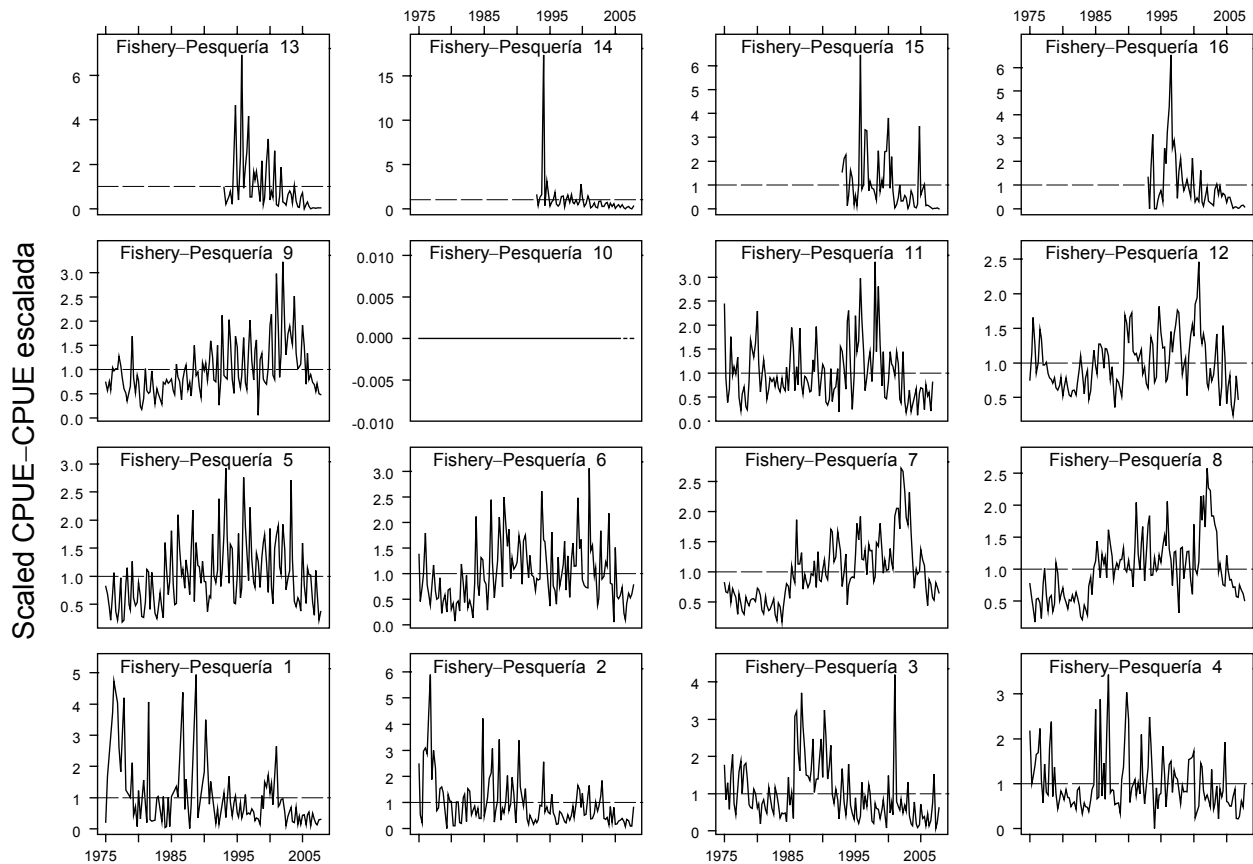
FIGURE 4.1. CPUEs for the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of CPUE for each year. The CPUEs for Fisheries 1-10 and 13-16 are in kilograms per day fished, and those for Fisheries 11 and 12 are standardized units based on numbers of hooks. The data are adjusted so that the mean of each time series is equal to 1.0. Note that the vertical scales of the panels are different.

FIGURA 4.1. CPUE 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 1-10 y 13-16 en kilogramos por día de pesca, y las de las Pesquerías 11 y 12 en unidades estandarizadas basadas en 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.
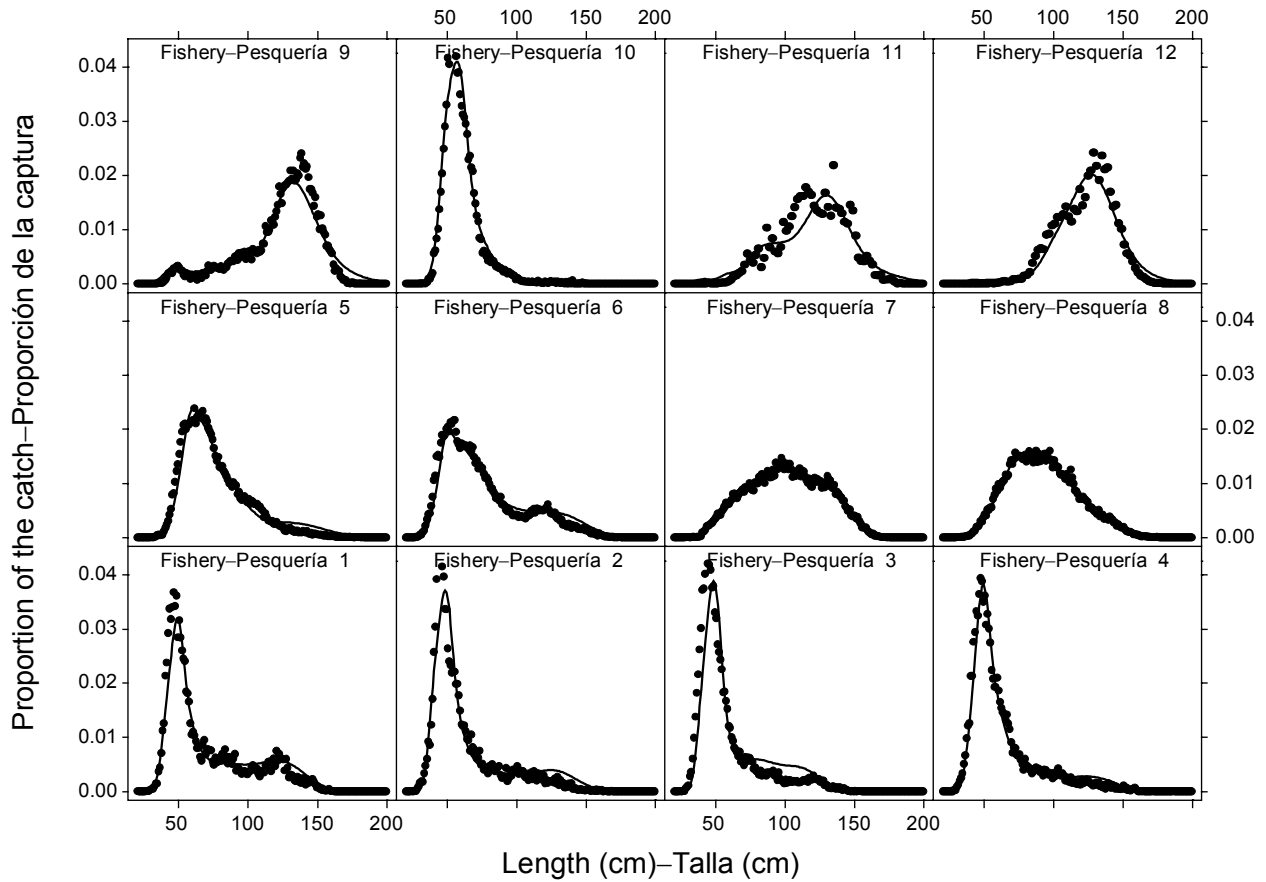
FIGURE 4.2. Average observed (dots) and predicted (curves) size compositions of the catches taken by the fisheries defined for the stock assessment of yellowfin tuna in the EPO.

FIGURA 4.2. Composición media por tamaño 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.
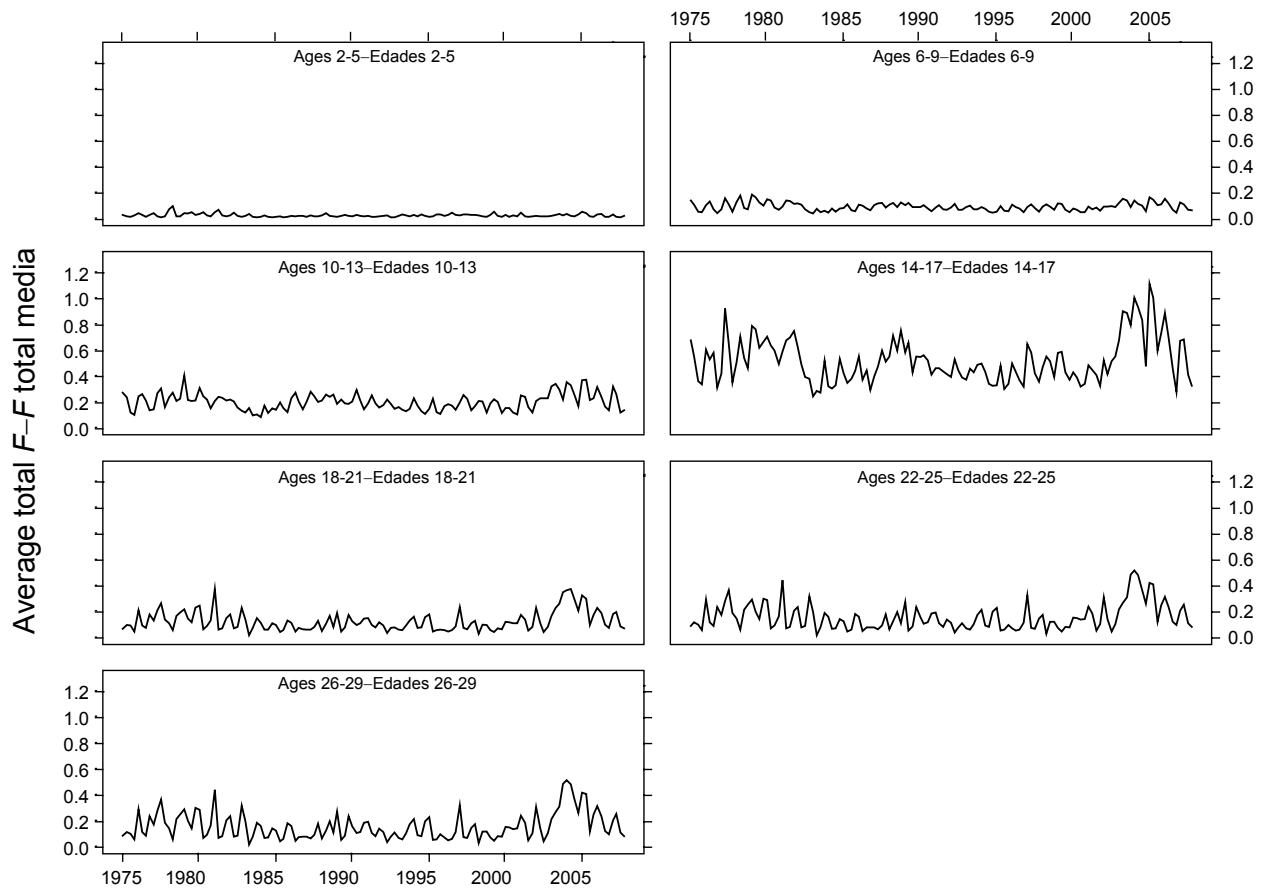
FIGURE 4.3a. Average quarterly fishing mortality (*F*) at age, by all gears, of yellowfin tuna recruited to the fisheries of the EPO. Each panel illustrates an average of four quarterly fishing mortality vectors that affected the fish within the range of ages indicated in the title of each panel. For example, the trend illustrated in the upper-left panel is an average of the fishing mortalities that affected the fish that were 2-5 quarters old.

FIGURA 4.3a. Mortalidad por pesca (*F*) trimestral media por edad, por todas las artes, de atún aleta amarilla reclutado a las pesquerías del OPO. Cada recuadro ilustra un promedio de cuatro vectores trimestrales de mortalidad por pesca que afectaron los peces de la edad indicada en el título de cada recuadro. Por ejemplo, la tendencia ilustrada en el recuadro superior izquierdo es un promedio de las mortalidades por pesca que afectaron a los peces de entre 2 y 5 trimestres de edad.
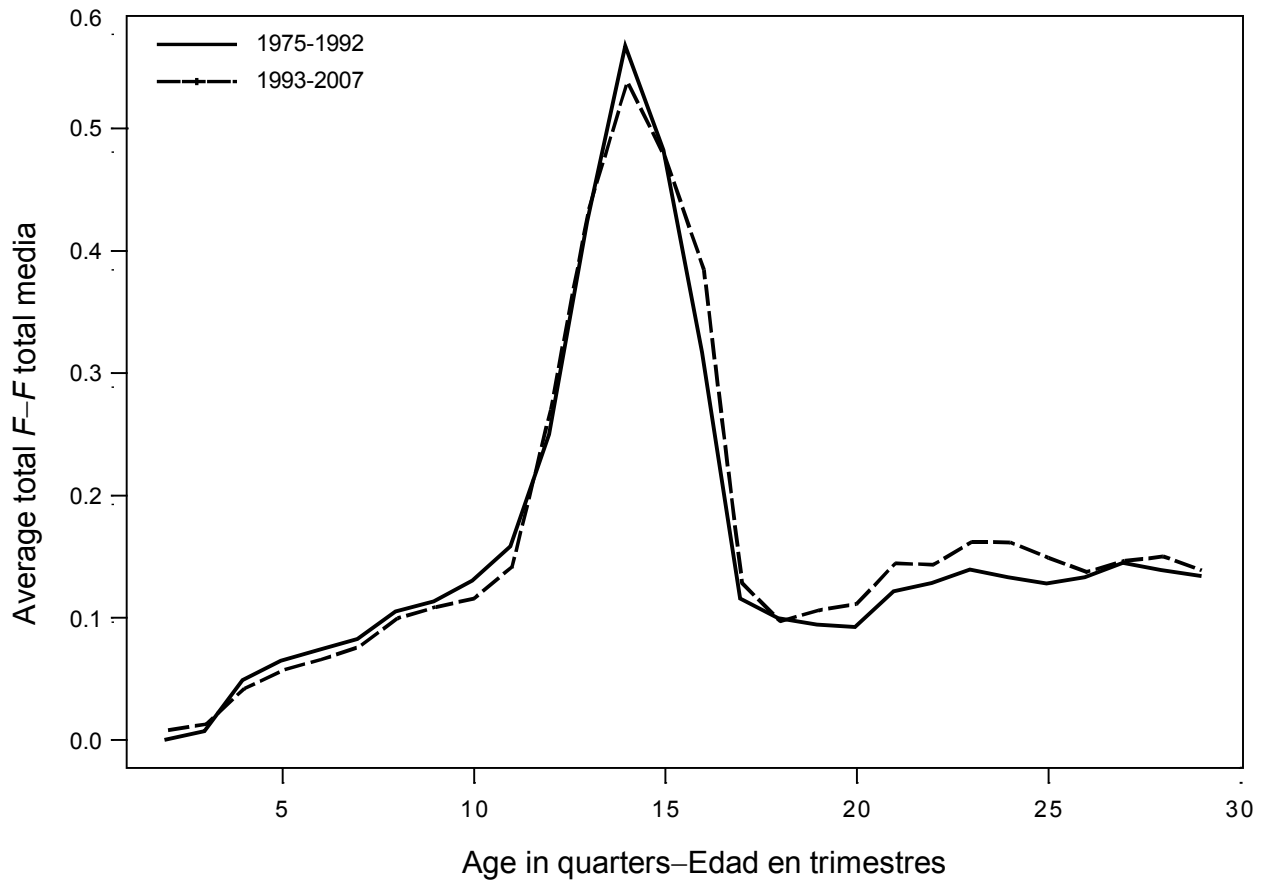
FIGURE 4.3b. Average quarterly fishing mortality (*F*) of yellowfin tuna by age in the EPO, by all gears. The estimates are presented for two periods, before and after the increase in effort associated with floating objects.

FIGURA 4.3b. Mortalidad por pesca (*F*) trimestral 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.
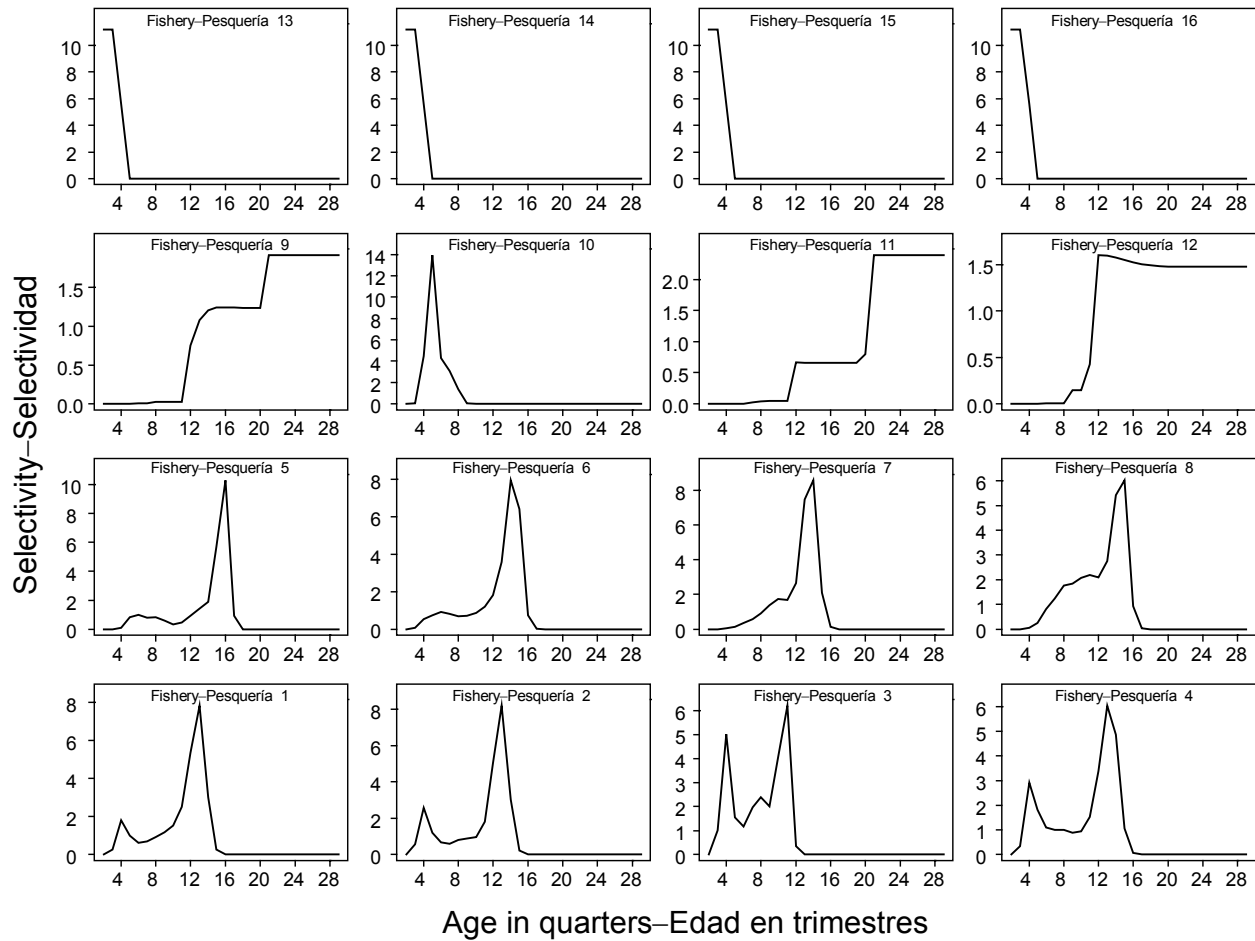
FIGURE 4.4. Selectivity curves for the 16 fisheries that take yellowfin tuna in the EPO. The curves for Fisheries 1-12 were estimated with the A-SCALA method, and those for Fisheries 13-16 are based on assumptions. Note that the vertical scales of the panels are different.

FIGURA 4.4. Curvas de selectividad para las 16 pesquerías que capturan atún aleta amarilla en el OPO. Se estimaron las curvas de las Pesquerías 1-12 con el método A-SCALA, y las de la Pesquerías 13-16 se basan en supuestos. Nótese que las escalas verticales de los recuadros son diferentes.
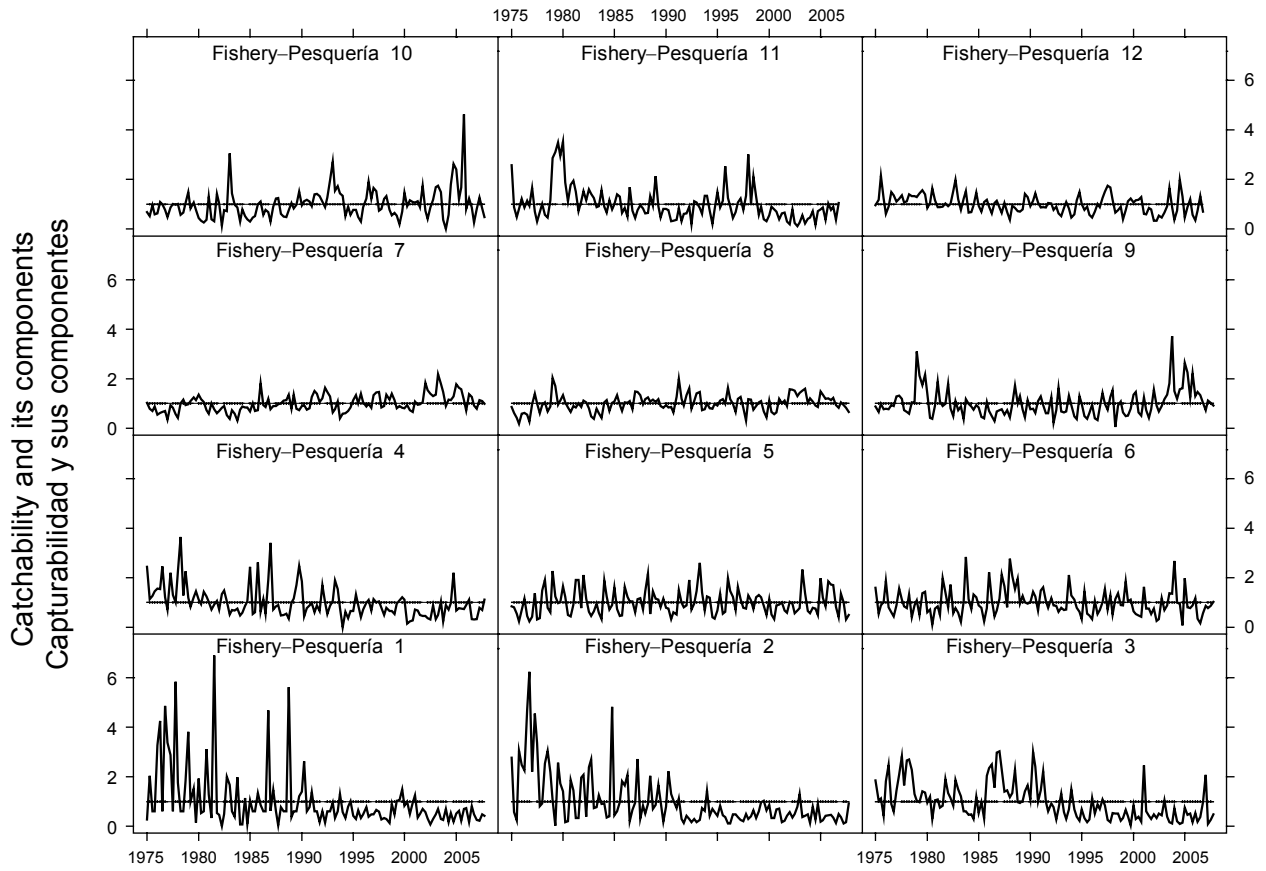
FIGURE 4.5a. Trends in catchability (*q*) for the 12 retention fisheries that take yellowfin tuna in the EPO. The estimates are scaled to average 1.

FIGURA 4.5a. Tendencias de la capturabilidad (*q*) en las 12 pesquerías de retención que capturan atún aleta amarilla en el OPO. Se escalan las estimaciones a un promedio de 1.
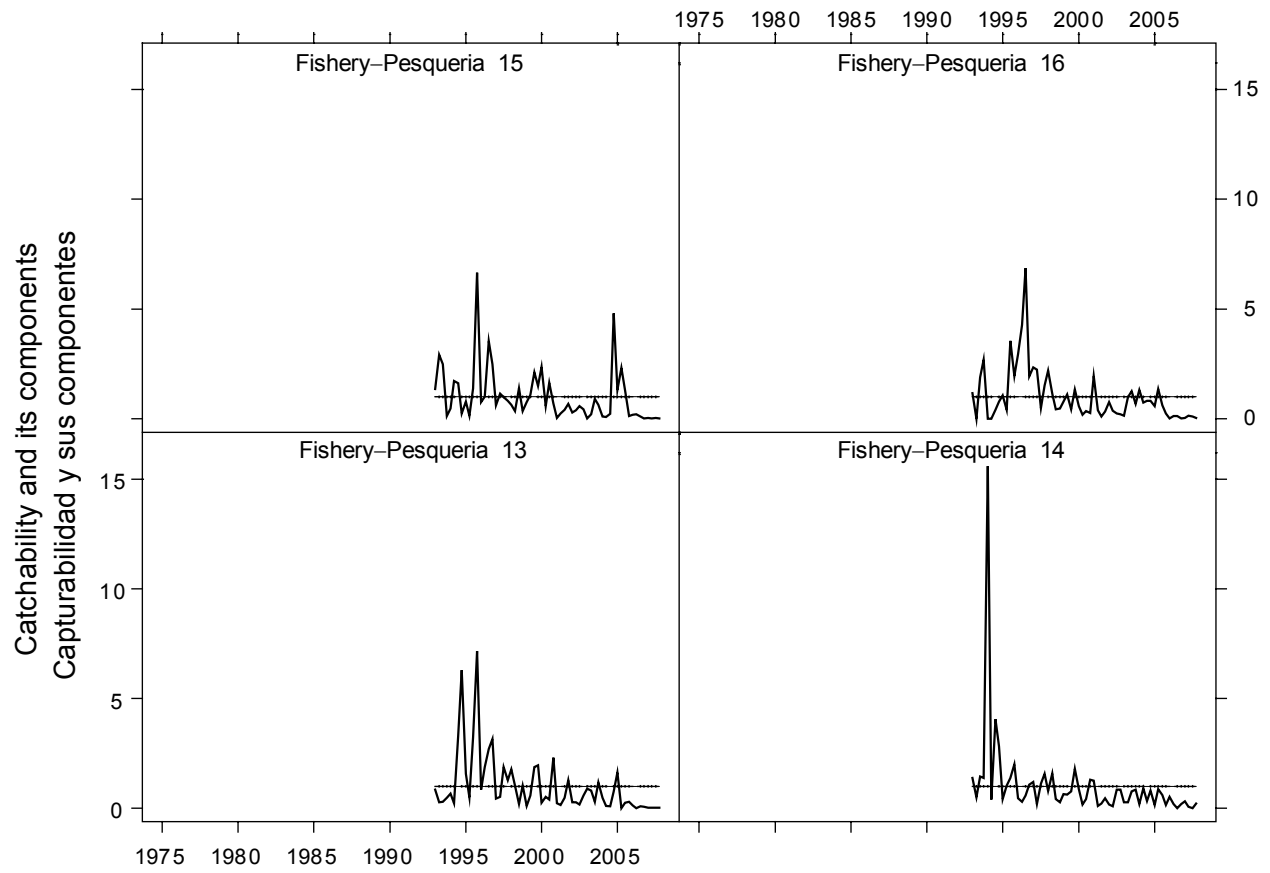
FIGURE 4.5b. Trends in catchability (*q*) for the four discard fisheries that take yellowfin tuna in the EPO. The estimates are scaled to average 1.

FIGURA 4.5b. Tendencias de la capturabilidad (*q*) en las cuatro pesquerías de descarte que capturan atún aleta amarilla en el OPO. Se escalan las estimaciones a un promedio de 1.
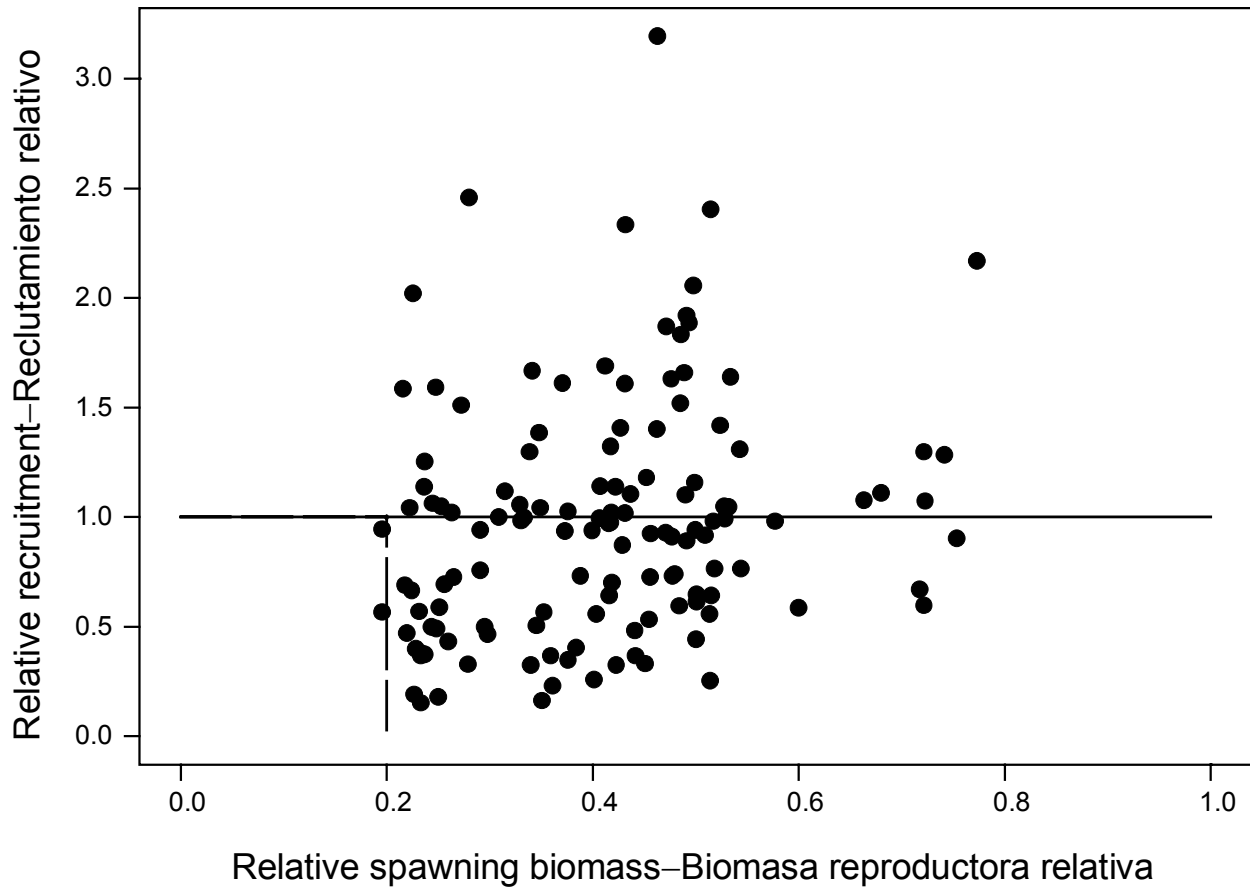
FIGURE 4.6. Estimated relationship between recruitment of yellowfin tuna and spawning biomass. The recruitment is scaled so that the average recruitment is equal to 1.0. The spawning biomass is scaled so that the average unexploited spawning biomass is equal to 1.0.

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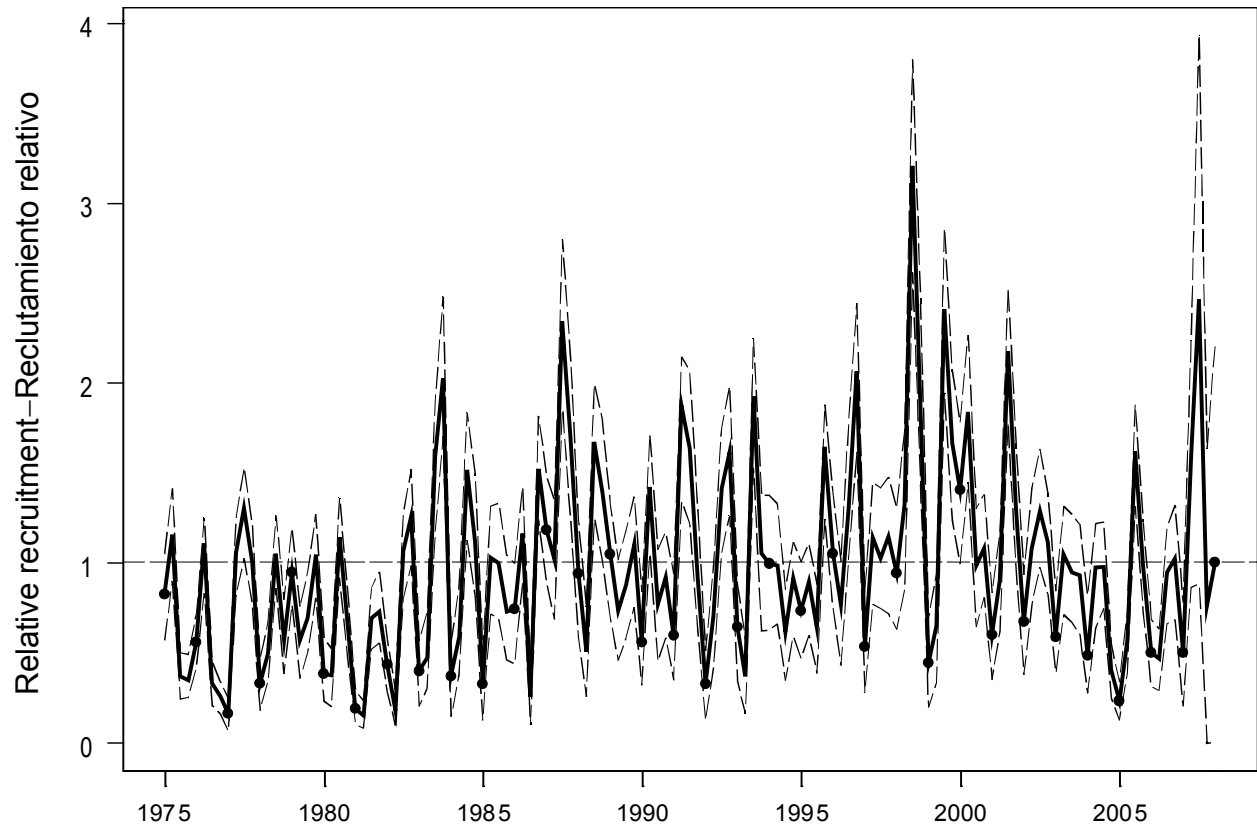
FIGURE 4.7. Estimated recruitment of yellowfin tuna to the fisheries of the EPO. The estimates are scaled so that the average recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the shaded area indicates the approximate 95% confidence intervals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

FIGURA 4.7. Reclutamiento 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.
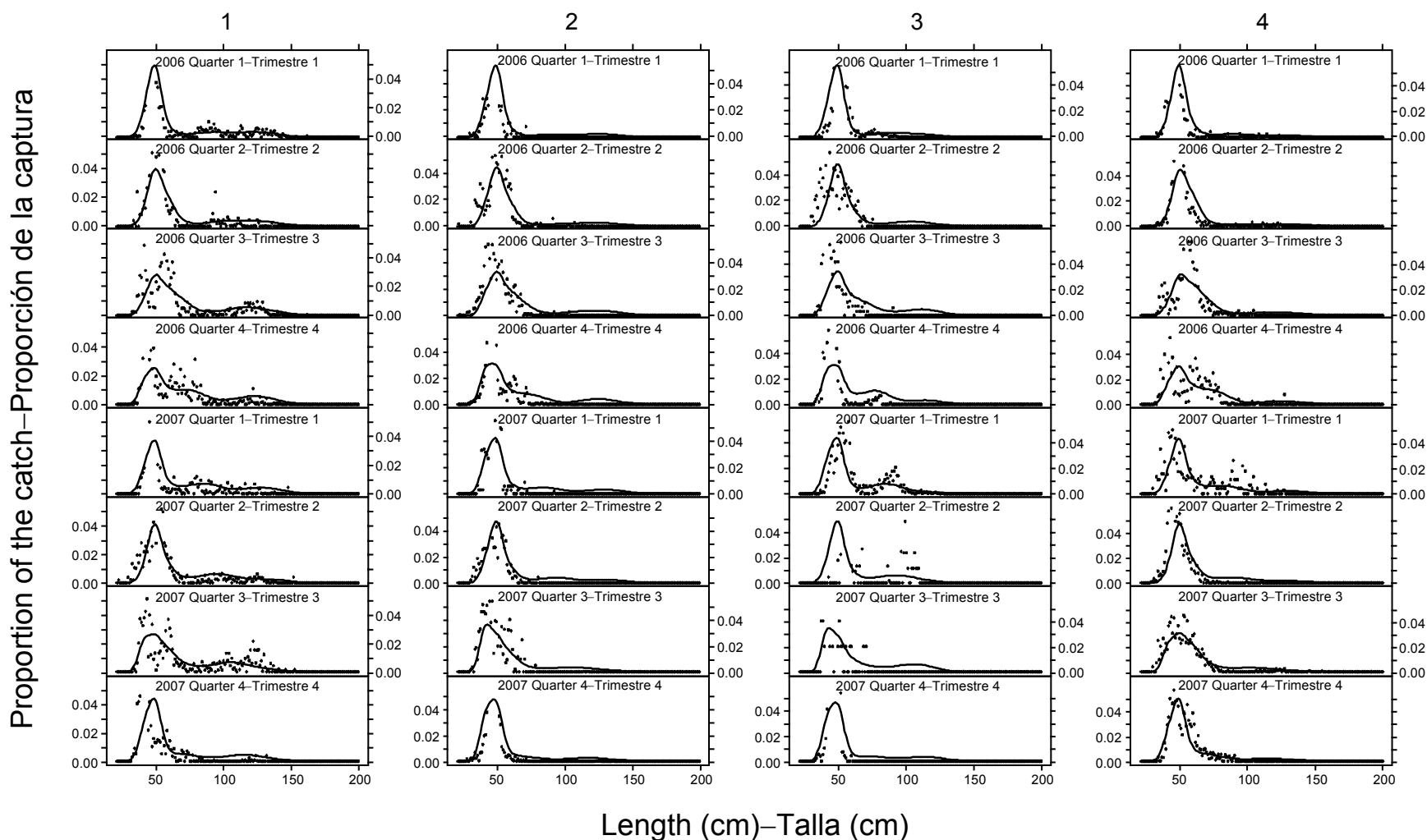
FIGURE 4.8a. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin by the fisheries that take tunas in association with floating objects (Fisheries 1-4).
FIGURA 4.8a. Composiciones por tamaño observadas (puntos) y predichas (curvas) de las capturas recientes de aleta amarilla por las pesquerías que capturan atún en asociación con objetos flotantes (Pesquerías 1-4).
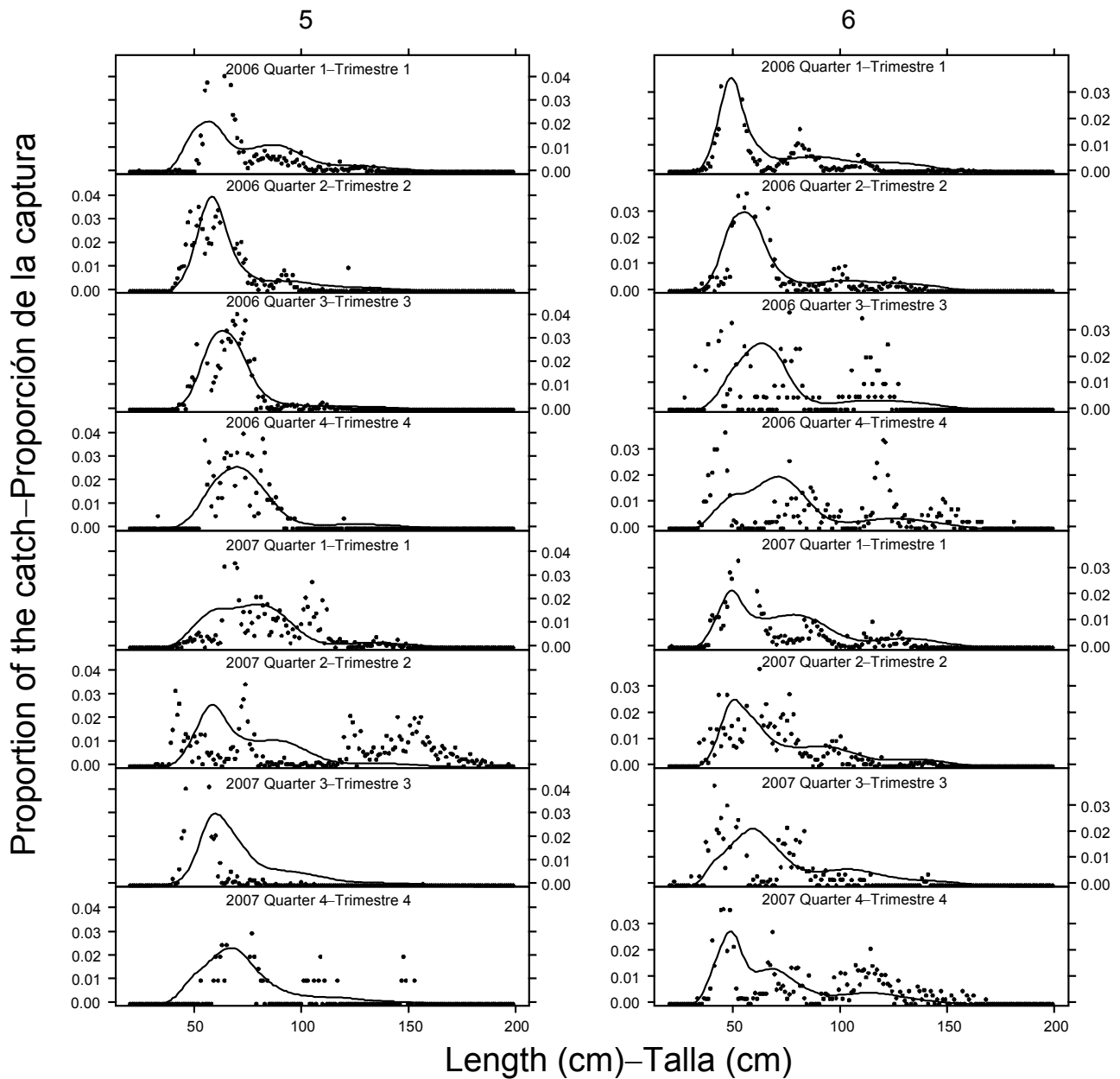
FIGURE 4.8b. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin tuna by the fisheries that take tunas in unassociated schools (Fisheries 5 and 6).

FIGURA 4.8b. Composiciones por tamaño observadas (puntos) y predichas (curvas) de las capturas recientes de atún aleta amarilla por las pesquerías que capturan atún en cardúmenes no asociados (Pesquerías 5 y 6).
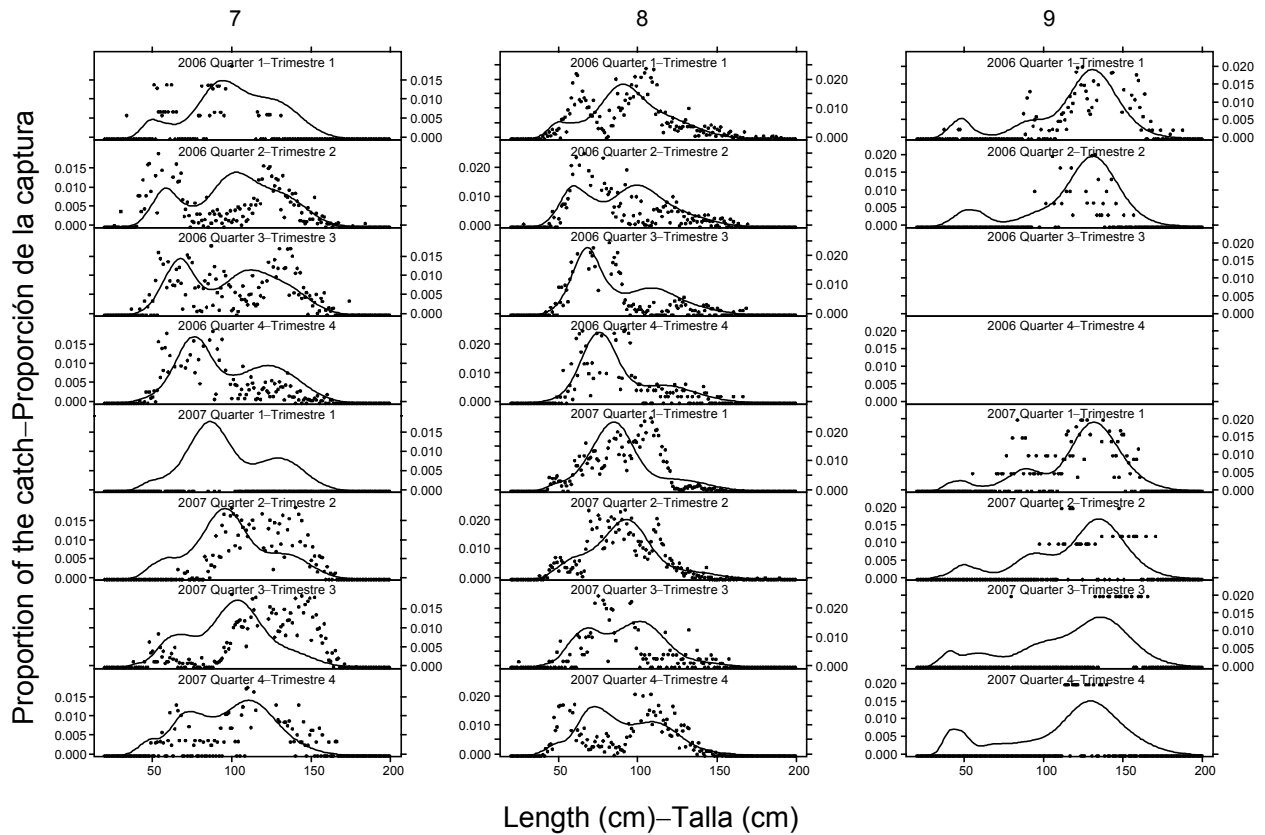
FIGURE 4.8c. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin tuna by the fisheries that take tunas in association with dolphins (Fisheries 7-9).

FIGURA 4.8c. Composiciones por tamaño observadas (puntos) y predichas (curvas) de las capturas recientes de atún aleta amarilla por las pesquerías que capturan atún en asociación con delfines (Pesquerías 7-9).
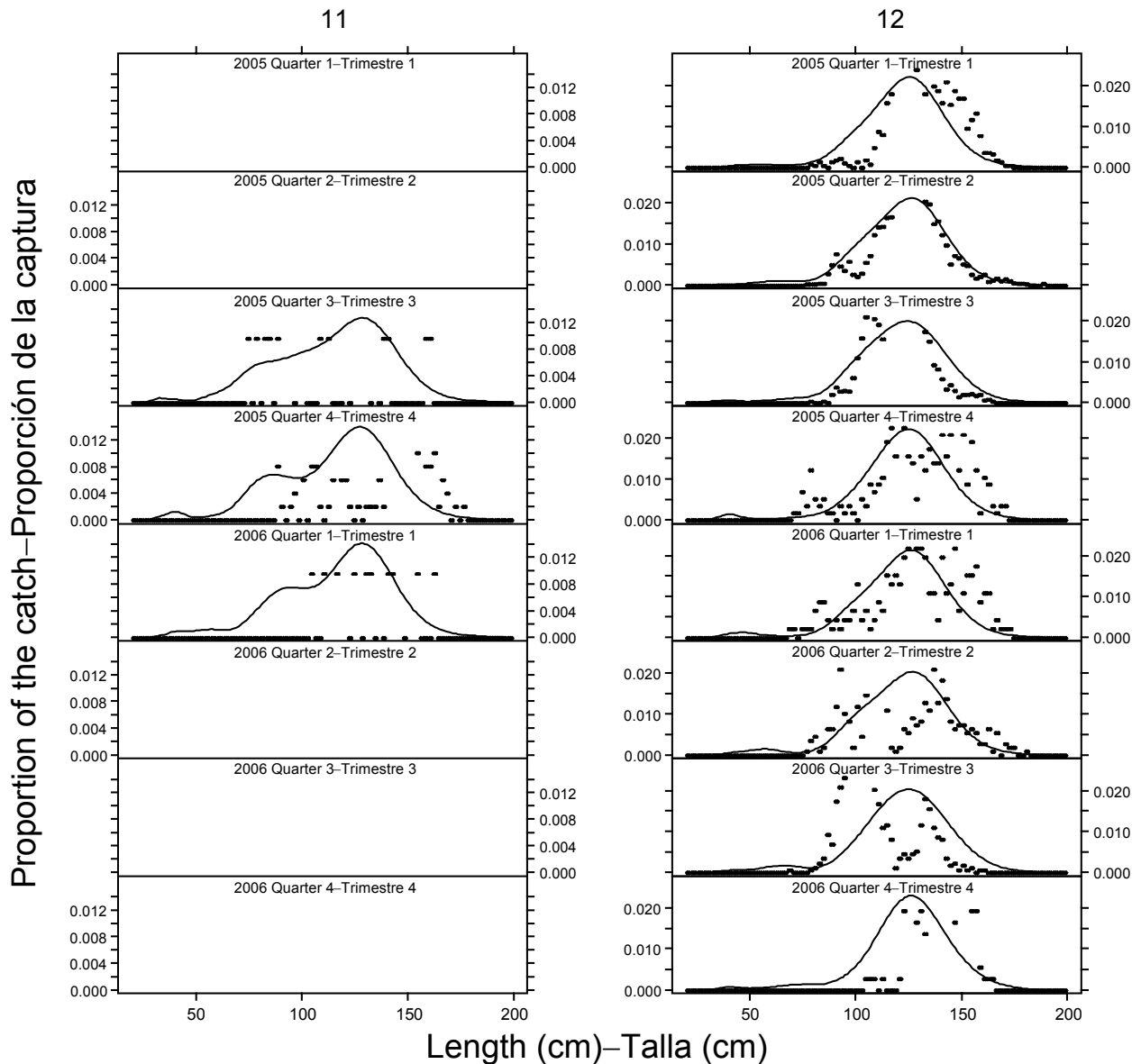
FIGURE 4.8d. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin tuna by the longline fisheries (Fisheries 11-12).
FIGURA 4.8d. Composición por talla observada (puntos) y predicha (curvas) de las capturas recientes de atún aleta amarilla por las pesquerías palangreras (Pesquerías 11 y 12).
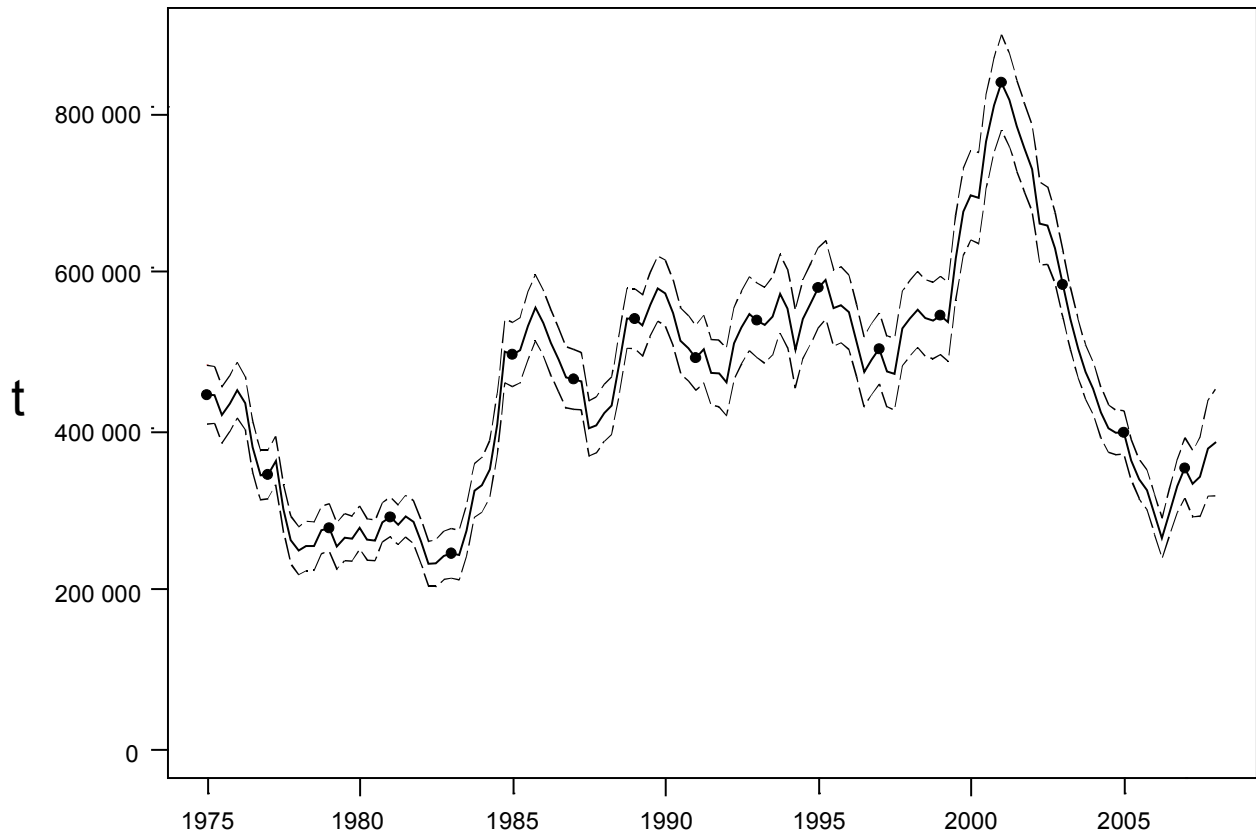
FIGURE 4.9a. Estimated biomass of yellowfin tuna in the EPO. The bold line illustrates the maximum likelihood estimates of the biomass, and the thin dashed lines the approximate 95% confidence intervals around those estimates. Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year. t = metric tons.

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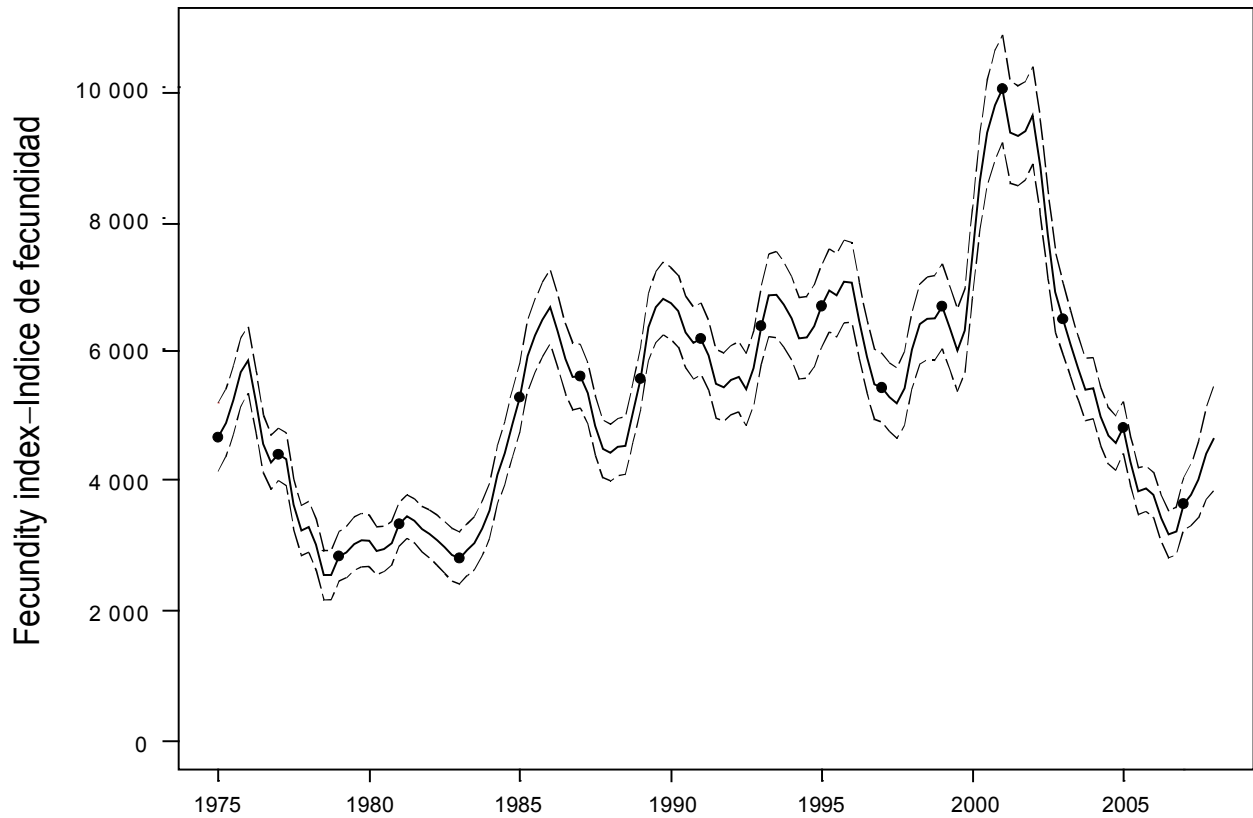
FIGURE 4.9b. Estimated relative spawning biomass of yellowfin tuna in the EPO. The bold line illustrates the maximum likelihood estimates of the biomass, and the thin dashed lines the approximate 95% confidence intervals around those estimates. Since the assessment model represents time on a quarterly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

FIGURA 4.9b. Biomasa reproductora relativa estimada del atún aleta amarilla en el OPO. La línea gruesa ilustra las estimaciones de verosimilitud máxima de la biomasa, y las líneas delgadas de trazos los límites de confianza de 95% aproximados de las estimaciones. Ya que el modelo de evaluación representa el tiempo por trimestres, hay cuatro estimaciones de biomasa para cada año.

FIGURE 4.10a. Biomass trajectory of a simulated population of yellowfin tuna that was never exploited ("no fishing") and that predicted by the stock assessment model ("fishing"). t = metric tons.
FIGURA 4.10a. Trayectoria de la biomasa de una población simulada de atún aleta amarilla que nunca fue explotada ("sin pesca") y aquélla predicha por el modelo de evaluación de la población ("con pesca"). t = toneladas métricas.

FIGURE 4.10b. Comparison of the relative impacts of the major fisheries on the biomass of yellowfin tuna in the EPO.
FIGURA 4.10b. Comparación de los impactos relativos de las pesquerías más importantes sobre la biomasa de atún aleta amarilla en el OPO.
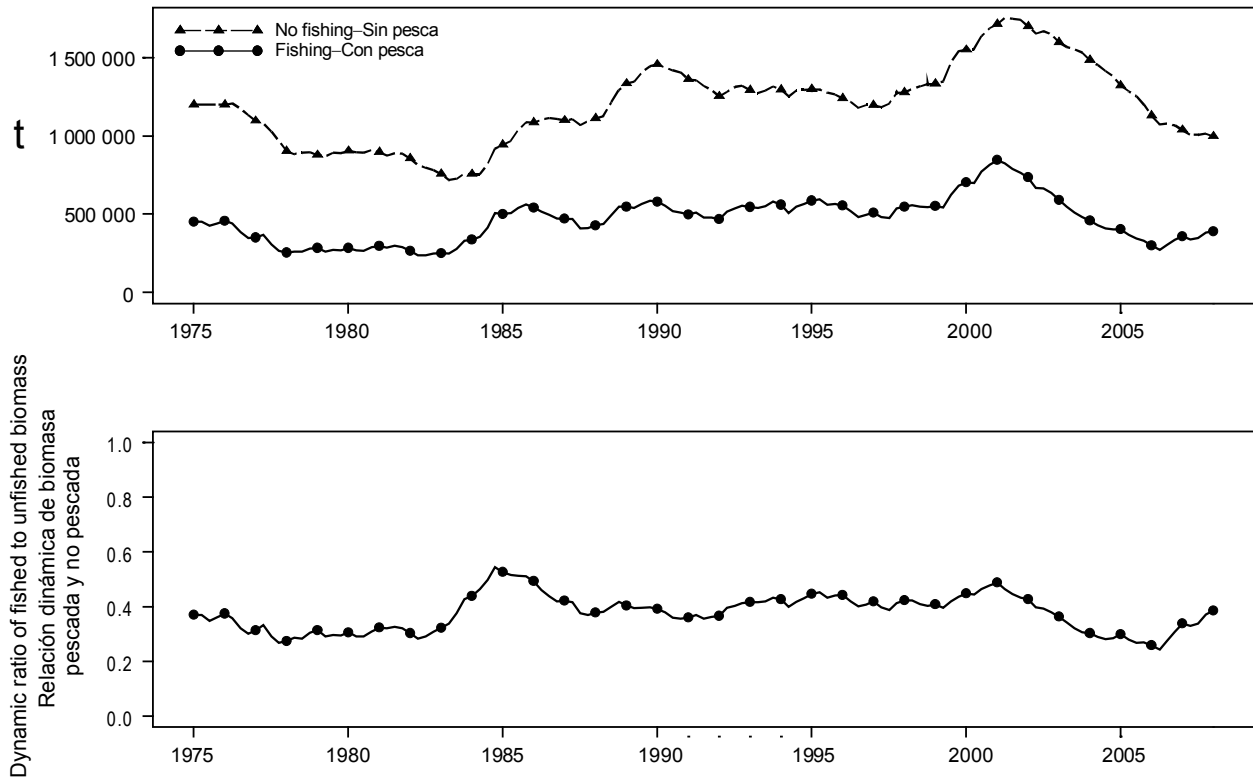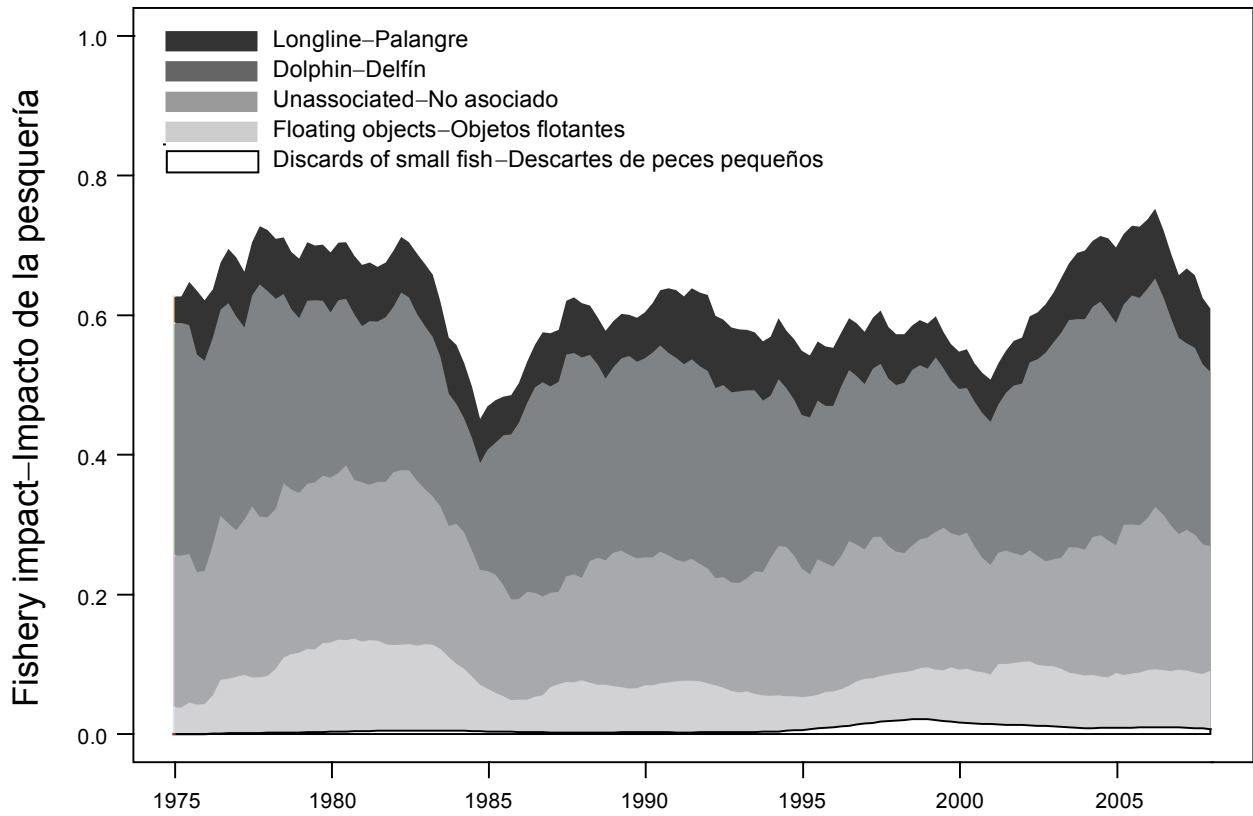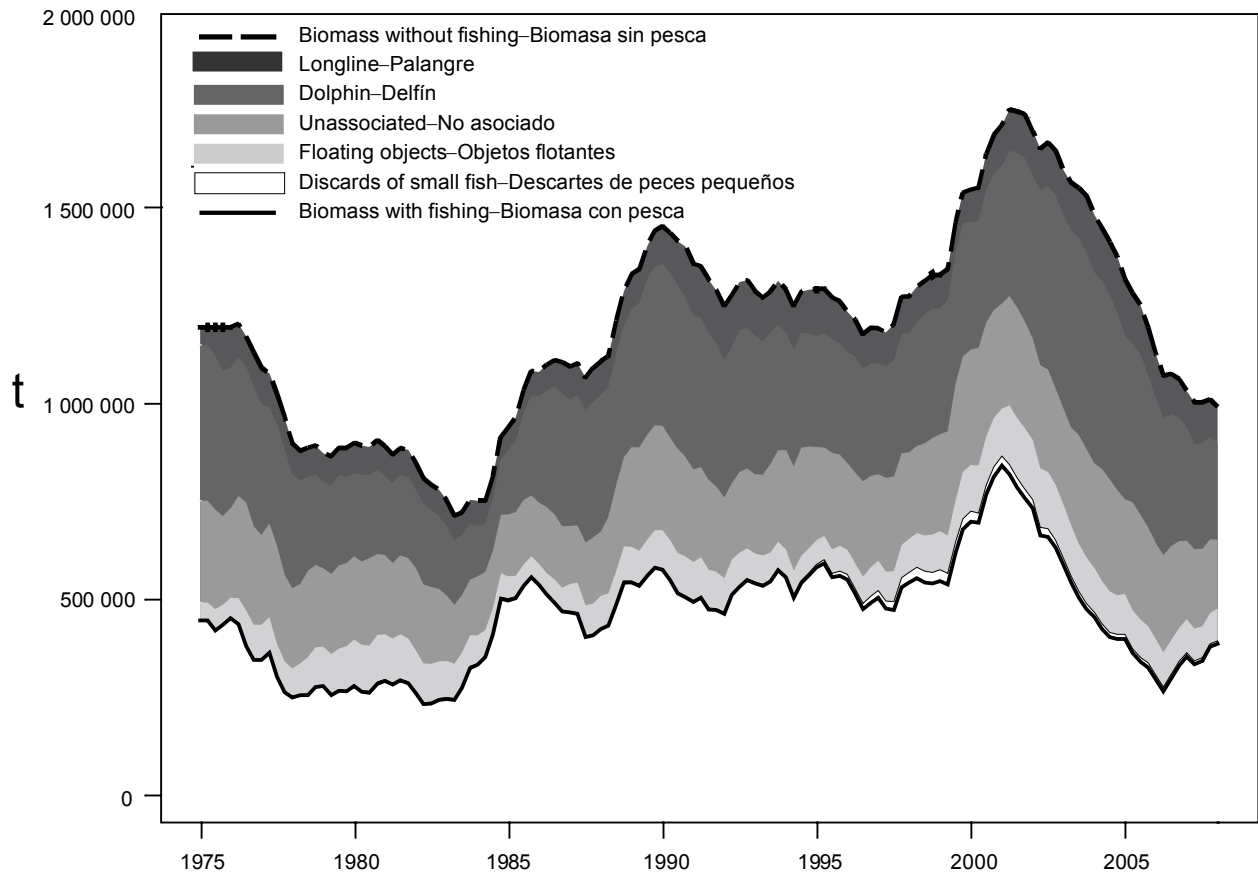
FIGURE 4.10c. Biomass trajectory of a simulated population of yellowfin tuna that was never exploited (dashed line) and that predicted by the stock assessment model (solid line). The shaded areas between the two lines show the portions of the fishery impact attributed to each fishing method. t = metric tons.

FIGURA 4.10c. 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 represantan la porción del impacto de la pesca atribuida a cada método de pesca. t = toneladas métricas.
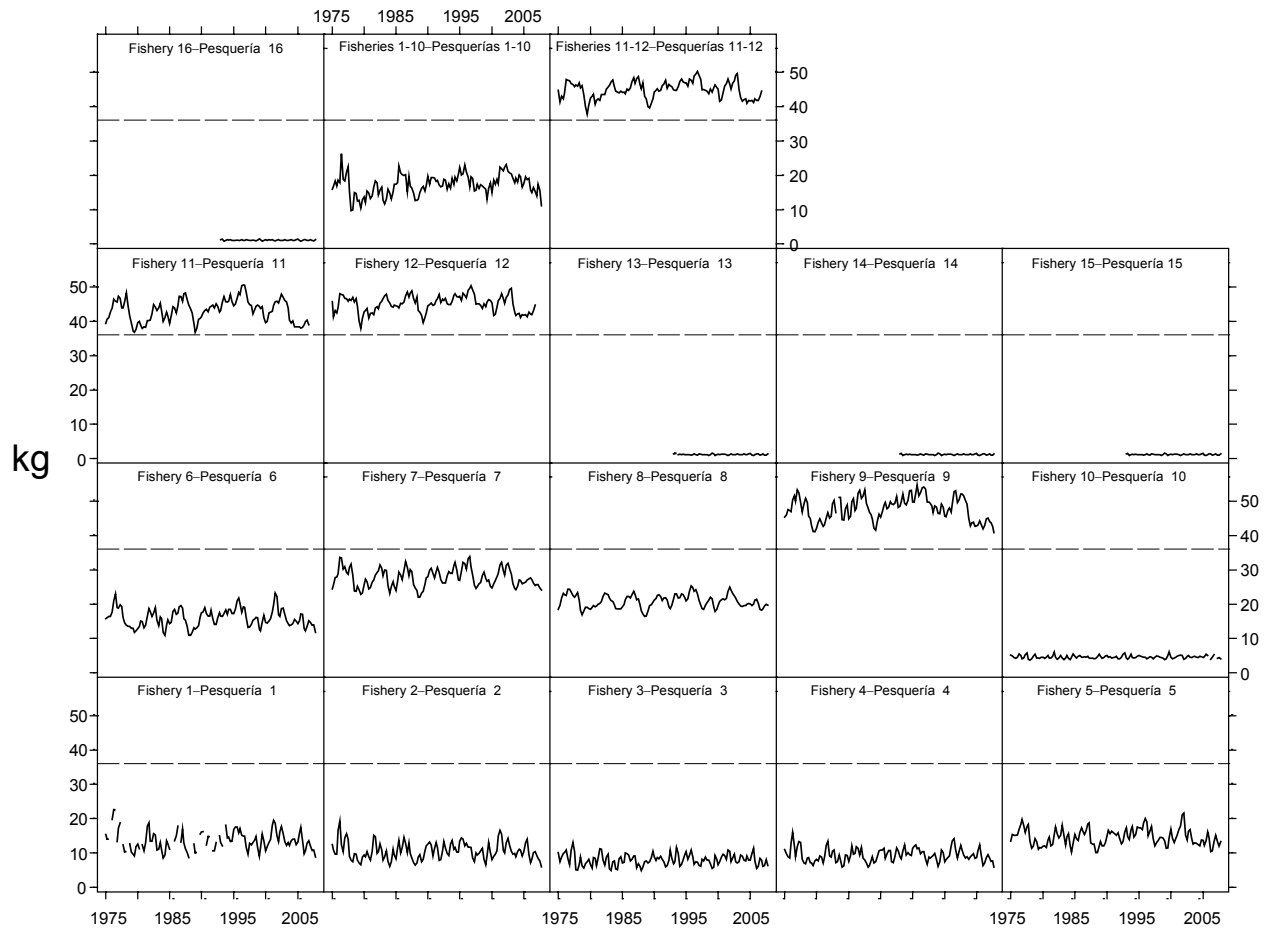
FIGURE 4.11. Estimated average weights of yellowfin tuna caught by the fisheries of the EPO. The time series for "Fisheries 1-10" is an average of Fisheries 1 through 10, and that for "Fisheries 11-12" is an average of Fisheries 11 and 12. The dashed line identifies the critical weight (35.2 kg).

FIGURA 4.11. Peso medio estimado de atún aleta amarilla capturado en las pesquerías del OPO. La serie de tiempo de "Pesquerías 1-10" es un promedio de las Pesquerías 1 a 10, y la de "Pesquerías 11-12" un promedio de las Pesquerías 11 y 12. La línea de trazos identifica el peso crítico (35,2 kg).
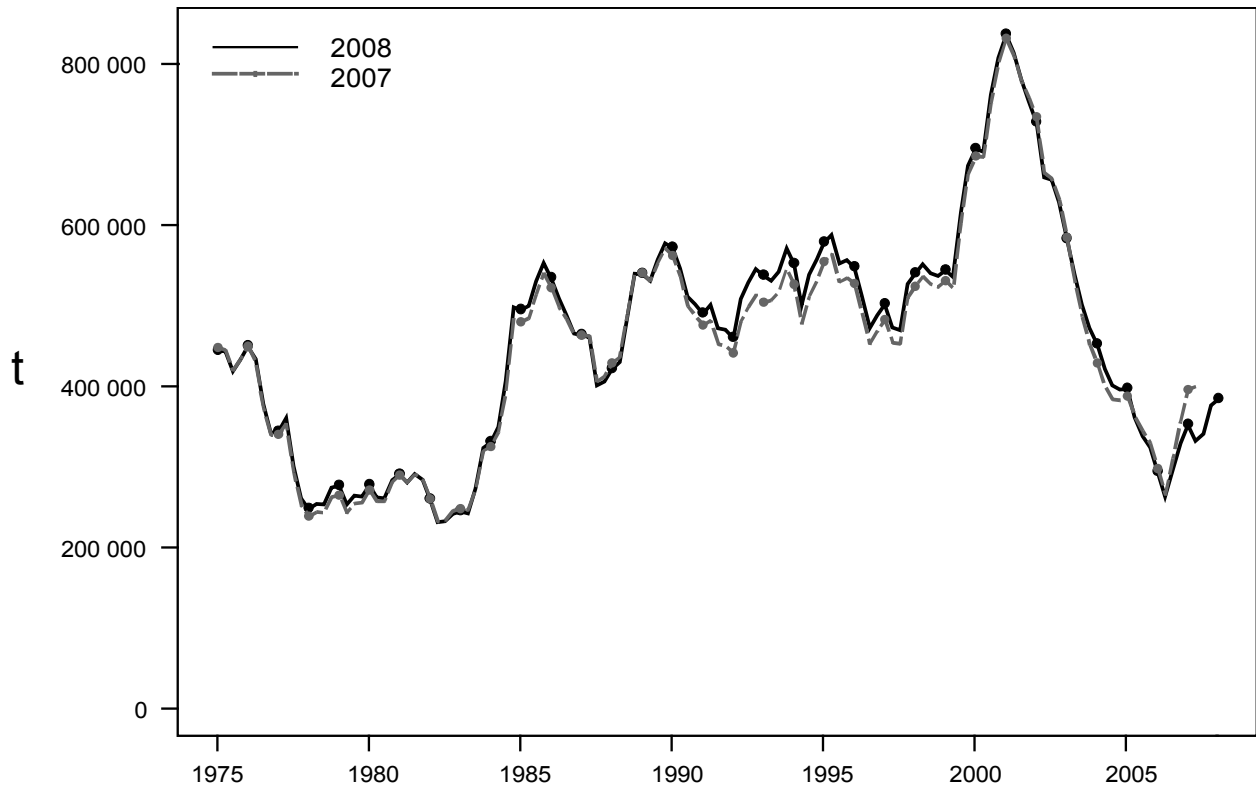
FIGURE 4.12a. Comparison of estimated biomasses of yellowfin tuna in the EPO from the most recent previous assessment and the current assessment. t = metric tons.
FIGURA 4.12a. Comparación de la biomasa estimada de atún aleta amarilla en el OPO de la evaluación previa más reciente y de la evaluación actual. t = toneladas métricas.
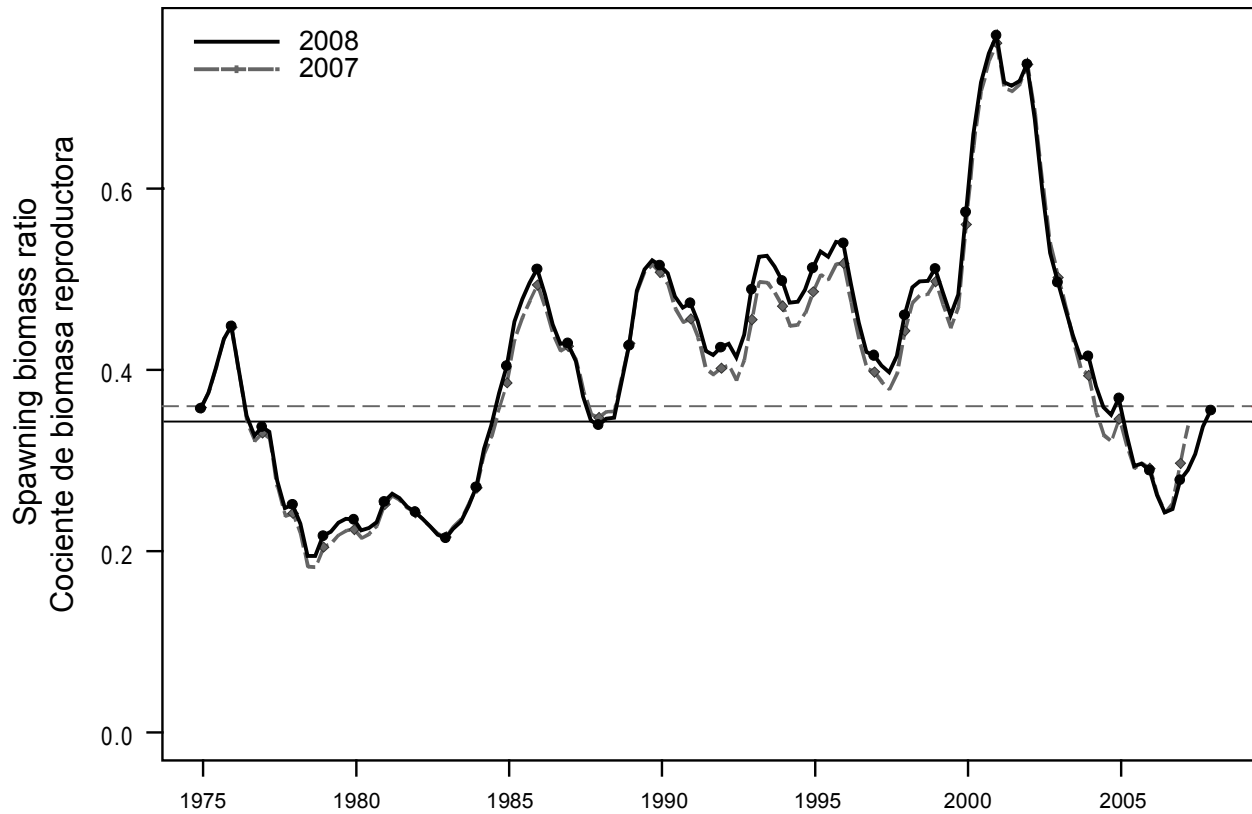
FIGURE 4.12b. Comparison of estimated spawning biomass ratios (SBRs) of yellowfin tuna from the current assessment with the most three recent previous assessments. The horizontal lines identify the SBRs at MSY.

FIGURA 4.12b. Comparación del cociente de biomasa reproductora (SBR) estimado de atún aleta amarilla de la evaluación actual y las tres evaluaciones previas más recientes. Las líneas horizontales identifican el SBR en RMS.
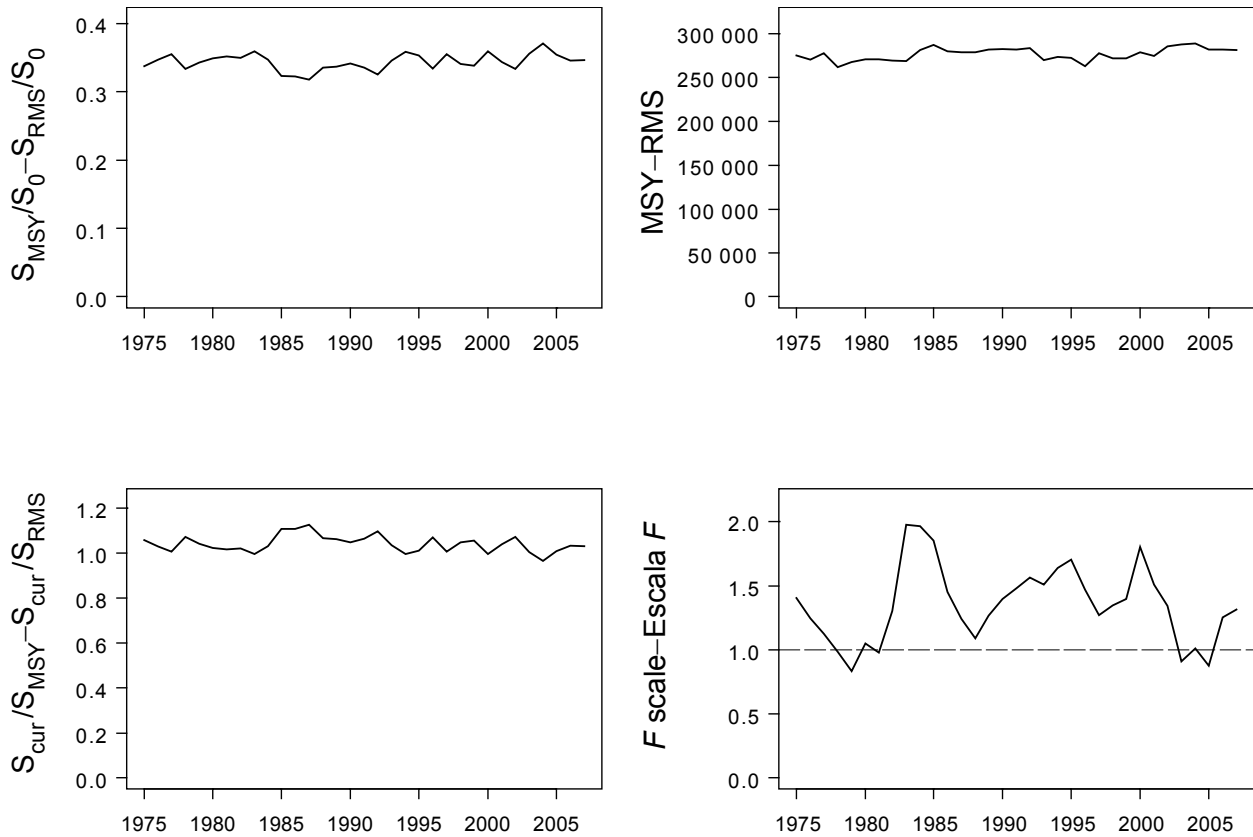
FIGURE 4.12c. Estimates of MSY-related quantities calculated using the average age-specific fishing mortality for each year (*i.e.* the values for 2006 are calculated using the average age-specific fishing mortality in 2006 scaled by the quantity *F*scale, which maximizes the equilibrium yield). (S_{cur} is the spawning biomass at the start of the second quarter of 2007). See the text for definitions.

FIGURA 4.12c. Estimaciones de cantidades relacionadas con el RMS calculadas a partir de la mortalidad por pesca media por edad para cada año (o sea, se calculan los valores de 2006 usando la mortalidad por pesca media por edad escalada por la cantidad *F*scale, que maximiza el rendimiento de equilibrio). (S_{cur} es la biomasa reproductora al principio del segundo trimestre de 2007). Ver definiciones en el texto.
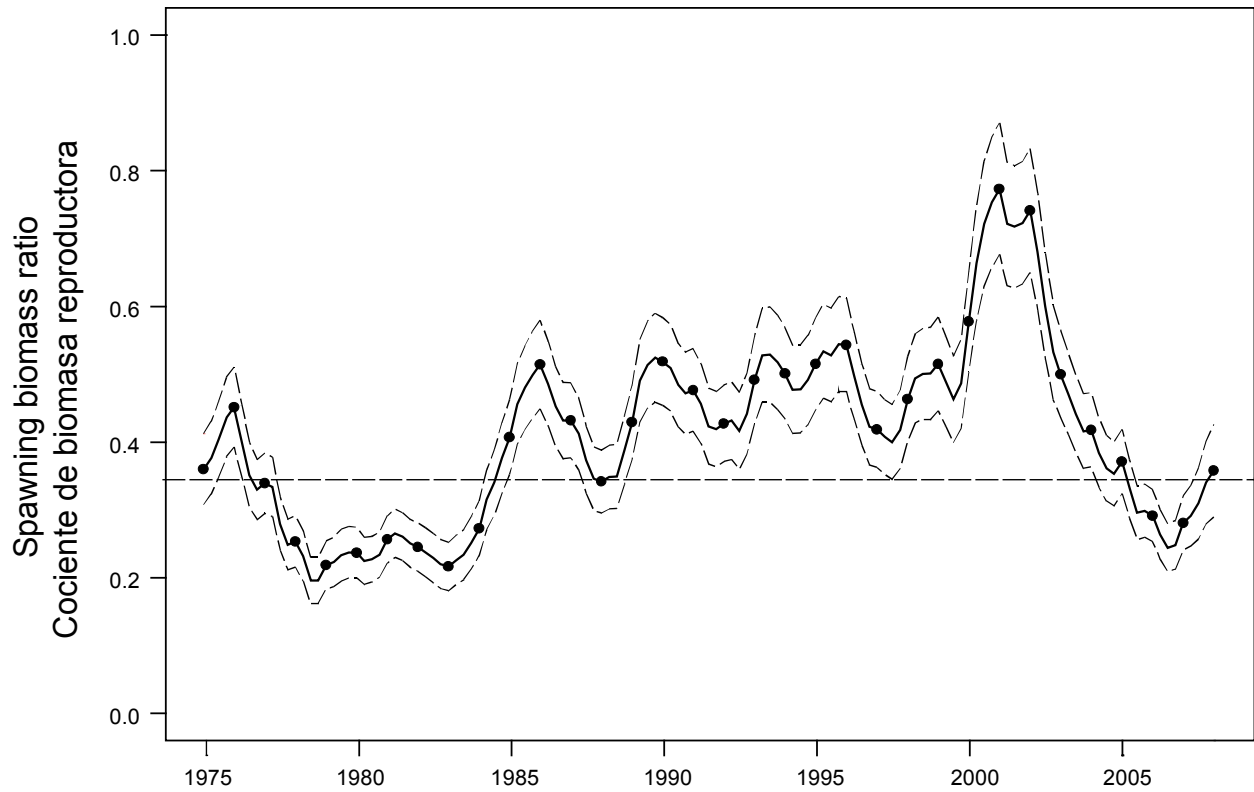
FIGURE 5.1a. Estimated spawning biomass ratios (SBRs) for yellowfin tuna in the EPO. The thin dashed lines represent approximate 95% confidence intervals. The dashed horizontal line identifies the SBR at MSY.

FIGURA 5.1a. Cocientes de biomasa reproductora (SBR) estimados del atún aleta amarilla en el OPO. Las líneas delgadas de trazos representan los intervalos de confianza de 95% aproximados. La línea de trazos horizontal identifica el SBR en RMS.
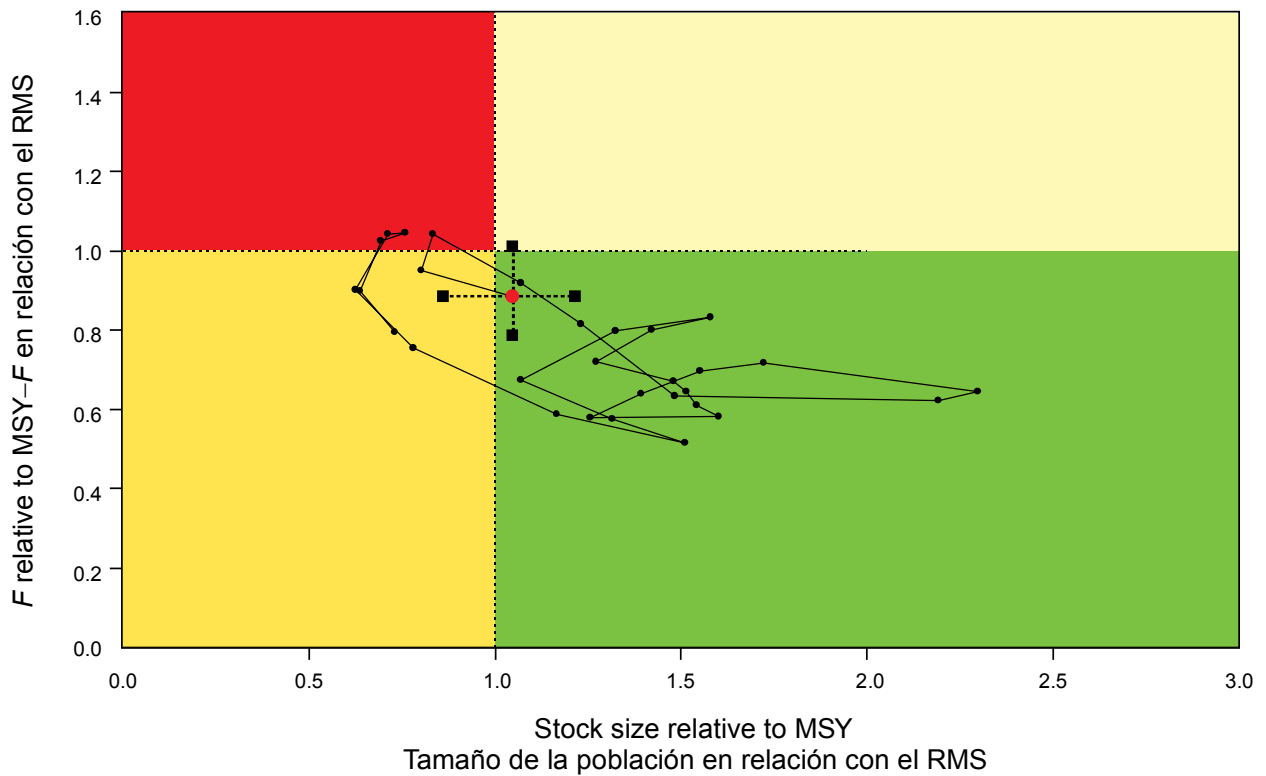
FIGURE 5.1b. Phase plot of the time series of estimates for stock size and fishing mortality relative to their MSY reference points. Each dot is based on the average exploitation rate over three years; the large red dot indicates the most recent estimate. The squares represent approximate 95% confidence intervals.
FIGURA 5.1b. Gráfica de fase de la serie de tiempo de las estimaciones del tamaño de la población y la mortalidad por pesca en relación con sus puntos de referencia de RMS. Cada punto se basa en la tasa de explotación media de tres años; el punto rojo grande indica la estimación valor más reciente. Los puntos cuadrados representan los intervalos de confianza de 95% aproximados.
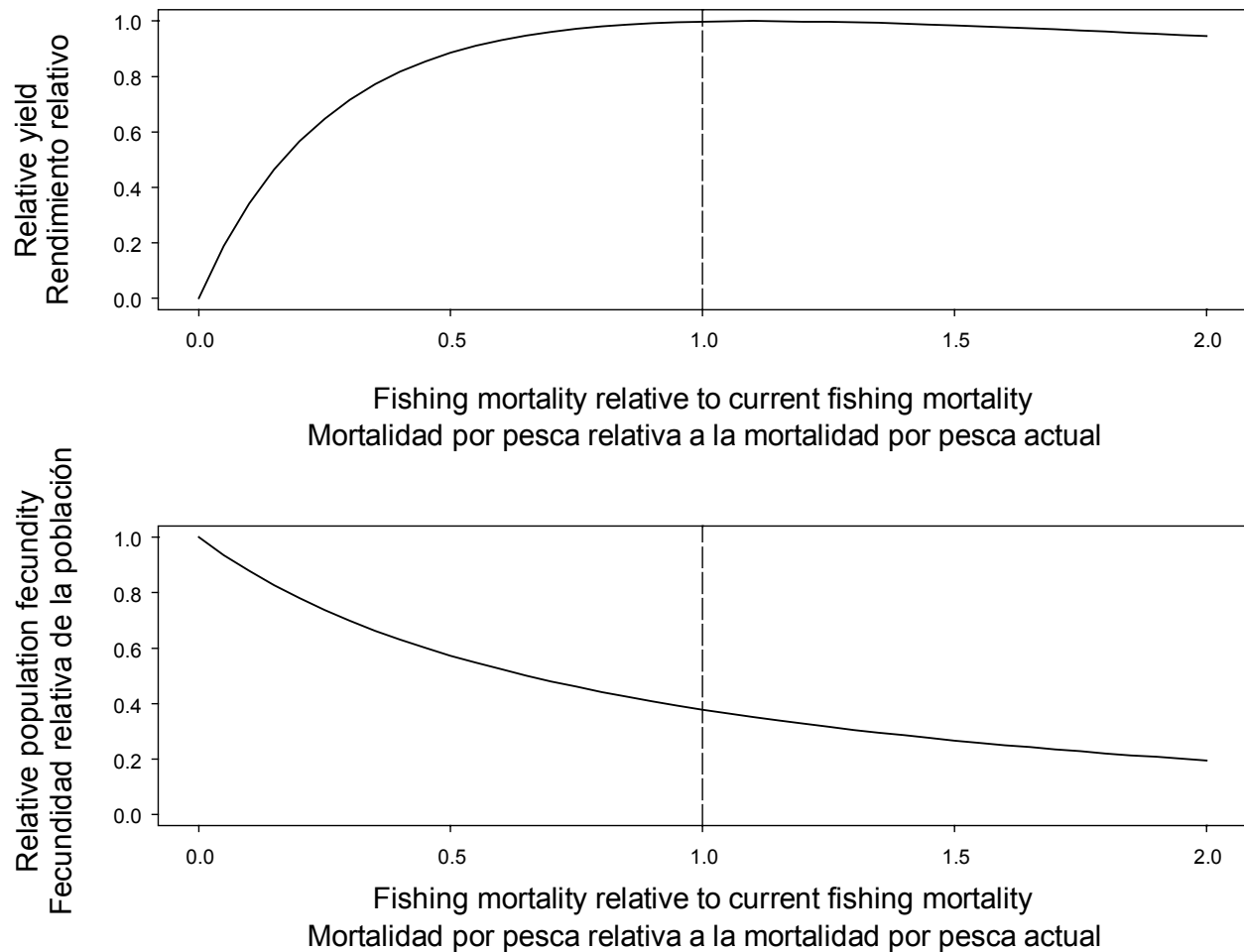
FIGURE 5.2. Predicted effects of long-term changes in fishing effort on the yield (upper panel) and spawning biomass (lower panel) of yellowfin tuna under average environmental conditions, constant recruitment, and the current age-specific selectivity pattern of all fisheries combined. The yield estimates are scaled so that the MSY is at 1.0, and the spawning biomass estimates so that the spawning biomass is equal to 1.0 in the absence of exploitation.

FIGURA 5.2. Efectos predichos de cambios a largo plazo en el esfuerzo de pesca sobre el rendimiento (recuadro superior) y la biomasa reproductora (recuadro inferior) del atún aleta amarilla, bajo condiciones ambientales medias, reclutamiento constante, y el patrón actual de selectividad por edad de todas las pesquerías combinadas. Se escalan las estimaciones de rendimiento para que el RMS esté en 1,0, y las de biomasa reproductora para que ésta equivalga a 1,0 en ausencia de explotación.
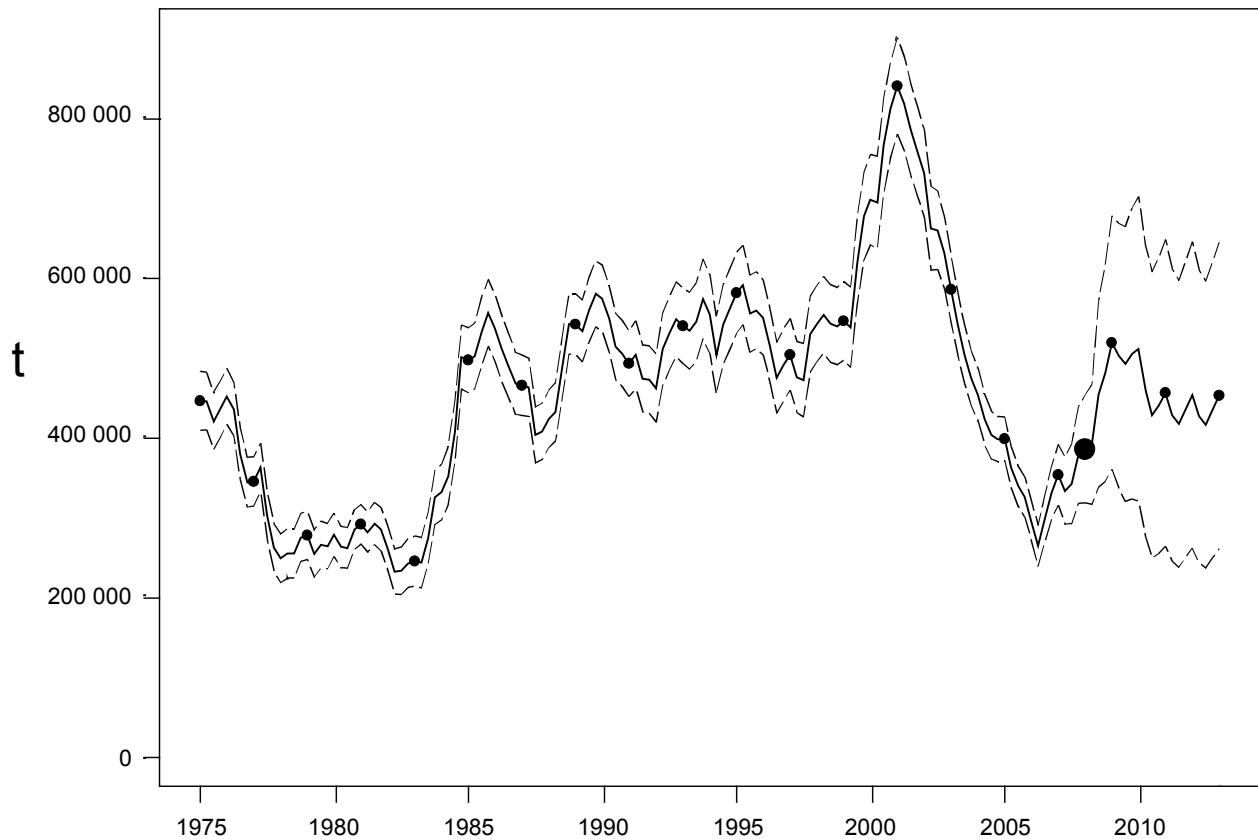
FIGURE 6.1. Biomasses projected for yellowfin tuna in the EPO during 2008-2012 under current effort. The thin dashed lines represent the 95% confidence intervals. The estimates after 2008 indicate the biomasses predicted if the fishing mortality continues at the average of that observed during 2005-2007, and average environmental conditions occur during the next 5 years. t = metric tons.

FIGURA 6.1. Biomasa predicha de atún aleta amarilla en el OPO durante 2008-2012 con el esfuerzo actual. Las líneas delgadas de trazos representan los intervalos de confianza de 95%. Las estimaciones a partir de 2008 señalan la biomasa predicha si la mortalidad por pesca continúa en el nivel medio observado durante 2005-2007, y con condiciones ambientales promedio en los 5 años próximos. t = toneladas métricas.

FIGURE 6.2. Spawning biomass ratios (SBRs) for 1975-2007 and SBRs projected during 2008-2012 for yellowfin tuna in the EPO. The dashed horizontal line identifies SBR$_{MSY}$ (Section 5.3), and the thin dashed lines represent the 95% confidence intervals of the estimates. The estimates after 2008 indicate the SBR predicted if the fishing mortality continues at the average of that observed during 2005-2007, and average environmental conditions occur during the next 5 years.

FIGURA 6.2. Cocientes be biomasa reproductora **(**SBR) de 1975-2007 y SBR proyectados durante 2008-2012 para el atún aleta amarilla en el OPO. La línea de trazos horizontal identifica el SBR$_{RMS}$ (Sección 5.3), y las líneas delgadas de trazos representan los intervalos de confianza de 95% de las estimaciones. Las estimaciones a partir de 2008 señalan el SBR predicho si la mortalidad por pesca continúa en el nivel medio observado durante 2005-2007 y con condiciones ambientales promedio en los 5 años próximos.
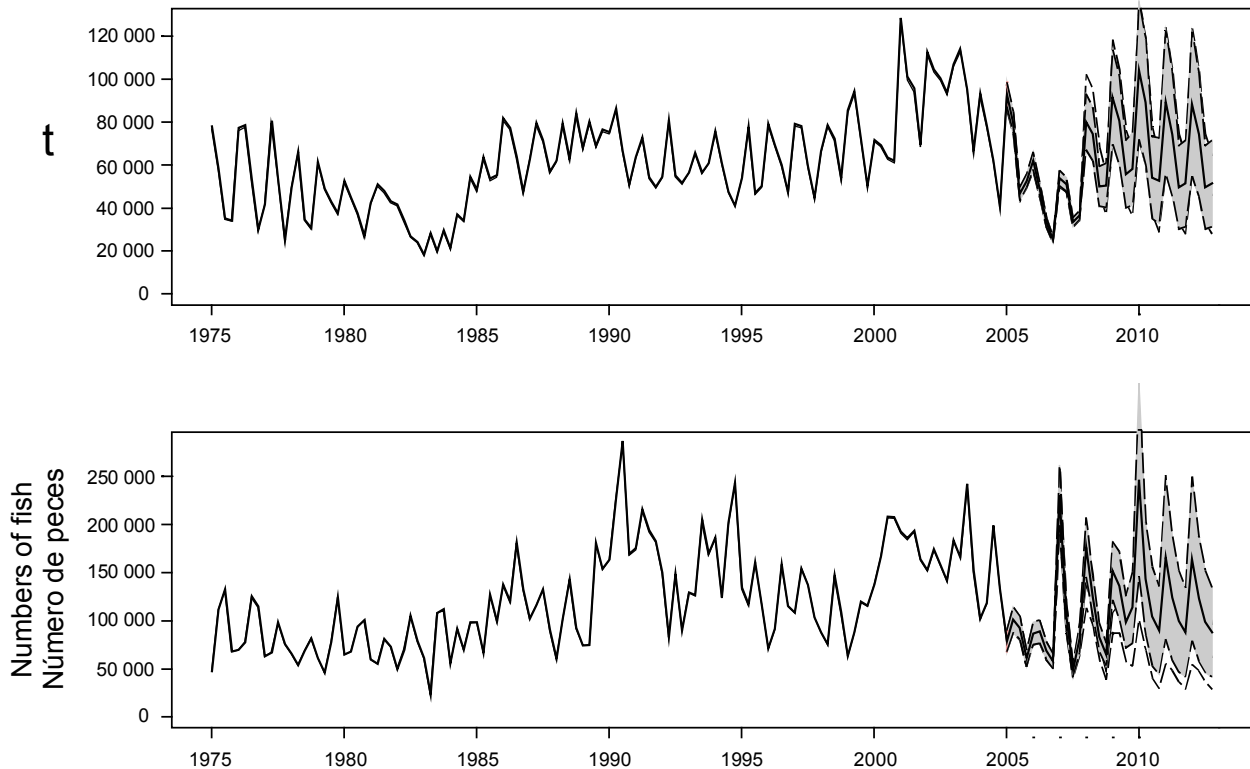
FIGURE 6.3. Catches of yellowfin tuna during 1975-2007 and simulated catches of yellowfin tuna during 2008-2012 by the purse-seine and pole-and-line fleets (upper panel) and the longline fleet (lower panel). The thin dashed lines represent the estimated 95% confidence limits of the estimates. The estimates after 2007 indicate the catches predicted if the fishing mortality continues at the average of that observed during 2005-2007, and average environmental conditions occur during the next 5 years. t = metric tons.

FIGURA 6.3. Capturas de atún aleta amarilla durante 1975-2007 y capturas simuladas de atún aleta amarilla durante 2008-2012 por las flotas de cerco y caña (recuadro superior) y la flota palangrera (recuadro inferior). Las líneas delgadas de trazos representan los intervalos de confianza de 95% de las estimaciones. Las estimaciones a partir de 2007 señalan las capturas predichas si la mortalidad por pesca continúa en el promedio del nivel observado durante 2005-2007, y con condiciones ambientales medias en los 5 años próximos. t = toneladas métricas.
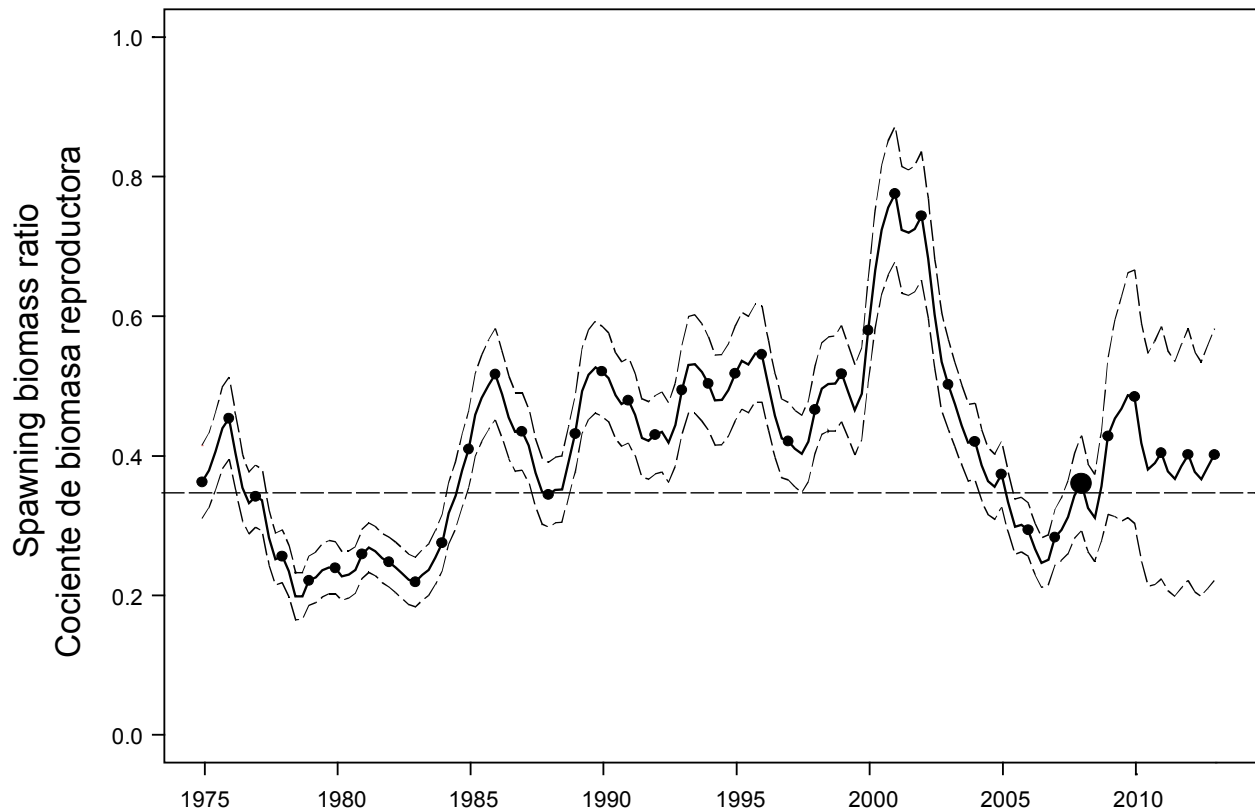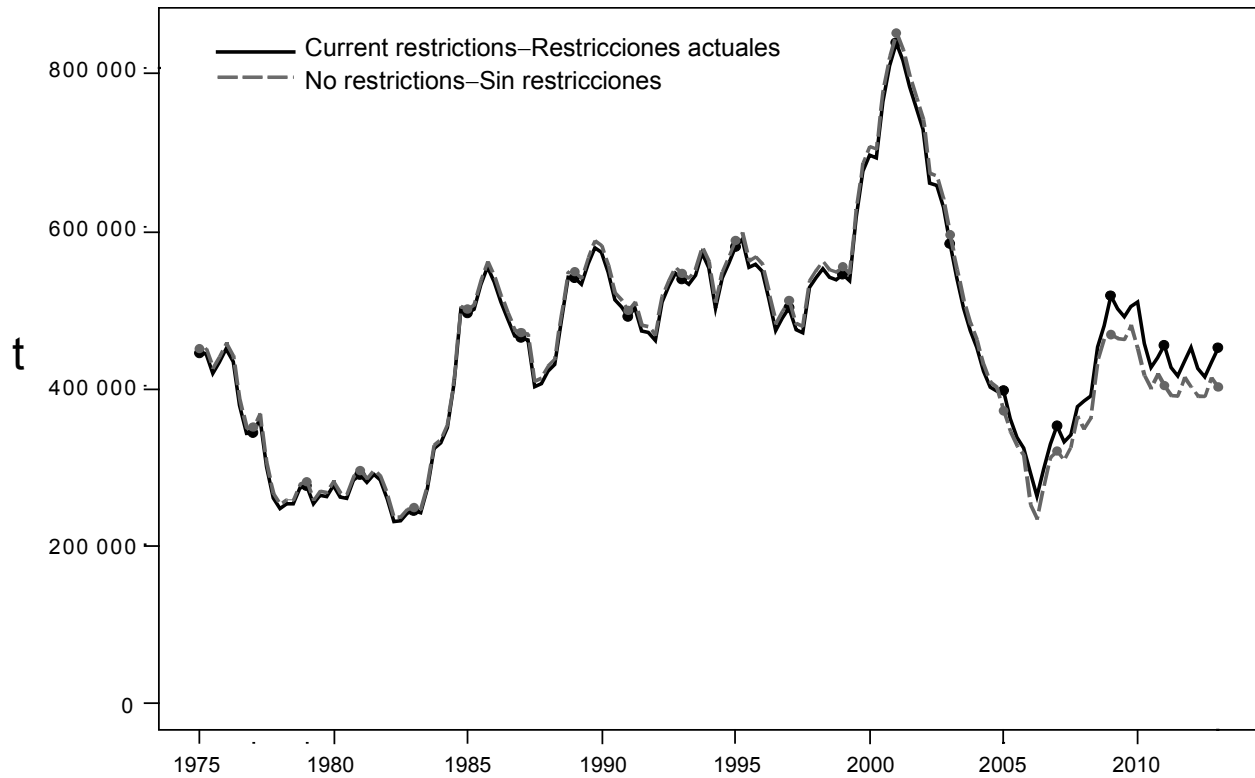
FIGURE 6.4. Biomass projected for yellowfin tuna in the EPO during 2005-2013 under Resolutions C-04-09 and C-06-02, and under effort projected without the resolutions. t = metric tons.

FIGURA 6.4. Proyección de la biomasa de atún aleta amarilla en el OPO durante 2005-2013, bajo las Resoluciones C-04-09 y C-06-02, y con el esfuerzo proyectado sin las resoluciones. t = toneladas métricas.
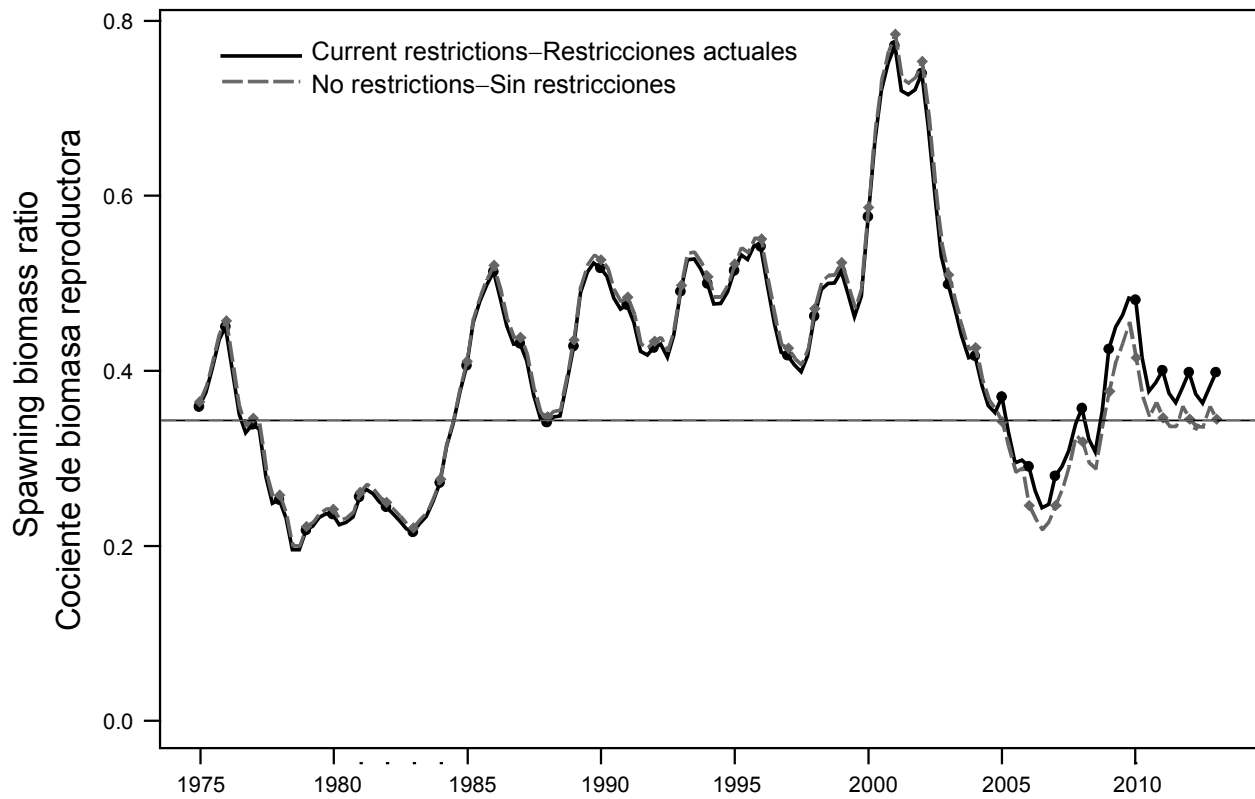
FIGURE 6.5. Spawning biomass ratios (SBRs) projected for yellowfin tuna in the EPO during 2005-2013 under Resolutions C-04-09 and C-06-02, and under effort projected without the Resolutions. The horizontal line (at 0.37) identifies SBR$_{MSY}$ (Section 5.3).

FIGURA 6.5. Cocientes de biomasa reproductora (SBR) de atún aleta amarilla en el OPO proyectados durante 2005-2013, bajo las Resoluciones C-04-09 y C-06-02, y con el esfuerzo proyectado sin las resoluciones. La línea horizontal (en 0.38) identifica SBR$_{RMS}$ (Sección 5.3).

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

TABLA 2.1. Pesquerías definidas por el personal de la CIAT para la evaluación del stock de atún aleta amarilla en el OPO. PS = red de cerco; LP = caña; LL = palangre; OBJ = lances sobre objeto flotante; NOA = lances sobre atunes no asociados; DEL = lances sobre delfines. En la Figura 3.1 se ilustran las zonas de muestreo, y en la Sección 2.2.2 se describen los descartes.

| Fishery	Gear type	Set type	Years	Sampling areas	Catch data
Pesquería	Tipo de arte	Tipo de lance	Año	Zonas de muestreo	Datos de captura
1	PS	OBJ	1975-2007	11-12	retained catch + discards from inefficiencies in fishing process–captura retenida + descartes por ineficacias en el proceso de pesca
2	PS	OBJ	1975-2007	7, 9	
3	PS	OBJ	1975-2007	5-6, 13	
4	PS	OBJ	1975-2007	1-4, 8, 10	
5	PS	NOA	1975-2007	1-4, 8, 10	retained catch + discards– captura retenida + descartes
6	PS	NOA	1975-2007	5-7, 9, 11-13	
7	PS	DEL	1975-2007	2-3, 10	
8	PS	DEL	1975-2007	1, 4-6, 8, 13	
9	PS	DEL	1975-2007	7, 9, 11-12	
10	LP		1975-2007	1-13	retained catch only— captura retenida solamente
11	LL		1975-2007	N of-de 15°N	
12	LL		1975-2007	S of-de 15°N	
13	PS	OBJ	1993-2007	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	1993-2007	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	1993-2007	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	1993-2007	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 age of two quarters (thousands of fish), initial biomass (metric tons present at the beginning of the year), and spawning biomass (relative to maximum spawning biomass) of yellowfin tuna in the EPO. Biomass is defined as the total weight of yellowfin one and half years of age and older; spawning biomass is estimated with the maturity schedule and sex ratio data of Schaefer (1998) and scaled to have a maximum of 1.

TABLA 4.1. Reclutamiento anual total estimado a la pesquería a la edad de dos trimestres (en miles de peces), biomasa inicial (toneladas métricas presentes al principio de año), y biomasa reproductora relativa del atún aleta amarilla en el OPO. Se define la biomasa como el peso total de aleta amarilla de año y medio o más de edad; se estima la biomasa reproductora con el calendario de madurez y datos de proporciones de sexos de Schaefer (1998) y la escala tiene un máximo de 1.

Year	Total recruitment	Biomass of age-1.5+ fish	Relative spawning biomass
Año	Reclutamiento total	Biomasa de peces de edad 1.5+	Biomasa reproductora relativa
1975	114,444	446,742	0.47
1976	95,744	452,388	0.58
1977	149,444	345,700	0.44
1978	103,651	249,422	0.33
1979	137,895	278,246	0.28
1980	108,846	278,712	0.31
1981	74,865	292,245	0.33
1982	124,490	261,217	0.32
1983	190,245	246,023	0.28
1984	152,489	332,510	0.35
1985	130,630	497,627	0.53
1986	156,136	537,416	0.67
1987	264,530	466,116	0.56
1988	191,059	423,918	0.44
1989	159,516	542,701	0.55
1990	155,640	575,129	0.67
1991	213,508	493,254	0.62
1992	171,988	462,779	0.55
1993	169,155	540,737	0.64
1994	148,736	555,343	0.65
1995	166,150	581,959	0.67
1996	220,183	551,002	0.70
1997	162,990	504,760	0.54
1998	312,177	543,030	0.60
1999	219,089	547,056	0.67
2000	225,099	698,714	0.75
2001	211,166	841,411	1.00
2002	176,001	731,587	0.96
2003	148,982	586,082	0.65
2004	120,449	454,463	0.54
2005	144,313	399,137	0.48
2006	124,520	295,340	0.38
2007	225,527	354,047	0.36
2008		386,284	0.46

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

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

Age (quarters) Edad (trimestres)	Average length (cm) Talla media (cm)	Average weight (kg) Peso medio (kg)	Age (quarters) Edad (trimestres)	Average length (cm) Talla media (cm)	Average weight (kg) Peso medio (kg)
2	33.06	0.7	16	154.22	80.98
3	40.76	1.33	17	159.06	89.08
4	48.92	2.34	18	163.25	96.52
5	58.32	4.03	19	166.84	103.22
6	68.47	6.61	20	169.89	109.16
7	78.72	10.16	21	172.48	114.38
8	89.2	14.95	22	174.67	118.92
9	99.43	20.9	23	176.51	122.83
10	109.28	27.97	24	178.06	126.18
11	118.64	36.04	25	179.35	129.03
12	127.37	44.87	26	180.43	131.44
13	135.18	53.92	27	181.33	133.47
14	142.29	63.16	28	182.08	135.18
15	148.64	72.28	29	182.7	136.61

TABLE 5.1. MSY and related quantities for the base case and the stock-recruitment relationship sensitivity analysis, based on average fishing mortality (F) for 2005-2007. The quantities are also given based on average F for 2005-2006. B_{recent} and B_{MSY} are defined as the biomass of fish 2+ quarters old at the start of the second quarter of 2007 and at MSY, respectively, and S_{recent} and S_{MSY} are defined as indices of spawning biomass (therefore, they are not in metric tons). C_{recent} is the estimated total catch from the second quarter of 2006 through the first quarter of 2007.

TABLA 5.1. RMS y cantidades relacionadas para el caso base y los análisis de sensibilidad a la relación población-reclutamiento, basados en la mortalidad por pesca (F) media de 2005-2007. Se presentan también las cantidades basadas en la F media de 2005-2006. Se definen B_{recent} y B_{RMS} como la biomasa de peces de 2+ trimestres de edad al principio del segundo trimestre de 2007 y en RMS, respectivamente, y S_{recent} y S_{RMS} como los índices de biomasa reproductora (por lo tanto, no se expresan en toneladas métricas). C_{recent} es la captura total estimada desde el segundo trimestre de 2006 hasta el primer trimestre de 2007, inclusive.

	Base case Caso base	h = 0.75	Average F F promedio 2005-2006
MSY–RMS	281,902	290,236	282,043
$B_{MSY}-B_{RMS}$	400,484	530,326	399,405
$S_{MSY}-S_{RMS}$	4,489	6,224	4,474
C_{recent}/MSY—C_{recent}/RMS	0.68	0.67	0.68
B_{recent}/$B_{MSY}-B_{recent}$/B_{RMS}	0.96	0.72	0.97
S_{recent}/$S_{MSY}-S_{recent}$/S_{RMS}	1.04	0.74	1.04
S_{MSY}/$S_{F=0}-S_{RMS}$/$S_{F=0}$	0.34	0.40	0.34
F multiplier—Multiplicador de F	1.13	0.77	1.06

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 (Figure 4.4). Se expresan las estimaciones de RMS y B_{RMS} en toneladas métricas. OBJ = lance sobre objeto flotante; NOA = lance sobre atunes no asociados; DEL = lances sobre delfines; LL = palangre.

Fishery	MSY	B_{MSY}	S_{MSY}	$B_{MSY}/B_{F=0}$	$S_{MSY}/S_{F=0}$	F multiplier
Pesquería	RMS	B_{RMS}	S_{RMS}	$B_{RMS}/B_{F=0}$	$S_{RMS}/S_{F=0}$	Multiplicador de F
All—Todas	281,902	400,484	4,489	0.34	0.34	1.13
OBJ	212,479	308,808	3,377	0.26	0.26	9.26
NOA	260,293	395,167	4,558	0.33	0.35	3.70
DEL	306,525	397,836	4,213	0.33	0.32	2.56
LL	358,755	461,893	4,962	0.39	0.38	47.19

TABLE 5.2b. Estimates of the MSY and its associated quantities, obtained by assuming that one fishery is not 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 5.2b. Estimaciones del RMS y sus cantidades asociadas, obtenidas suponiendo que una pesquería no opera en el OPO y que cada pesquería mantiene su patrón actual de selectividad por edad (Figure 4.4). Se expresan las estimaciones de RMS y B_{RMS} en toneladas métricas. OBJ = lance sobre objeto flotante; NOA = lance sobre atunes no asociados; DEL = lances sobre delfines; LL = palangre.

Fishery	MSY	B_{MSY}	S_{MSY}	$B_{MSY}/B_{F=0}$	$S_{MSY}/S_{F=0}$	F multiplier
Pesquería	RMS	B_{RMS}	S_{RMS}	$B_{RMS}/B_{F=0}$	$S_{RMS}/S_{F=0}$	Multiplicador de F
All—Todas	281,902	400,484	4,489	0.34	0.34	1.13
No OBJ	291,443	408,154	4,533	0.34	0.35	1.35
No NOA	290,590	407,747	4,524	0.34	0.35	1.61
No DEL	259,384	403,265	4,702	0.34	0.36	2.08
No LL	277,741	396,828	4,442	0.33	0.34	1.19

TABLE 5.2c. Estimates of the MSY and its associated quantities, obtained by assuming that each fishery maintains its current pattern of age-specific selectivity (Figure 4.4), and by adjusting the effort to obtain MSY. Either all gears are adjusted, one fishery only is adjusted while the other is set to zero, or one fishery is adjusted while the other remains at its current level. The estimates of the MSY and B_{MSY} are expressed in metric tons.

TABLA 5.2c. Estimaciones del RMS y sus cantidades asociadas, obtenidas suponiendo que cada pesquería mantiene su patrón actual de selectividad por edad (Figure 4.4) y ajustando el esfuerzo para obtener el RMS. Se ajustan todas las artes de pesco, o se ajusta solamente una pesquería y se fija la otra en cero, o se ajusta una pesquería y la otra sigue en su nivel actual. Se expresan las estimaciones de RMS y B_{RMS} en toneladas métricas.

	All gears	Purse-seine only	Longline only	Purse-seine adjusted	Longline adjusted
	Todas artes	Cerco solamente	Palangre solamente	Cerco ajustado	Palangre ajustado
Steepness—Inclinación = 1 (Base case-Caso base)					
MSY—RMS	281,902	277,741	358,755	281,367	307,647
B_{MSY}—B_{RMS}	400,484	396,828	461,893	414,427	320,750
S_{MSY}—S_{RMS}	4,489	4,442	4,962	4,686	3,138
B_{MSY}/B_0—B_{RMS}/B_0	0.34	0.33	0.39	0.35	0.27
S_{MSY}/S_0—S_{RMS}/S_0	0.34	0.34	0.38	0.36	0.24
F multiplier—Multiplicador de F	1.13	1.19	47.19	1.07	37.46
Steepness—Inclinación = 0.75					
MSY—RMS	290,236	285,335	376,352	292,627	287,643
B_{MSY}—B_{RMS}	530,326	528,075	577,587	553,679	391,912
S_{MSY}—S_{RMS}	6,224	6,173	6,727	6,534	4,367
B_{MSY}/B_0—B_{RMS}/B_0	0.37	0.37	0.41	0.39	0.28
S_{MSY}/S_0—S_{RMS}/S_0	0.40	0.40	0.43	0.42	0.28
F multiplier—Multiplicador de F	0.77	0.82	22.99	0.71	5.32

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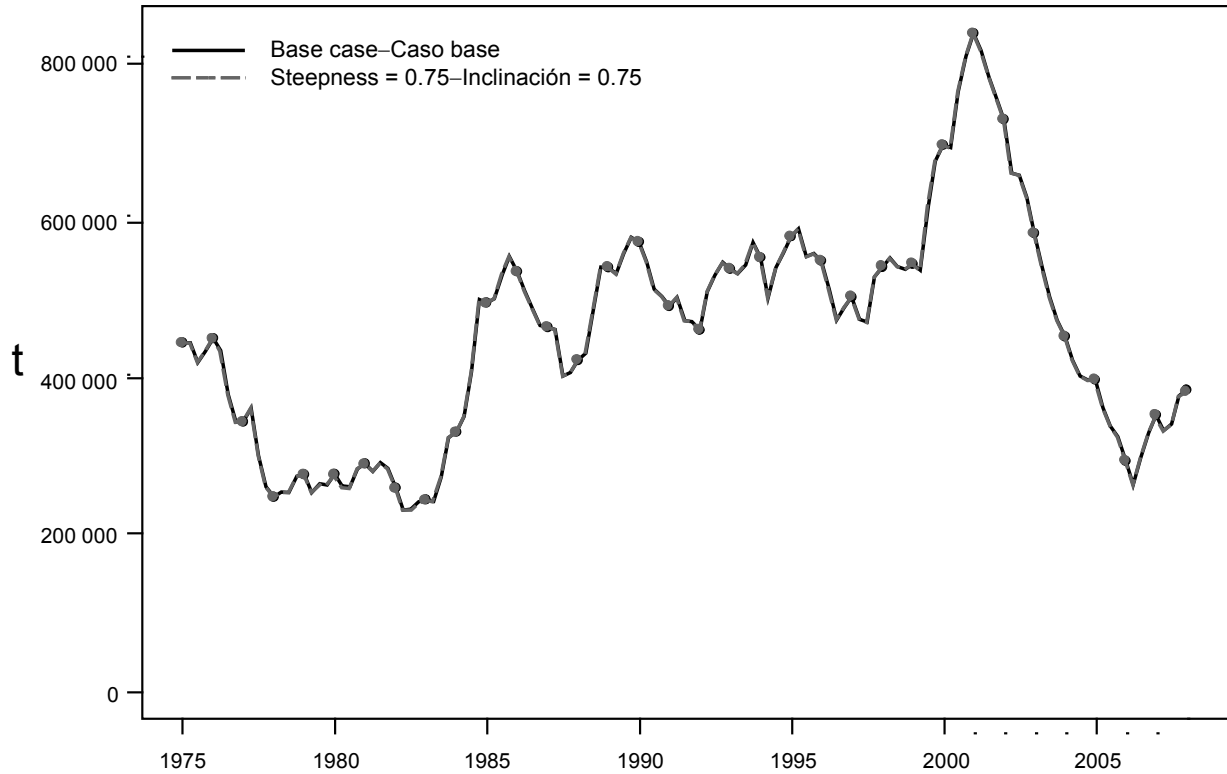RECLUTAMIENTO**

FIGURE A.1. Comparison of the estimates of biomass of yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).
FIGURA A.1. Comparación de las estimaciones de la biomasa de atún aleta amarilla del análisis sin relación población-reclutamiento (caso base) y con relación población-reclutamiento (inclinación = 0,75).
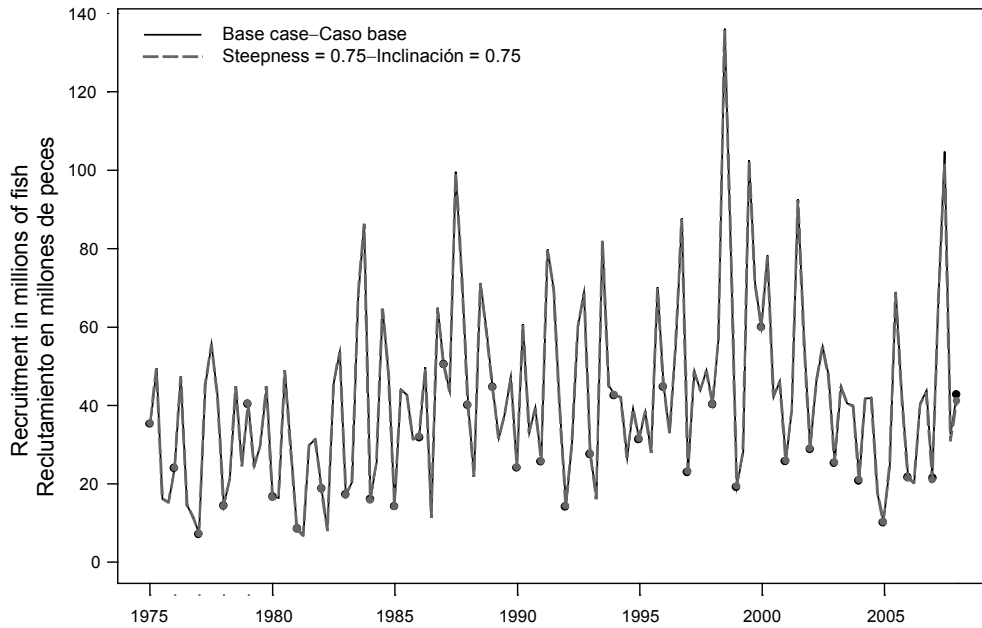
FIGURE A.2. Comparison of estimates of recruitment of yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).
FIGURA A.2. Comparación de las estimaciones de reclutamiento de atún aleta amarilla del análisis sin relación población-reclutamiento (caso base) y con relación población-reclutamiento (inclinación = 0,75).
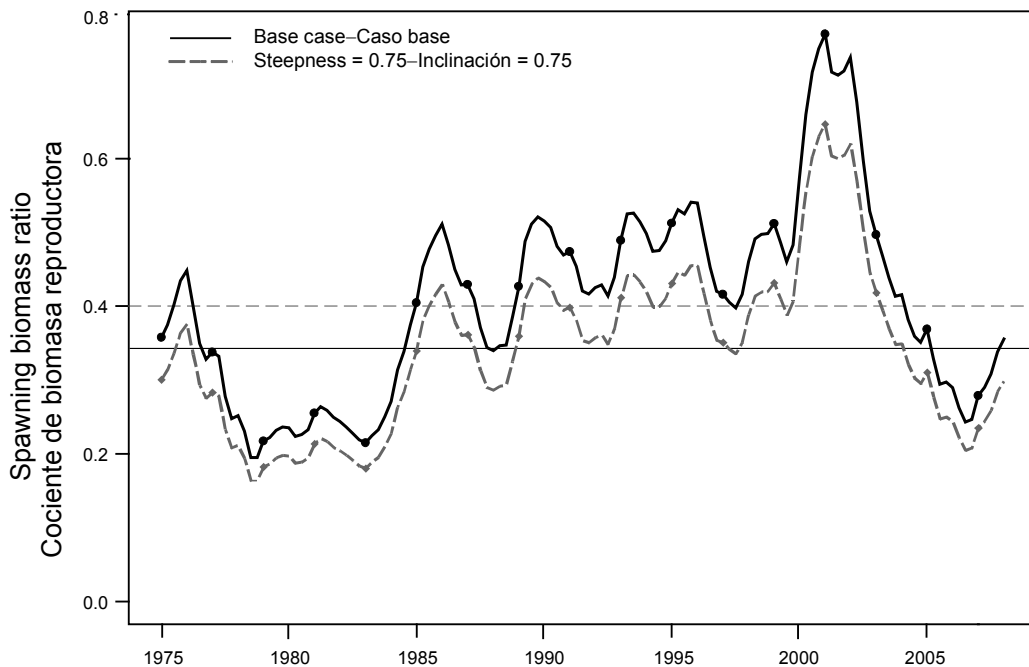

FIGURE A.3a. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). The horizontal lines represent the SBRs associated with MSY for the two scenarios.
FIGURA A.3a. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún aleta amarilla del análisis sin (caso base) y con relación población-reclutamiento (inclinación = 0,75). Las líneas horizontales representan el SBR asociado con el RMS para los dos escenarios.
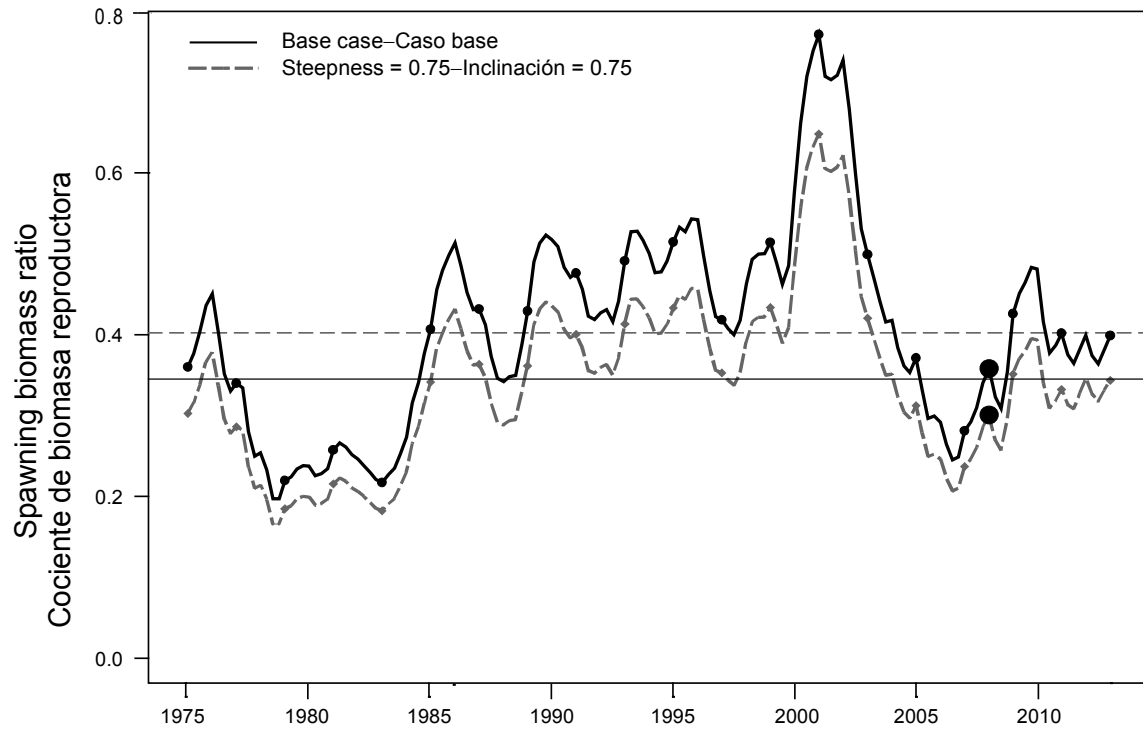
FIGURE A.3b. Comparison of estimates of the spawning biomass ratios (SBRs) projected during 2008-2013 for yellowfin tuna from the analysis without (base case) and with (steepness = 0.75) a stock-recruitment relationship. The horizontal lines represent the SBRs associated with MSY for the two scenarios.

FIGURA A.3b. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún aleta amarilla durante 2008-2013 del análisis sin (caso base) y con (inclinación = 0,75) una relación población-reclutamiento. Las líneas horizontales representan el SBR asociado con el RMS para los dos escenarios.
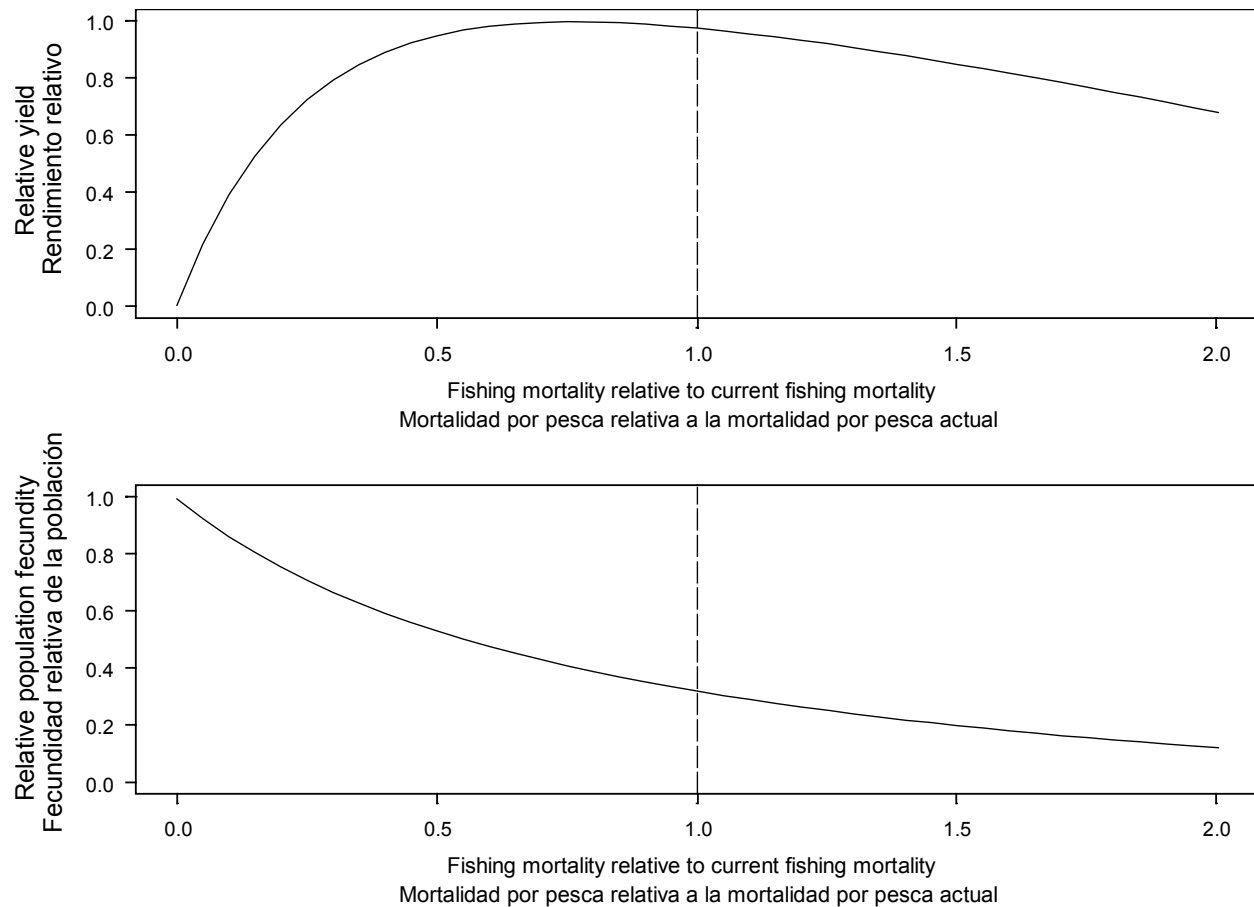
FIGURE A.4. Relative yield (upper panel) and the associated spawning biomass ratio (lower panel) of yellowfin tuna when the stock assessment model has a stock-recruitment relationship (steepness = 0.75).
FIGURA A.4. Rendimiento relativo (recuadro superior) y el cociente de biomasa reproductora asociado (recuadro inferior) de atún aleta amarilla cuando el modelo de evaluación de la población incluye una relación población-reclutamiento (inclinación = 0.75).
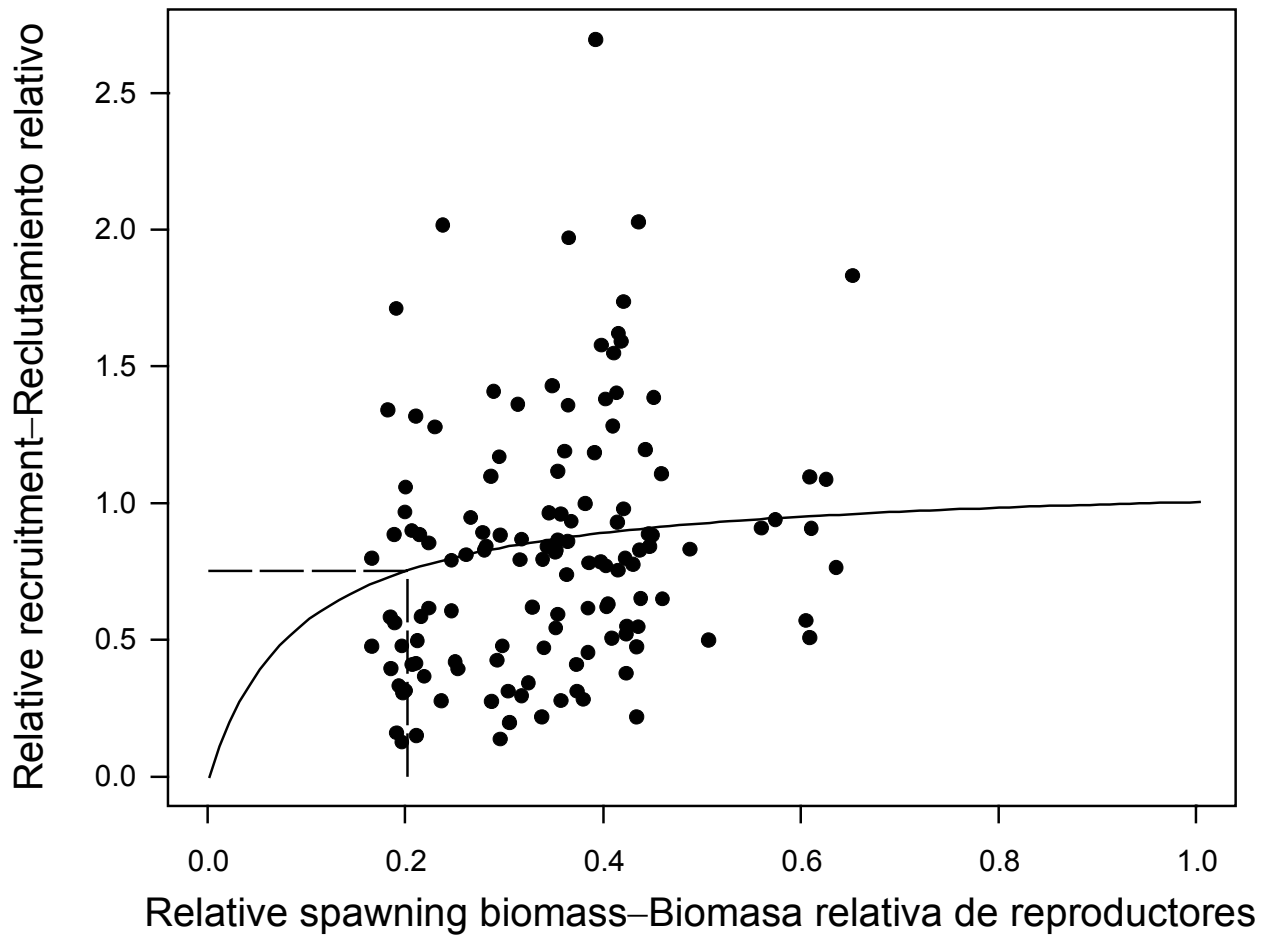
FIGURE A.5. Recruitment plotted against spawning biomass of yellowfin tuna when the analysis has a stock-recruitment relationship (steepness = 0.75).
FIGURA A.5. Reclutamiento graficado contra biomasa reproductora de atún aleta amarilla cuando el análisis incluye una relación población-reclutamiento (inclinación = 0,75).

APPENDIX B: 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 B: 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.
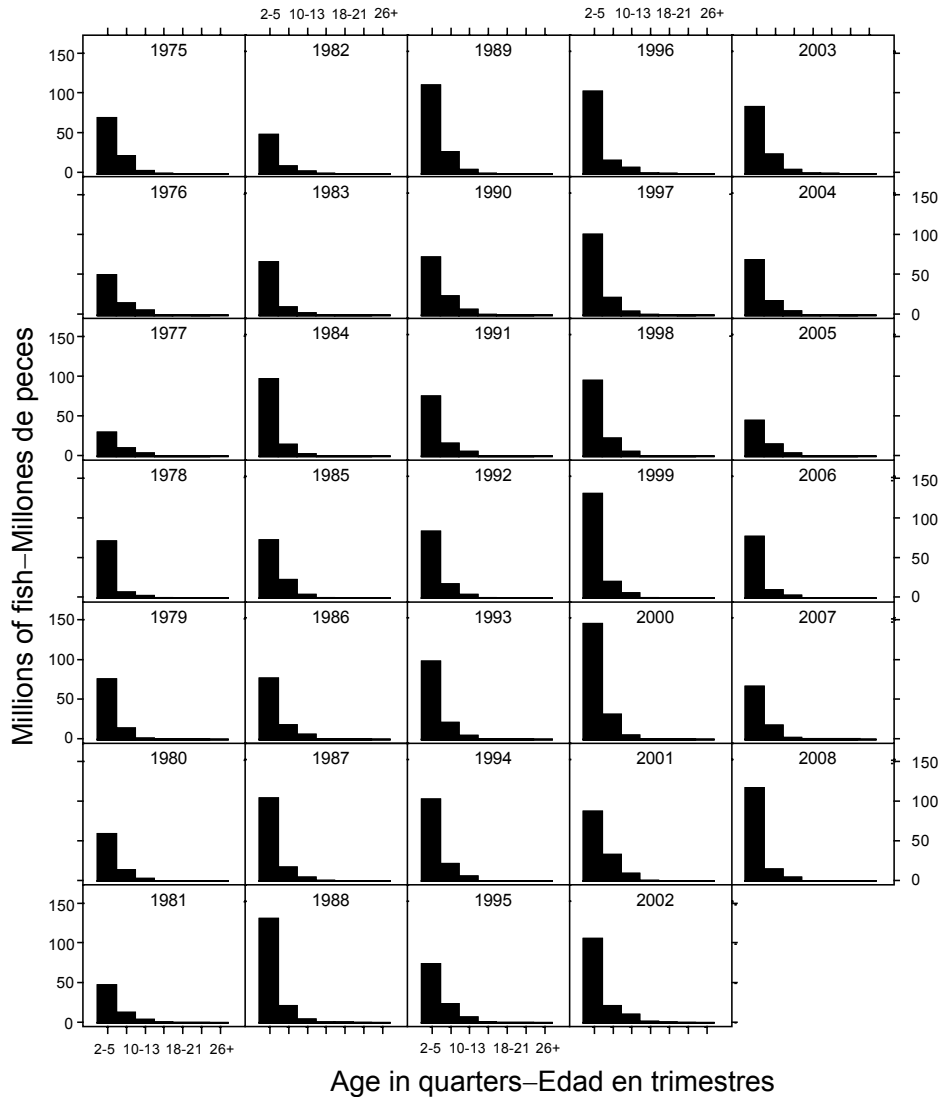

FIGURE B.1. Estimated numbers of yellowfin tuna present in the EPO on January 1 of each year.
FIGURA B.1. Número estimado de atunes aleta amarilla presentes en el OPO el 1 de enero de cada año.

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

Year / Año	Age in quarters—Edad en trimestres						
	2-5	6-9	10-13	14-17	18-21	22-25	26+
1975	0.1353	0.4398	1.2080	1.9906	0.3053	0.3594	0.3593
1976	0.1958	0.4488	1.2114	1.8056	0.6246	0.7895	0.7879
1977	0.2540	0.4984	1.2176	1.7920	0.8133	0.9407	0.9420
1978	0.3561	0.6355	1.2993	2.1678	0.5187	0.5870	0.5878
1979	0.2551	0.7006	1.7628	2.6919	0.7733	0.9531	0.9523
1980	0.2148	0.5188	1.4321	2.2090	0.6212	0.6963	0.6942
1981	0.2928	0.5046	1.1953	2.0784	0.8731	1.0119	1.0091
1982	0.1658	0.4296	1.0375	2.0607	0.5970	0.6971	0.6968
1983	0.1391	0.2251	0.7750	0.8861	0.3909	0.4833	0.4827
1984	0.1122	0.2812	0.7409	0.9669	0.3646	0.4451	0.4444
1985	0.0953	0.3947	0.8816	1.2262	0.3343	0.3823	0.3823
1986	0.1336	0.4718	1.1340	1.3740	0.3101	0.3868	0.3860
1987	0.1463	0.5328	1.3005	1.1472	0.3243	0.3594	0.3601
1988	0.1969	0.5222	1.3269	1.7163	0.3983	0.4419	0.4429
1989	0.1355	0.4842	1.0610	1.7283	0.5377	0.6868	0.6856
1990	0.1455	0.4103	1.1874	1.6206	0.4803	0.5445	0.5444
1991	0.1453	0.4132	1.0383	1.3850	0.4641	0.5481	0.5471
1992	0.1580	0.4373	1.0619	1.3132	0.2933	0.3270	0.3267
1993	0.1534	0.3900	0.9575	1.3463	0.3200	0.3465	0.3473
1994	0.1150	0.3256	1.0397	1.4313	0.5007	0.5965	0.5956
1995	0.1107	0.2940	0.8658	0.9784	0.4195	0.5061	0.5043
1996	0.1361	0.3970	0.8785	1.5281	0.2452	0.2702	0.2704
1997	0.1556	0.4163	1.1710	1.9020	0.5782	0.7385	0.7364
1998	0.1686	0.4103	0.9842	1.5064	0.3671	0.4515	0.4508
1999	0.1771	0.4285	1.0702	1.8994	0.2256	0.2569	0.2570
2000	0.1095	0.3119	0.8601	1.2065	0.4805	0.5745	0.5743
2001	0.1712	0.3622	1.1377	1.4116	0.5205	0.6726	0.6706
2002	0.1451	0.4910	1.1447	1.3856	0.5699	0.7420	0.7393
2003	0.1921	0.6255	1.8508	2.4975	0.9689	1.0859	1.0878
2004	0.1643	0.5385	1.7254	3.3270	1.4271	1.8529	1.8514
2005	0.2634	0.6628	1.7725	3.6479	1.1377	1.4090	1.4067
2006	0.1545	0.5302	1.3250	2.8573	0.7217	0.9191	0.9170
2007	0.1403	0.4529	1.4326	2.0955	0.6337	0.7289	0.7278

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