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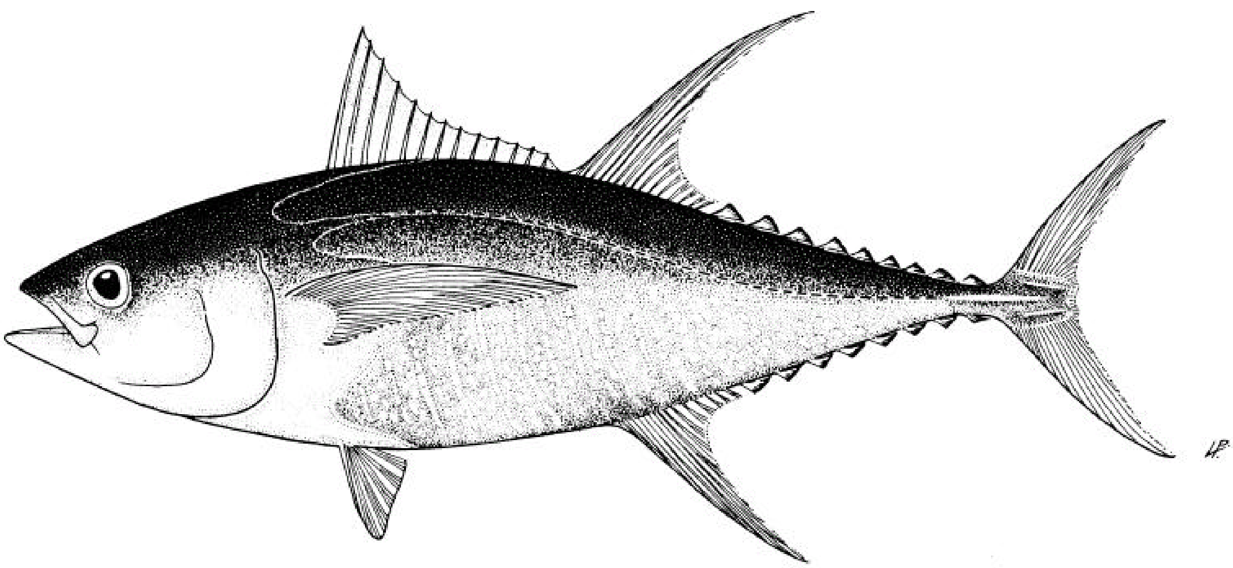
Status of yellowfin tuna in the eastern Pacific Ocean in 2001 and outlook for 2002



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STATUS OF YELLOWFIN TUNA IN THE EASTERN PACIFIC OCEAN IN 2001 AND OUTLOOK FOR 2002

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1. EXECUTIVE SUMMARY

This document 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) is used to conduct this assessment. The analysis method is described by Maunder and Watters (submitted), and readers are referred to that manuscript for technical details. The A-SCALA method was used for the two most recent assessments of yellowfin in the EPO.

The stock assessment requires a substantial amount of information. Data on landings, discards, fishing effort, and the size compositions of the catches from several different fisheries have been analyzed. Several assumptions regarding processes such as growth, recruitment, movement, natural mortality, fishing mortality, and stock structure have also been made. The assessment for 2002 differs in several from the previous assessment carried out in 2001:

1. Catch, effort, and length-frequency data for the surface fisheries have been updated to include new data for 2001 and revised data for previous years.
2. Catch and effort data for the Japanese longline fisheries have been updated to include new data for 2000 and updated data for 1998 and 1999. Effort data are extrapolated for 2001 and catch is predicted by the assessment model.
3. Effort data for the Taiwan longline fisheries have been updated to include data for 1998.
4. Longline effort data are based on habitat-standardized effort data supplied by the Secretariat for the Pacific Community (SPC).
5. The modeling period was changed to start in the first quarter of 1975 and run through to the start of 2002, to enable a better coverage of the regime shift that occurred in 1984.
6. Due to the extension of the modeling period to before the start of the environmental data, the environmental data are correlated with recruitment outside the model.
7. The model is fitted to otolith length-at-age data to provide information for estimating mean length at age and variation in length at age.

It appears that the yellowfin population has experienced two different productivity regimes (1975-1983 and 1984-2001), with greater recruitment during the second than the first. The two recruitment regimes correspond to two regimes in biomass, the high-recruitment regime producing greater biomasses. The spawning biomass ratio (the ratio of spawning biomass to that for the unfished stock; SBR) of yellowfin in the EPO was below the level that will support the average maximum sustainable yields (AMSYs) during the low-recruitment regime, but above that level during the high-recruitment regime. The two different productivity regimes may support two different levels of AMSY and associated SBRs. The current SBR is above the SBR level at AMSY. The effort levels are estimated to be less than the levels that will support the AMSY (based on the current distribution of effort among the different fisheries). However, due to the large recruitment that entered the fishery in 1998, the catch levels are greater than the corresponding values at the AMSY. Because of the flat yield curve, current effort levels are estimated to produce, under average conditions, catch that is only slightly less than AMSY. Future projections under the current effort levels and average recruitment indicate that the population will decline to an SBR level less than the current level, but will remain above that which will support the AMSY. These simulations were carried out using the average recruitment for the 1975-2001 period. If they had been carried out using the average recruitment for the 1984-2001 period it is likely that the estimates of SBR and catches would be higher.

The analysis indicates that strong cohorts entered the fishery in 1998 through 2000 and that these cohorts increased the population biomass during 1999 and 2000. However, they have now moved through the population, and the biomass decreased in 2001.

The overall average weights of yellowfin tuna that are caught have consistently been much less than the critical weight, indicating that, from the yield-per-recruit standpoint, the yellowfin in the EPO are not harvested at the optimal size. There is substantial variability in the average weights of the yellowfin taken by the different fisheries, however. In general, the floating-object (Fisheries 1-4), unassociated (Fisheries 5 and 6), and baitboat (Fishery 10) fisheries capture younger, smaller fish than do the dolphin-associated (Fisheries 7-9) and longline (Fisheries 11 and 12) fisheries. The longline fisheries and the purse-seine sets in the southern area on yellowfin associated with dolphins (Fishery 9) capture older, larger yellowfin than do the coastal (Fishery 8) and northern (Fishery 7) dolphin-associated fisheries. The AMSY calculations indicate that the yield levels could be greatly increased if the fishing effort were directed toward the fisheries that catch yellowfin closest to the critical weight (longlining and purse-seine sets on yellowfin associated with dolphins, particularly in the southern area). This would also increase the SBR levels.

Moderate changes in the level of surface fishing effort are predicted to affect the SBR, the total catch of the longline fleet, and the average weight of fish in the catch from all fisheries combined. Increasing the level of surface fishing effort to 125% of its recent average would decrease the SBR, average weight of fish in the combined catch, and total catch taken by the longline fleet. Reducing the level of surface fishing effort to 75% of its recent average would have the opposite effects. The catch from surface fisheries would increase only slightly with a 25% increase in the level of surface fishing effort. The catch from surface fisheries would decrease moderately with a 25% decrease in the level of surface fishing effort. Avoiding the capture of unmarketable yellowfin tuna around floating objects, particularly fish-aggregating devices (FADs), would not significantly affect the SBRs and catches, but would moderately increase the average weight.

A sensitivity analysis was carried out to determine the effect of a stock-recruitment relationship. The results suggest that the model with a stock-recruitment relationship fits the data slightly better than the base case. The results from the analysis with a stock-recruitment relationship are more pessimistic, and they suggest that the effort level is greater than that which would produce AMSY; however the yield at this effort level is only slightly less than AMSY. The biomass is estimated to have been less than the biomass that would give rise to AMSY for most of the modeling period, except for the last two years.

The assessment results are very similar to the results from the previous assessments. The major differences occur, as expected, in the most recent years. The current assessment estimates that the biomass increased in 2000 whereas the previous assessment estimated a decline. In addition, SBR and the SBR required to produce AMSY have increased compared to the previous assessment because average recruitment has been calculated over a longer period which includes more years from the low-recruitment regime.

2. DATA

Catch, effort, and size-composition data for January 1975-December 2001 were used to conduct the stock assessment of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean (EPO). The data for 2001, which are preliminary, include records that had been entered into the IATTC databases as of early April 2001. All data are summarized and analyzed on a quarterly basis.

The number of years included in the analysis was increased from the 2001 assessment (Maunder and Watters 2002) to enable a better coverage of the regime shift that occurred in 1984. However, the environmental data series used does not start until 1980, so correlations between recruitment and the environmental index were done outside the model.

2.1. Definitions of the fisheries

Sixteen fisheries are defined for the stock assessment of yellowfin tuna. These fisheries are defined on the basis of gear type (purse seine, baitboat, and longline), purse-seine set type (sets on 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 the spatial extent of each fishery is illustrated in Figure 2.1. The boundaries of the length-frequency sampling areas are also shown in Figure 2.1.

In general, fisheries are defined such 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 a mix 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 presented in Table 2.1. The three definitions relating to catch data used throughout this report (landings, discards, and catch) are described by Maunder and Watters (2001).

All three of these types of data are used to assess the stock of yellowfin. Removals by Fisheries 10-12 are simply landings (Table 2.1). Removals by Fisheries 1-4 are landings plus some discards resulting from inefficiencies in the fishing process (see Section 2.2.2) (Table 2.1). The removals by Fisheries 5-9 are landings 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. The data for 1975 to 2000 have been updated, and those for 2001 are new (compared to those presented by Maunder and Watters (2002) in the previous assessment of yellowfin from the EPO). New data on catch for the longline fisheries (Fisheries 11 and 12) during 2000 for Japan and 1998 for Taiwan have been incorporated into the current assessment.

2.2.1. Catch

For this assessment, the Japanese longline data are available through 2000. This includes one additional year compared to the previous assessment. For the assessment it is assumed that the total longline effort (scaled to include nations other than Japan) in 2001 is equal to the longline effort in 2000. The total 2001 longline catch is thus a function of the 2000 effort, the estimated numbers in 2001, and the estimated selectivities and catchabilities for the longline fisheries.

Trends in the catch of yellowfin tuna in the EPO during each quarter from January 1975 to December 2001 are illustrated in Figure 2.2. The majority of catch of yellowfin has been taken by purse-seine sets on yellowfin associated with dolphins and in unassociated schools. It should be noted that there was a substantial fishery for yellowfin prior to 1975. Maunder and Watters (2001, 2002) have described the yellowfin catch in the EPO from 1975 to 2000. One main characteristic of the catch during that period is the increase in catch taken since about 1993 by purse-seine sets associated with floating objects.

Compared to 2000, surface fishery catches in 2001 increased in Fisheries 1 (by 92%), 3 (by 263%), 4 (by 40%), 5 (by 5%), 6 (by 48%), 7 (by 32%), 8 (by 55%), 9 (by 91%), and 10 (by 61%), and decreased in Fishery 2 (49%). This indicates that there was more catch taken in most areas in 2001 than in 2000. Compared to 1999, estimated longline catches in numbers decreased in 2000 by 55% for the northern fishery and increased by 93% for the southern fishery.

Although the catch data presented in Figure 2.2 are in weight, the catches in numbers of fish are used to account for longline removals of yellowfin in the stock assessment.

2.2.2. Effort

New effort for this assessment includes 2001 effort data for the surface fisheries and 2000 effort data for the Japanese longline fishery.

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 longlining effort data for yellowfin have been provided by the SPC (Bigelow *et al*. 1999). These effort data have been standardized with the habitat-based method (Hinton and Nakano 1996). The most reliable, consistent, and complete effort data are available for the Japanese longline fleet, and these are used in the standardization. To enable the inclusion of catch data from the other nations into the assessment, the Japanese effort data are scaled by the ratio of the Japanese catch to the total catch. This allows the inclusion of all the longline catch data into the assessment, while using only the Japanese effort data to provide information on abundance.

The following is a brief description of the habitat-based effort standardization method (see Bigelow *et al*. (1999, in press) and the references therein for a detailed description). The effectiveness of longline effort with respect to yellowfin tuna is strongly affected by the fishing depth of the gear, due to the preferences of the species with regard to habitat characteristics (*e.g*. temperature and oxygen levels). Since the mid-1970s, longlines have fished at greater depths in attempts to increase catches of bigeye. Therefore, it is important that standardized longline effort, which is used with catch to provide information on abundance, take into consideration the depth of the longline and the relationship between this depth and the habitat preference of yellowfin. This preference, in terms of the temperature differential from the mixed layer, is calculated by coupling acoustic tracking information with temperature data for the associated area. Preferred oxygen levels were calculated from physiological experiments and tracking studies. The depths of the longlines are calculated with the approximated length of mainline between buoys, applying a catenary curve to represent the shape of the longline. The depth is modified by a shoaling effect of ocean currents, which reduces the fishing depth of the longline. The relative habitat preference associated with each hook, which are distributed uniformly between buoys, is calculated using a time series of temperature at depth (with pre-1980 represented by a monthly climatology) and average (1934-1994) dissolved oxygen at depth for each 5° area-month stratum. The effective effort is then calculated as the sum of the habitat preference for each hook. Only Japanese effort data is used in the model, because it includes information on the number of hooks per basket, provides the only consistent large area coverage of the distribution of yellowfin, and represents the majority of the effort.

The IATTC databases do not contain catch and effort information from longlining operations conducted in the EPO during 2001. To conduct the stock assessment of yellowfin tuna, it is assumed that the amount of longlining effort exerted during each quarter of 2001 was equal to that exerted during the corresponding quarter of 2000.

Trends in the amount of fishing effort exerted by the 16 fisheries defined for the stock assessment of yellowfin tuna in the EPO are plotted in Figure 2.3. Fishing effort for surface gears (Fisheries 1-10 and 13-16) is in days fishing. It is assumed that 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 numbers of hooks. Maunder and Watters (2001, 2002) discuss the historic fishing effort.

Compared to 2000, surface fishery effort in 2001 increased in Fisheries 1 (by 121%), 3 (by 2%), 4 (by 35%), and 10 (by 46%), and decreased in Fisheries 2 (by 12%), 5 (by 2%), 6 (by 40%), 7 (by 23%), 8 (by 14%), and 9 (by 7%). The decreased effort was in part due to the restrictions on yellowfin catch in the Commission's Yellowfin Regulatory Area (CYRA) in the last quarter of 2001. Compared to 1999, estimated total effective longline effort (calculated using a habitat-based model) in 2000 decreased by 8% for the northern fishery and increased by 276% for the southern fishery .

2.2.3. Discards

For the purposes of stock assessment, it is assumed that yellowfin tuna are discarded from catches made by purse-seine vessels because of inefficiencies in the fishing process (*e.g.* 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 observers, applying methods described by Maunder and Watters (submitted). Regardless of why yellowfin are discarded, it is assumed that all discarded fish die. Maunder and Watters (2001) describe how discards are implemented into the yellowfin assessment. One difference from the method described by Maunder and Watters (2001) is that the discard rates are not smoothed over time. Not including temporal smoothing should allow for a better representation of recruitment in the model.

2.3. Size-composition data

The fisheries of the EPO catch yellowfin tuna of various sizes. The average size composition of the catch from each fishery defined in Table 2.1 is illustrated in Figure 2.4. Maunder and Watters (2001) describe the sizes of yellowfin caught by each fishery. In general, floating-object, unassociated, and baitboat fisheries catch small yellowfin, while dolphin-associated and longline fisheries catch large yellowfin.

The length frequencies of the catch during 2000 from the 10 surface fisheries were similar to those seen over the whole modeling period (compare Figures 4.2 and 4.8). The strong cohort that was seen in the floating-object fisheries during 1998 and 1999 moved through the unassociated fisheries during 1999 and 2000 and entered the dolphin-associated fisheries in 2000. This cohort can be seen moving through the dolphin-associated fisheries length-frequency data during 2001. A large cohort of yellowfin tuna about 125 cm in length was evident in the length-frequency data for the first quarter of 2001 in the southern surface fisheries (Fisheries 1, 3, 6, and 9), but was not seen in any other quarters. The model was unable to adequately represent this cohort in the catch, and therefore the model removed a large number of small fish rather than large fish. There is evidence of a strong cohort entering the floating-object fisheries in 2001.

The length frequencies of the catch during 1999 for the longline fisheries were very different from those seen over the whole modeling time period. There is an indication of a cohort of medium-size fish moving into the longline fisheries. This cohort was not predicted by the model, and the fish are too large to be consistent with the strong cohort seen in the other fisheries. However, it may be consistent with the strong cohort seen in the southern surface fisheries length-frequency data during the first quarter of 2001.

2.4. Auxiliary data

Otolith data described by Wild (1986) are integrated into the stock assessment model to provide information on mean length at age and variation in length at age. The data consist of 196 fish collected between 1977 and 1979. The numbers of increments on the otolith were used to estimate the age in days. The length of each fish was also recorded. The sampling design involved collecting 15 yellowfin in each 10-cm interval in the length range of 30-170 cm. This sampling design may cause some bias in the estimates of variation of length at age.

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 can be constrained to be similar to a specific growth curve (perhaps taken from the literature) or fixed so that the growth curve can be treated as something that is known with certainty. If the growth increments are estimated as free parameters they are constrained so that the mean length is a monotonically increasing function of age. The modified growth model is also designed so that the size and age at which fish are first recruited to the fishery must be specified. For the current assessment, it is assumed that yellowfin are recruited to the discard fisheries (Fisheries 13-16) when they are 30 cm long and two quarters old.

The growth of yellowfin tuna was estimated by Wild (1986), who used the Richards growth equation and counts of daily increments in yellowfin otoliths (L_∞ = 188.2, annual k = 0.724, t_0 = 1.825 years, m = 1.434). In the assessment for yellowfin, the growth model is fitted to otolith data from Wild (1986), assuming that the variation of length at age in the otolith data represents the variation of length at age in the population. The mean lengths of older yellowfin are assumed to be close to 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.

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 spawning stock size 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 the spawning stock may not have been reduced to less than 20% of its unexploited level and because there are other factors (*e.g.* environmental influences) that cause recruitment to be extremely variable. 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 2000 and 2001 assessments (Maunder and Watters 2001, 2002). The influence of a Beverton-Holt stock-recruitment relationship is investigated in a sensitivity analysis.

It is assumed that yellowfin tuna can be recruited to the fishable population during every quarter of the year. Recruitment may occur more than twice per year because individual fish can spawn almost every day if the water temperatures are in an appropriate range (Schaefer 1998). It is also assumed that recruitment may have a seasonal pattern.

An assumption is made about the way that recruitment can vary around its expected level, as determined from the stock-recruitment relationship. It is assumed that recruitment should not be less than 25 percent of its expected level and not greater than four times its expected level more often than about 1 percent of the time. These constraints imply that, on a quarterly time step, extremely small or large recruitments should not occur more than about once every 25 years.

Yellowfin tuna are assumed to be recruited to the discard fisheries in the EPO at about 30 cm (about 2 quarters old) (see Section 2.3). At this size (age), the fish are vulnerable to being discarded from 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 calculated from the numbers of fish, proportion of females, percent mature, batch fecundity, and spawning frequency (Schaefer 1998). These quantities (except numbers) are calculated for each age class, based on the mean length at age given by the von Bertalanffy growth equation fitted to the otolith data of Wild (1986; see Maunder and Watters 2002). The spawning potential of the population is used in the stock-recruitment relationship and to determine the ratios of spawning biomass to that for the unfished stock (spawning biomass ratios; SBRs). The relative fecundity at age and the sex ratio at age are shown in Figures 3.3 and 3.4, respectively.

3.1.3. Movement

The evidence of yellowfin tuna movement in the EPO is summarized by Maunder and Watters (2001). For the purposes of the current assessment, it is assumed that yellowfin move around the EPO at rates that are rapid enough to ensure that the population is randomly mixed at the start of each quarter of the year. However, this is not necessarily the best representation of the population structure.

3.1.4. Natural mortality

For the current stock assessment, it is assumed that, as yellowfin tuna grow older, the natural mortality rate (M) changes. This assumption is similar to that made in previous assessments by the IATTC staff, where the natural mortality rate is assumed to increase for females after they reach the age of 30 months (*e.g.* Anonymous 1999). 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 3.1. These values were calculated by making the assumptions described above, fitting to sex ratio data (Schaefer 1998), and comparing the values with those estimated for yellowfin in the western and central Pacific Ocean (Hampton 2000; Hampton and Fournier 2000). Maunder and Watters (2001) describe in detail how the age-specific natural mortality schedule for yellowfin in the EPO is calculated.

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*., 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 are two stocks, one in the EPO and the other in the western and central Pacific.

3.2. Environmental influences

Previous stock assessments have included the assumption that oceanographic conditions might influence recruitment of yellowfin tuna in the EPO (Maunder 2001, 2002). 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 the previous stock assessment model to determine whether there is a statistically-significant relationship between this temperature variable and estimates of recruitment. However, because the model has been extended back to 1975, the environmental time series does not cover the same period (the environmental data start in 1980). The previous assessments (Maunder and Watters 2001, 2002) showed that estimates of recruitment were essentially identical with or without the inclusion of the environmental data. This is also supported by the results of Maunder and Watters (submitted). Therefore, recruitment is correlated with the environmental time series outside the stock assessment model. For the current assessment, 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, are used as the candidate environmental variables. The data were related to recruitment, adjusted to the time period of hatching. The temperature data are posted on the Internet (http://Ingrid.ldeo.Columbia.edu) by the U.S. National Oceanographic and Atmospheric Administration, National Center for Environmental Prediction, and made available through the Lamont-Doherty Earth Observatory/International Research Institute for Climate Prediction Data Library.

In previous assessments it has also 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 estimated to be significant. Therefore, because of the change in the period of the model, 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, submitted) and information contained in catch, effort, and size-composition data are used to assess the status of the yellowfin tuna stock 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 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 tuna in the EPO in 2000 (Maunder and Watters, 2001) and modified and used for the 2001 assessment (Maunder and Watters 2002). The main changes in the method from 2000 to 2001 were the inclusion of a Beverton-Holt stock-recruitment relationship (as a sensitivity analysis), the omission of the random-walk component of catchability, the estimation of mean length at age and the standard deviation of length at age, and shortening of the modeling period (July 1980 to January 2001). In this assessment the main changes are the increase in the modeling period (January 1975 to January 2002), inclusion of otolith data, and removal of environmental indices for recruitment and catchability.

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

1. recruitment to the fishery in every quarter from the first quarter of 1975 through the last quarter of 2001 (this includes estimation of recruitment anomalies, and a seasonal effect);
2. quarterly catchability coefficients for the 16 fisheries that take yellowfin from the EPO (this includes estimation of random effects);
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 3.2);
6. amount of variation in length at age;

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

1. natural mortality at age (Figure 3.1);
2. fecundity of females at age (Figure 3.3);
3. sex ratio 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 basecase assessment).

4.1. Indices of abundance

Catches per unit of effort (CPUEs) have been used as indices of abundance in previous assessments of yellowfin tuna from 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 fishermen become more or less efficient at catching fish while the biomass is not changing the CPUEs would increase or decrease despite the lack of trend in biomass. The CPUEs of the 16 fisheries defined for the current assessment of yellowfin in the EPO are illustrated in Figure 4.1. Trends in longline CPUE are based only on the Japanese data. A discussion of historical catch rates can be found in Maunder and Watters (2001, 2002), but trends in CPUE should be interpreted with caution. Trends in estimated biomass are discussed in Section 4.2.3.

On average, CPUE was less in 2001 than it was in 2000 for Fisheries 1 (by 13%) and 2 (by 42%) and greater for Fisheries 3 (by 256%), 4 (by 4%), 5 (by 7%), 6 (by 147%), 7 (by 72%), 8 (by 82%), 9 (by 105%), and 10 (by 11%). On average, CPUE for the Japanese longline fisheries was less in the north (by 51%) and south (by 49%) during 2000 than during 1999.

4.2. Assessment results

The A-SCALA method provides a reasonably good fit to the catch and size-composition data for the 16 fisheries that catch yellowfin tuna 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 the total amount of fish removed from the stock is not well known.

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. Predictions of the size compositions of yellowfin tuna 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. (The 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 composition for several fisheries have lower peaks than the observed size composition (Figure 4.2). The model also tends to over-predict for the larger yellowfin in most fisheries. A description of the size distribution of the catch for each fishery is given in Section 2.3.

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 tuna in the EPO, with fishing mortality being higher before 1984, during the lower productivity regime (Figure 4.3). Fishing mortality changes with age (Figure 4.3b). The fishing mortality for young and old yellowfin is low. There is a peak at around age 13 quarters, which corresponds to peaks in the selectivity curves for fisheries on floating objects, unassociated and dolphin-associated yellowfin (Figure 4.4). The population has not been greatly impacted by 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 tuna of different ages (the effect of selectivity), and because the efficiencies of various fisheries change over time (the effect of catchability). The latter two effects are discussed in the following paragraphs; the first effect (changes in effort) was addressed in Section 2.2.1 (also see Figure 2.3).

Selectivity curves estimated for the 16 fisheries defined in the stock assessment of yellowfin tuna 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 of similar size to those caught by sets on floating objects (about 4 to 14 quarters old, Figure 4.4, Fisheries 5 and 6), but these catches contain a greater proportion 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 mid-aged fish (7 to 15 quarters old, Fisheries 7 and 8). The dolphin-associated fishery in the south (Fishery 9) selects mainly older yellowfin (12 or more quarters). Longline fisheries for yellowfin also select mainly older individuals (about 9 or more quarters, Figure 4.4, Fisheries 11 and 12). Baitboats (Fishery 10) select small yellowfin (about 4 to 7 quarters old).

Discards resulting from sorting purse-seine catches of yellowfin tuna taken in association with floating objects are assumed to be composed only of yellowfin recruited to the fishery for 3 quarters or less (aged 2-4 quarters, Figure 4.4, Fisheries 13-16). (Additional information regarding the treatment of discards is given in Section 2.2.2.)

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

The ability of purse-seine vessels to capture yellowfin tuna 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 tuna 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). These fisheries show a slight increasing trend over time. The catchability in the southern fishery (Fishery 9) is more variable. All three dolphin-associated fisheries have had an increase in catchability during 2001.

The ability of baitboats to capture yellowfin tuna has been highly variable over time (Figure 4.5a, Fishery 10). There are multiple periods of high and low catchability and a slight increase over time. The catchability during 2001 was greater than average.

The ability of longline vessels to capture yellowfin tuna has been more variable in the northern fishery (Fishery 11), which catches fewer yellowfin, than in the southern fishery (Fishery 12). In the southern fishery, the catchability appears to have decreased in the last few years.

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

Of the environmental variables tested, only the SST for the southern longline fishery has shown a highly significant correlation with the catchability (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 the previous assessment, the abundance of yellowfin tuna being recruited to fisheries in the EPO appeared to be correlated to SST anomalies at the time that these fish were hatched. Due to the extension of the modeling period and the shorter length of the environmental time series, recruitment was correlated with environmental variables outside the model. No relationship was apparent between the environmental indices and recruitment (Figure 4.6b). However, inclusion of a seasonal component in recruitment was significant, as in the previous assessment (Maunder and Watters 2002).

It is possible that other oceanographic variables influence the recruitment, and the IATTC staff intends to consider other environmental indices as candidates for explaining the variation in recruitment. This will include trying to determine whether the environmental index should be based on conditions during the early juvenile phase, rather than solely during the larval phase. Identifying one or more environmental variables that are correlated with recruitment would be useful for making predictions about future recruitments.

Over the range of predicted biomasses shown in Figure 4.8, 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 what is thought to be a 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, high recruitment is related to high biomass and low recruitment to low biomass. The two regimes of recruitment can be seen as two clouds of points in Figure 4.6a.

A sensitivity analysis was carried out, fixing the Beverton-Holt 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. (The best estimate of steepness in the previous assessment was 0.66 (Maunder and Watters 2002).) Given the current information and the lack of contrast in the biomass since 1985, the hypothesis of two regimes in recruitment is as plausible as a relationship between population size and recruitment. The results when a stock-recruitment relationship is used are described in Section 4.4.

The estimated time series of yellowfin recruitment is shown in Figure 4.7, and the total recruitment estimated to occur during each year is presented 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 seen since 1975. The recruitments in 1999, 2000, and in the second quarter of 2001 were estimated to be high. Another characteristic of the recruitment that was also apparent in previous assessments is the regime change in the recruitment levels, starting during the last quarter of 1983. The recruitment was, on average, greater after than before 1983. This change in recruitment levels produces a similar change in biomass (Figure 4.8). 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 average coefficient of variation (CV) on the estimates of recruitment is 0.20.

The recruitment for 2000, which was estimated in the previous assessment to be low, is now estimated to be much higher. This is not surprising, given the large confidence intervals for these recruitments in the previous assessment, indicating that they are not well estimated.

The estimates of the most recent recruitments are highly uncertain, as can be seen from the large confidence intervals (Figure 4.7), due to the limited data available for these cohorts. In addition, the floating-object fisheries account for only a small portion of the total catch of yellowfin, and the catch during the last quarter of 2001 was low for all surface fisheries due to a regulation restricting the catch of yellowfin in surface fisheries imposed to prevent overfishing of the species.

4.2.3. Biomass

Biomass is defined as the total weight of yellowfin tuna that are 1.5 or more years old. The trends in the biomass of yellowfin in the EPO are shown in Figure 4.9, 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 200,000 mt; it then increased rapidly during 1983-1986, and reached about 490,000 mt in 1986. Since then it has been relatively constant at about 470,000-500,000 mt, except for a peak in 2001. The confidence intervals for the biomass estimates are relatively narrow, indicating that the biomass is fairly well known. The average CV of the estimates of the biomass is 0.15.

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 also shown in Figure 4.9, 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 the spawning biomass is also fairly well known. The average CV of the estimates of the spawning biomass is 0.11.

It appears that trends in the biomass of yellowfin tuna can be explained by the trends in fishing mortality and recruitment. Simulation results (see Maunder and Watters (2001) for a description) suggest that the fishing mortality affects the total biomass. The simulated biomass trajectory without fishing and the biomass trajectory estimated from the stock assessment model are overlaid in Figure 4.10. The large difference in biomass indicates that fishing has a large impact on the biomass of yellowfin in the EPO. The large increase in biomass during 1984-1985 was caused by an increase in average recruitment (Figure 4.7) and an increase in the average size of the fish caught (Anonymous, 1999), but increased fishing pressure prevented the biomass from increasing further during the 1986-1990 period.

4.2.4. Average weights of fish in the catch

The overall average weights of the yellowfin tuna caught in the EPO predicted by the analysis have been consistently around 10-20 kg for most of the period from 1975 to 2001, but have differed considerably among fisheries (Figures 4.10 and 5.2). The average weight was greatest during the 1985-1992 period (Figure 5.2) when the effort from the floating-object and unassociated fisheries was lower (Figure 2.3). The average weight of yellowfin caught by the different gears varies widely, but remains fairly consistent over time within each fishery (Figure 4.10). The lowest average weights (about 1 kg) are produced by the discard fisheries, followed by the baitboat fishery (about 4-5 kg), the floating-object fisheries (about 5-10 kg for Fishery 3, 10-15 kg for Fisheries 2 and 4, and 15-20 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. Sensitivity to assumptions

A sensitivity analysis was carried out to determine the effect of the stock-recruitment relationship. The basecase analysis was carried out with no stock-recruitment relationship. 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. Previous results (Maunder and Watters 2002) suggest that the analysis with a stock-recruitment relationship fits the data better than the analysis without the stock-recruitment relationship, but, given the amount of data used in the analysis, the difference is probably not statistically significant (see Maunder and Watters 2002: Table 4.3). When a Beverton-Holt stock recruitment relationship (steepness = 0.75) is included, the estimated biomass (Figure A.1) and recruitment (Figure A.2) are almost identical to the base case.

4.5. Comparison to previous assessments

The assessment results are very similar to the results from the previous assessments presented by Maunder and Watters (2001, 2002) and the results using cohort analysis (Figure 4.12). The current assessment indicates that the biomass increased in 2000, whereas the previous assessment indicated a decline.

4.6. Summary of the results from the assessment model

The catch rates of yellowfin increased for most of the surface fisheries in 2001 relative to 2000.

The recruitment of yellowfin tuna to the fisheries in the EPO is variable, and appears to be related to the SSTs. High levels of recruitment to the fishery (at age 6 months) are related to high SSTs at the time of spawning 6 months earlier. However, this correlation may be an artifact of seasonal recruitment. This analysis and previous analyses have indicated that the yellowfin population has experienced two different recruitment regimes (1975-1983 and 1984-2001) and that the population has been in the high-recruitment regime for approximately the last 17 years. The two recruitment regimes correspond to two regimes in biomass, the higher recruitment regime producing greater biomass levels. A stock-recruitment relationship is also supported by the data from these two regimes, but the evidence is weak and is probably biased, due to the apparent regime shift. Biomass increased during 1999 and 2000, but is estimated to have decreased during 2001.

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 (Fisheries 1-4), unassociated

(Fisheries 5 and 6), and baitboat (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 coastal (Fishery 8) and northern region (Fishery 7) dolphin-associated fisheries.

5. STOCK STATUS

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

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 it manages, but some possible reference points are described in the following three subsections. Possible candidates for reference points are:

1. S_{AMSY} as a target reference point.
2. F_{MSY} as a limit reference point
3. S_{min}, the minimum spawning biomass seen in the model period, as a limit reference point.

Maintaining tuna stocks at levels capable of producing the AMSY is the current 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). Development of reference points that are consistent with the precautionary appoach to fisheries management will continue.

5.1. Assessment of stock status based on spawning biomass

The ratio of spawning biomass during a period of harvest to that which might accumulate in the absence of fishing is useful for assessing the status of a stock. This ratio, termed the "spawning biomass ratio" (SBR), is described by Maunder and Watters (2001). The equation defining the SBR is

$$\mathrm{SBR}_t = \frac{S_t}{S_{F=0}}$$

where S_t is the spawning biomass at any time (t) during a period of exploitation, and $S_{F=0}$ is the spawning biomass that might be present if there were no fishing for a long period (*i.e.* the equilibrium spawning biomass if $F = 0$). The SBR has a lower bound of zero. If the SBR is zero, or slightly greater than that, the population has been severely depleted and is probably overexploited. If the SBR is one, or slightly less than that, the fishery has probably not reduced the spawning stock. If the SBR is greater than one, it is possible that the stock has entered a regime of increased production.

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 AMSY when the SBR is somewhere in the range 0.3 to 0.5, and that some fish populations are not able to produce the AMSY 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 AMSY ($\mathrm{SBR}_{AMSY} = S_{AMSY}/S_{F=0}$). S_{AMSY} is the spawning biomass at AMSY (see Section 5.3 for details regarding calculation of AMSY and related quantities).

Estimates of quarterly SBR_t for yellowfin in the EPO have been computed for every quarter represented in the stock assessment model (the first quarter of 1975 to the first quarter of 2002). Estimates of the spawning biomass during the period of harvest (S_t) are presented in Section 4.2.2. 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. The SBR level that would give rise to AMSY (SBR_{AMSY}) is estimated to be about 0.36.

At the beginning of 2002, the spawning stock of yellowfin tuna in the EPO was considerably reduced. The estimate of SBR at this time was about 0.53, with lower and upper 95% confidence limits of 0.42 and 0.65, respectively. It is important to note that the estimate of the lower confidence limit is greater than the estimate of SBR_{AMSY} (0.36), indicating that, at the beginning of 2002, the spawning stock of yellowfin in the EPO was probably greater than the level that might be expected if the stock were at the AMSY level.

A time series of SBR estimates for yellowfin tuna in the EPO is shown in Figure 5.1. The historical trends in SBR are similar to those described by Maunder and Watters (2001, 2002). However, the SBR and SBR required to produce AMSY have increased compared to the previous assessment because average recruitment has been calculated over a longer period that includes more years from the low-recruitment regime.

In general, the SBR estimates for yellowfin in the EPO are reasonably precise; the average CV of these estimates is about 0.07. The relatively narrow confidence intervals around the SBR estimates suggest that for most quarters during 1985-2001 the spawning biomass of yellowfin in the EPO was greater than the level that would be expected to occur if the population were at the AMSY level (see Section 5.3). This level is shown as the dashed horizontal line drawn at 0.36 in Figure 5.1. For most of the early period (1975-1984), however, the spawning biomass was estimated to be below the AMSY level.

5.2. Assessment of stock status based on yield per recruit

Yield-per-recruit calculations, which are also useful for assessing the status of a stock, are described by Maunder and Watters (2001). The critical weight for yellowfin tuna in the EPO has been estimated to be about 49.5 kg (Figure 5.2). This value is greater than the value of 32 kg reported by Anonymous (2000a). The difference is due to the time step of the calculation (quarterly versus monthly) and differences in weight-at-age.

The average weight of yellowfin tuna in the combined catches of the fisheries operating in the EPO was only about 20 kg at the end of 2001 (Figure 5.2), which is considerably less than the critical weight. The average weight of yellowfin in the combined catches has, in fact, been substantially less than the critical weight since 1975 (Figure 5.2).

The various fisheries that catch yellowfin tuna in the EPO take fish of different average weights (Section 4.2.4). The longline fisheries (Fisheries 11 and 12) and the dolphin-associated fishery in the southern region (Fishery 9) catch yellowfin with average weights close to the critical weight (Figure 4.11). All the remaining fisheries catch yellowfin of average sizes that are less than the critical weight. Of the fisheries that catch the majority of yellowfin (unassociated and dolphin-associated fisheries, Fisheries 5-8), the dolphin-associated fisheries perform better under the critical-weight criterion.

5.3. Assessment of stock status based on AMSY

Maintaining stocks at levels capable of producing the AMSY is the management objective specified by the IATTC Convention. One definition of AMSY is the maximum long-term yield that can be achieved under average conditions, using the current, age-specific selectivity pattern of all fisheries combined. AMSY calculations are described by Maunder and Watters (2001). The calculations are changed from Maunder and Watters (2001) to include the Beverton-Holt stock-recruitment relationship where applicable.

At the start of 2002, the biomass of yellowfin tuna in the EPO appears to have been above the level that would be expected to produce the AMSY, and the recent catches have been above the AMSY 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 level of fishing effort that is estimated to produce the AMSY is greater than the current level of effort, as the effort at AMSY is 113% of the current level of effort. It is important to note, however, that the curve relating the average sustainable yield to the long-term fishing mortality is very flat around the AMSY level. Therefore changes in the long-term levels of effort will only marginally change the catches, while considerably changing the biomass. The spawning stock biomass changes substantially with changes in the long-term fishing mortality (Figure 5.3). Decreasing the effort, which will increase CPUE and thus may also reduce the cost of fishing, 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 may require a different approach to estimating the AMSY. Different regimes will give rise to different values for the AMSY. This is discussed by Maunder and Watters (2001). If average recruitment from the 1975-1983 time period is used, AMSY is 26% less than when the whole time period is used. If the 1984-2002 time period is used AMSY is 13% greater.

The estimation of the AMSY, and its associated quantities, is sensitive to the age-specific pattern of selectivity that is used in the calculations. To illustrate how AMSY might change if the effort is reallocated among the various fisheries (other than the discard fisheries) that catch yellowfin tuna in the EPO, the previously-described calculations were repeated, using the age-specific selectivity pattern estimated for each fishery. If the management objective is to maximize the AMSY, the longline fisheries (Fisheries 11 and 12) and the southern dolphin-associated fishery (Fishery 9) will perform the best, followed by the northern and coastal dolphin-associated fisheries (Fisheries 7 and 8), and then the unassociated fisheries (Fisheries 5 and 6) and the southern floating-object fishery (Fishery 1) (Table 5.2). The fisheries that catch yellowfin by making purse-seine sets on floating objects (except in the southern region, Fisheries 2-4) and the baitboat fishery (Fishery 10) will perform the worst (Table 5.2). If an additional management objective is to maximize the S_{AMSY}, the southern dolphin-associated fishery (Fishery 9) will perform the best, followed by the northern and southern longline fisheries (Fisheries 11 and 12) and the northern dolphin-adssociated fishery (Fishery 7). Of the fisheries that catch the majority of yellowfin (unassociated and dolphin-associated fisheries, Fisheries 5-8), the dolphin-associated fisheries perform better under both the AMSY and S_{AMSY} objectives. Maunder and Watters (2002) present results that are restricted to each type of fishery. It is not known, however, whether the fisheries that would produce greater AMSYs would be efficient enough to catch the full AMSYs predicted.

5.4. Lifetime reproductive potential

One common management objective is the conservation of spawning biomass. Conservation of spawning biomass allows an adequate supply of eggs, so that future recruitment is not detrimentally affected. If reduction in catch is required to protect the spawning biomass, it is advantageous to know at which ages to avoid catching fish to maximize the benefit to the spawning biomass. This can be achieved by calculating the lifetime reproductive potential for each age-class. If a fish of a given age is not caught it has an expected (average over many fish of the same age) lifetime reproductive potential (i.e. the expected number of eggs that fish will produce over its remaining lifetime). This value is a function of the fecundity of the fish at the different stages of its remaining life and the mortality (both natural and fishing mortality) it is subjected to. The higher the mortality, the less likely the individual is to survive and continue reproducing.

Younger individuals may appear to have longer period in which to reproduce, and therefore a higher lifetime reproductive potential. However, because the rate of natural mortality of younger individuals is greater, their expected lifespan is shorter. An older individual, which has already made it through the ages for which mortality is high, has a greater expected lifespan, and thus may have a greater lifetime reproductive potential. Mortality rates may be greater at the oldest ages and reduce the expected lifespan of these ages, thus reducing lifetime reproductive potential. Therefore, the maximum lifetime reproductive potential may occur at an intermediate age.

The lifetime reproductive potential for each quarterly age class was calculated, using the average fishing mortality at age over the most recent two years. Because current fishing mortality is included, the calculations are based on marginal changes (*i.e.* the marginal change in egg production if one individual or one unit of weight is removed from the population) and any large changes in catch would produce somewhat different results because of changes in the future fishing mortality rates.

The calculations based on avoiding capturing a single individual indicated that the greatest benefit to the spawning biomass would be achieved by avoiding an individual at age 14 quarters (Figure 5.4, upper panel). This suggests that restricting the catch from fisheries that capture intermediate-aged yellowfin (ages 10-15 quarters) would provide the greatest benefit to the spawning biomass. However, this is not a fair comparison because an individual of age 14 quarters is much heavier than an individual recruited to the fishery at age 2 quarters. The calculations based on avoiding capturing a single unit of weight indicated that the greatest benefit to the spawning biomass would be achieved by avoiding catching fish recruited to the fishery at age 2 quarters (Figure 5.4, lower panel). These calculations suggest that restricting catch from fisheries that capture young yellowfin would provide the greatest benefit to the spawning biomass. The results also suggest that reducing catch by one ton of young yellowfin would protect approximately the same amount of spawning biomass as reducing the catch of middle-aged yellowfin by about three tons.

5.5. Sensitivity analysis

When the Beverton-Holt stock-recruitment relationship is included in the analysis with a steepness of 0.75, the SBR is reduced and the SBR level that produces AMSY is increased (Figure A.3). The SBR is estimated to be less than that at AMSY for most of the model period, except for the last two years. The current effort level is estimated to be above the level required to produce AMSY (Figure A.4), but, due to the recent large recruitment, current catch is greater than AMSY (Table 5.1). In contrast to the analysis without a stock-recruitment relationship, the addition of this relationship may cause catch to be significantly reduced as effort is increased beyond the level required for AMSY. As can be seen in Figure A.4, the analysis without a stock-recruitment relationship has a relative yield curve equal to the relative yield-per-recruit curve (similar to the yield-per-recruit curve in Figure A.4, see Figure 5.3) because recruitment is constant. The equilibrium catch under the current effort levels is estimated to be only slightly less than AMSY, indicating that reducing effort will not greatly increase the catch.

5.6. Summary of stock status

Historically, the SBR of yellowfin tuna in the EPO has been below the level that will support the AMSY, but above that level for most of the last 17 years. The increase in the SBR is attributed to a regime change in the productivity of the population. The two different productivity regimes may support two different AMSY levels and associated SBR levels. The effort levels are estimated to be less than those that will support the AMSY (based on the current distribution of effort among the different fisheries). However, due to the large number of recruits entering the fishery in 1998 to 2000, the catch levels are higher than the corresponding values at AMSY. Because of the flat yield curve, the average equilibrium yield at current effort levels is only slightly less than AMSY.

If a stock-recruitment relationship is assumed, the results are more pessimistic, and current biomass is estimated to be below the level that would support AMSY for most of the model period, except for the last few years.

The current average weight of yellowfin in the catch is much less than the critical weight, and therefore, from the yield-per-recruit standpoint, yellowfin in the EPO are overfished. The AMSY calculations indicate that catches could be greatly 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.

6. SIMULATED EFFECTS OF FUTURE FISHING OPERATIONS

A simulation study, using the method described by Maunder and Watters (2001), was conducted to gain further understanding of how, in the future, hypothetical changes in the amount of fishing effort exerted by the surface fleet might simultaneously affect the stock of yellowfin tuna 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.

6.1. Assumptions about fishing operations

6.1.1. Fishing effort

The following scenarios have been specified to describe the hypothetical amount of fishing effort that might be exerted by the surface fleet during 2002-2006.

1. The surface fleet will exert an amount of effort that is equal to 75% of the average amount of effort it exerted during 2000-2001.
2. The surface fleet will exert an amount of effort that is equal to the average amount of effort it exerted during 2000-2001.
3. The surface fleet will exert an amount of effort that is equal to 125% of the average amount of effort it exerted during 2000-2001.

These scenarios are based on quarterly levels of fishing effort. For example, in the first scenario, the effort during the fourth quarters of 2002, 2003, 2004, 2005, and 2006 is equal to 75% of the average effort exerted during the fourth quarters of 2000 and 2001.

All of the simulations were conducted under the assumption that, from 2002 through 2006, the longline fleet will exert an amount of effort equal to the amount of effort it exerted during 2000 (again by quarter). Assumptions about selectivity, catchability, discards, and population dynamics are the same as these in the assessment model (Maunder and Watters 2001).

It was assumed that the catchability of yellowfin tuna for each fishery included in the simulation study does not change during the course of the simulation. Future levels of catchability for each fishery were assumed to be equal to the average catchability for that fishery during 2000 and 2001. (These averages for fishing effort are computed on a quarterly basis.)

Two scenarios have been specified to describe the future status of discarded yellowfin tuna. In the first scenario, it is assumed that all discarded fish will die. In the second scenario, it is assumed that either there are no discards because the fish that are usually discarded will not be caught or, equivalently, that all discarded yellowfin will survive.

The recruitment during 2002 through 2006 was assumed to vary randomly around the same expected level from the stock-recruitment relationship (*i.e.* average recruitment in the base case because it does not assume a stock-recruitment relationship) and to be as variable as the recruitment during 1975-2001. It should be noted that the estimates of recruitment from the stock assessment model appear to be autocorrelated (Figure 4.7), but in the simulation study the recruitment was not autocorrelated. Adding autocorrelation to the simulated time series of recruitment would cause the simulation results to be more variable.

6.2. Assumptions about population dynamics

The simulation study was conducted using the same asumptions about population dynamics used during the period 1975-2001 (*see* Maunder and Watters, 2001). Stochasticity is added to each simulation by randomly sampling from a distribution of recruitment anomalies. These anomalies are assumed to come from the same distribution as those estimated for 1975-2001.

6.3. Simulation results

The simulations were used to predict future levels of the SBR, the average weight of yellowfin tuna in the catch of all fisheries combined, the total catch taken by the primary surface fisheries that would presumably continue to operate in the EPO (Fisheries 1-10), and the total catch taken by the longline fleet (Fisheries 11 and 12). It is important to note that there is probably more uncertainty in the future levels of these outcome variables than suggested by the results presented in Figures 6.1-6.4 and Table 6.1. The amount of uncertainty is probably underestimated because the simulations were conducted under the assumption that the parameters estimated by the stock assessment model correctly describe the dynamics of the system. As mentioned in Section 4, this assumption is not likely to be fulfilled.

6.3.1. Predicted SBRs

Within the range of scenarios specified for the simulation study, future changes in the amount of fishing effort exerted by the surface fleet are predicted to have substantial effects on the SBR (Figure 6.1 and Table 6.1). Increasing the surface effort to 125% of its recent, average level is predicted to decrease the median estimate of the SBR by about 17% by the end of 2006 (Table 6.1; compare 50% quantiles for "average surface effort" to those for "125% surface effort"). Decreasing the surface effort to 75% of its recent average is predicted to increase the median estimate of the SBR by about 24% (Table 6.1; compare 50% quantiles for "average surface effort" to those for "75% surface effort"). Under current effort levels, it is predicted that at the end of 2006 the SBR would remain, on average, higher than SBR_{AMSY} (Table 6.1; compare the 20% quantiles for the SBR to the estimated SBR_{AMSY} of 0.36). This result is consistent with the previous estimate that, under average conditions, current levels of fishing effort should be increased to achieve the AMSY (Section 5.3). However, SBR is estimated to fall during the projection time period due to lower recruitment estimated during 2001.

If the surface fleet continues to exert an average amount of fishing effort, the SBR is predicted to be insensitive to assumptions about the status of discarded yellowfin tuna (Figure 6.1 and Table 6.1). If small yellowfin that are usually discarded are not captured, or if the discarded fish survive, the SBR is predicted to be about 2% higher than that predicted when the discarded yellowfin are assumed to die (Table 6.1; compare 50% quantiles for "average surface effort" to those for "average, no discards"). This is an important result because it suggests that preventing catches of unmarketable yellowfin around floating objects (or ensuring that the discarded fish will survive) would not significantly increase the spawning stock.

6.3.2. Predicted average weights of yellowfin tuna in the combined catch

The average weight of individuals in the catch is expected to increase in the next few years as the large recruitments to the fishery that occurred during 1998 to 2000 increase in size. Within the range of scenarios specified for the simulation study, future changes in the amount of fishing effort exerted by the surface fleet are predicted to have moderate effects on the average weight of fish caught by fisheries operating in the EPO (Figure 6.2 and Table 6.1). Increasing the surface effort to 125% of its recent average would, after 5 years, decrease the average weight of fish in the combined catch by about 13% (Table 6.1; compare 50% quantiles for "average surface effort" to those for "125% surface effort"). Decreasing the surface effort to 75% of its recent average would increase the average weight of fish in the catch by about 14% (Table 6.1; compare 50% quantiles for "average surface effort" to those for "75% surface effort"). Under all of the simulated effort scenarios, the average weight of fish in the combined catch taken during 2005 would be substantially less than the critical weight (compare the estimated critical weight of about 49.5 kg to the 80% quantiles in Table 6.1). Thus, it appears that it will not be possible to maximize the yield per recruit without substantially reducing the amount of fishing effort exerted by the surface fleet. This conclusion could change if, in the future, the surface fleet is able to catch larger (older) yellowfin.

If the fisheries that catch yellowfin in association with floating objects continue to exert an average amount of effort, preventing the capture of fish vulnerable to the discard fisheries (or ensuring that discarded fish survive) would moderately increase (13%) the average weight of fish in the combined catch during 2006 (Figure 6.1 and Table 6.1). This result is to be expected because the discard fisheries (Fisheries 13-16) catch large numbers of small fish, and this influences the estimates of the average weight.

6.3.3. Predicted catches taken by the primary surface fisheries

Since the simulation study was conducted under the assumptions that the catchability will remain constant for every fishery continuing to operate in the EPO (see Section 6.1.2) and that recruitment will vary randomly around the average, increases in future levels of surface fishing effort would cause short-term increases in the catches taken by these fisheries (Fisheries 1-10). The reverse is also true; decreases in the future level of surface fishing effort would cause short-term decreases in the catch. It is also important to note that if the future level of effort increases (or decreases) by 25%, the catch would not necessarily increase (or decrease) by the same percentage. For example, if the future level of effort increases by 25%, the quarterly catches taken by the surface fleet during 2006 would increase by only 3% compared to that predicted under average levels of effort (Table 6.1; compare 50% quantiles from "average surface effort" to those from "125% surface effort). Similarly, if the future level of effort decreases by 25%, the quarterly catches taken by the surface fleet during 2006 would decrease by about 7% (Table 6.1; compare 50% quantiles from "average surface effort" to those from "75% surface effort"). This lack of sensitivity of the future catch by the surface fishery to increases in the effort of the surface fishery is consistent with the fact that the curve relating average sustainable yield to fishing effort is nearly flat at the top and that the current amount of fishing effort being exerted in the EPO produces an average yield that is very close to the AMSY (see Section 5.3 and Figure 5.3).

If the fisheries that catch yellowfin tuna in association with floating objects continue to exert an average amount of effort, preventing the capture of unmarketable fish (or ensuring that the discarded fish survive) would not change the future catches of the surface fleet (Figure 6.3 and Table 6.1; compare 50% quantiles from "average surface effort" to those from "average, no discards").

6.3.4. Predicted catches taken by the longline fleet

The catch by the longline fisheries is expected to increase substantially in the next few years. This is probably due to the large cohorts recruited in the late 1990s entering the longline fishery. The results from the simulation study suggest that future changes in the amount of effort exerted by the surface fleet would substantially affect the catches by the longline fleet (Figure 6.4 and Table 6.1). The quarterly longline catch during 2006 would increase by about 29% if the surface effort were reduced to 75% of its recent average for the next 5 years (Table 6.1; compare 50% quantiles from "average surface effort" to those from "75% surface effort"). Similarly, the quarterly longline catch during 2006 would decrease by about 19% if the surface fishing effort were increased to 125% of its recent average (Table 6.1; compare 50% quantiles from "average surface effort" to those from "125% surface effort").

The future catch taken by longline vessels is predicted to be insensitive to whether the surface fleet continues to catch unmarketable yellowfin around floating objects (Figure 6.4 and Table 6.1). Preventing catches of unmarketable yellowfin would increase the quarterly longline catch during 2006 by about 2% (Table 6.1; compare 50% quantiles from "average surface effort" to those from "average, no discards"). This result is consistent with prediction that the SBR would increase only slightly if the catches of unmarketable fish are prevented.

6.4. Summary of the simulation results

It is predicted that the SBR will reduce in the next few years, but will still remain above the level required to produce AMSY.

It is predicted that future changes in the level of surface fishing effort would substantially affect the SBR, moderately affect the average weight of fish in the catch of all fisheries combined, and substantially affect the total catch of the longline fleet (Fisheries 11 and 12) (Table 6.1). Increasing the level of surface fishing effort to 125% of its recent average would decrease the SBR (Figure 6.1), decrease the average weight of fish in the combined catch (Figure 6.2), and decrease the total catch taken by the longline fleet (Figure 6.4). Reducing the level of surface fishing effort to 75% of its recent average would have the opposite effects. The catch from surface fisheries would increase only slightly with a 25% increase in the level of surface fishing effort. The catch from surface fisheries would decrease moderately with a 25% decrease in the level of surface fishing effort.

It is predicted that preventing the catches of unmarketable yellowfin tuna occurring around floating objects, particularly FADs (or ensuring that the discarded fish survive), would have insignificant effects on the SBRs and catches, but increase the average weight moderately.

The results from these simulations have been calculated, using the average recruitment for the 1975-2001 period. As was mentioned in Section 4, it appears that yellowfin have been in a higher productivity regime for the last 15 years. If the simulations were repeated, using an average recruitment based on the 1985-2001 period, it is likely that the estimates would be different.

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 from the fisheries that catch yellowfin tuna in the EPO. New data collected during 2002 and updated data for 2001 will be incorporated into the next stock assessment.

The IATTC staff also intends to screen other types of environmental data for use in the stock assessment model.

7.2. Refinements to the assessment model and methods

The IATTC staff intends to continue to develop the A-SCALA method and further refine the stock assessment of yellowfin tuna in the EPO. In particular, the staff plans to extend the model so that information obtained from the tagging studies that the IATTC staff has conducted over the years can be incorporated into the A-SCALA analyses. The staff also intends to reinvestigate indices of yellowfin abundance from the CPUEs of purse seiners fishing in the EPO. If this work is successful, the results will, as far as possible, be integrated into future stock assessments.

Development of reference points that are consistent with the precautionary approach to fisheries management will continue.

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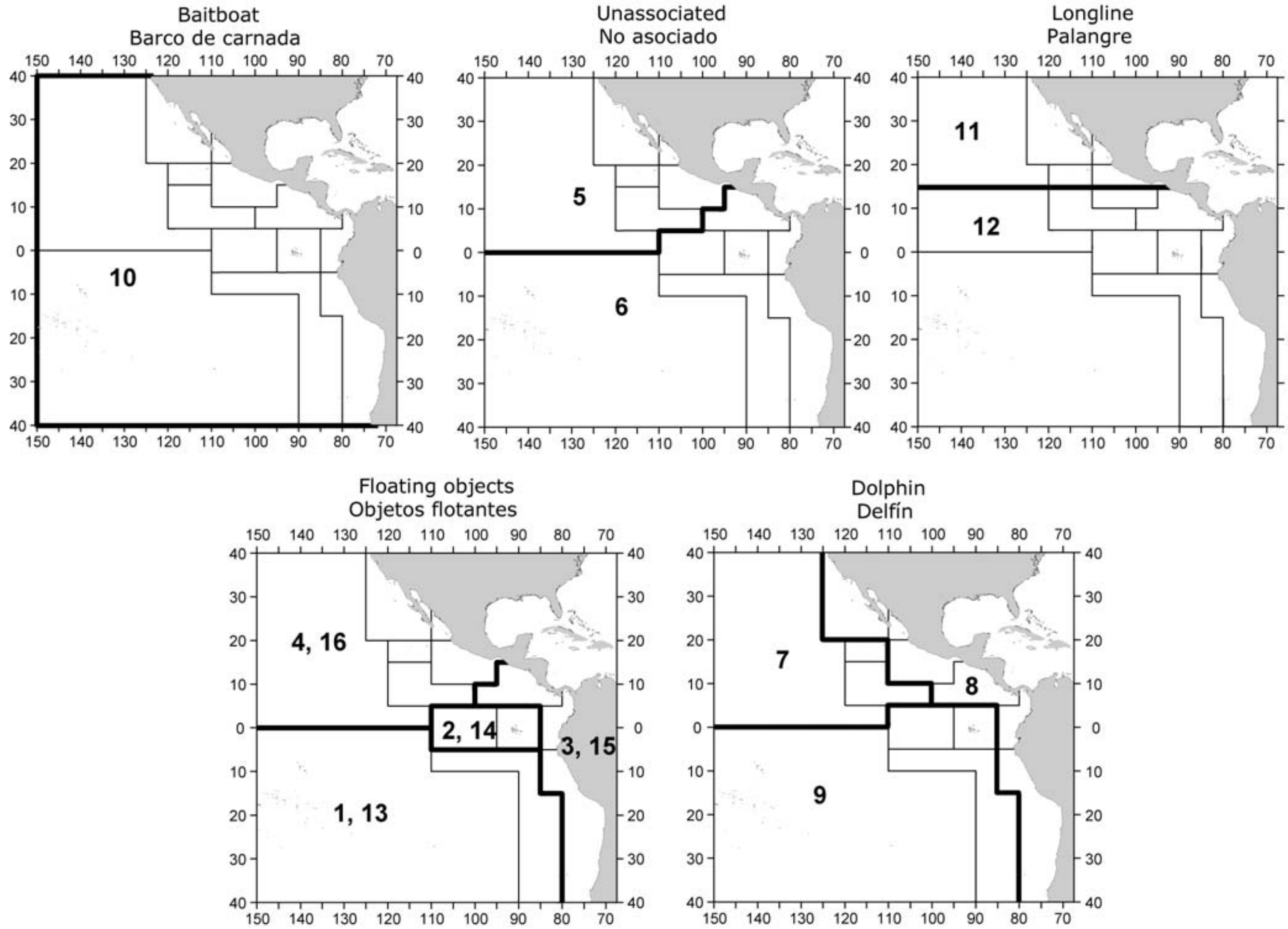


FIGURE 2.1. Spatial extents of the fisheries defined by the IATTC staff for the stock assessment of yellowfin tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the bold numbers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

FIGURA 2.1. Extensión espacial de las pesquerías definidas por el personal de la CIAT para la evaluación del atún aleta amarilla en el OPO. Las líneas delgadas indican los límites de 13 zonas de muestreo de frecuencia de tallas, las líneas gruesas los límites de cada pesquería definida para la evaluación del stock, y los números en negritas las pesquerías correspondientes a estos últimos límites. En la Tabla 2.1 se describen las pesquerías.

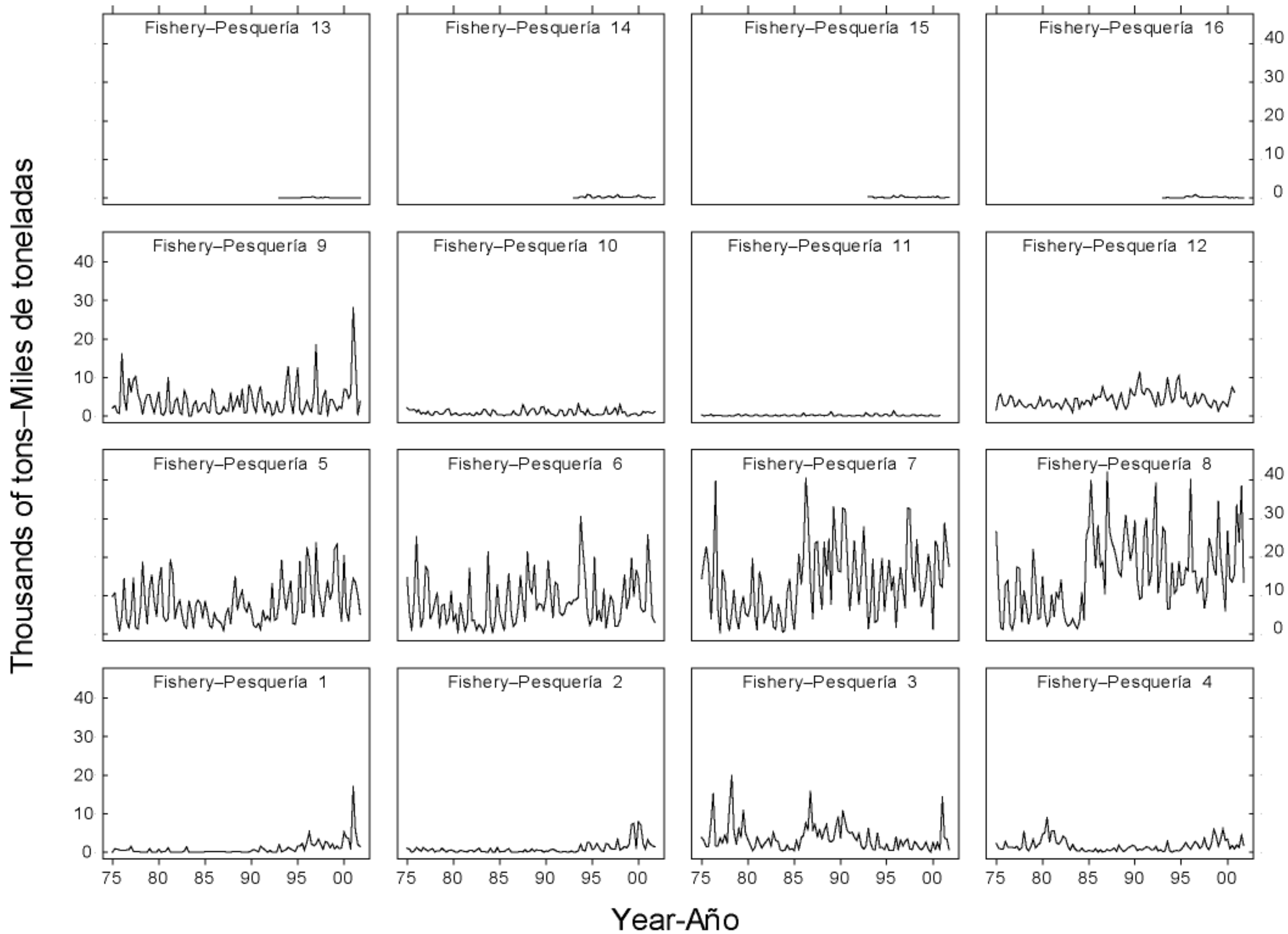


FIGURE 2.2. Catches by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were analyzed on a quarterly basis, there are four observations of catch for each year. Although all the catches are displayed as weights, the stock assessment model uses catch in numbers 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.

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.

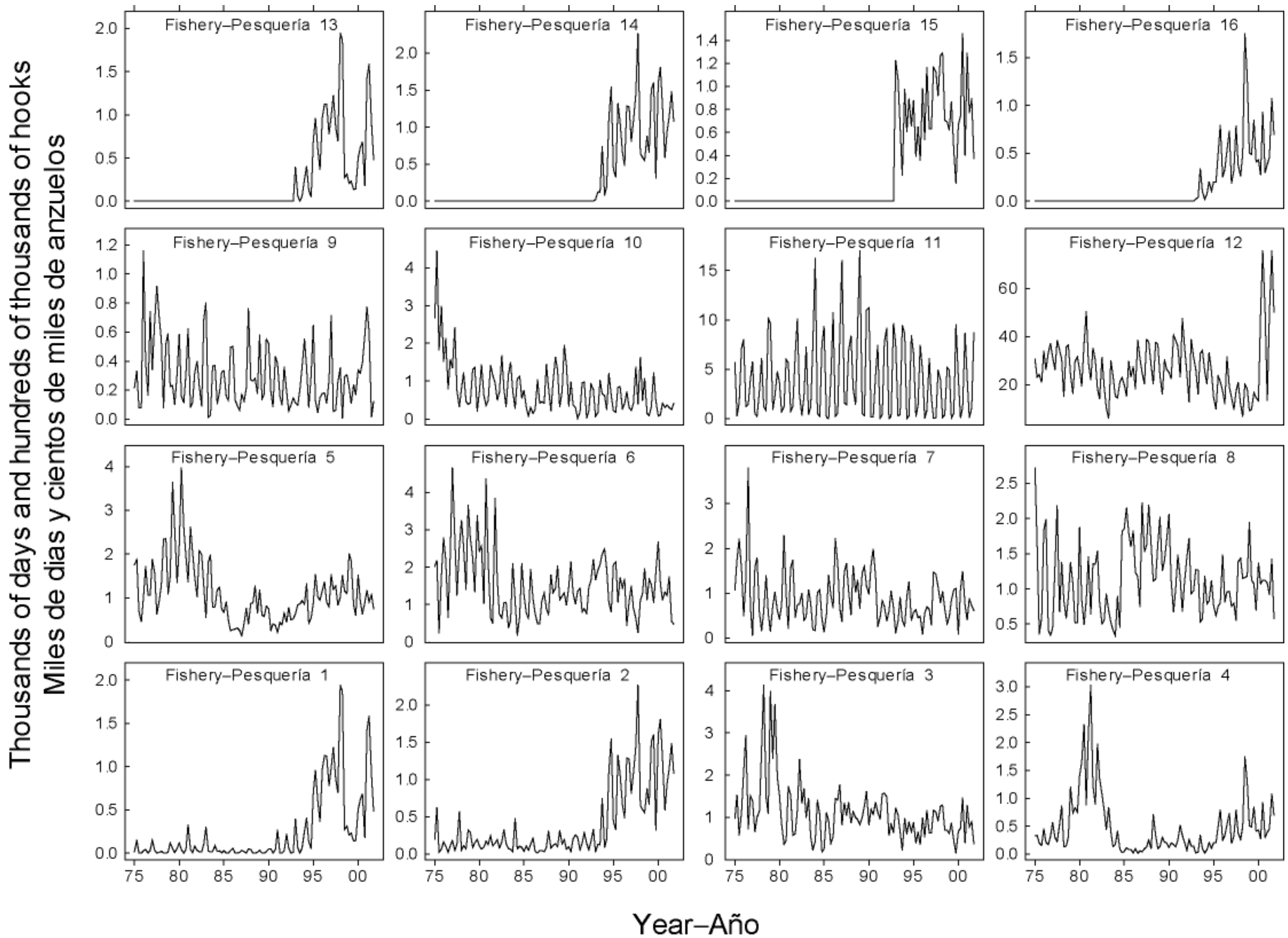


FIGURE 2.3. Fishing effort exerted by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of effort for each year. The effort for Fisheries 1-10 and 13-16 is in days fished, and that for Fisheries 11 and 12 is in numbers of hooks.

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 de anzuelos.

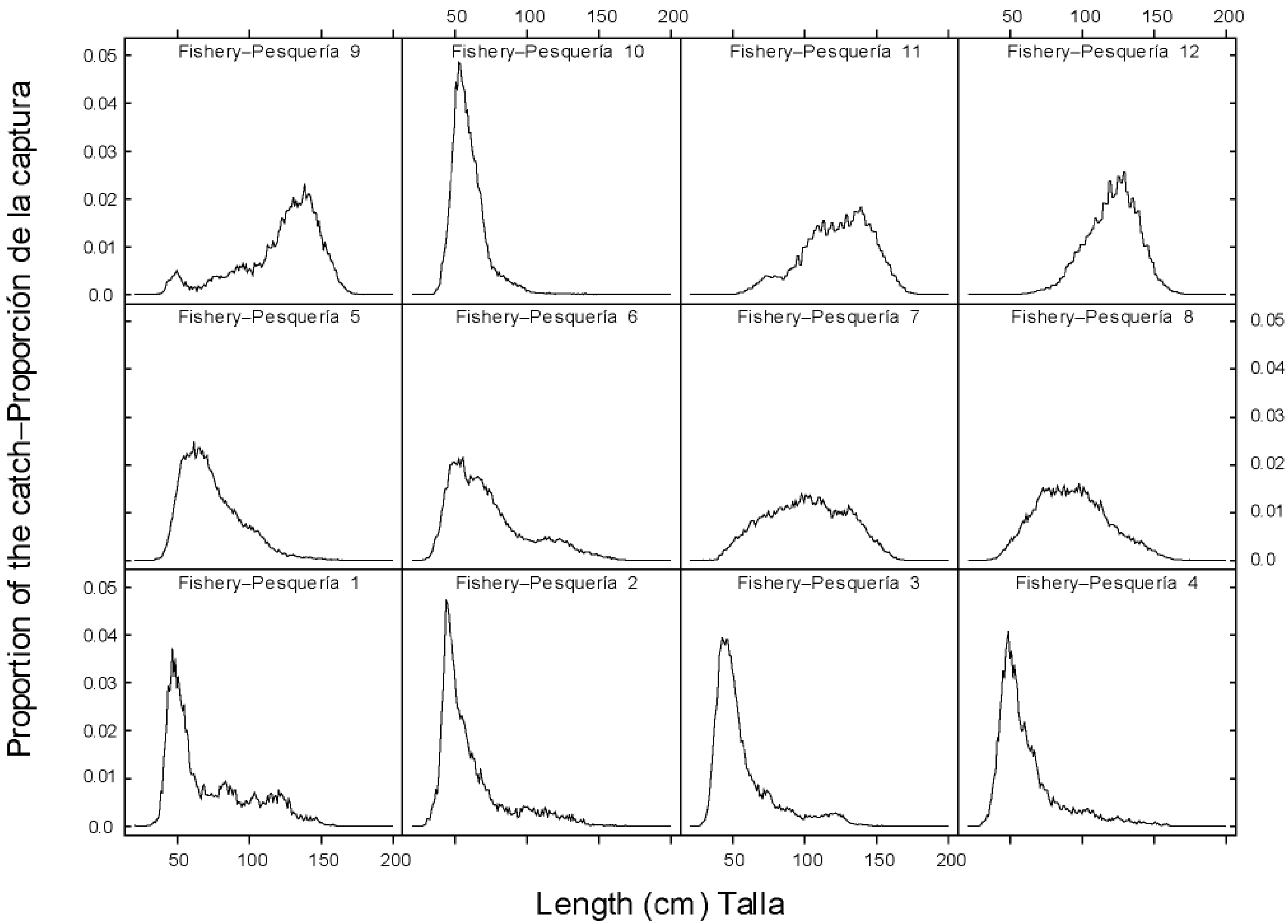


FIGURE 2.4. Average size compositions of the catches made by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). The data cover the period of January 1975 through December 2001.

FIGURA 2.4. Composición media por tamaño de las capturas realizadas por las pesquerías definidas para la evaluación del stock de atún aleta amarilla en el OPO (Tabla 2.1). Los datos abarcan el período de enero de 1975 a diciembre de 2001.

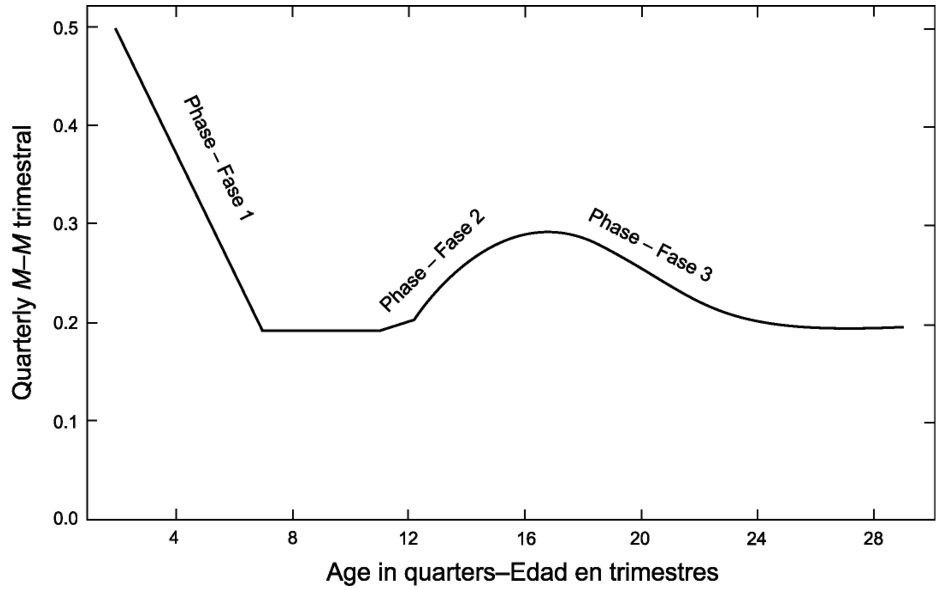


FIGURE 3.1. Natural mortality (*M*) rates, at quarterly intervals, used for the assessment of yellowfin tuna in the EPO. Descriptions of the three phases of the mortality curve are provided in Section 3.1.4.
FIGURA 3.1. Tasas de mortalidad natural (*M*), a intervalos trimestrales, usadas para la evaluación del atún aleta amarilla en el OPO. En la Sección 3.1.4 se describen las tres fases de la curva de mortalidad.

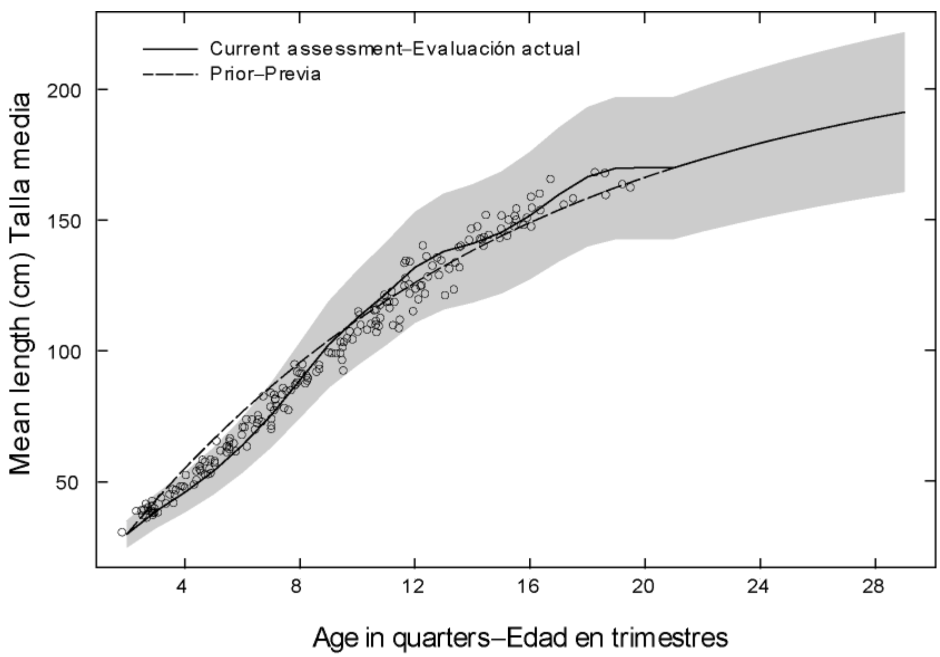


FIGURE 3.2. Growth curve estimated for the assessment of yellowfin tuna in the EPO (solid line). The dashed line is the mean length-at-age prior used in the assessment. The circles represent length-at-age data from otoliths (Wild 1986). The shaded region represents the variance of length at age (± 2 sd)
FIGURA 3.2. Curva de crecimiento usada para la evaluación del atún aleta amarilla en el OPO (línea sólida). La línea de trazos es la distribución previa (*prior*) de la talla a edad usada en la evaluación. Los círculos representan datos de otolitos de talla a edad (Wild 1986). La región sombreada representa la varianza de la talla a edad (± 2 de).

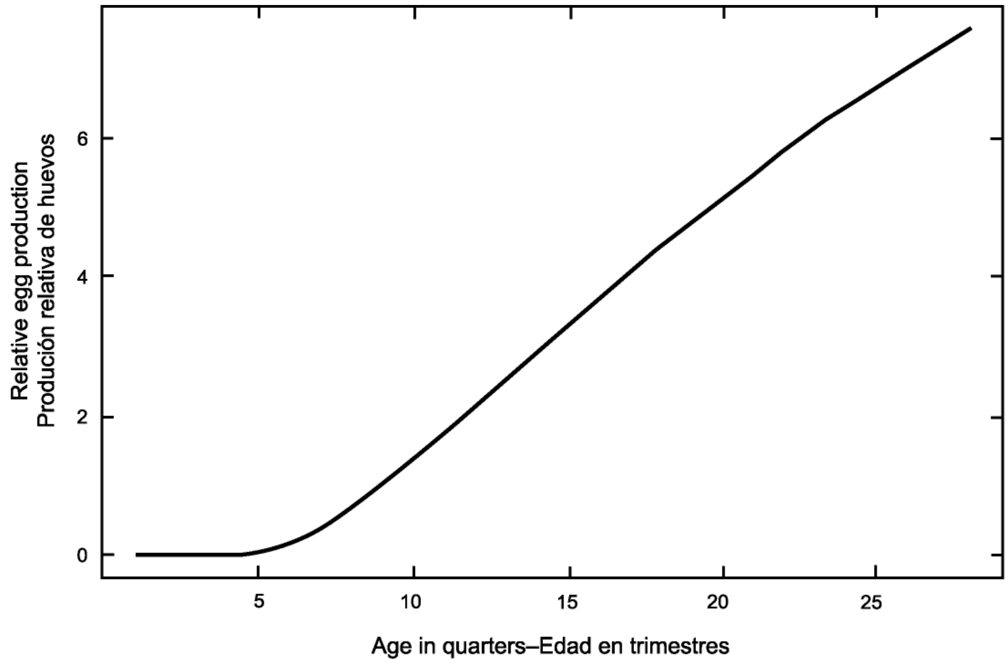


FIGURE 3.3. Relative fecundity-at-age curve (from Schaefer 1998) used to estimate the spawning biomass of yellowfin tuna in the EPO.
FIGURA 3.3. Curva de madurez relativa a edad (de Schaefer 1998) usada para estimar la biomasa reproductora de atún aleta amarilla en el OPO.

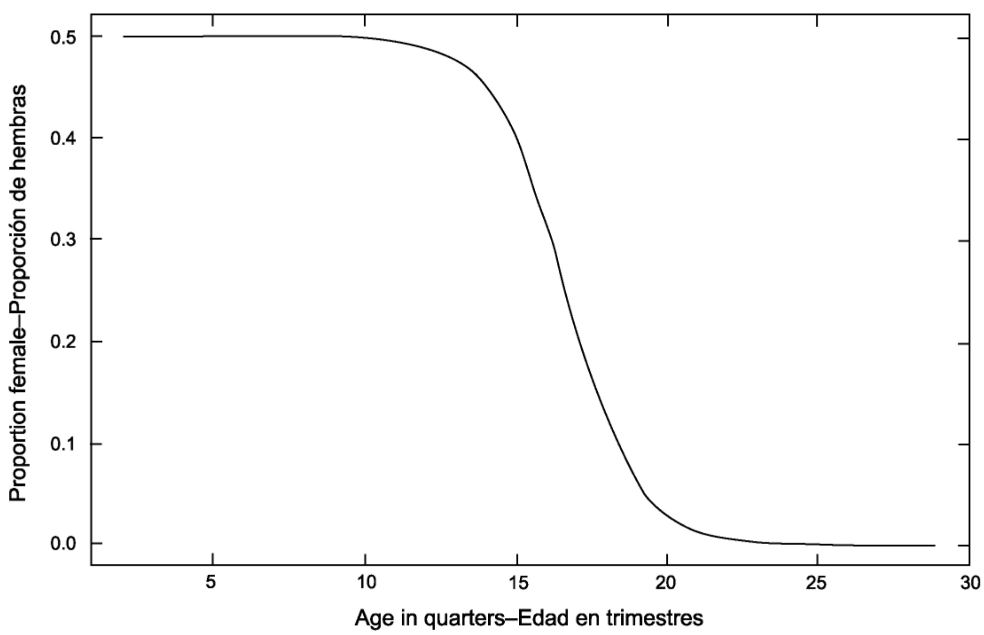


FIGURE 3.4. Sex ratio (from Schaefer 1998) curve used to estimate the spawning biomass of yellowfin tuna in the EPO.
FIGURA 3.4. Curva de proporciones de sexos (de Schaefer 1998) usada para estimar la biomasa reproductora de atún aleta amarilla en el OPO.

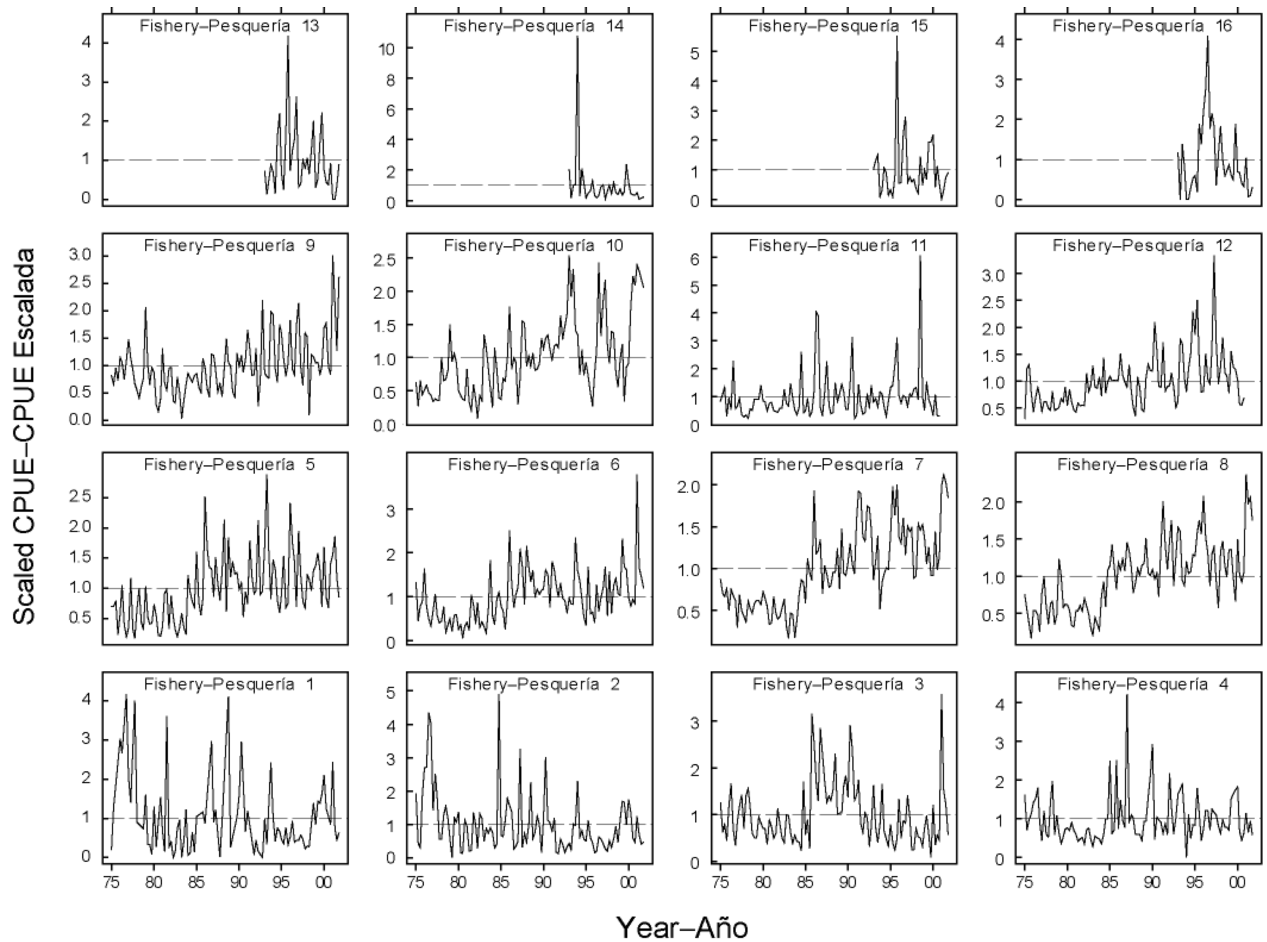


FIGURE 4.1. CPUEs for the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of CPUE for each year. The CPUEs for Fisheries 1-10 and 13-16 are in kilograms per day fished, and those for Fisheries 11 and 12 are in numbers of fish caught per number of hooks. The data are adjusted so that the mean of each time series is equal to 1.0. It should be noted that the vertical scales of the panels are different.

FIGURA 4.1. CPUE de las pesquerías definidas para la evaluación del stock 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 número de peces capturados por 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.

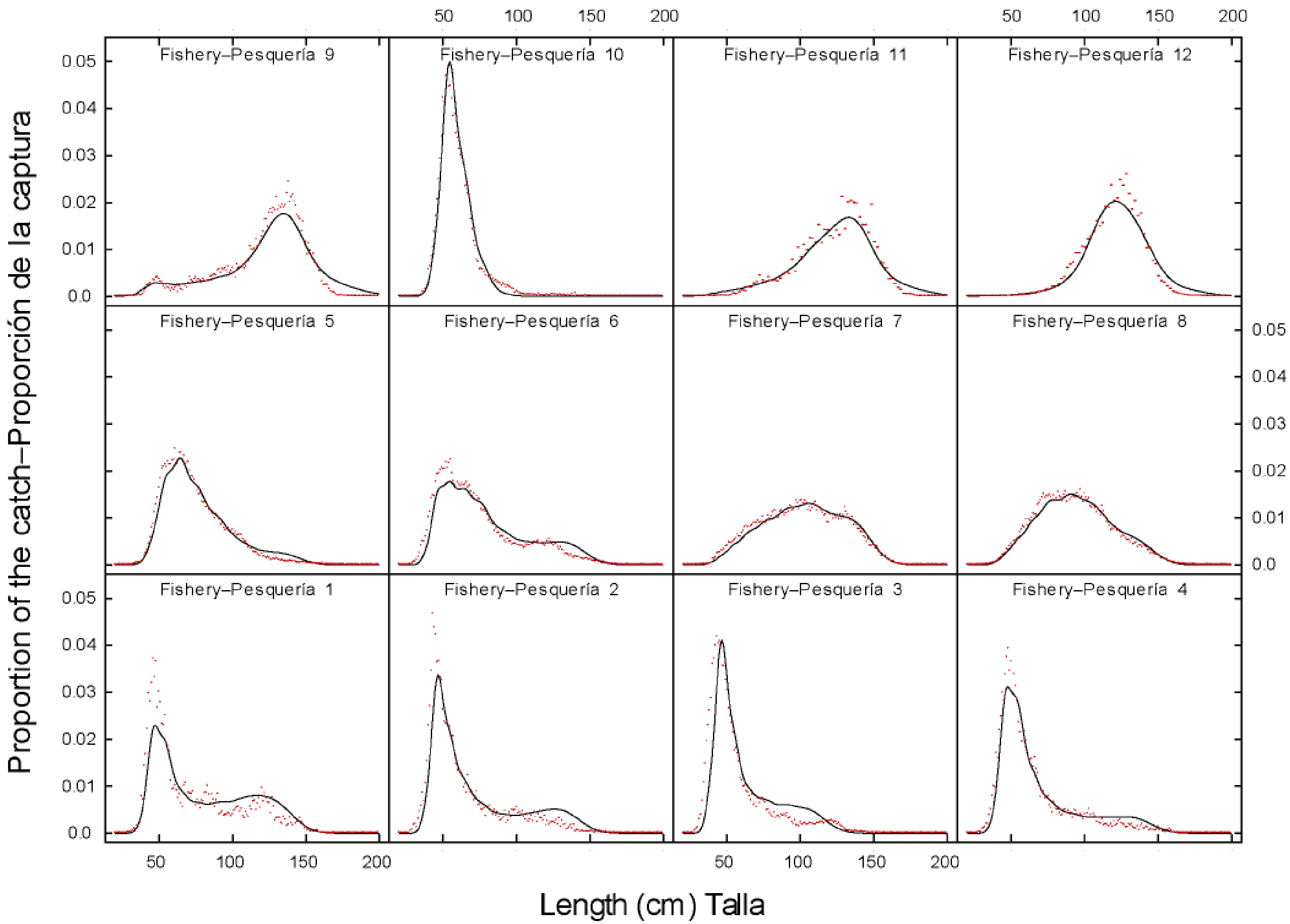


FIGURE 4.2. Average observed (dots) and predicted (curves) size compositions of the catches taken by the fisheries defined for the stock assessment of yellowfin tuna in the EPO.
FIGURA 4.2. Composición media por tamaño observada (puntos) y predicha (curvas) de las capturas realizadas por las pesquerías definidas para la evaluación del stock de atún aleta amarilla en el OPO.

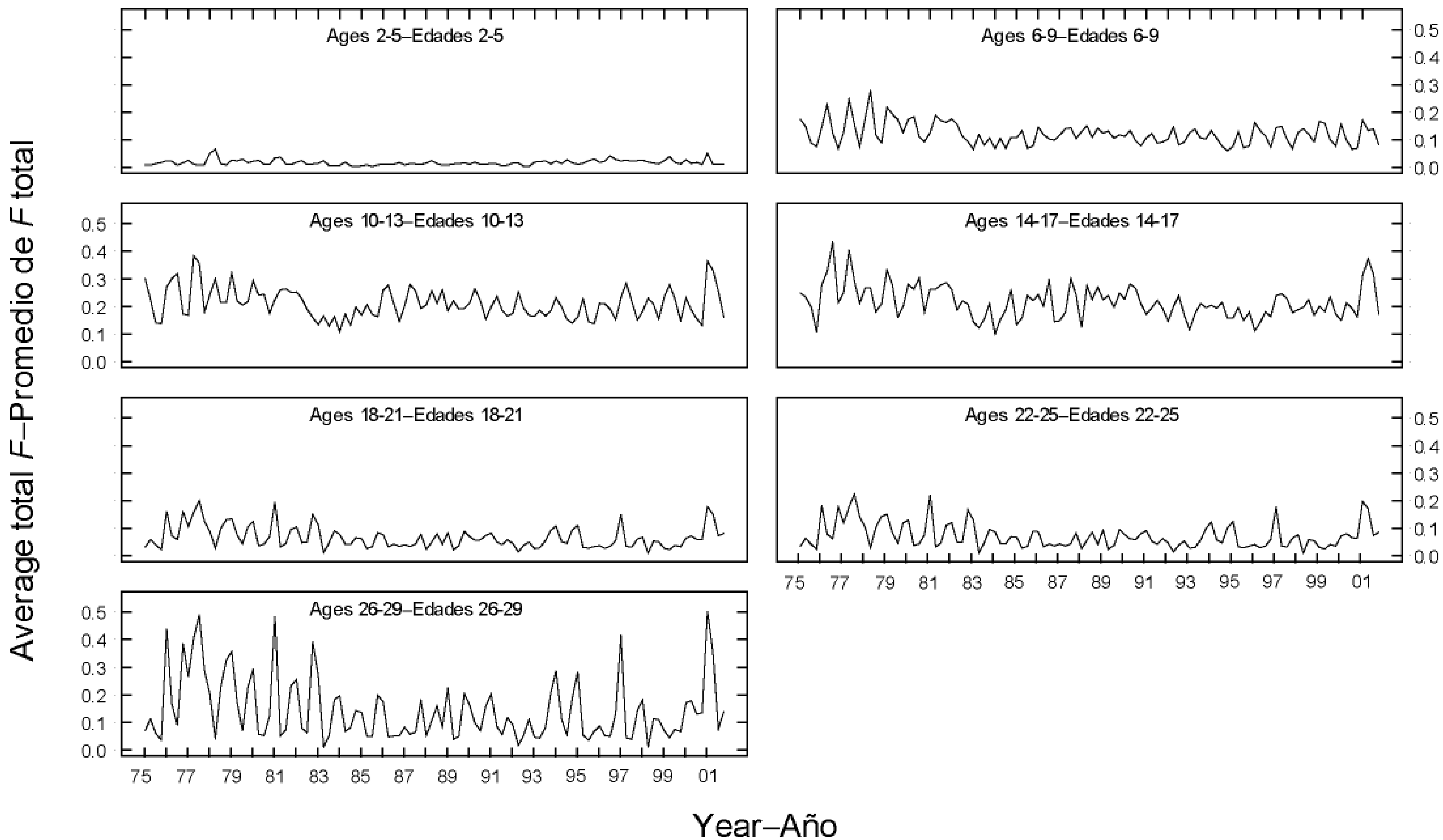


FIGURE 4.3a. Time series of average total quarterly fishing mortality of yellowfin tuna that have been recruited to the fisheries of the EPO. Each panel illustrates an average of four quarterly fishing mortality vectors that affected the fish that were as old as the range of ages indicated in the title of each panel. For example, the trend illustrated in the upper-left panel is an average of the fishing mortalities that affected fish that were 2-5 quarters old.

FIGURA 4.3a. Series de tiempo de la mortalidad por pesca trimestral total media 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 peces de entre 2 y 5 trimestres de edad.

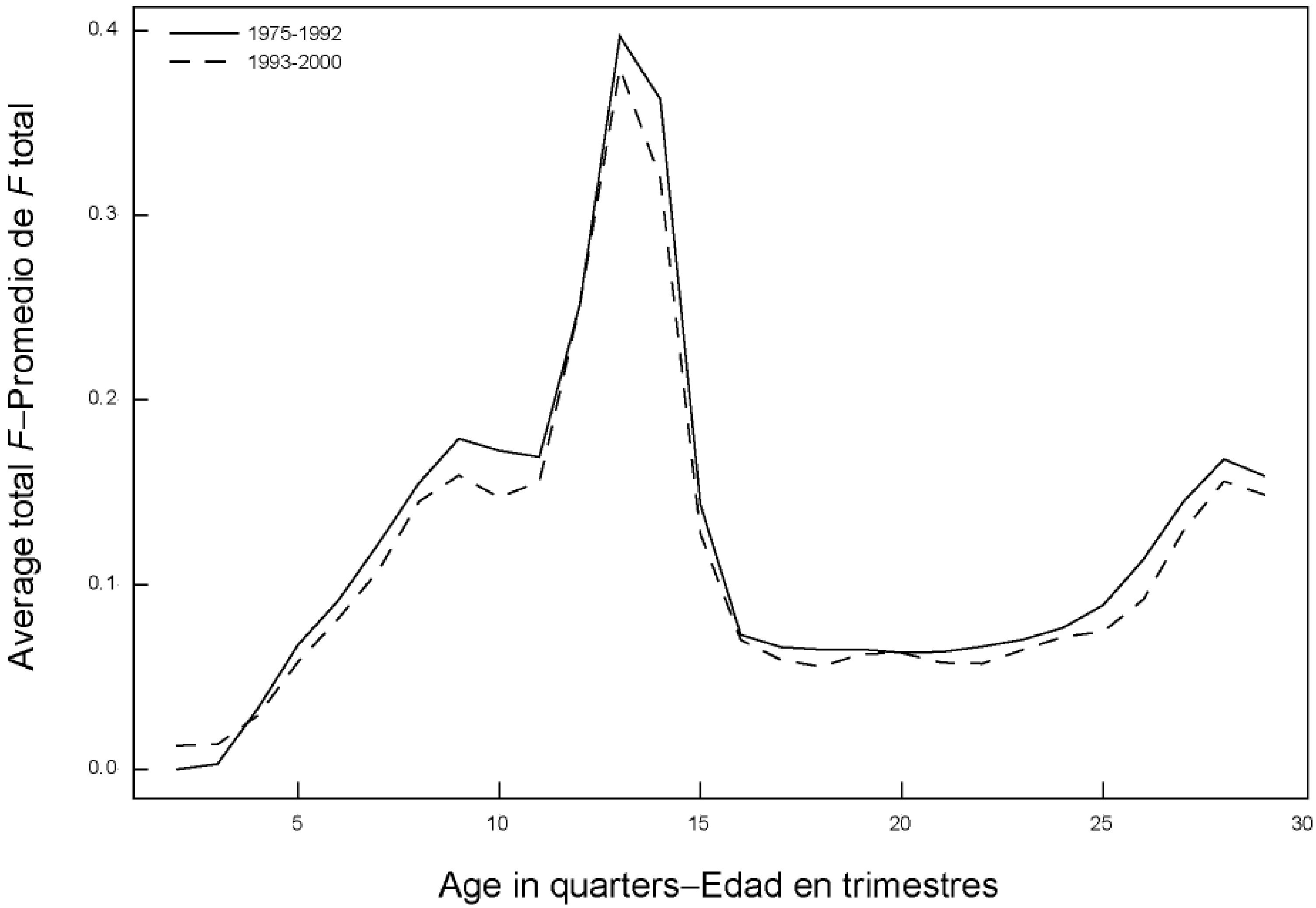


FIGURE 4.3b. Average total quarterly fishing mortality by age of yellowfin tuna that have been recruited to the fisheries of the EPO. The estimates are presented for two time periods, the latter time period relating to the increase in effort associated with floating objects.
FIGURA 4.3b. Mortalidad por pesca total trimestral por edad de atún aleta amarilla reclutado a las pesquerías del OPO. Se presentan estimaciones para dos períodos, el segundo relacionado con aumento en el esfuerzo asociado con objetos flotantes.

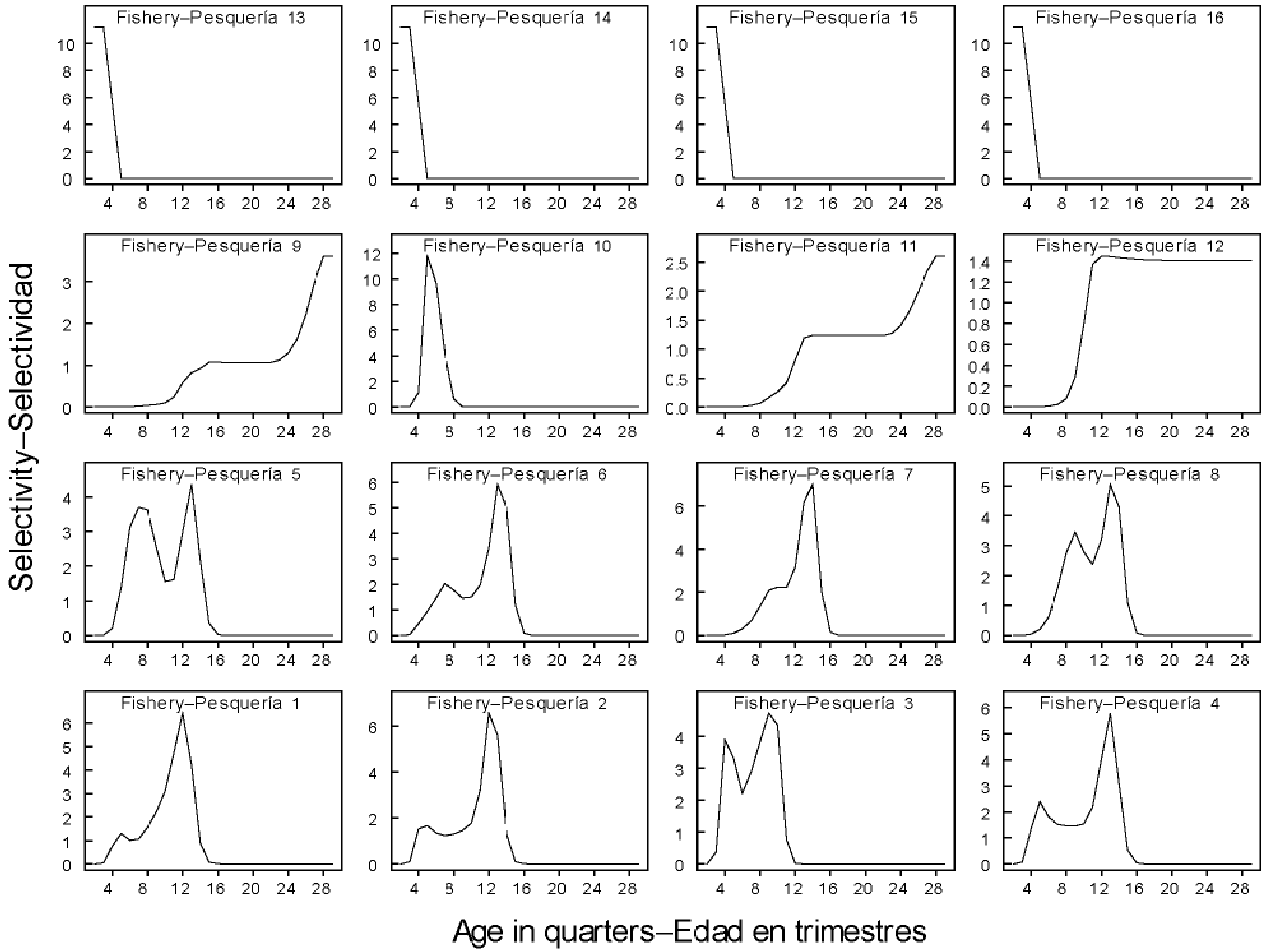


FIGURE 4.4. Selectivity curves for the 16 fisheries that take yellowfin tuna in the EPO. The curves for Fisheries 1-12 were estimated with the A-SCALA method. The curves for Fisheries 13-16 are based on assumptions.

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; las de la Pesquerías 13-16 se basan en supuestos.

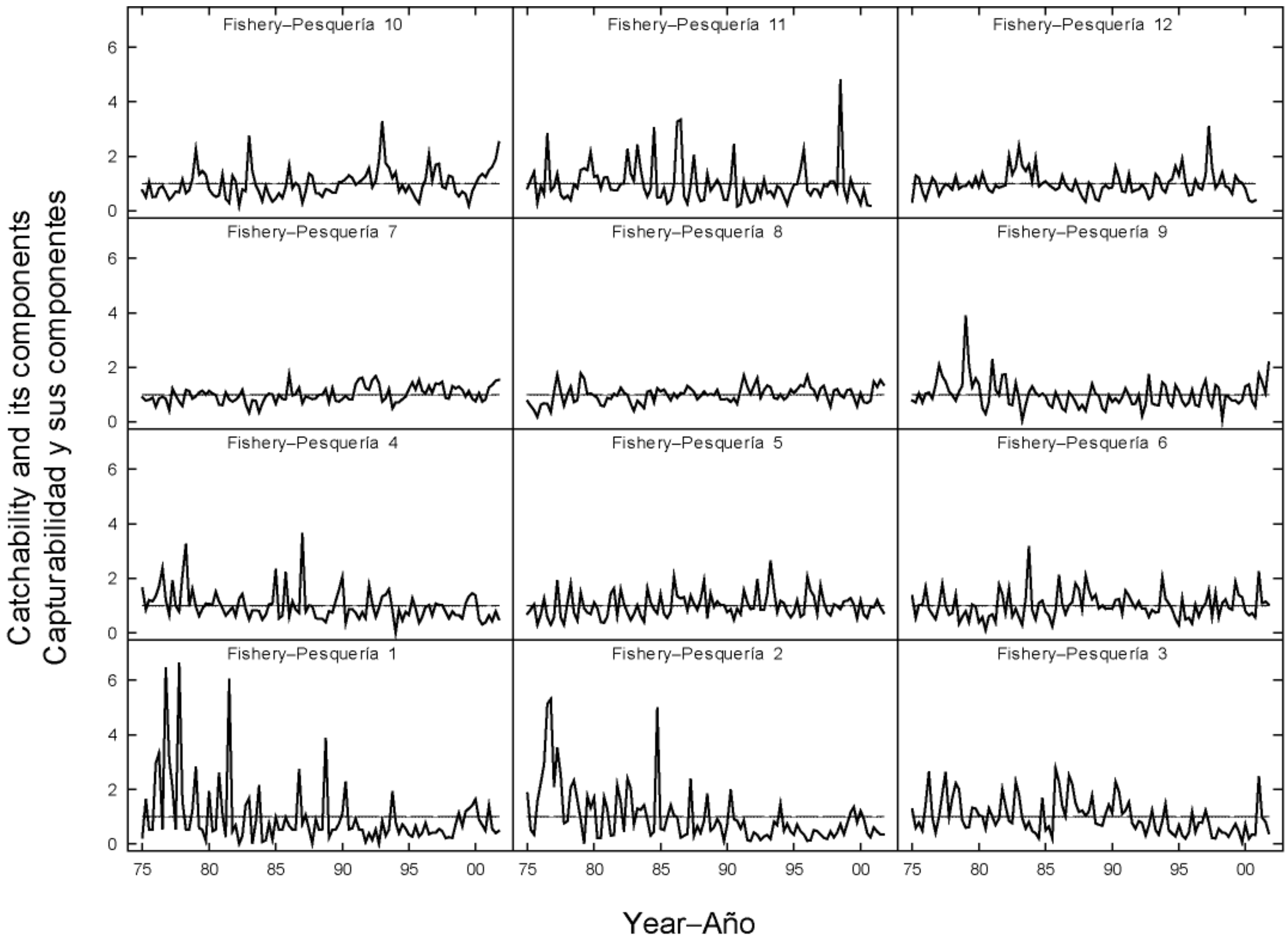


FIGURE 4.5a. Trends in catchability (*q*) for the 16 fisheries that take yellowfin tuna in the EPO. The estimates are scaled to average 1.
FIGURA 4.5a. Tendencias en capturabilidad (*q*) para las 16 pesquerías que capturan atún aleta amarilla en el OPO. Se escalan las estimaciones a un promedio de 1.

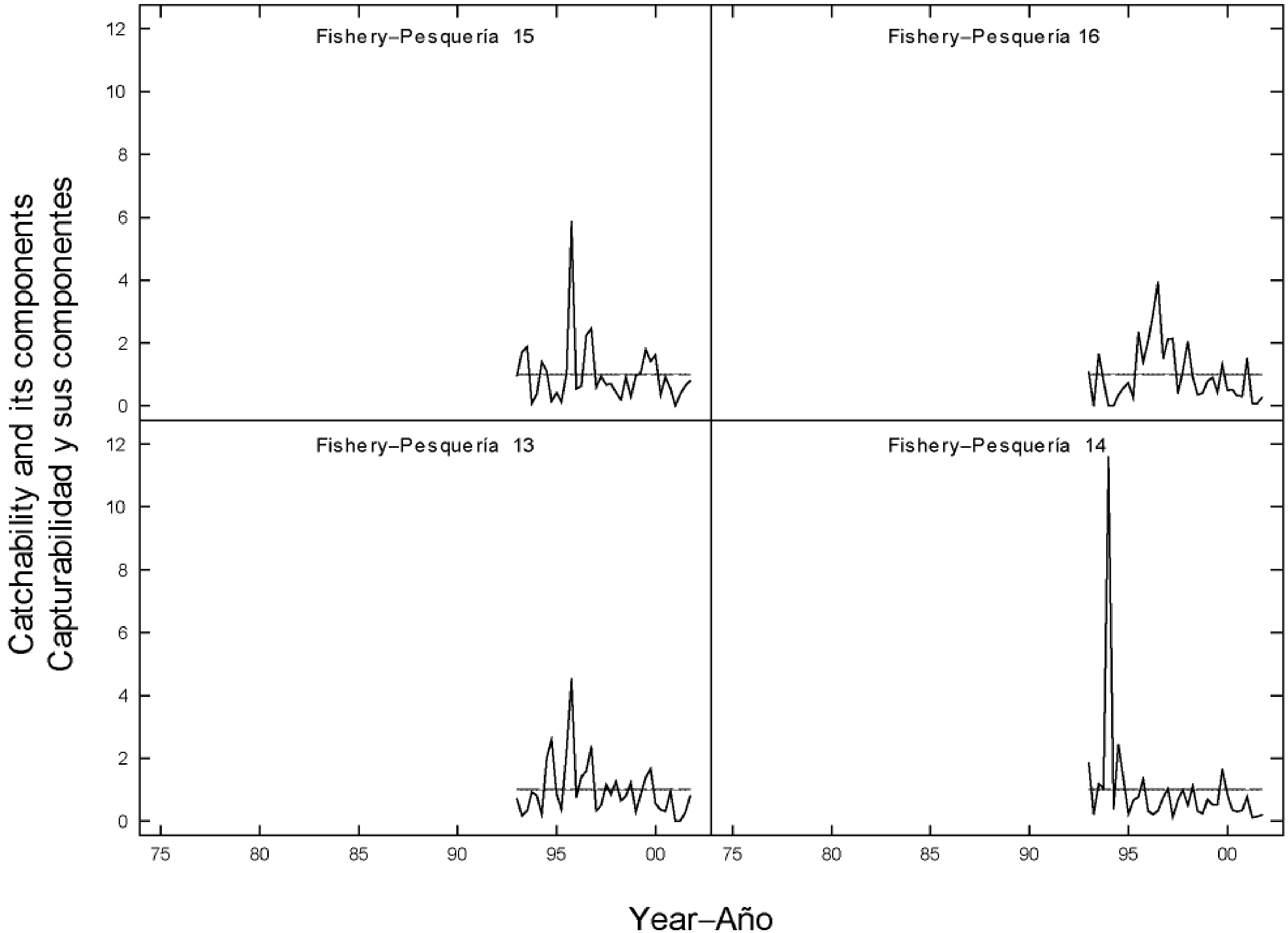


FIGURE 4.5b. Trends in catchability (q) for the 16 fisheries that take yellowfin tuna in the EPO. See Figure 4.5a for additional detail.
FIGURA 4.5b. Tendencias en capturabilidad (q) para las 16 pesquerías que capturan atún aleta amarilla en el OPO. Ver Figura 4.5a para mayor detalle.

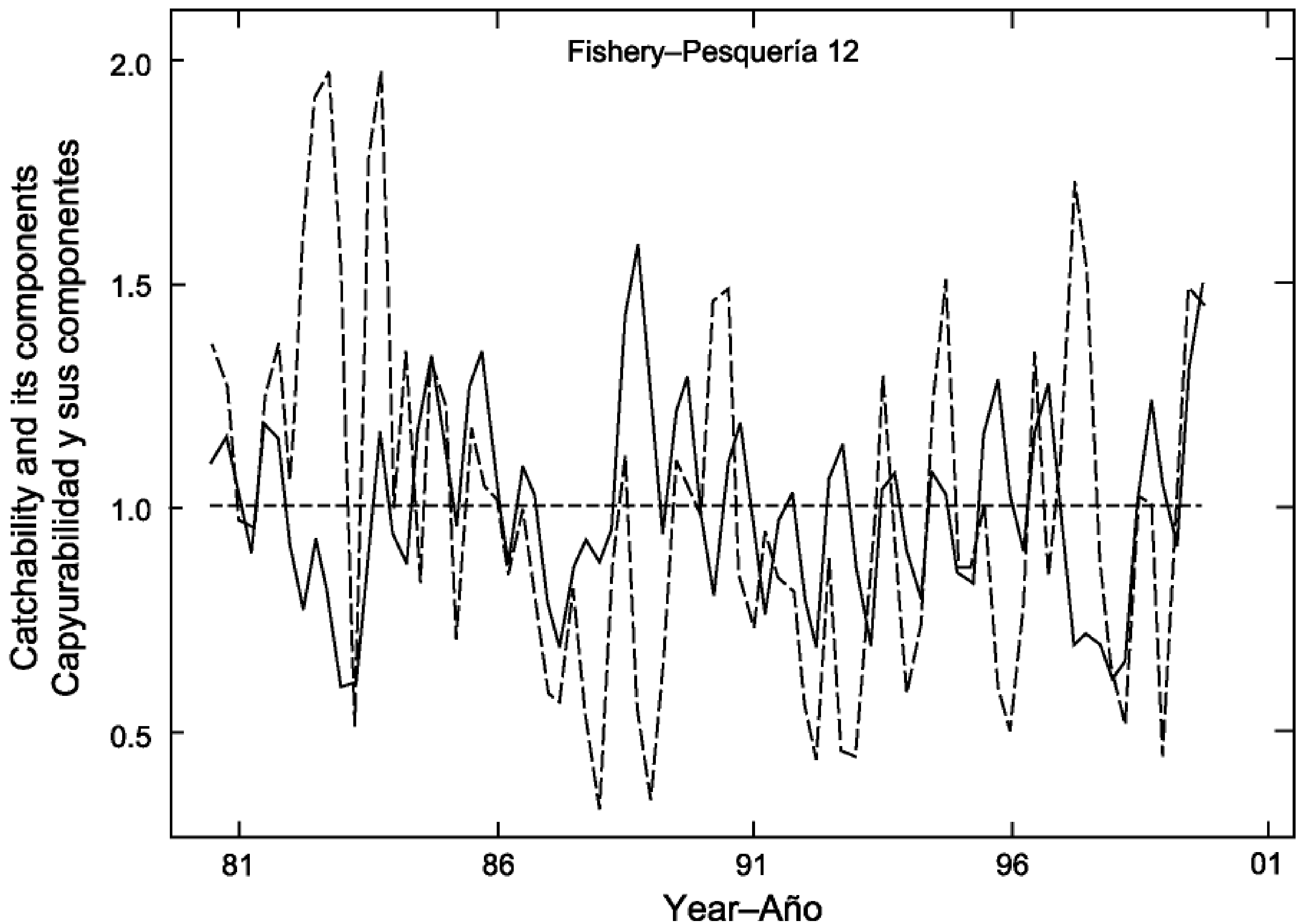


FIGURE 4.5c. Trends in catchability (q) for the southern longline fishery (Fishery 12) when SST is used as an environmental index to explain changes in catchability. The dashed line represents the environmental effect. See Figure 4.5a for additional detail.

FIGURA 4.5c. Tendencias en capturabilidad (q) para la pesquería palangrera del sur (Pesquería 12) cuando se usa la TSM como índice ambiental para explicar cambios en la capturabilidad. La línea de trazos representa el efecto ambiental. Ver Figura 4.5a para mayor detalle.

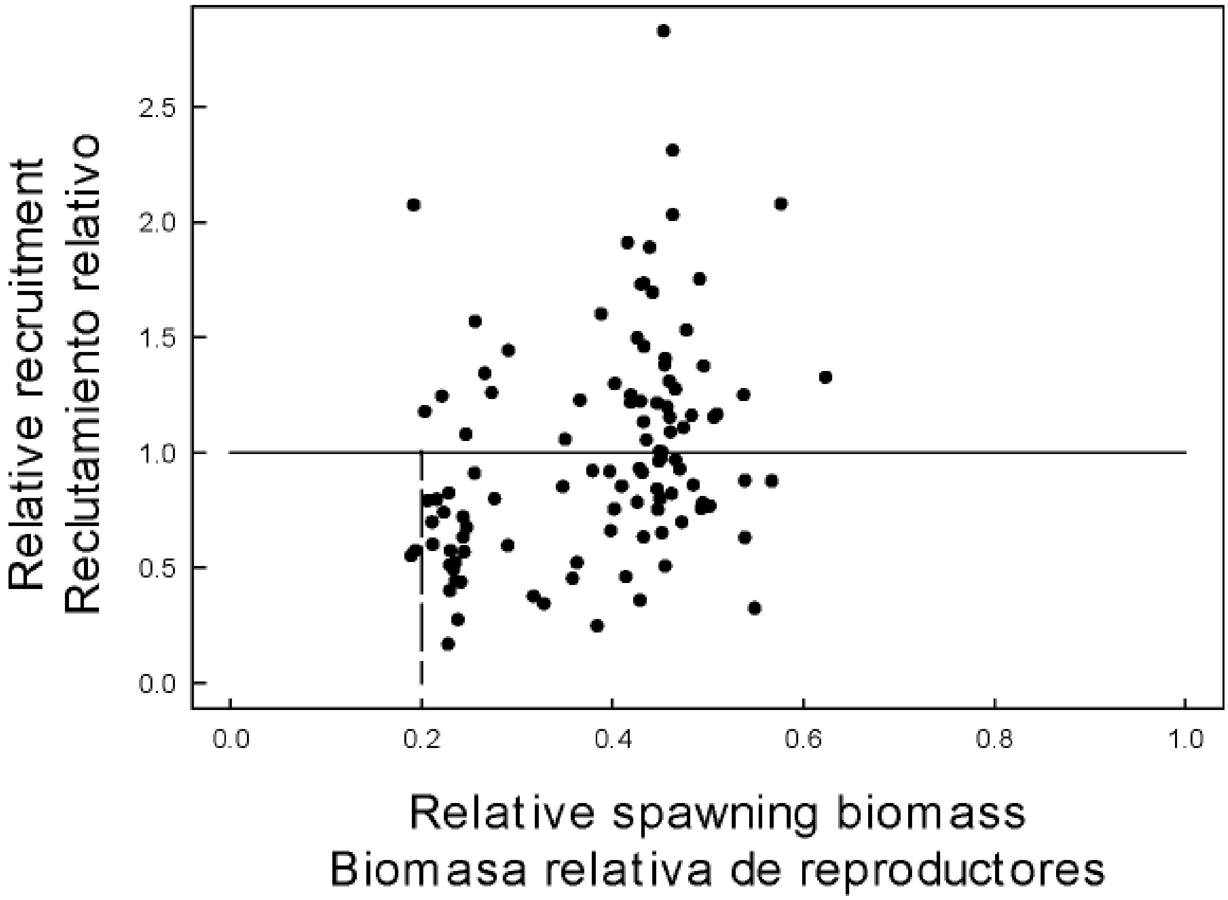


FIGURE 4.6a. Estimated relationships between recruitment of yellowfin tuna and spawning biomass. The recruitment is scaled so that the average recruitment is equal to 1.0. The spawning biomass is scaled so that the average unexploited spawning biomass is equal to 1.0.
FIGURA 4.6a. Relaciones estimadas entre reclutamiento de atún aleta amarilla y biomasa reproductora . Se escala el reclutamiento para que el reclutamiento medio equivalga a 1,0. Se escala la biomasa reproductora para que la biomasa reproductora media no explotada equivalga a 1,0.

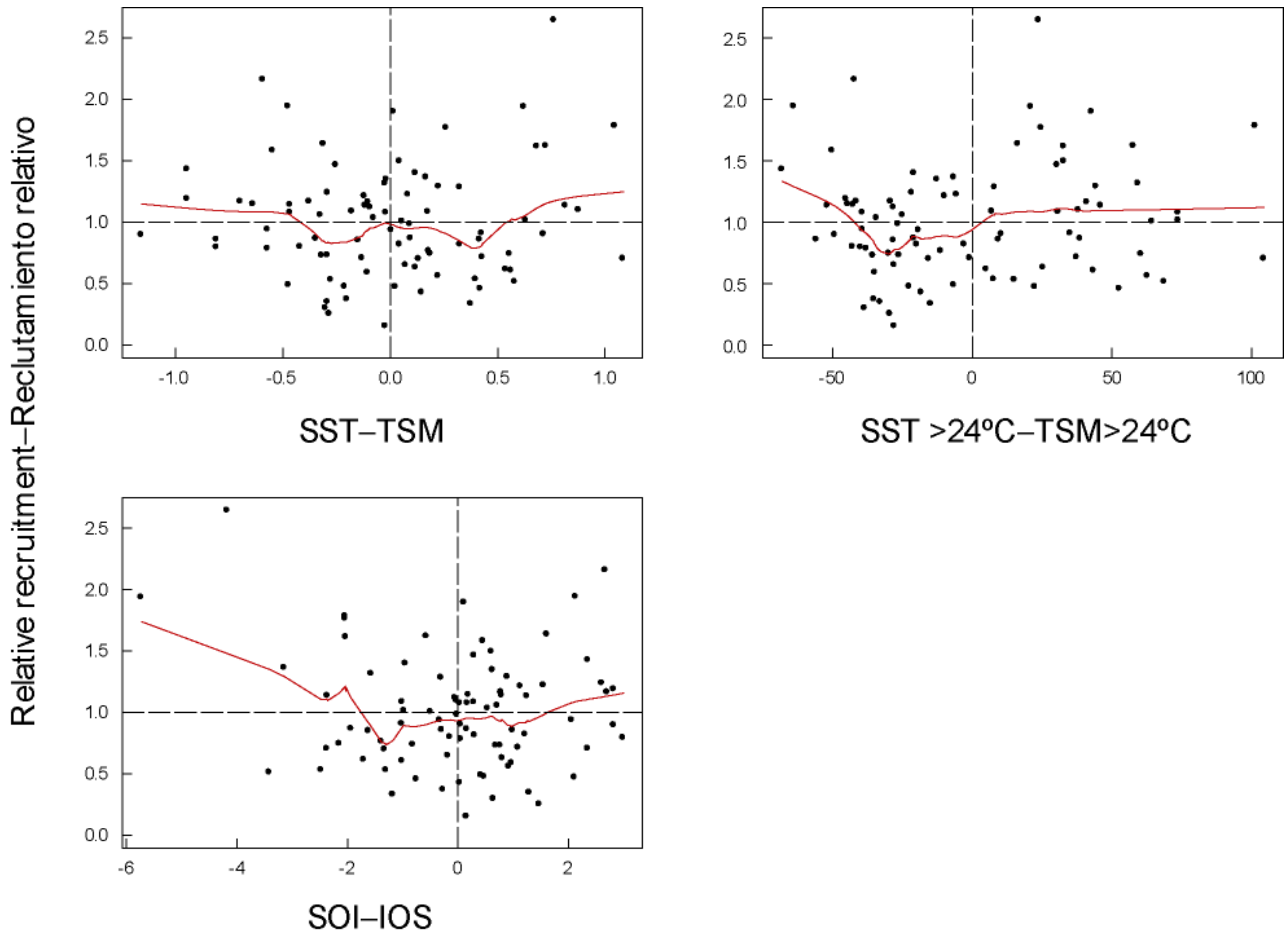


FIGURE 4.6b. Estimated relationships between recruitment of yellowfin tuna and environmental indices. SST >24°C is the frequency of 1° x 1° areas with monthly average temperatures greater than 24°C. SOI is the Southern Oscillation Index. The recruitment and environmental indices are scaled so that they average 1.0 and 0.0, respectively.

FIGURA 4.6b. Relaciones estimadas entre reclutamiento de atún aleta amarilla e índices ambientales. TSM >24°C: frecuencia de zonas de 1° x 1° con temperatura mensual media de más de 24°C; IOS: Indice de Oscilación del Sur. Se escalan los índices de reclutamiento y ambiental medios para que equivalgan a 1,0 y 0,0, respectivamente.

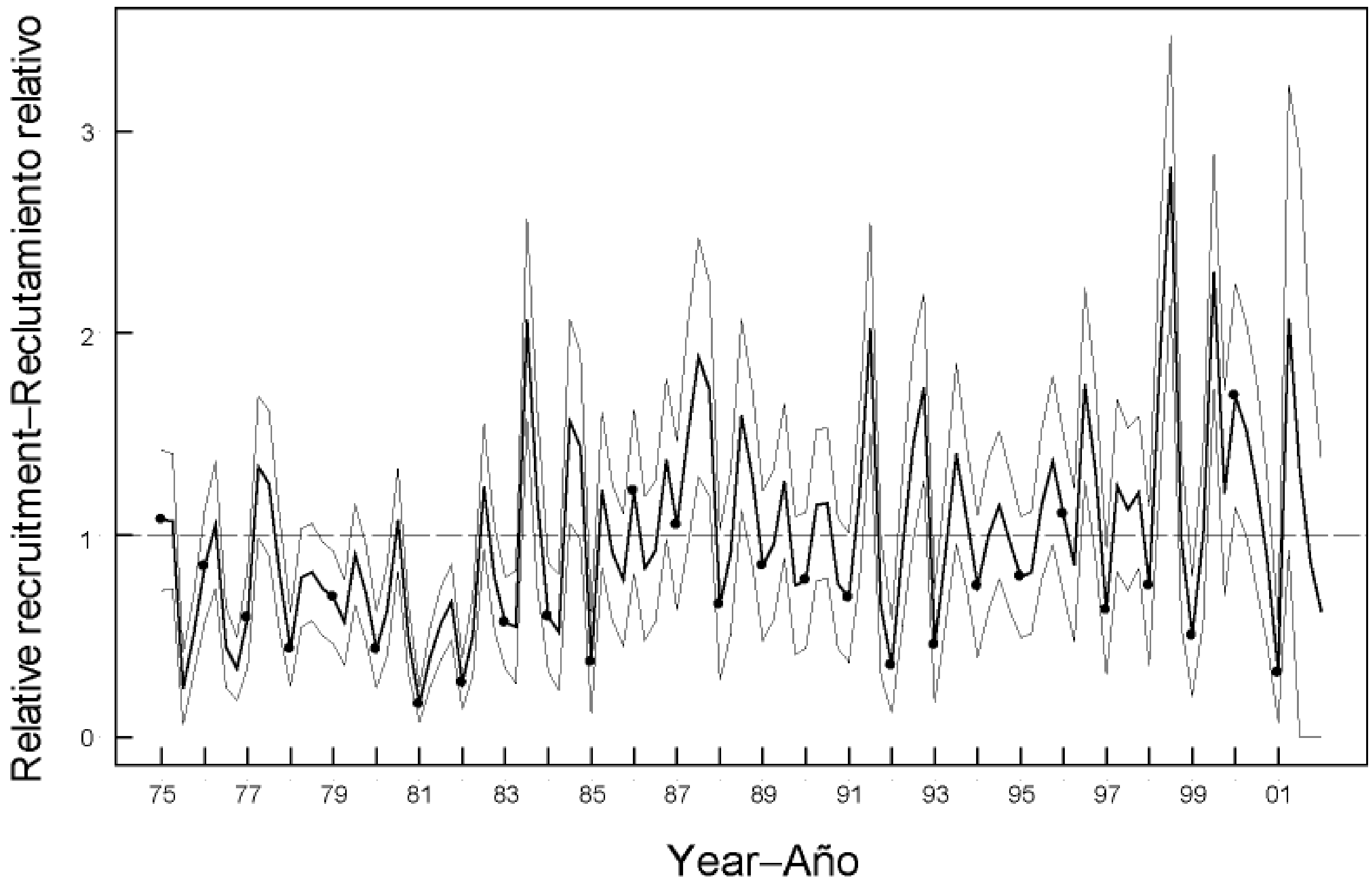


FIGURE 4.7. Estimated recruitment of yellowfin tuna to the fisheries of the EPO. The estimates are scaled so that the average recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the thin lines indicate the approximate 95% confidence intervals around 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 probabilidad máxima del reclutamiento, y las líneas delgadas los intervalos de confianza de 95% aproximados de las 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.

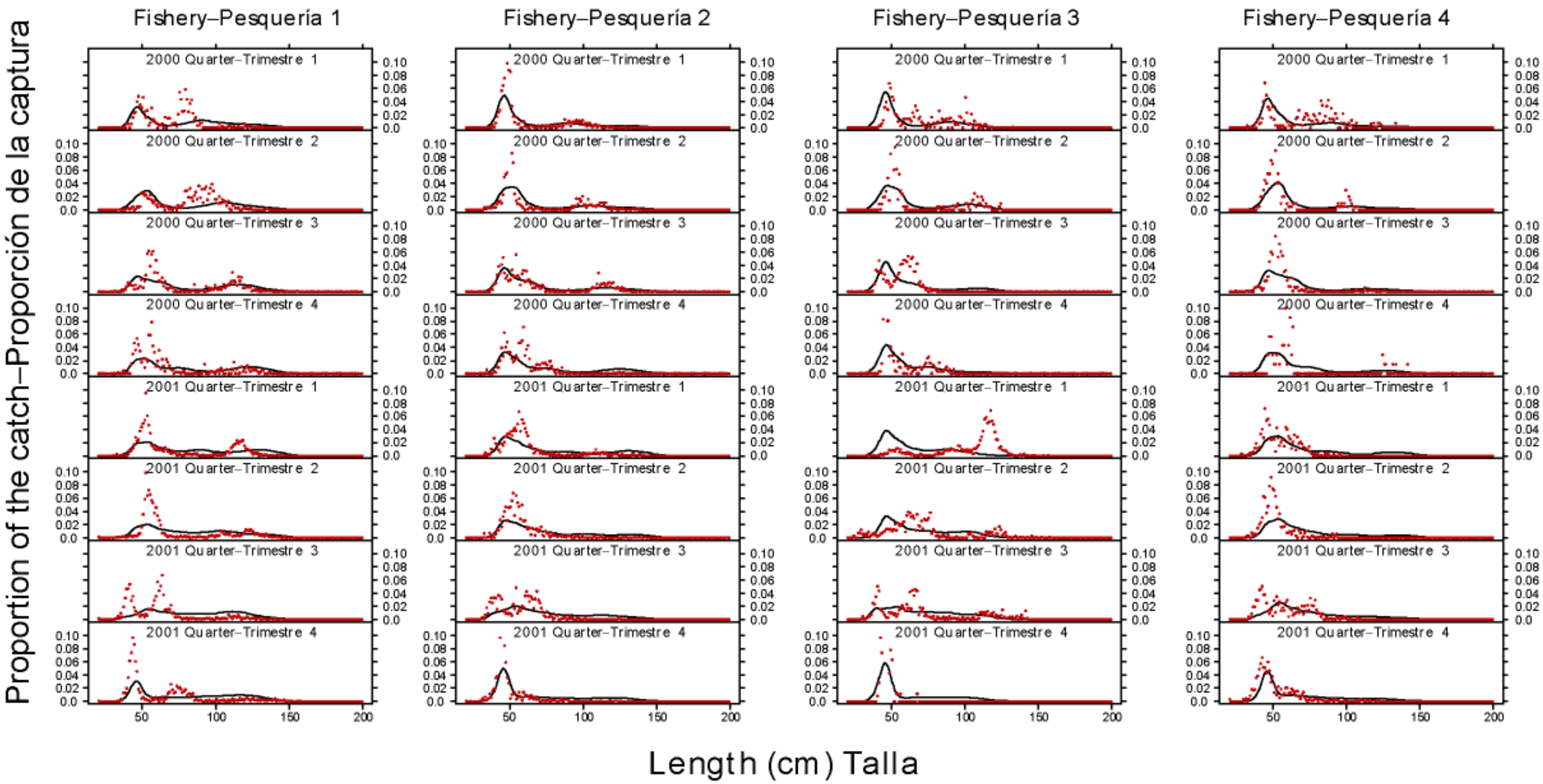


FIGURE 4.8a. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin by the fisheries that take tunas in association with floating objects.

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.

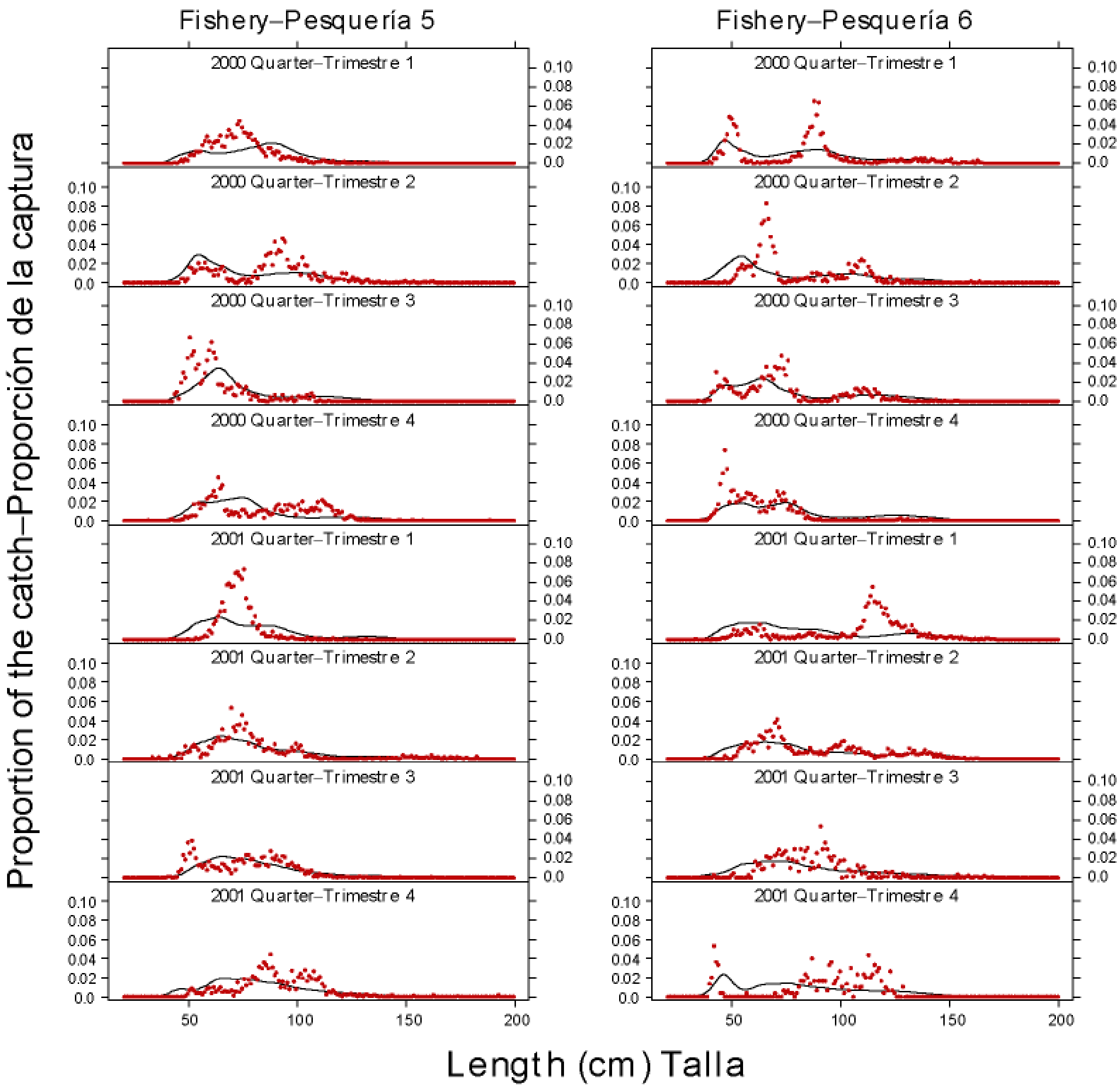


FIGURE 4.8b. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin by the fisheries that take tunas in unassociated schools.

FIGURA 4.8b. Composiciones por tamaño observadas (puntos) y predichas (curvas) de las capturas recientes de aleta amarilla por las pesquerías que capturan atún en cardúmenes no asociados.

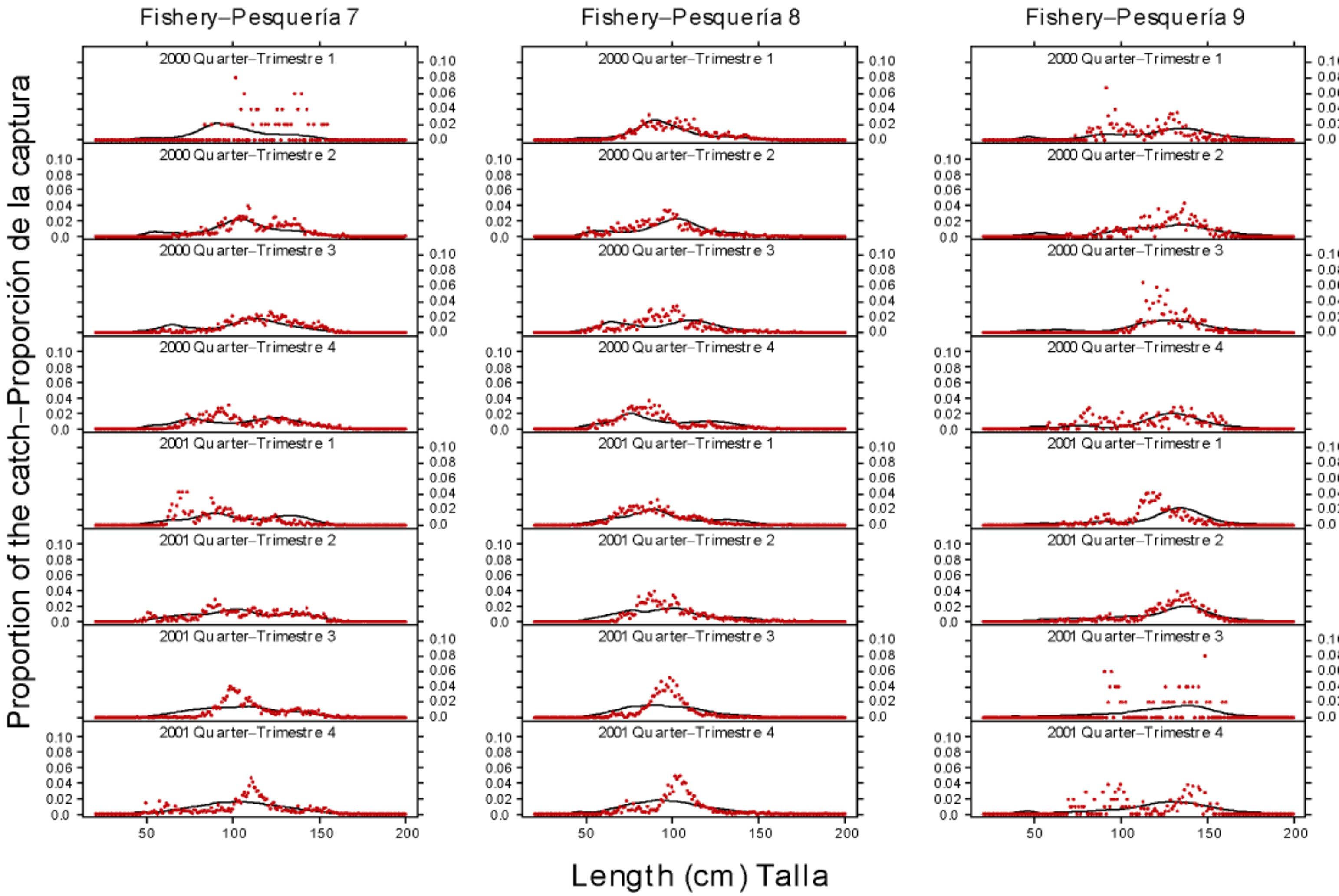


FIGURE 4.8c. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin by the fisheries that take tunas in association with dolphins.
FIGURA 4.8c. Composiciones por tamaño observadas (puntos) y predichas (curvas) de las capturas recientes de aleta amarilla por las pesquerías que capturan atún en asociación con delfines.

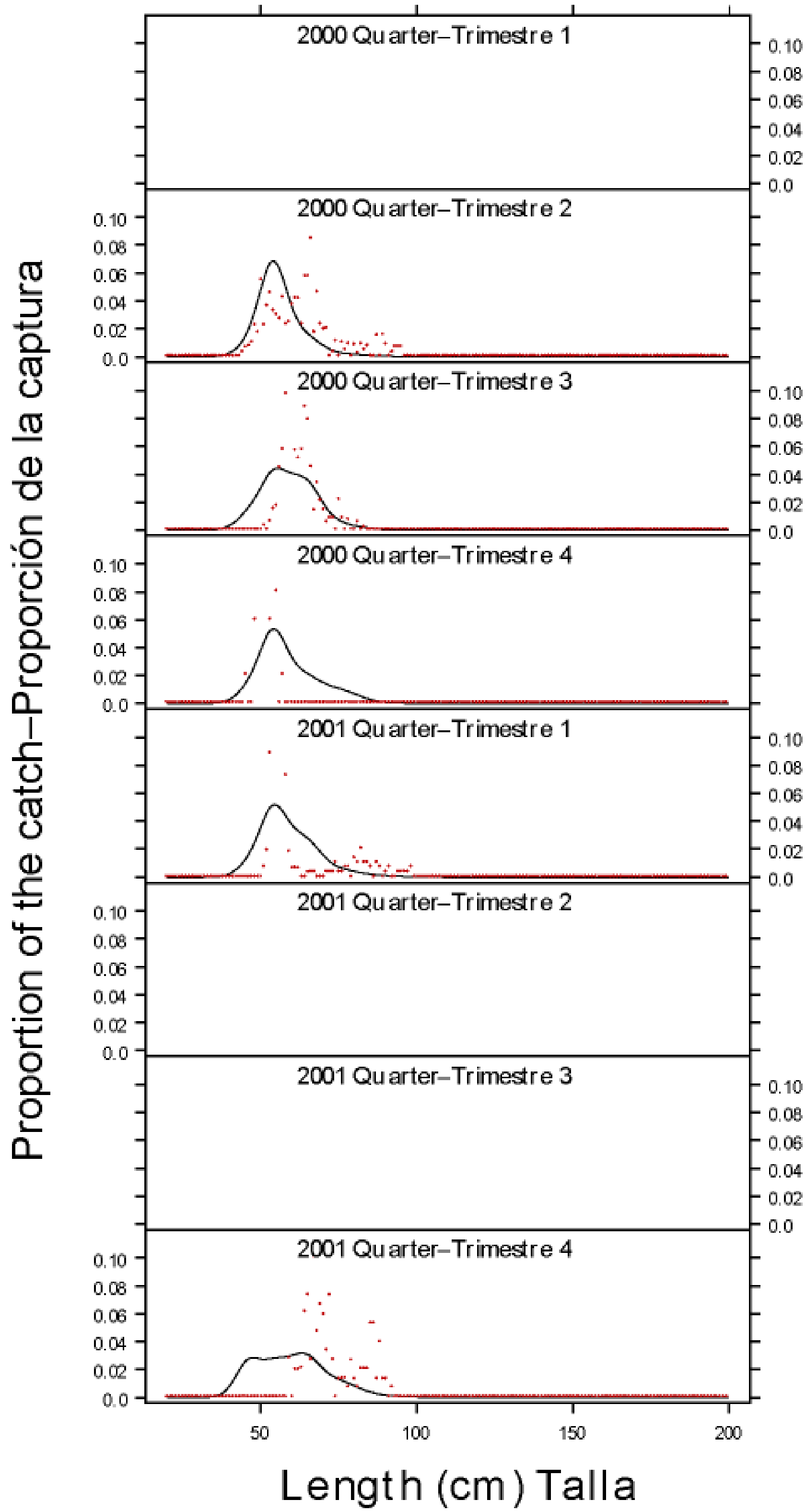


FIGURE 4.8d. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin by the baitboat fishery (Fishery 10).

FIGURA 4.8d. Composiciones por tamaño observadas (puntos) y predichas (curvas) de las capturas recientes de aleta amarilla por la pesquería de carnada (Pesquería 10).

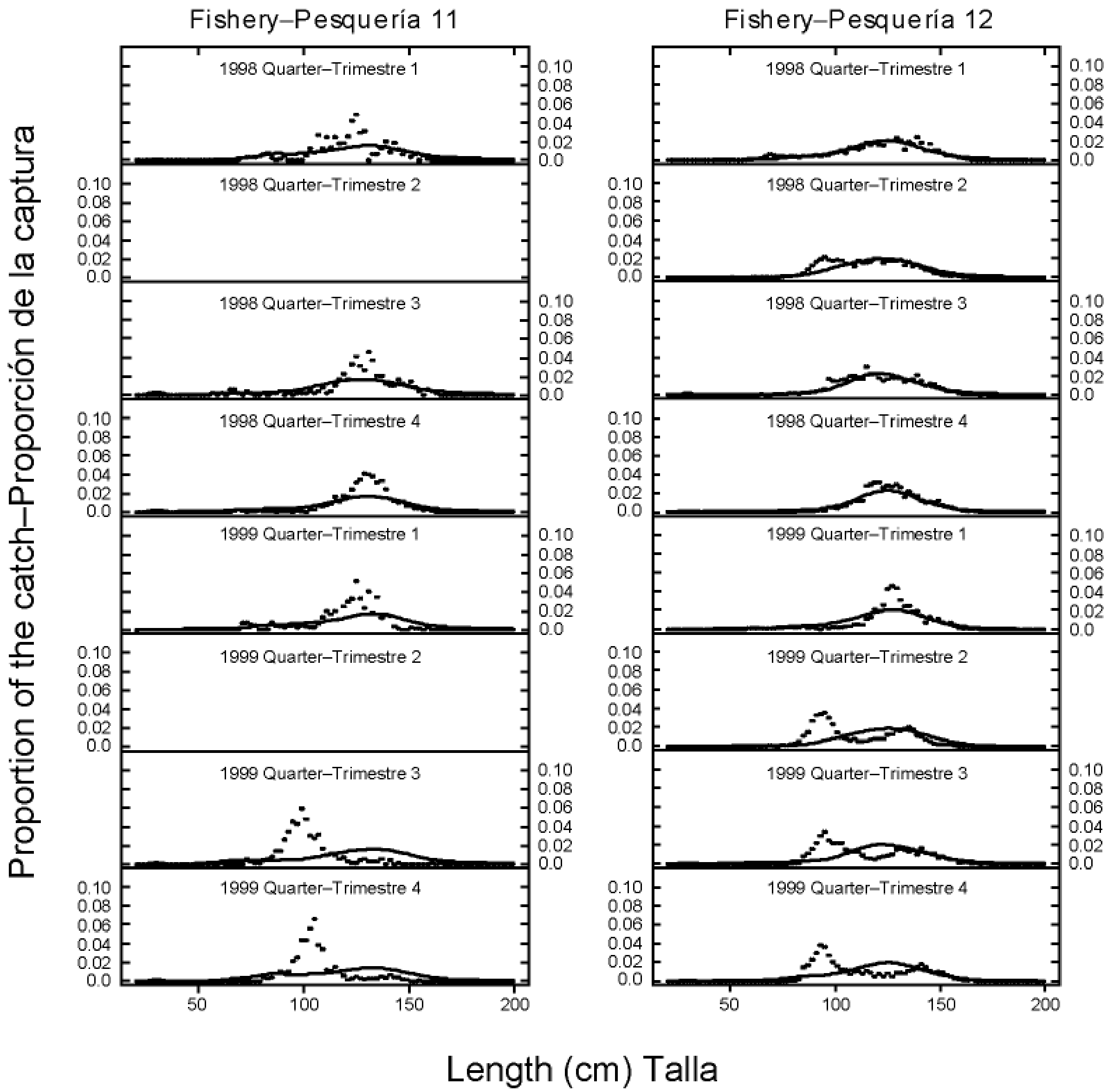
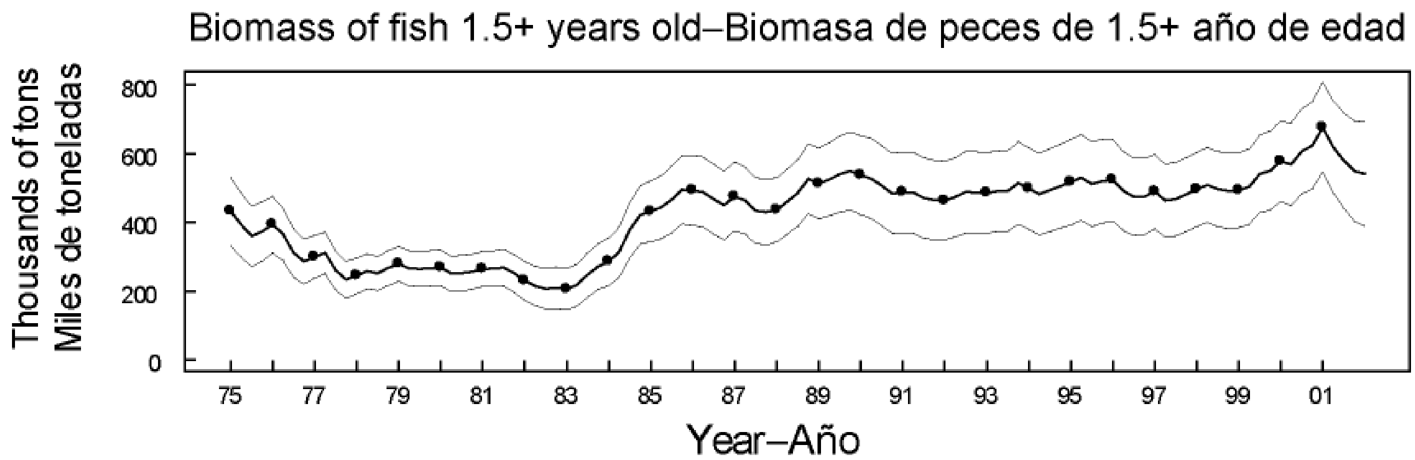


FIGURE 4.8e. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin by the longline fisheries.

FIGURA 4.8e. Composiciones por tamaño observadas (puntos) y predichas (curvas) de las capturas recientes de aleta amarilla por las pesquerías palangreras.



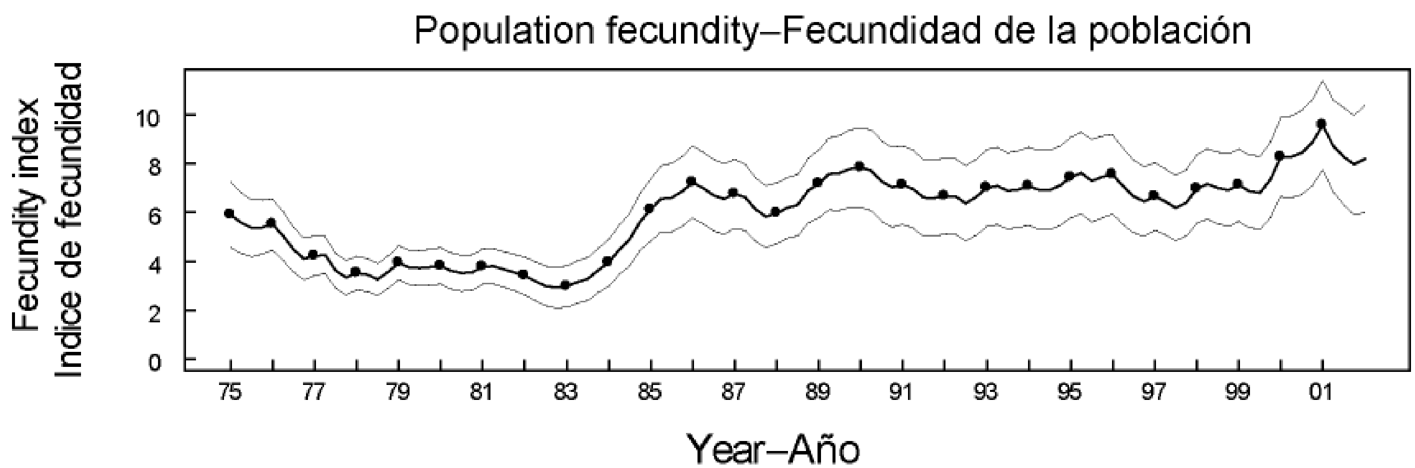


FIGURE 4.9. Estimated biomass and spawning biomass of yellowfin tuna in the EPO. The bold lines illustrate the maximum likelihood estimates of the biomass, and the thin lines the approximate 95% confidence intervals around those estimates. Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year.

FIGURA 4.9. Biomasa estimada y biomasa reproductora de atún aleta amarilla en el OPO. Las líneas gruesas ilustran las estimaciones de probabilidad máxima de la biomasa, y las delgadas 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.

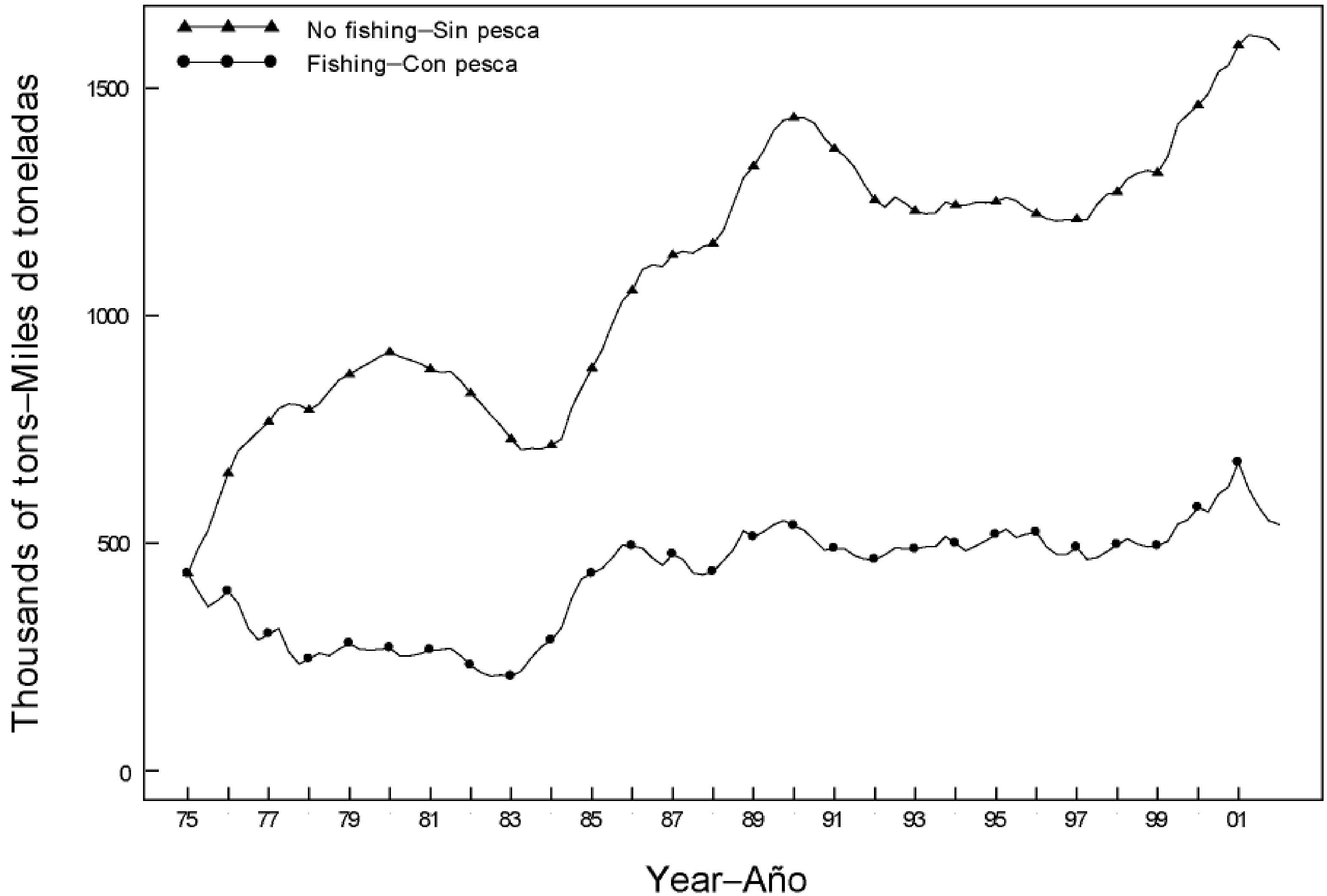


FIGURE 4.10. Biomass trajectory of a simulated population of yellowfin tuna that was not exploited during 1975-2001 ("no fishing") and that predicted by the stock assessment model ("fishing").
FIGURA 4.10. Trayectoria de biomasa de una población simulada de atún aleta amarilla no explotada durante 1975-2001 ("sin pesca") y la predicha por el modelo de evaluación del stock ("con pesca").

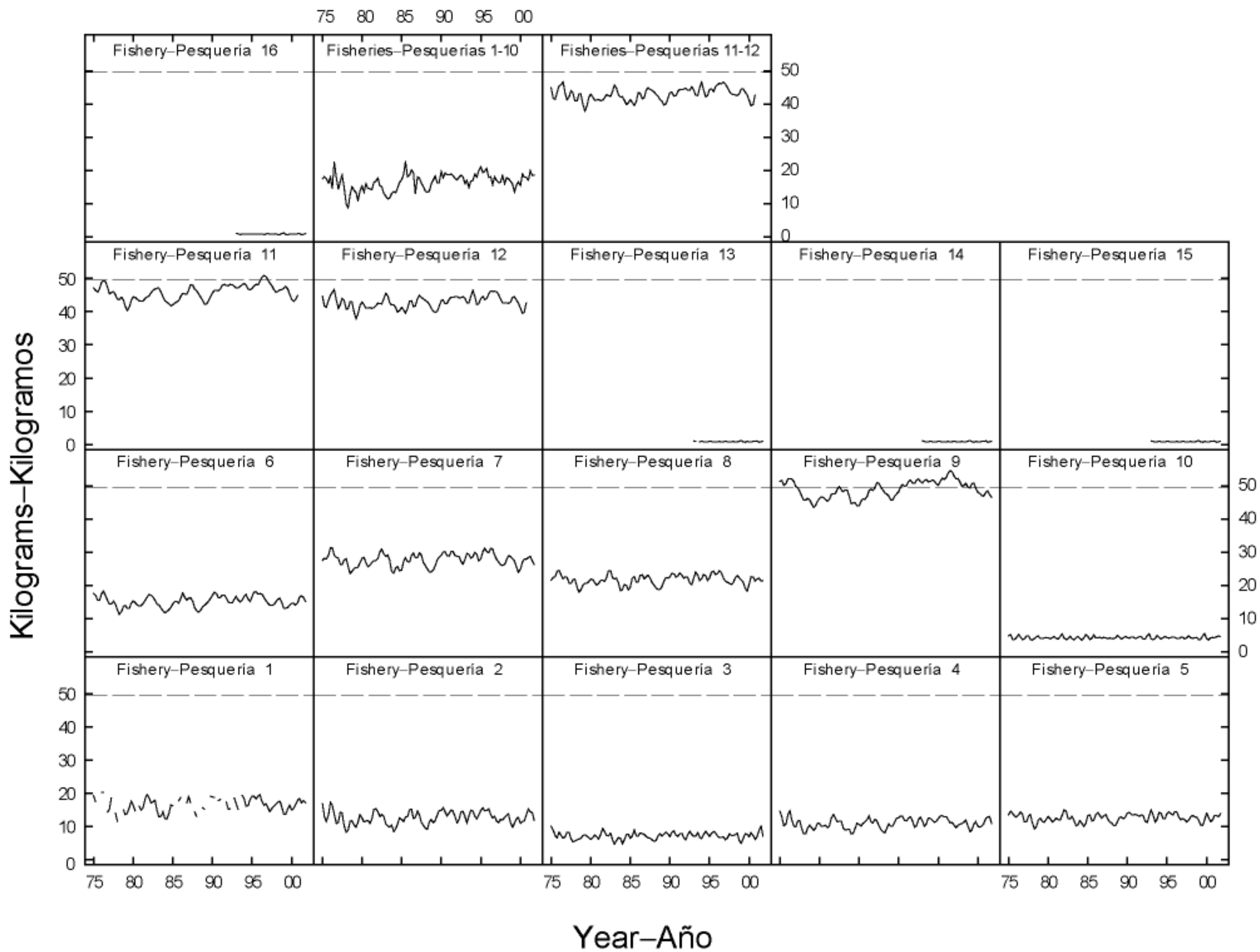


FIGURE 4.11. Estimated average weights of yellowfin tuna caught by the fisheries of the EPO. The time series for "Fisheries 1-10" is an average of Fisheries 1 through 10, and the time series for "Fisheries 11-12" is an average of Fisheries 11 and 12. The dashed line identifies the critical weight.

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.

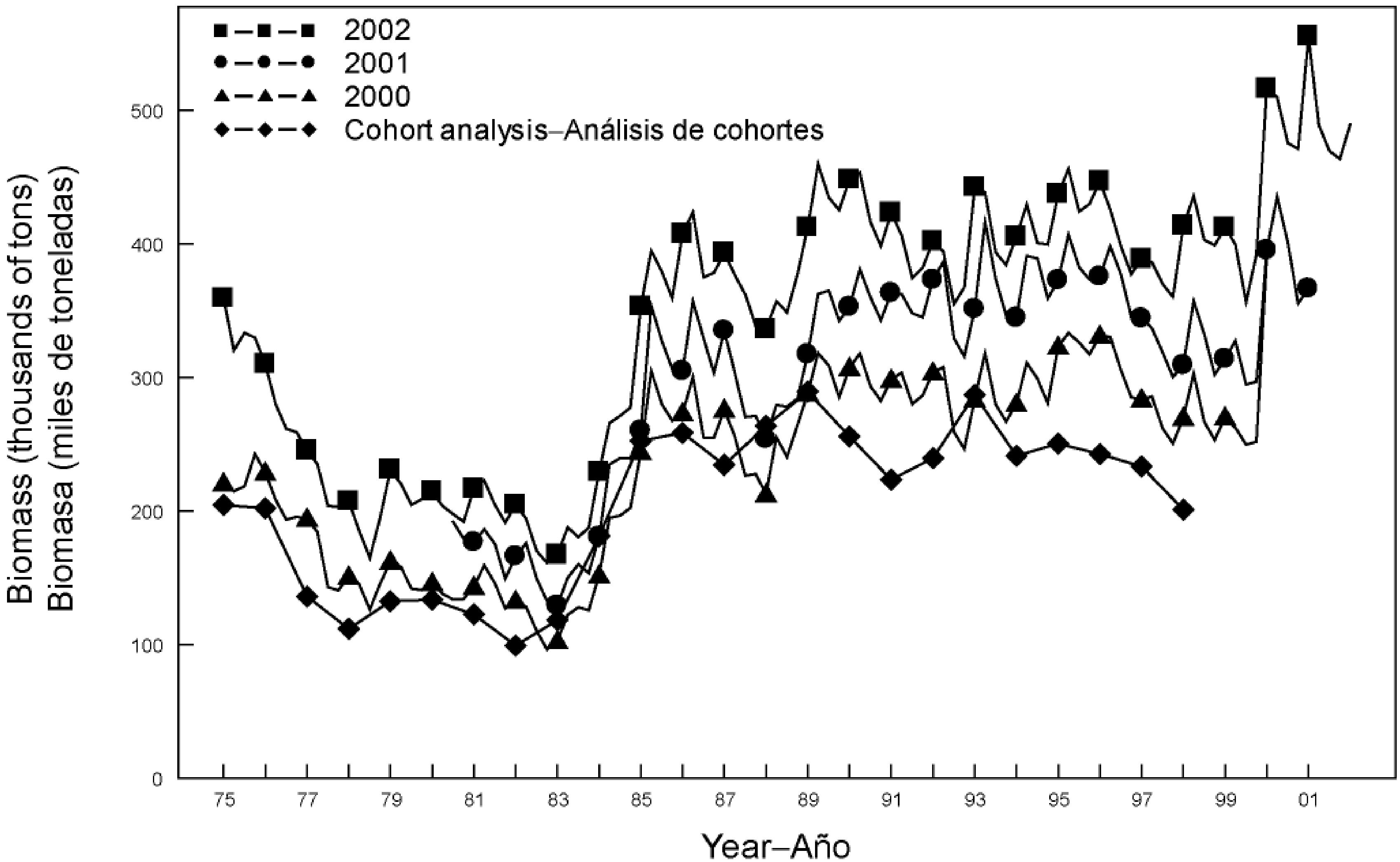


FIGURE 4.12. Comparison of biomass (2 years of age and older) from previous assessments and the current assessment.
FIGURA 4.12. Comparación de biomasa (edades de dos años y más) de evaluaciones previas y de la evaluación actual.

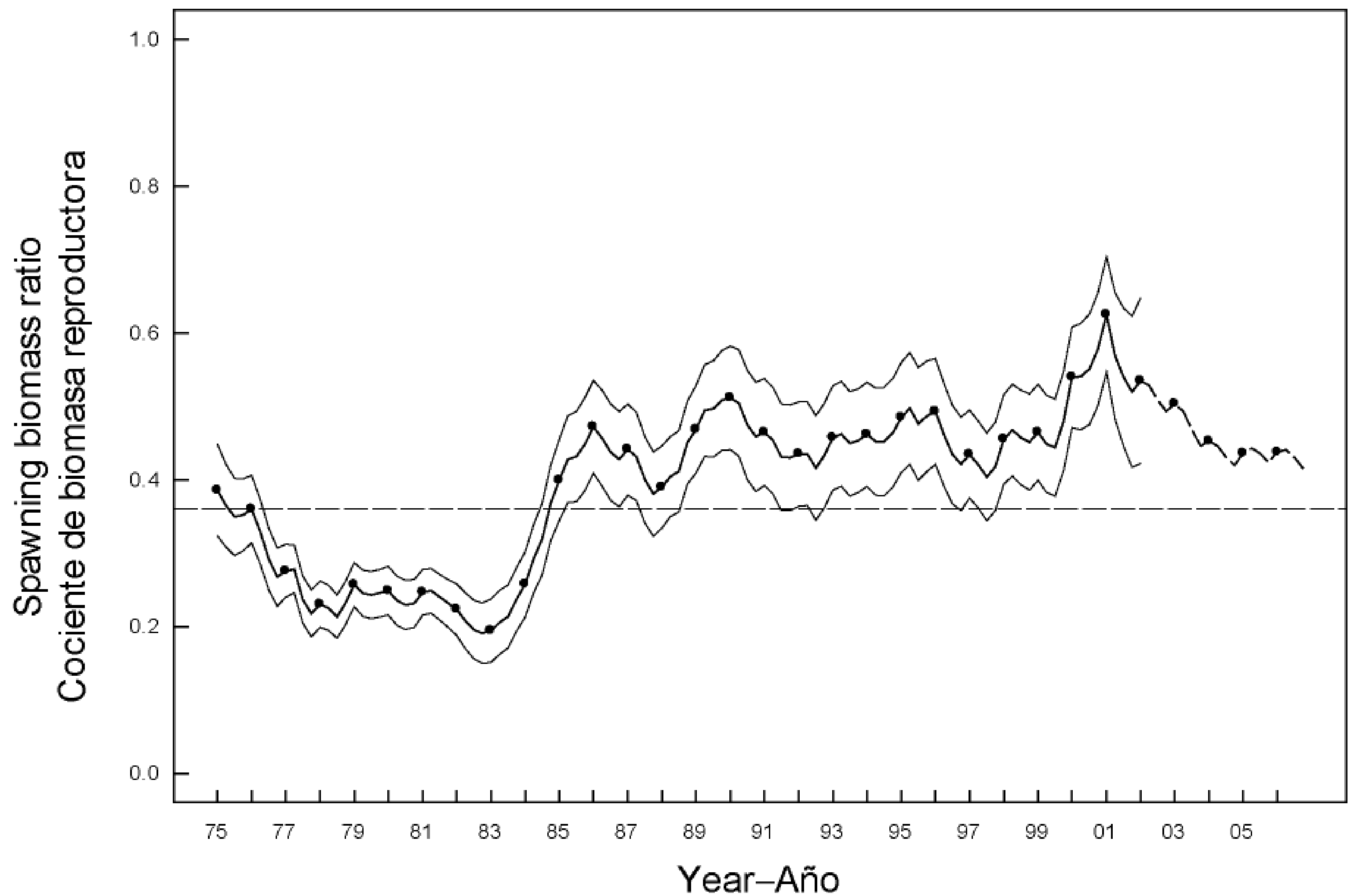


FIGURE 5.1. Estimated time series of spawning biomass ratios (SBRs) for yellowfin tuna in the EPO. The dashed extension to the solid line represents the projected SBR under current effort and average recruitment. The thin lines represent approximate 95% confidence intervals. The dashed horizontal line (at about 0.36) identifies the SBR at AMSY.

FIGURA 5.1. Series de tiempo estimadas de los cocientes de biomasa reproductora (SBR) de atún aleta amarilla en el OPO. La extensión de trazos de la línea sólida representa el SBR proyectado con el esfuerzo y el reclutamiento medio actuales. Las líneas delgadas representan los intervalos de confianza de 95% aproximados. Las líneas de trazos horizontal (en aproximadamente 0,36) identifican el SBR en RPMS.

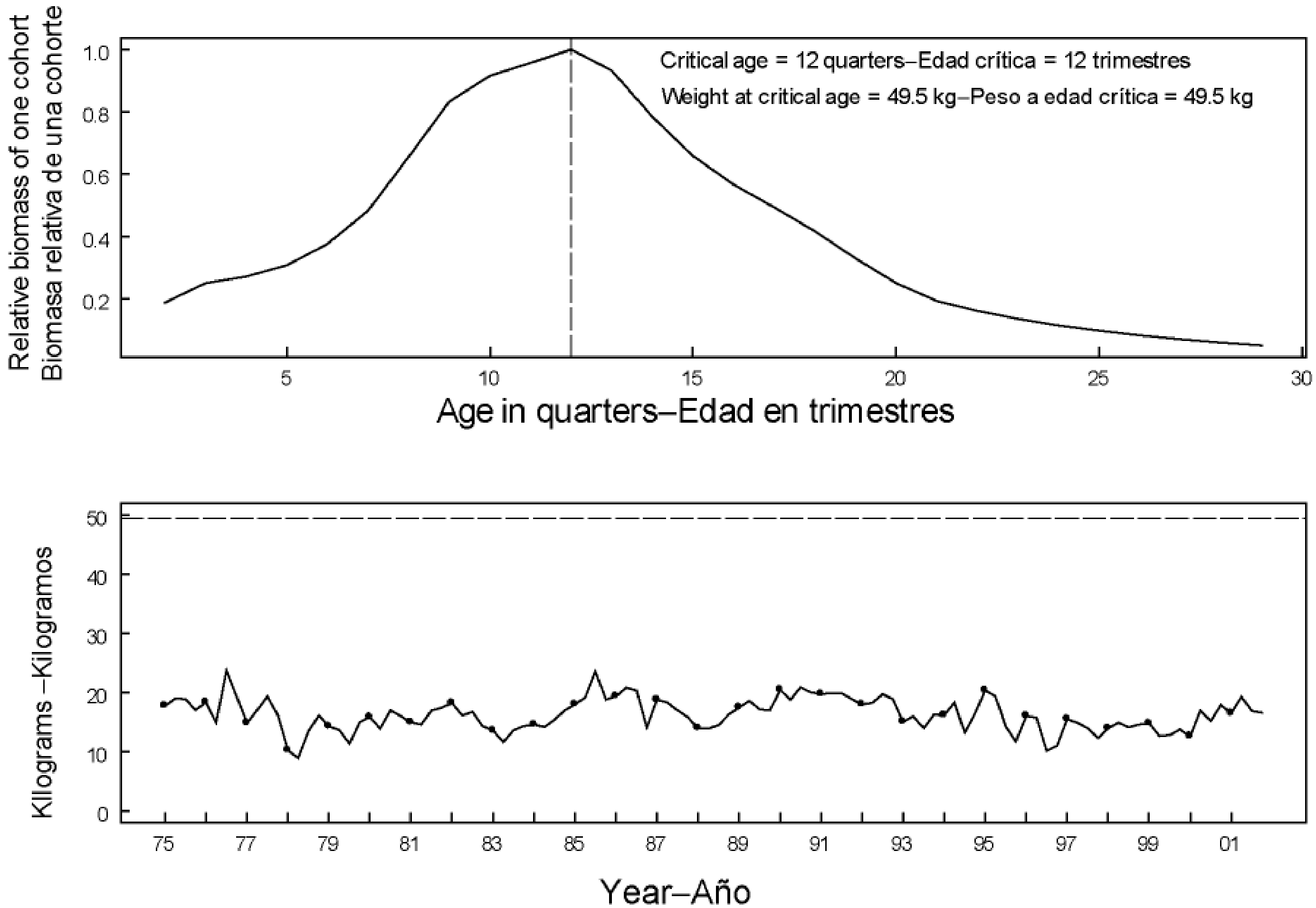


FIGURE 5.2. Combined performance of all fisheries that take yellowfin tuna in the EPO at achieving the maximum yield per recruit. The upper panel illustrates the growth (in weight) of a single cohort of yellowfin, and identifies the "critical age" and "critical weight" (Section 5). The lower panel illustrates the estimated average weight of yellowfin tuna caught in all fisheries combined. The critical weight is drawn as the horizontal dashed line in the lower panel, and is a possible reference point for determining whether the fleet has been close to maximizing the yield per recruit.

FIGURA 5.2. Desempeño combinado de todas las pesquerías que capturan atún aleta amarilla en el OPO con respecto al rendimiento por recluta máximo. El recuadro superior ilustra el crecimiento (en peso) de una sola cohorte de aleta amarilla, e identifica la "edad crítica" y el "peso crítico" (Sección 5). El recuadro inferior ilustra el peso medio estimado del atún aleta amarilla capturado en todas las pesquerías combinadas. El peso crítico es representado por la línea de trazos horizontal en el recuadro inferior, y constituye un posible punto de referencia para determinar si la flota estuvo cerca de maximizar el rendimiento por recluta.

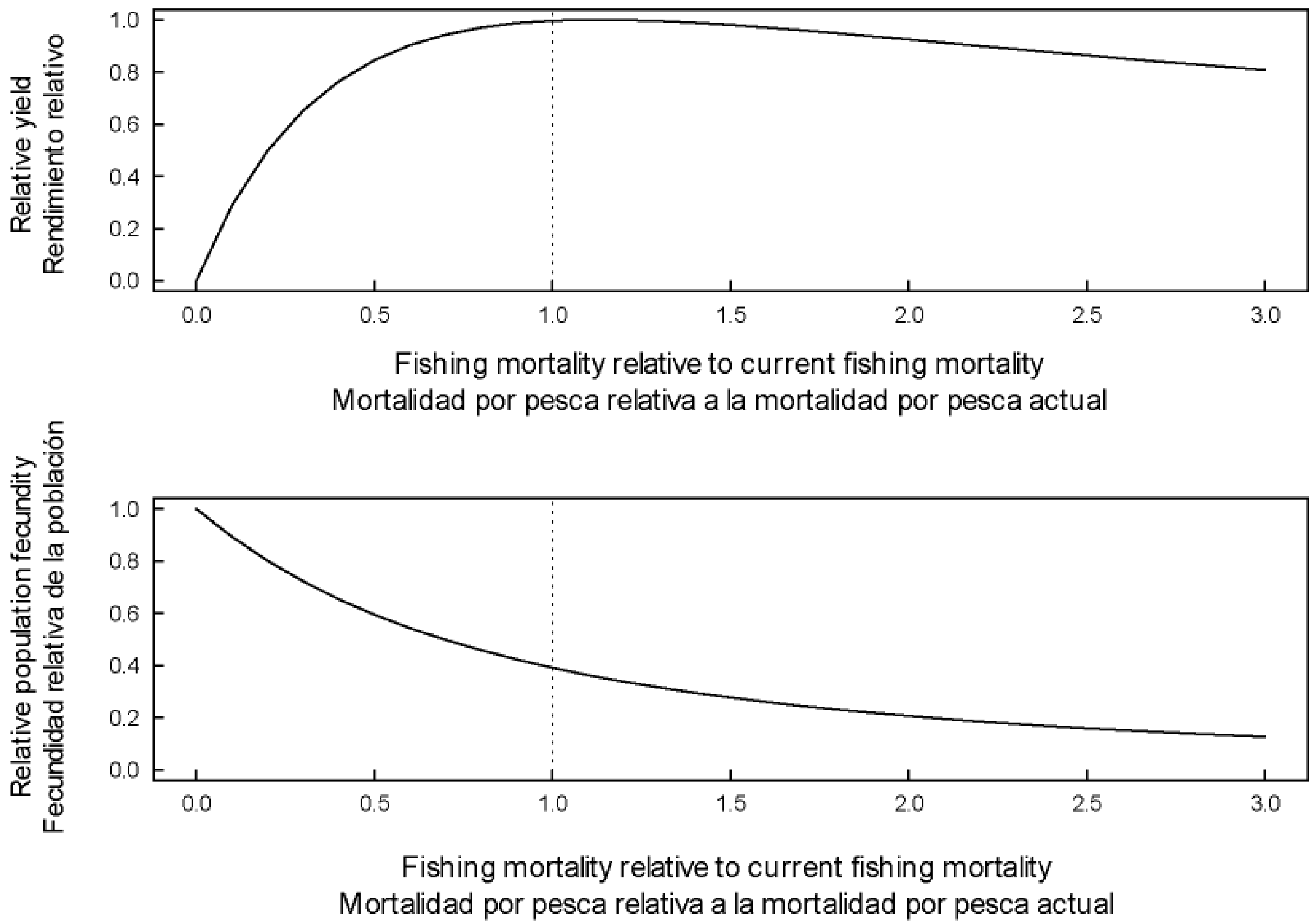


FIGURE 5.3. Predicted effects of long-term changes in fishing effort on the yield (upper panel) and spawning biomass (lower panel) of yellowfin tuna under average environmental conditions, constant recruitment, and the current age-specific selectivity pattern of all fisheries combined. The yield estimates are scaled so that the AMSY 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 5.3. Efectos predichos de cambios a largo plazo en el esfuerzo de pesca sobre el rendimiento (recuadro superior) y la biomasa reproductora (recuadro inferior) de 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 RPMS esté en 1,0, y las de biomasa reproductora para que ésta equivalga a 1,0 en ausencia de explotación.

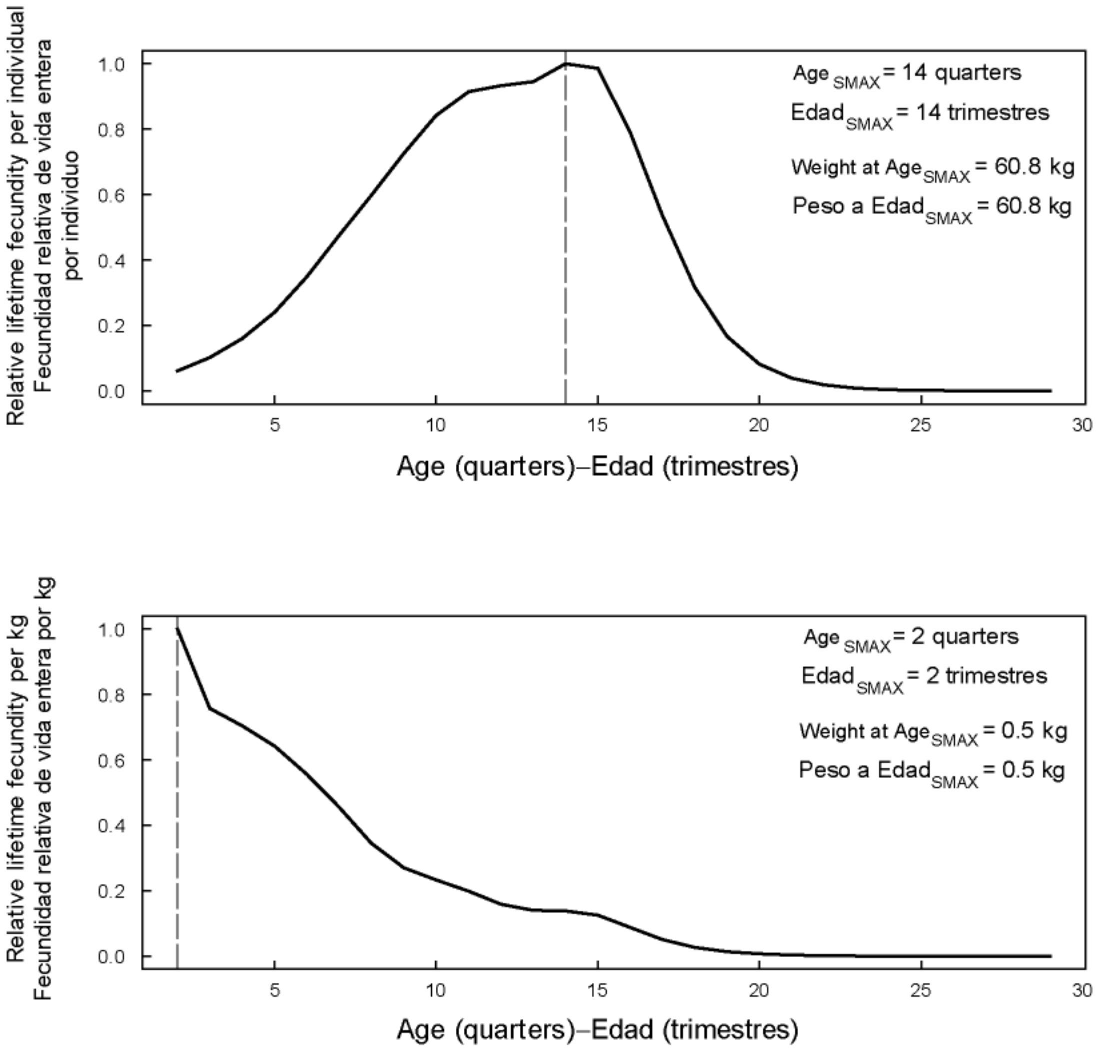


FIGURE 5.4. Marginal relative lifetime reproductive potential at age based on individuals (upper panel) and weight (lower panel). Age_{SMAX} is the age at which the maximum marginal relative lifetime reproductive potential is realized. The vertical lines indicate the locations of Age_{SMAX} **.**

FIGURA 5.4. Potencial de reproducción relativo marginal a edad basado en individuos (recuadro superior) y peso (recuadro inferior). $Edad_{SMAX}$ es la edad a la cual se logra el potencial de reproducción relativo marginal máximo. Las líneas verticales señalan la posición de $Edad_{SMAX}$

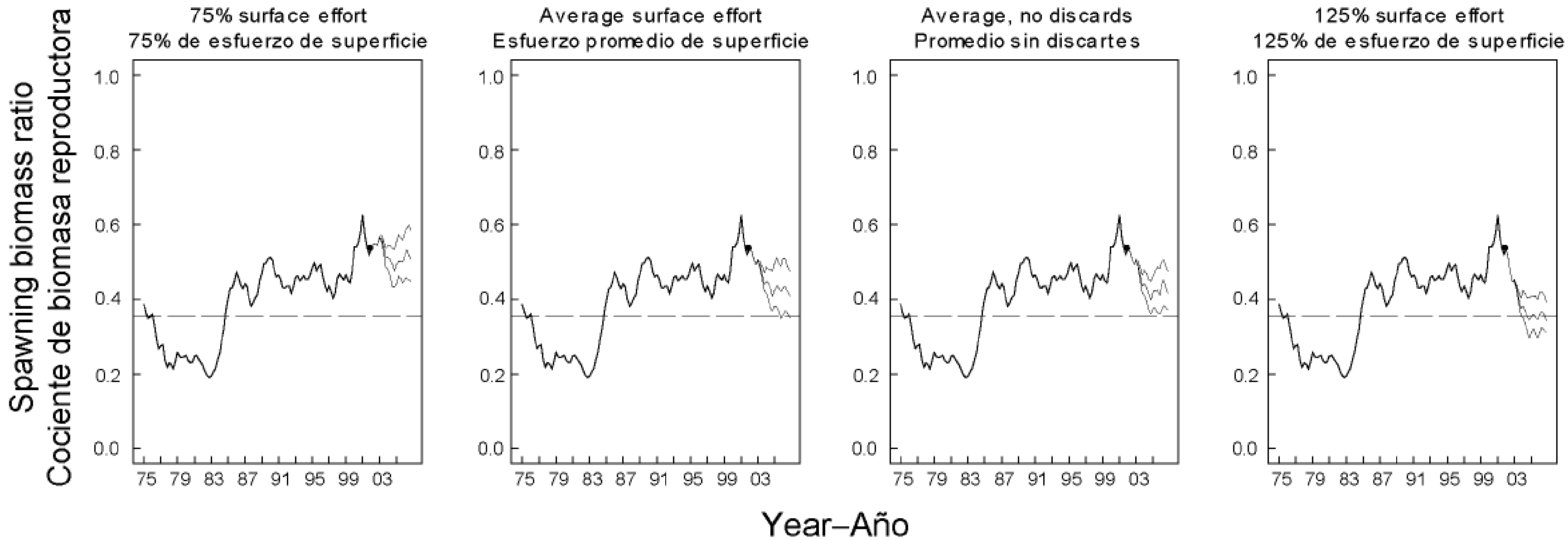


FIGURE 6.1. Simulated SBRs during 2002-2006 for yellowfin tuna in the EPO. Each panel illustrates the results of 101 simulations using different scenarios described in Sections 6.1 and 6.2. The thin lines to the right of the each dot represent the median and 20% and 80% quantiles of the simulated SBRs. The dashed horizontal lines (at 0.36) identify SBR_{AMSY} (Section 5.3).

FIGURA 6.1. SBR simulados durante 2002-2006 para el atún aleta amarilla en el OPO. Cada recuadro ilustra los resultados de 101 simulaciones usando distintos escenarios descritos en las Secciones 6.1 y 6.2. Las líneas delgadas a la derecha de cada punto representan la mediana y los cuantiles de 20% y 80% de los SBR simulados. Las líneas de trazos horizontales (en 0.36) identifican SBR_{RPMS} (Sección 5.3).

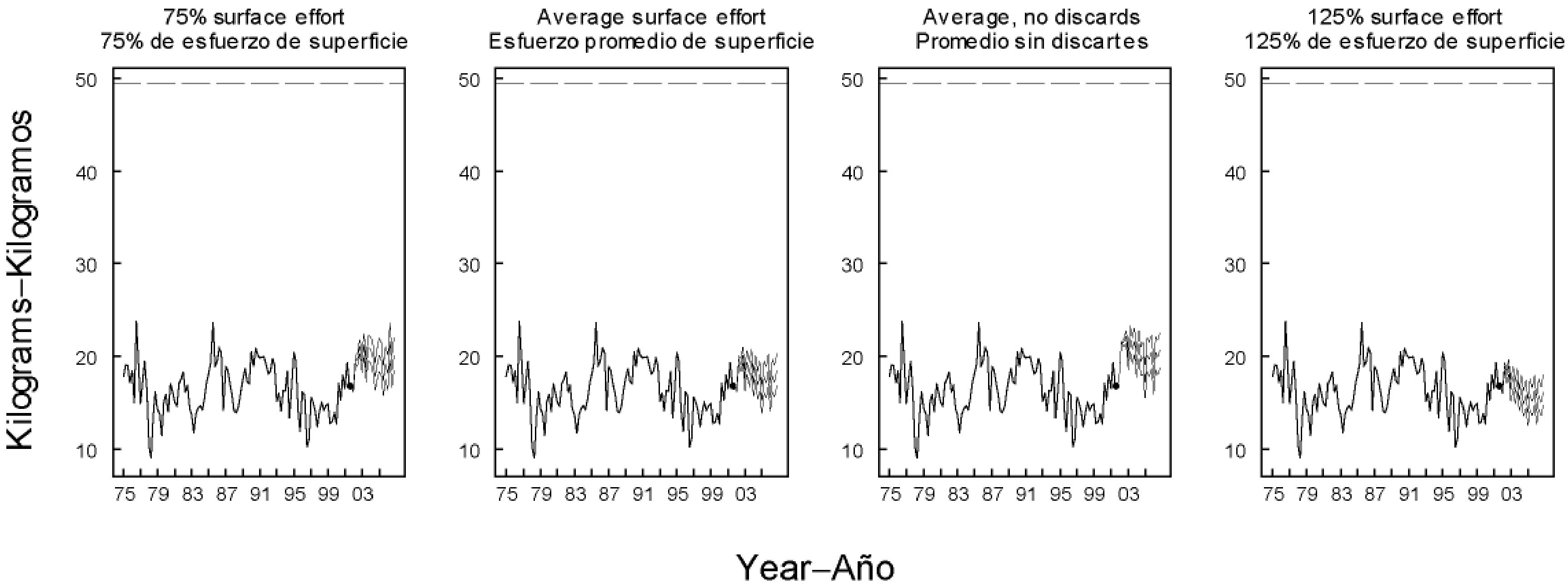


FIGURE 6.2. Simulated estimates of the average weight of yellowfin tuna in the combined catch during 2002-2006. Each panel illustrates the results of 101 simulations using different scenarios described in Sections 6.1 and 6.2. The thin lines to the right of the each dot represent the median and 20% and 80% quantiles of the simulated average weights. The estimated critical weight is drawn as a horizontal dashed line in each panel.

FIGURA 6.2. Estimaciones simuladas del peso medio del atún aleta amarilla en la captura combinada durante 2002-2006. Cada recuadro ilustra los resultados de 101 simulaciones usando distintos escenarios descritos en las Secciones 6.1 y 6.2. Las líneas delgadas a la derecha de cada punto representan la mediana y los cuantiles de 20% y 80% de los pesos medios simulados. La línea de trazos horizontal en cada recuadro representa el peso crítico estimado.

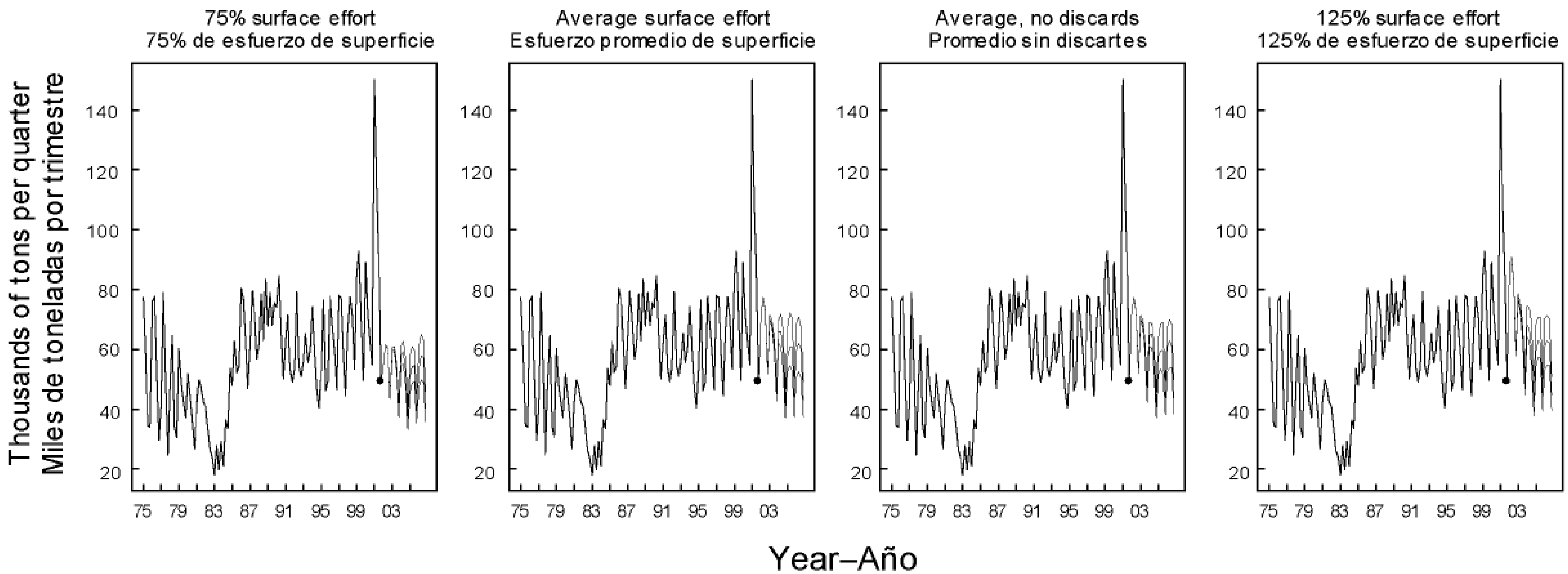


FIGURE 6.3. Simulated catches of yellowfin tuna taken by the primary surface fleet (Fisheries 1-10) during 2002-2006. Each panel illustrates the results of 101 simulations using different scenarios described in Sections 6.1 and 6.2. The thin lines to the right of the each dot represent the median and 20% and 80% quantiles of the simulated catches taken by these fisheries.

FIGURA 6.3. Capturas simuladas de atún aleta amarilla por la flota primaria de superficie (Pesquerías 1-10) durante 2002-2006. Cada recuadro ilustra los resultados de 101 simulaciones usando distintos escenarios descritos en las Secciones 6.1 y 6.2. Las líneas delgadas a la derecha de cada punto representan la mediana y los cuantiles de 20% y 80% de las capturas simuladas de estas pesquerías.

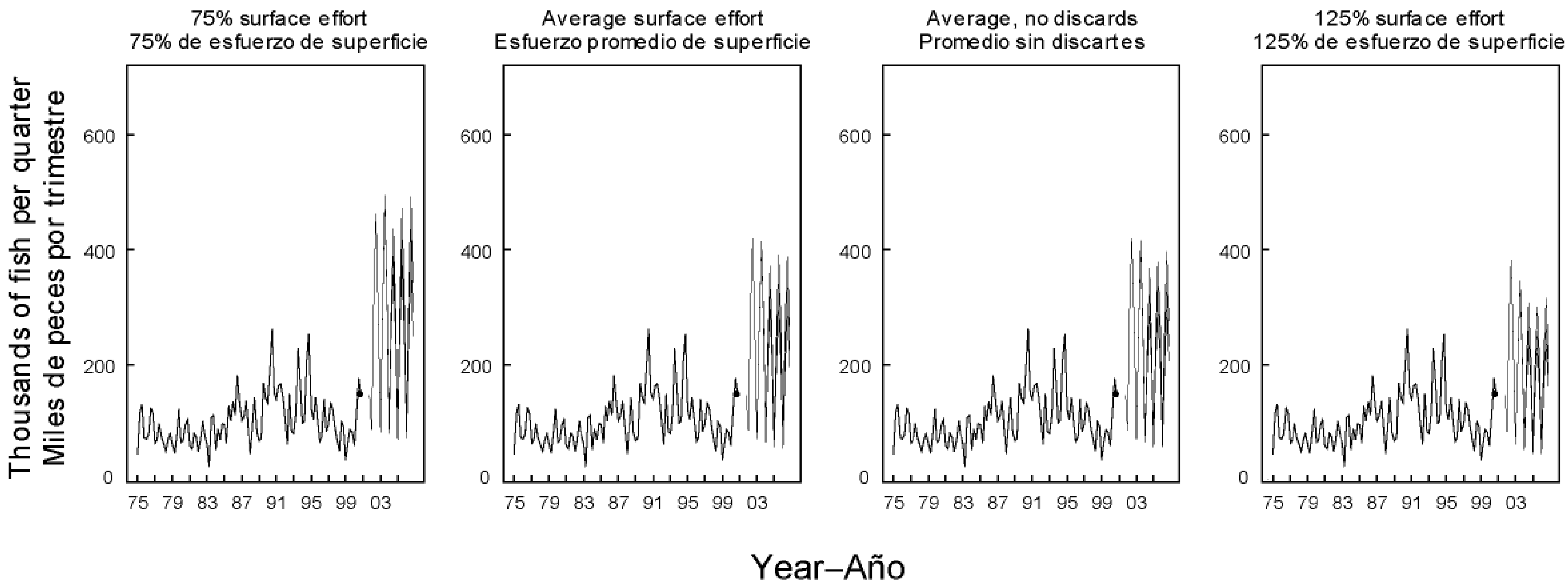


FIGURE 6.4. Simulated catches of yellowfin tuna taken by the longline fleet (Fisheries 11 and 12) during 2002-2006. Each panel illustrates the results of 101 simulations using different scenarios described in Sections 6.1 and 6.2. The thin lines to the right of the each dot represent the median and 20% and 80% quantiles of the simulated catches of the fish taken by these fisheries.

FIGURA 6.4. Capturas simuladas de atún aleta amarilla por la flota palangrera (Pesquerías 11 y 12) durante 2002-2006. Cada recuadro ilustra los resultados de 101 simulaciones usando distintos escenarios descritos en las Secciones 6.1 y 6.2. Las líneas delgadas a la derecha de cada punto representan la mediana y los cuantiles de 20% y 80% de las capturas simuladas de estas pesquerías.

TABLE 2.1. Fisheries defined by the IATTC staff for the stock assessment of yellowfin tuna in the EPO. PS = purse seine; BB = baitboat; LL = longline; FLT = sets on floating objects; UNA = sets on unassociated fish; DOL = 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; BB = carnada; LL = palangre; FLT = lance sobre objeto flotante; UNA = lance sobre atunes no asociados; DOL = 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	FLT	1975-2001	11-12	landings + discards from inefficiencies in fishing process–descargas + descartes de ineficacias en el proceso de pesca
2	PS	FLT	1975-2001	7, 9	
3	PS	FLT	1975-2001	5-6, 13	
4	PS	FLT	1975-2001	1-4, 8, 10	
5	PS	UNA	1975-2001	1-4, 8, 10	landings + discards–descargas + descartes
6	PS	UNA	1975-2001	5-7, 9, 11-13	
7	PS	DOL	1975-2001	2-3, 10	
8	PS	DOL	1975-2001	1, 4-6, 8, 13	
9	PS	DOL	1975-2001	7, 9, 11-12	
10	BB		1975-2001	1-13	landings only—descargas solamente
11	LL		1975-2001	N of-de 15°N	
12	LL		1975-2001	S of-de 15°N	
13	PS	FLT	1993-2001	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	FLT	1993-2001	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	FLT	1993-2001	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	FLT	1993-2001	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 relative 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	118,619	432,753	0.62
1976	109,468	394,151	0.58
1977	162,514	299,806	0.44
1978	113,537	245,173	0.37
1979	117,692	279,321	0.41
1980	107,012	269,135	0.40
1981	73,110	264,950	0.39
1982	114,470	231,076	0.36
1983	177,927	206,490	0.31
1984	168,258	286,540	0.41
1985	134,148	432,549	0.64
1986	177,887	493,496	0.76
1987	251,341	475,510	0.71
1988	182,273	437,002	0.62
1989	156,288	512,948	0.75
1990	157,149	537,909	0.82
1991	186,180	487,847	0.74
1992	182,364	463,707	0.70
1993	157,150	486,482	0.73
1994	157,771	499,103	0.74
1995	168,872	517,740	0.78
1996	204,616	523,764	0.79
1997	171,984	490,262	0.70
1998	263,249	496,094	0.73
1999	205,071	493,646	0.74
2000	217,886	578,156	0.86
2001	187,220	676,756	1.00
2002		541,390	0.86

TABLE 4.2. Estimates of the average sizes of yellowfin tuna. The ages are expressed in quarters after hatching.
TABLA 4.2. Estimaciones del tamaño medio de atún aleta amarilla. Se expresan las edades en trimestres desde la cría.

Age (quarters)	Average length (cm)	Average weight (kg)	Age (quarters)	Average length (cm)	Average weight (kg)
Edad (trimestres)	**Talla media (cm)**	**Peso medio (kg)**	**Edad (trimestres)**	**Talla media (cm)**	**Peso medio (kg)**
2	30.00	0.51	16	151.78	76.23
3	38.71	1.13	17	159.81	89.37
4	45.85	1.90	18	166.60	101.61
5	53.98	3.14	19	169.95	108.06
6	63.86	5.28	20	170.01	108.17
7	75.36	8.79	21	170.01	108.17
8	88.79	14.58	22	173.37	114.91
9	102.40	22.63	23	176.51	121.45
10	112.67	30.40	24	179.43	127.77
11	121.92	38.78	25	182.16	133.84
12	131.95	49.49	26	184.69	139.68
13	138.06	56.90	27	187.06	145.27
14	141.06	60.81	28	189.26	150.61
15	145.28	66.60	29	191.31	155.71

TABLE 5.1. AMSY and related quantities for the base case and the stock recruitment relationship sensitivity analysis.
TABLA 5.1. RPMS y cantidades relacionadas para el caso base y los análisis de sensibilidad de la relación stock-reclutamiento.

	Basecase Caso base	**h = 0.75**
AMSY–RPMS	275,925	283,847
B_{msy} –B_{rms}	383,651	501,836
S_{msy}—S_{rms}	5,459	7186
C_{2001}/AMSY—C_{2001}/RPMS	1.59	1.55
B_{2002}/B_{AMSY} –B_{2002}/B_{RMS}	1.41	1.09
S_{2002}/S_{AMSY} –S_{2002}/S_{RMS}	1.5	1.15
$S_{AMSY}/S_{F=0}$ –$S_{RPMS}/S_{F=0}$	0.36	0.39
F multiplier—Multiplicador de *F*	1.12	0.83

TABLE 5.2. Estimates of the AMSY (value in brackets represents the component of AMSY made up of discards of small tunas), and its associated quantities, obtained by assuming that each fishery maintains its current pattern of age-specific selectivity (Figure 4.4) and that each fishery is the only fishery operating in the EPO. The estimates of the AMSY, B_{AMSY}, and S_{AMSY} are in metric tons.
TABLA 5.2. Estimaciones del RPMS (el valor en paréntesis representa el componente de RPMS compuesto de descartes de atunes pequeños) y sus cantidades asociadas, obtenidas suponiendo que cada pesquería mantiene su patrón actual de selectividad por edad (Figure 4.4) y que cada pesquería es la única operando en el OPO. Se expresan las estimaciones de RPMS, B_{RPMS}, y S_{RPMS} en toneladas métricas.

Fishery	AMSY	$\boldsymbol{B}_{\mathbf{AMSY}}$	$\boldsymbol{S}_{\mathbf{AMSY}}$	$\boldsymbol{B}_{\mathbf{AMSY}}/\boldsymbol{B}_{F=0}$	$\boldsymbol{S}_{\mathbf{AMSY}}/\boldsymbol{S}_{F=0}$	***F* multiplier**
Pesquería	**RPMS**	$\boldsymbol{B}_{\mathbf{RPMS}}$	$\boldsymbol{S}_{\mathbf{RPMS}}$	$\boldsymbol{B}_{\mathbf{RPMS}}/\boldsymbol{B}_{F=0}$	$\boldsymbol{S}_{\mathbf{RPMS}}/\boldsymbol{S}_{F=0}$	**Multiplica-dor de *F***
1	252,060 (2,197)	338,703	4,579	0.28	0.30	26.1
2	190,841 (15,026)	341,264	4,664	0.28	0.30	25.5
3	131,883 (12,702)	215,353	2,659	0.18	0.17	28.3
4	188,828 (10,968)	332,511	4,558	0.28	0.30	39.6
5	210,915	278,760	3,591	0.23	0.23	11.4
6	248,827	353,460	4,883	0.29	0.32	10.8
7	314,863	388,424	5,438	0.32	0.35	8.1
8	280,658	329,700	4,395	0.27	0.29	6.4
9	361,414	489,645	7,240	0.41	0.47	25.5
10	121,950	24,171	278	0.02	0.02	206.8
11	359,332	464,253	6,777	0.38	0.44	1302.1
12	364,777	426,196	6,075	0.35	0.40	26.1

TABLE 6.1. Summary of the outcomes from 100 simulations using the scenarios described in Sections 6.1 and 6.2. "Quantiles" identify the levels at which 20%, 50%, and 80% of the predicted outcomes are less than or equal to the value provided in the table. The 50% quantile is equal to the median.
TABLA 6.1. Resumen de los resultados de 100 simulaciones usando los escenarios descritos en las Secciones 6.1 y 6.2. Los "cuantiles" identifican los niveles a los cuales el 20%, 50%, y 80% de los resultados predichos son menores o iguales al valor en la tabla. El cuantil de 50% equivale a la mediana.

	75% surface effort	**Average surface effort**	**Average surface effort, no discards**	**125% surface effort**
Cuantil	**75% del esfuerzo de superficie**	**Esfuerzo de superficie medio**	**Esfuerzo de superficie medio, sin descartes**	**125% del esfuerzo de superficie**
SBR for fourth quarter of 2006–SBR para el cuarto trimestre de 2006				
20%	0.45	0.35	0.37	0.31
50%	0.51	0.41	0.42	0.34
80%	0.58	0.48	0.47	0.39
Average weight (kg) of fish in the combined catch during 2006– Peso medio (kg) de los peces en la captura combinada durante el cuarto trimestre de 2006				
20%	17.4	15.4	17.7	13.4
50%	20.0	17.5	19.7	15.3
80%	22.0	19.5	21.8	17.2
Median of quarterly catches (mt) by the primary surface fleet (Fisheries 1-10) during 2006– Mediana de las capturas trimestrales (tm) por la flota primaria de superficie (Pesquerías 1-10) durante 2006				
20%	43,666	45,466	47,072	48,170
50%	52,140	56,350	56,386	58,119
80%	61,250	66,162	67,166	68,712
Median of quarterly catches, in thousands of fish, by the longline fleet (Fisheries 11 and 12) during 2006–Mediana de las capturas trimestrales, en miles de peces, por la flota palangrera (Pesquerías 11 y 12) durante 2006				
20%	93	79	78	62
50%	290	225	229	182
80%	384	307	305	245

APPENDIX A: SENSITIVITY ANALYSIS
ANEXO A: ANALISIS DE LA SENSIBILIDAD

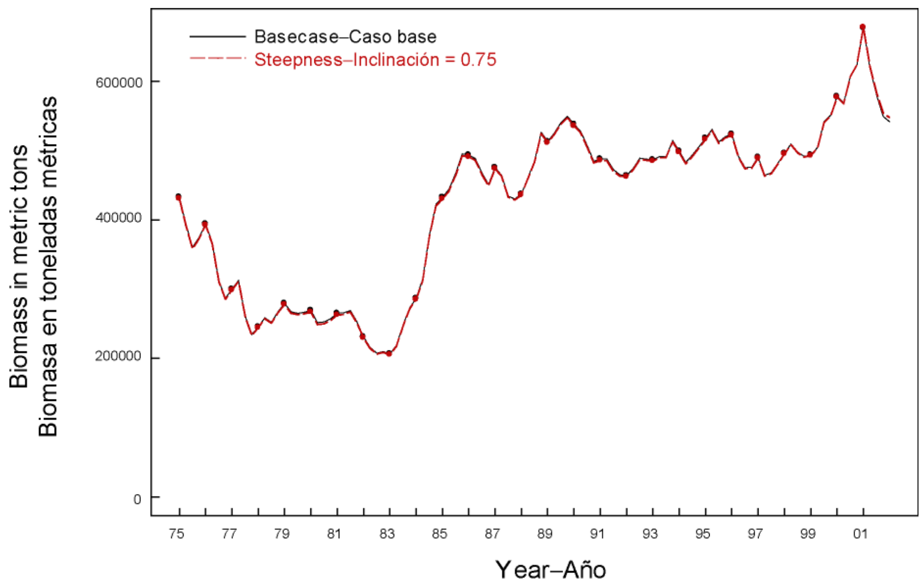


FIGURE A.1. Comparison of estimates of biomass from the analysis without a stock recruitment relationship (base case) and with a stock recruitment relationship (steepness = 0.75).
FIGURA A.1. Comparación de las estimaciones de biomasa del análisis sin relación stock-reclutamiento (caso base) y con (inclinación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

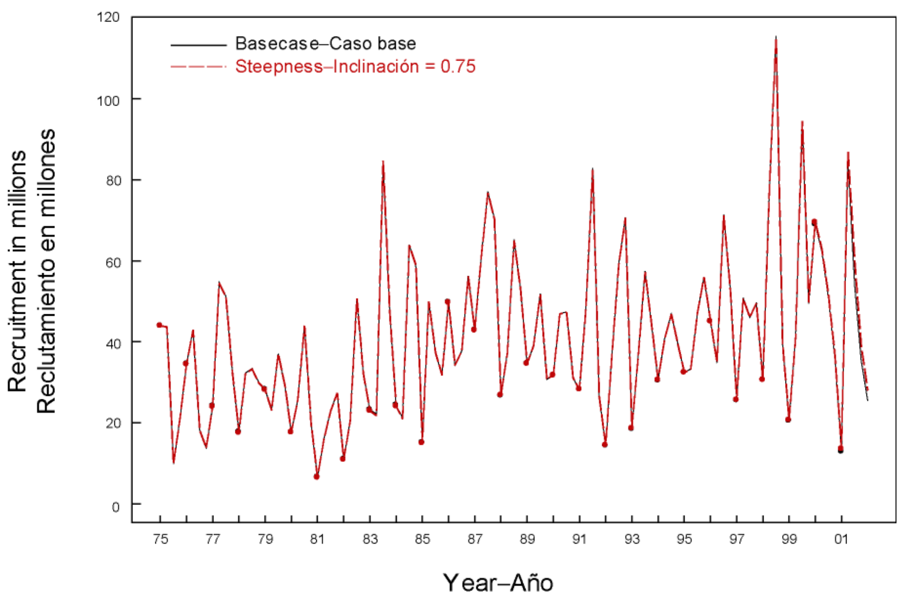


FIGURE A.2. Comparison of estimates of recruitment from the analysis without a stock recruitment relationship (base case) and with a stock recruitment relationship (steepness = 0.75).
FIGURA A.2. Comparación de las estimaciones de reclutamiento del análisis sin relación de reclutamiento de stock (caso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

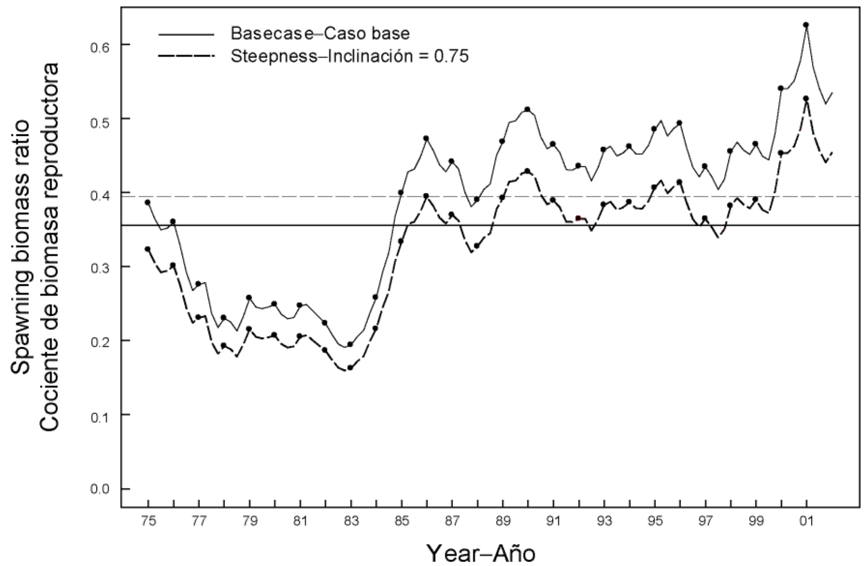


FIGURE A.3. Comparison of estimates of the spawning biomass ratio (SBR) from the analysis without a stock recruitment relationship (base case) and with a stock recruitment relationship (steepness = 0.75). The horizontal lines represent the SBR associated with AMSY.
FIGURA A.3. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) del análisis sin (caso base) y con relación stock-reclutamiento (inclinación = 0,75). Las líneas horizontales representan el SBR asociado con el RPMS.

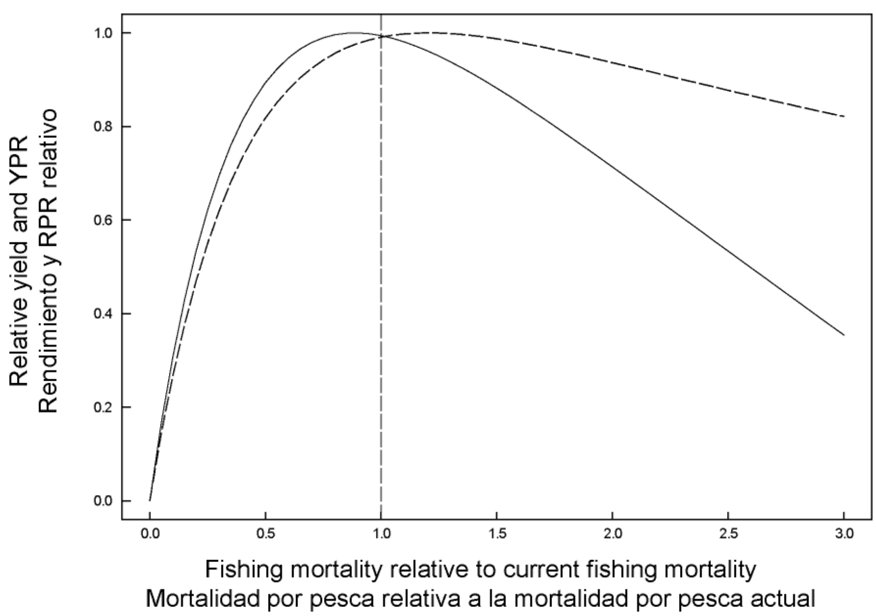


FIGURE A.4. Comparison of the relative yield (solid line) with the relative yield per recruit (dashed line) when the stock assessment model has a stock recruitment relationship (steepness = 0.75).
FIGURA A4. Comparación del rendimiento relativo (línea sólida) con el rendimiento por recluta relativo (línea de trazos) cuando el modelo de evaluación del stock incluye una relación stock-reclutamiento (inclinación = 0.75).

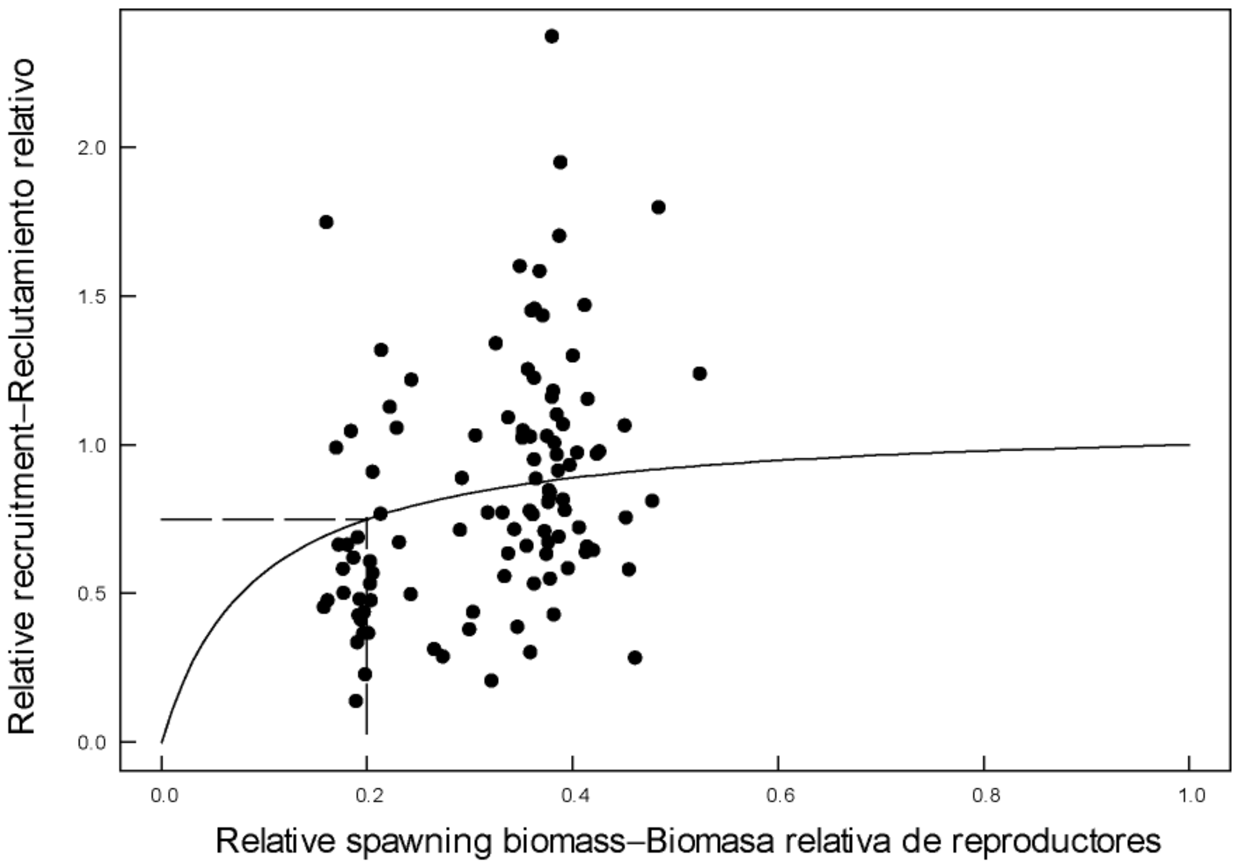


FIGURE A.5. Recruitment plotted against spawning biomass when the analysis has a stock recruitment relationship (steepness = 0.75).
FIGURA A.5. Reclutamiento graficado contra biomasa reproductora cuando el análisis incluye una relación stock-reclutamiento (inclinación = 0,75).

APPENDIX B: ADDITIONAL RESULTS FROM THE BASECASE ASSESSMENT

This appendix contains additional results from the basecase 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.

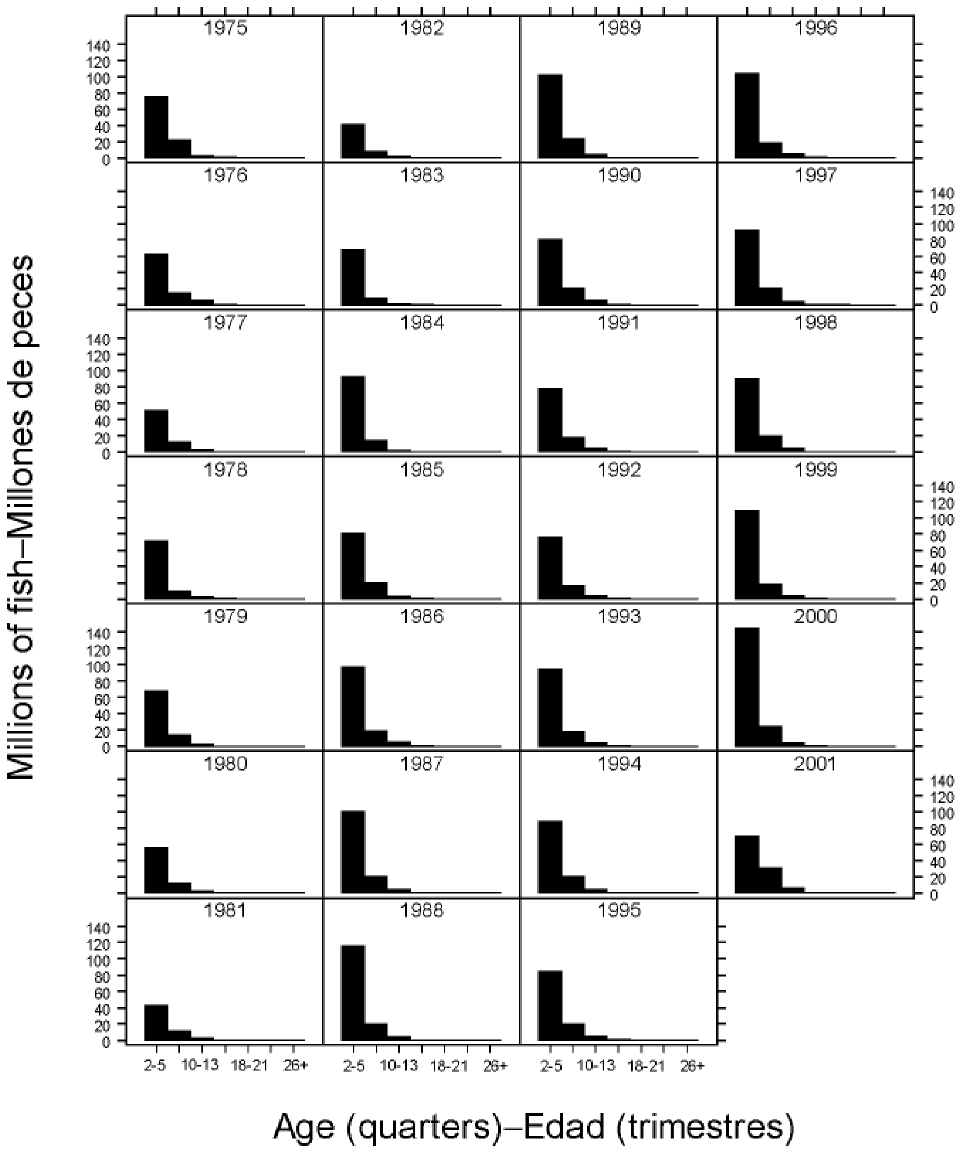


FIGURE B.1. Numbers of yellowfin tuna present in the EPO on 1 January of each calendar year.
FIGURA B.1. Número de atunes aleta amarilla presentes en el OPO el 1 de enero de cada año.

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

	Age (quarters) – Edad (trimestres)						
	2-5	**6-9**	**10-13**	**14-17**	**18-21**	**22-25**	**26+**
1975	0.0946	0.5982	1.1387	0.5761	0.1608	0.1878	0.3192
1976	0.1837	0.7159	1.2273	0.7281	0.4772	0.6184	1.2875
1977	0.2079	0.7934	1.2605	0.9289	0.5682	0.7793	1.5157
1978	0.3482	0.8789	1.0850	0.7016	0.3249	0.4855	0.7745
1979	0.2399	0.8467	1.2069	0.8183	0.3919	0.4854	1.0337
1980	0.1895	0.7009	1.2318	0.6376	0.3097	0.3302	0.6638
1981	0.2982	0.7169	1.1794	0.6097	0.4438	0.5346	1.1290
1982	0.1888	0.6724	1.0495	0.6495	0.3480	0.4761	0.8096
1983	0.1556	0.4031	0.7143	0.3539	0.2785	0.3475	0.6101
1984	0.1184	0.4280	0.7355	0.2876	0.2380	0.2993	0.5557
1985	0.0864	0.5373	0.8680	0.3399	0.2041	0.2706	0.4548
1986	0.1214	0.6222	1.1031	0.5407	0.2084	0.2370	0.3980
1987	0.1385	0.6269	1.1251	0.3919	0.1822	0.2499	0.3847
1988	0.1914	0.6545	1.0798	0.3656	0.1824	0.2512	0.4245
1989	0.1401	0.5973	0.9563	0.5435	0.2371	0.3131	0.5916
1990	0.1389	0.5567	1.0586	0.5831	0.2595	0.3212	0.5299
1991	0.1389	0.5364	0.9526	0.4269	0.2496	0.2940	0.5382
1992	0.1571	0.5744	0.9773	0.3502	0.1448	0.1779	0.2794
1993	0.1746	0.5717	0.8625	0.3394	0.1753	0.2507	0.3500
1994	0.1280	0.5077	0.9520	0.5078	0.3177	0.3873	0.7681
1995	0.1126	0.4387	0.8408	0.3533	0.2465	0.2831	0.5894
1996	0.1461	0.6092	0.9273	0.2811	0.1490	0.2034	0.3288
1997	0.1599	0.6087	1.1212	0.5487	0.3389	0.4208	0.8963
1998	0.1788	0.5840	0.9509	0.4350	0.1873	0.2504	0.4796
1999	0.2112	0.6760	1.1470	0.4491	0.1190	0.1575	0.2722
2000	0.1273	0.5527	0.9676	0.4259	0.2600	0.3424	0.6782
2001	0.2301	0.6896	1.4864	0.8614	0.5593	0.6452	1.5176