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STATUS OF YELLOWFIN TUNA IN THE EASTERN PACIFIC OCEAN IN 2003 AND OUTLOOK FOR 2004

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CONTENTS

1. EXECUTIVE SUMMARY

This report presents the most current stock assessment of yellowfin tuna (*Thunnus albacares*) in the eastern Pacific Ocean (EPO). An age-structured, catch-at-length analysis (A-SCALA) is used to conduct this assessment. The analysis method is described by Maunder and Watters (2003), and readers are referred to that report for technical details. The A-SCALA method was used for four previous assessments of yellowfin in the EPO.

A mid-year technical meeting on reference points was held in La Jolla, California, USA, on October 27-29, 2003. The outcome from this meeting was (1) a set of general recommendations on the use of reference points and research, and (2) specific recommendations for the IATTC stock assessments. Several of the recommendations have been incorporated into this assessment.

The stock assessment requires a substantial amount of information. Data on retained catch, 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 2004 differs from the previous one carried out for 2003 in the following ways:

1. Catch and length-frequency data for the surface fisheries have been updated to include new data for 2003.
2. Effort data for the surface fisheries have been updated to include new data for 2003 and revised data for 1975 to 2002.
3. Catch data for the Japanese longline fisheries have been updated to include new data for 2002.
4. Catch data for the longline fisheries of Chinese Taipei have been updated for 1975 to 1999 and new data added for 2000 and 2001.

5. Catch data for the longline fisheries of the Peoples Republic of China have been included for 2001 and 2002.
6. Catch data for the longline fisheries of the Republic of Korea have been updated for 1987 to 1997 and new data added for 1998-2002.
7. Longline effort data based on neural-network standardization of catch per unit of effort have been updated to include data for 2001.
8. Longline catch-at-length data for 1975-2001 were updated and new data added for 2002.
9. Future projections are based on a new method that allows the inclusion of parameter uncertainty in the calculation of confidence intervals for future quantities.

Significant levels of fishing mortality have been observed in the yellowfin tuna fishery in the EPO. These levels are greatest for middle-aged fish (except for the estimates for the oldest fish, which is an artifact of the model). Both recruitment and exploitation have had substantial impacts on the biomass trajectory. Dolphin associated fishing has had the largest impact on the yellowfin tuna popualtion. It appears that the yellowfin population has experienced two different productivity regimes (1975-1983 and 1984-2001), with greater recruitment during the second regime. The two recruitment regimes correspond to two regimes in biomass, the high-recruitment regime corresponding to greater biomasses. The spawning biomass ratio (the ratio of the spawning biomass to that for the unfished stock; SBR) of yellowfin in the EPO was below the level capable of supporting 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 slightly below the SBR level at AMSY. The effort levels are estimated to be less than those capable of supporting 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. These simulations were carried out using the average recruitment for the 1975-2002 period. If they had been carried out using the average recruitment for the 1984-2002 period it is likely that the estimates of SBR and catches would be greater.

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 to 2003.

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 pole-and-line (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 diverted to 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.

Under 2003 levels of effort the biomass is predicted to increase during 2004, but then decrease in the following years. SBR is predicted to be above the level that will produce AMSY at the start of 2005, but drop below that level in the future. Closing the surface fisheries for six weeks is predicted to only slightly increase the biomass levels. Greater restrictions on the floating-object fishery cause only a small increase in biomass. Closing the dolphin fishery would cause the greatest increase in biomass.

A sensitivity analysis was carried out to estimate 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 model. The results from the analysis with a stock-recruitment relationship are more pessimistic, suggesting that the effort level is greater than that which would produce AMSY; however the yield at this effort level is still 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 most of the 2000-2002 period.

The assessment results are similar to the results from the previous assessments. The major differences occur, as expected, in the most recent years. The current assessment, and those for 2002 and 2003, indicates that the biomass increased in 2000, whereas the earlier assessments estimated a decline. In addition, SBR and the SBR required to produce AMSY have increased compared to the earlier assessments (2000 and 2001) because average recruitment has been calculated over a longer period, which includes more years from the low-recruitment regime, and changes in growth, fecundity, and current age-specific fishing mortality.

2. DATA

Catch, effort, and size-composition data for January 1975-December 2003 were used to conduct the stock assessment of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean (EPO). The data for 2003, which are preliminary, include records that had been entered into the IATTC databases as of the end of March 2003. All data are summarized and analyzed on a quarterly basis.

2.1. Definitions of the fisheries

Sixteen fisheries are defined for the stock assessment of yellowfin tuna. These fisheries are defined on the basis of gear type (purse seine, pole and line, 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 mixture 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 in previous reports (landings, discards, and catch) are described by Maunder and Watters (2001). The terminology for this report has been changed to be consistent with the terminology used in other IATTC reports. The correct usage of landings is catch landed in a given year even if it was not caught in that year. Previously, landings referred to retained catch caught in a given year. This catch will now be termed retained catch. Throughout the document the term "catch" will be used to reflect both total catch (discards plus retained catch) and retained catch and the reader is referred to the context to determine the appropriate definition.

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

New and updated catch and effort data for the surface fisheries (Fisheries 1-10 and 13-16) have been incorporated into the current assessment. The effort data for 1975 to 2002 have been updated, and catch and effort data for 2003 are new (compared to those presented by Maunder and Harley (2004) in the previous assessment of yellowfin from the EPO). Catch data for the Japanese longline fisheries have been updated to include new data for 2002. Catch data for the longline fisheries of Chinese Taipei have been updated for 1975 to 1999 and new data added for 2000 and 2001. Catch data for the longline fisheries of the Peoples Republic of China have been included for 2001 and 2002. Catch data for the longline fisheries of South Korea have been updated for 1987 to 1997 and new data added for 1998 to 2002. For this assessment, the Japanese longline data for one additional year, 2002, are available. However, detailed catch and effort data necessary to standardize the catch per unit of effort (CPUE) were available only through 2001.

2.2.1. Catch

No longline catch data is available for 2003, so effort data was assumed (see section 2.2.2) and the stock assessment model allowed to estimate the catch. Therefore, the total 2003 longline catch is a function of the assumed 2003 long line effort, the estimated number of yellowfin in 2003, and the estimated selectivities and catchabilities for the longline fisheries. Catches for the other longline fisheries for the recent years for which the data is not available are estimated using the ratio, by quarter, of the catch to the Japanese catch for the last year data is available for that fishery.

Trends in the catch of yellowfin tuna in the EPO during each quarter from January 1975 to December 2002 are shown in Figure 2.2. The majority of the catch 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), Maunder (2002), and Maunder and Harley (2004) have described the yellowfin catch in the EPO from 1975 to 2001. 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.

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

For the surface fisheries, this assessment includes updated effort data for 1975 to 2002 and new effort data for 2003.

A complex algorithm, described by Maunder and Watters (2001), was used to estimate the amount of fishing effort in days fished exerted by purse-seine vessels. The longline effort data for yellowfin have been calculated from standardized CPUE using neural networks. Detail catch, effort, hooks between floats data from the Japanese longline fleet, and environmental data were provided by Keith Bigelow of the National Marine Fisheries Service. These data were used in a neural network to produce an index of standardized CPUE (See Maunder and Harley 2004 for a description of the method). 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 relative abundance.

The IATTC databases do not contain catch and effort information from longlining operations conducted in the EPO during 2003, and detailed data required to apply the CPUE standardization were not available for 2002. To conduct the stock assessment of yellowfin tuna, the amount of longlining effort exerted during each quarter of 2002 was calculated using CPUE for the corresponding quarter for 2001 and effort for 2002. The amount of effort exerted during each quarter of 2003 was equal to the estimated effort exerted during the corresponding quarter of 2002.

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 standardized units. Maunder and Watters (2001, 2002), Maunder (2002), and Maunder and Harley (2004) discuss the historic fishing effort.

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 (2003). 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 pole-and-line fisheries catch small yellowfin, while dolphin-associated and longline fisheries catch large yellowfin. New purse-seine length-frequency data were included for 2003. Longline length-frequency data were updated for 1975-2001 and new data added for 2002.

The length frequencies of the catch during 2003 from the four floating-object fisheries were similar to those seen over the whole modeling period (compare Figures 4.2 and 4.8a). However, the unassociated fisheries and the dolphin-associated fisheries (Figures 4.8b and 4.8c) have additional large modes at about 120-130 cm. This may be related to the strong cohort that was seen in the floating-object fisheries during 1998 and 1999 (Maunder and Watters 2001), which moved through the unassociated fisheries during 1999 and 2000 (Maunder and Watters 2002) and entered the dolphin-associated fisheries in 2000. This cohort can be seen moving through the dolphin-associated fisheries length-frequency data during 2001. The appearance, disappearance, and subsequent reappearance of strong cohorts in the length-frequency data is a common phenomenon for yellowfin in the EPO. This may indicate spatial movement of cohorts or fishing effort, or inefficiencies in the length-frequency sampling. Groups of tagged fish have also disappeared and then reappeared, suggesting that vulnerability to capture fluctuates.

The length frequencies of the catch during 2001 and 2002 for the longline fisheries were available only for the southern fishery. These data showed a mode moving through the longline fishery, starting at about 125 cm, in the first quarter of 2001. This cohort was not predicted by the model.

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 to 170 cm. This sampling design may cause some bias in the estimates of variation in 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 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 in 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.

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

3.1.2. Recruitment and reproduction

The A-SCALA method allows a Beverton-Holt (1957) stock-recruitment relationship to be specified. The Beverton-Holt curve is parameterized so that the relationship between spawning biomass and recruitment is determined by estimating the average recruitment produced by an unexploited population (virgin recruitment) and a parameter called steepness. Steepness is defined as the fraction of virgin recruitment that is produced if the spawning stock size is reduced to 20% of its unexploited level, and it controls how quickly recruitment decreases when the size of the spawning stock is reduced. Steepness can vary between 0.2 (in which case recruitment is a linear function of spawning stock size) and 1.0 (in which case recruitment is independent of spawning stock size). In practice, it is often difficult to estimate steepness because of the lack of contrast in spawning stock size and the high inter-annual (and inter-quarter) variation in recruitment. 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, 2001, 2002, and 2003 assessments (Maunder and Watters 2001, 2002, Maunder 2002, maunder and Harley 2004). 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% of its expected level and not greater than four times its expected level more often than about 1% 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 movement does not bias the stock assessment results.

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: 38). Males and females are not treated separately in the current stock assessment, and *M* is treated as a rate for males and females combined. The values of quarterly *M* used in the current stock assessment are plotted in Figure 3.1. 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 2001). 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*. (Suzuki *et al.* 1998), and it appears that the mixing of fish between the EPO and the areas to the west of it is not extensive. Therefore, for the purposes of the current stock assessment, it is assumed that there is a single stock, with little or no mixing with the stock(s) 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; see Maunder and Watters 2003b for a description of the methodology). This assumption is supported by observations that spawning of yellowfin is temperature dependent (Schaefer 1998). To incorporate the possibility of an environmental influence on recruitment of yellowfin in the EPO, a temperature variable was incorporated into previous stock assessment models to determine whether there is a statistically-significant relationship between this temperature variable and estimates of recruitment. 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. Maunder (2002) correlated recruitment with the environmental time series outside the stock assessment model. For candidate variables, Maunder (2002) used the sea-surface temperature (SST) in an area consisting of two rectangles from 20°N-10°S and 100°W-150°W and 10°N-10°S and 85°W-

100°W, the total number of 1°x1° areas with average SST ≥24°C, and the Southern Oscillation Index. The data were related to recruitment, adjusted to the period of hatching. However, no relationship with these variables was found. No investigation using environmental variables was carried out in this assessment.

In previous assessments it has also 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 use of standardized longline CPUE, environmental effects on catchability were not investigated in this assessment.

4. STOCK ASSESSMENT

A-SCALA, an age-structured statistical catch-at-length analysis model (Maunder and Watters, 2003) 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 the 2002 assessment (Maunder 2002) the main changes were 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 main changes in the 2003 assessment (Maunder and Harley 2004) were the choice of weighting factors for the selectivity smoothness penalties based on cross validation and the iterative reweighting of the length-frequency sample size in a sensitivity analysis. The main change in this assessment is the removal of the seasonal effect in recruitment to allow for the new method used for future projections. However, previous analyses show that including a seasonal effect has little effect on the results.

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 2003;
2. quarterly catchability coefficients for the 16 fisheries that take yellowfin from the EPO;
3. selectivity curves for 12 of the 16 fisheries (Fisheries 13-16 have an assumed selectivity curve);
4. initial population size and age-structure;
5. mean length at age (Figure 3.2);
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).

The previous assessment (Maunder and Harley 2004) used effort averaged over the last two years (2001 and 2002) and catchability averaged, not for the last two years, but for the two years prior to those (1999 and 2000) for projections and similarly, used average fishing mortality for 1999 and 2000 for yield calculations. In this assessment effort for the last year (2003) and catchability averaged, weighted by effort to reduce the influence of extreme catchabilities in quarters where there was a closure, not for the last two years, but for the two years excluding the last year (2001 and 2002) were used for projections and similarly, average fishing mortality for 1999 and 2000 were used for yield calculations.l

4.1. Indices of abundance

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. As mentioned in section 2.2.2, CPUE for the longline fisheries was standardized using neural networks. A discussion of historical catch rates can be found in Maunder and Watters (2001, 2002), Maunder (2002), and Maunder and Harley (2004), but trends in CPUE should be interpreted with caution. Trends in estimated biomass are discussed in Section 4.2.3.

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 some fisheries have lower peaks than the observed size composition (Figure 4.2). The model also tends to over-predict for the larger yellowfin in some fisheries. A description of the size distribution of the catch for each fishery is given in Section 2.3. However, the fit to the length-frequency data for individual time periods shows much more variation (Figure 4.8).

The results presented in the following section are likely to change in future assessments because (1) future data may provide evidence contrary to these results, and (2) the assumptions and constraints used in the assessment model may change. Future changes are most likely to affect estimates of the biomass and recruitment in recent years.

4.2.1. Fishing mortality

There is variation in fishing mortality exerted by the fisheries that catch yellowfin 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 (except for the oldest few ages). There is a peak at around ages of 14-15 quarters, which corresponds to peaks in the selectivity curves for fisheries on unassociated and dolphin-associated yellowfin (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 first effect (changes in effort) was addressed in Section 2.2.1 (also see Figure 2.3); the latter two effects are discussed in the following paragraphs.

Selectivity curves estimated for the 16 fisheries defined in the stock assessment of yellowfin 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 similar in size to those caught by sets on floating objects (about 5 to 15 quarters old, Figure 4.4, Fisheries 5 and 6), but these catches contain 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 12 or more quarters, Figure 4.4, Fisheries 11 and 12). Pole-and-line gear (Fishery 10) selects small yellowfin (about 4 to 7 quarters old). The southern dolphin-associated and longline fisheries are highly selective for the oldest individuals. Because there are few fish that survive to this age, these large selectivities are most likely an artifact of the model, and do not influence the results.

Discards resulting from sorting purse-seine catches of yellowfin tuna taken in association with floating objects are assumed to be composed only of fish 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 (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 to 2003.

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

The ability of longline vessels to capture yellowfin tuna has been more variable in the northern fishery (Fishery 11), which catches fewer yellowfin, than the southern fishery (Fishery 12).

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

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

4.2.2. Recruitment

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

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 a 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 4.5.

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. A sustained period of high recruitment was estimated for 1999-2000. A large recruitment has been estimated in the second quarter of 2003, which is similar in size to the large 1998 cohort. However, there is substantial uncertainty associated with this estimate. 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, consistently greater after than before 1983. This change in recruitment levels produces a similar change in biomass (Figure 4.9). The confidence intervals for recruitment are relatively narrow, indicating that the estimates are fairly precise, except for that of the most recent year (Figure 4.7). The standard deviation of the estimated recruitment deviations (on the logarithmic scale) is 0.54, which is close to the 0.6 assumed in the penalty applied to the recruitment deviates. The average coefficient of variation (CV) of the estimates is 0.16. The estimates of uncertainty are surprisingly small, considering the inability of the model to fit modes in the length-frequency data (Figure 4.8). These modes often appear, disappear, and then reappear.

The estimates of the most recent recruitments are highly uncertain, as can be seen from the large confidence intervals (Figure 4.7), due to the limited time frame of the data available for these cohorts. In addition, the floating-object fisheries account for only a small portion of the total catch of yellowfin.

4.2.3. Biomass

Biomass is defined as the total weight of yellowfin 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 190,000 mt; it then increased rapidly during 1983-1986, and reached about 470,000 mt in 1986. Since then it has been relatively constant at about 400,000-500,000 mt, except for a peak in 2001. The confidence intervals for the biomass estimates are relatively narrow, indicating that the biomass is well estimated. The average CV of the estimates of the biomass is 0.05.

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 well estimated. The average CV of the estimates of the spawning biomass is 0.05.

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. The current method differs from Maunder and Watters (2001) in that the unfished biomass trajectory starts from a virgin population in 1975. Maunder and Watters (2001) started the unfished biomass trajectory from the estimated fished state in 1975.) 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.

Figure, 4.7b shows the impact of each fishery group on the yellowfin tuna stock. The estimates of biomass in the absence of fishing are computed as above. Then the biomass trajectory is estimated by setting in turn the effort for each fisheries group to zero. The biomass impact for each fishery group at each time step is derived as this biomass trajectory minus the biasmass trajectory with all fisheries active. When the impacts are summed for all fisheries they are greater than that of the combined impact. Therefore, the impacts are scaled so that the sum of the individual impacts equals the impact calculated when all fisheries are active.

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 to 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 less (Figure 2.3). The average weight was also greater in 1975-1977 and in the most recent few years. 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 pole-and-line fishery (about 4-5 kg), the floating-object fisheries (about 5-10 kg for Fishery 3, 10 kg for Fisheries 2 and 4, and 10-15 kg for Fishery 1), the unassociated fisheries (about 15 kg), the northern and coastal dolphin-associated fisheries (about 20-30 kg), and the southern dolphin-associated fishery and the longline fisheries (each about 40-50 kg).

4.3. Comparisons to external data sources

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

4.4. Diagnostics

A mid-year technical meeting on diagnostics was held in La Jolla, California, USA, on October 2-4, 2002.

The outcome from this meeting was (1) a set of diagnostics that should be evaluated regularly, (2) a set of diagnostics that should be evaluated periodically, and (3) a list of specific research questions. Several of the recommendations have been included in this and the previous (Maunder and Harley 2004) assessment. We present these in three sections; (a) residual plots, (b) parameter correlations, and (c) retrospective analysis.

4.4.1. Residual plots

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

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

The observed proportion of fish caught in a length class is assumed to be normally distributed around the predicted proportion with the standard deviation equal to the binomial variance, based on the observed proportions, divided by the square of the sample size (Maunder and Watters 2003). The length-frequency residuals appear to be smaller than the assumed standard deviation (Figures D1-D3), (*i.e.* the assumed sample size is too small; see Section 4.5 for a sensitivity analysis to the length-frequency sample size), they have a negative bias (Figure D1), and are more variable for some lengths than others (Figure D1), but tend to be consistent over time (Figure D2). The negative bias is due to the large number of zero observations. The zero observation causes a negative residual, and also causes a small standard deviation which inflates the normalized residual.

4.4.2. Parameter correlation

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

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

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

4.4.3. Retrospective analysis

Retrospective analysis is a useful method to determine how consistent a stock assessment method is from one year to the next. Inconsistencies can often highlight inadequacies in the stock assessment method. Figure 4.12 shows the estimated biomass from three previous assessments and the current assessment. However, the model assumptions differ among these assessments, and differences would be expected (see Section 4.6). Retrospective analyses are usually carried out by repeatedly eliminating one year of data from the analysis while using the same stock assessment method and assumptions. This allows the analyst to determine the change in estimated quantities as more data are included in the model. Estimates for the most recent years are often uncertain and biased. Retrospective analysis and the assumption that more data improves the estimates can be used to determine if there are consistent biases in the estimates. Retrospective analysis carried out by Maunder and Harley (2004) showed that the peak in biomass in 2001 has been consistently underestimated.

4.5. Sensitivity to assumptions

A sensitivity analyses was carried out to investigate the incorporation of a Beverton-Holt stock-recruitment relationship with a steepness of 0.75 The base case analysis was carried out with an assumption of 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 those of the base case.

There have been several other sensitivity analyses carried out in previous yellowfin tuna assessments. Increasing the sample size for the length frequency based on iterative reweighting to determine the effective sample size gave similar results, but smaller confidence intervals (Maunder and Harley 2004). The use of species composition to determine the surface fishery catch and different size of the selectivity smoothness penalties (if set at realistic values) gave similar results (Maunder and Harley 2004).

4.6. Comparison to previous assessments

The estimated biomass trajectory is similar to the results from the previous assessments presented by Maunder and Watters (2001, 2002) and Maunder (2002) (Figure 4.12). These results are also similar to the results obtained using cohort analysis (Maunder 2002). This result indicates that estimates of absolute biomass are robust to the assumptions that have been changed as the assessment procedure has been updated. The recent increase and decrease in biomass is the same as indicated by the previous assessment.

4.7. Summary of the results from the assessment model

In general, the recruitment of yellowfin tuna to the fisheries in the EPO is variable, with a seasonal component. This analysis and previous analyses have indicated that the yellowfin population has experienced two different recruitment regimes (1975-1983 and 1984-2001) and that the population has been in the high-recruitment regime for approximately the last 19 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 an artifact due to the apparent regime shift. Biomass increased during 1999 and

2000, but is estimated to have decreased during 2001 to 2003.

The average weights of yellowfin tuna 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 pole-and-line (Fishery 10) fisheries capture younger, smaller yellowfin than do the dolphin-associated (Fisheries 7-9) and longline (Fisheries 11 and 12) fisheries. The longline fisheries and the dolphin-associated fishery in the southern region (Fishery 9) capture older, larger yellowfin than do the 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 five subsections. Possible candidates for reference points are:

1. S_{AMSY}, the spawning biomass when the stock is as the AMSY level, 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). A mid-year technical meeting on reference points was held in La Jolla, California, USA, on October 27-29, 2003. The outcome from this meeting was (1) a set of general recommendations on the use of reference points and research, (2) specific recommendations for the IATTC stock assessments. Several of the recommendations have been included in this assessment. Development of reference points that are consistent with the precautionary approach to fisheries management will continue.

5.1. Assessment of stock status based on spawning biomass

The 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 would 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 in the range of about 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 ($SBR_{AMSY} = S_{AMSY}/S_{F=0}$).

Estimates of quarterly SBR_t for yellowfin tuna 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 2004). 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. SBR_{AMSY} is estimated to be about 0.38.

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 0.30, with lower and upper 95% confidence limits of 0.21 and 0.39, respectively. It is important to note that the estimate of the upper confidence limit is greater than the estimate of SBR_{AMSY} (0.38), indicating that at the beginning of 2002 the spawning stock of yellowfin in the EPO was estimated to be less than the level that might be expected if the stock were at the AMSY level, but there is a possibility that it could also be above this 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), Maunder (2002) and Maunder and Harley (2004) (Figure 4.12b). However, the SBR and SBR required to produce AMSY have increased compared to Maunder and Watters (2001 and 2002). The estimates of SBR have increased compared to those of Maunder and Watters (2002) because average recruitment has been calculated over a longer period that includes more years from the low-recruitment regime. The estimate of SBR_{AMSY} has increased compared to Maunder and Watters (2002) because of differences in the estimates of growth. The estimates of SBR and SBR_{AMSY} have increased compared to the estimates of Maunder and Watters (2001) because of differences in fecundity, growth, and recent fishing mortality.

In general, the SBR estimates for yellowfin tuna 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 0.38 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 36.2 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. This value is less than a previous estimate of 49 kg (Maunder 2002) because of differences in the weight at age.

The average weight of yellowfin tuna in the combined catches of the fisheries operating in the EPO was only about 12 kg at the end of 2003 (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 greater than the critical weight (Figure 4.11). All the remaining fisheries catch yellowfin with average weights 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 2003, the biomass of yellowfin tuna in the EPO appears to have been slightly below 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 current level of fishing effort is less than that estimated to produce the AMSY. The effort at AMSY is 112% 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 would increase CPUE and thus might 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 (Maunder and Watters 2001).

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 groups of fisheries. If the management objective is to maximize the AMSY, the longline fisheries will perform the best, followed by the dolphin-associated fisheries, and then the unassociated fisheries. The fisheries that catch yellowfin by making purse-seine sets on floating objects will perform the worst (Table 5.2). If an additional management objective is to maximize the S_{AMSY}, the order is the same. It is not known, however, whether the fisheries that would produce greater AMSYs would be efficient enough to catch the full AMSYs predicted. However, it is estimated that the effort for dolphin-associated fisheries would only have to be doubled.

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 adversely 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 natural and fishing mortality. 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 survived 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 estimated, using the average fishing mortality at age over 2001 and 2002. 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 11 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 11 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. $\mathrm{MSY_{ref}}$ and $\mathrm{SBR_{ref}}$

Section 5.3 discusses how AMSY and the SBR at AMSY are dependent on the selectivity of the different fisheries and the effort distribution among these fisheries. AMSY can be increased or decreased by applying more or less effort to the various fisheries. If the selectivity of the fisheries could be modified at will, there is an optimum yield that can be obtained (Global MSY, Beddington and Taylor 1973; Getz 1980; Reed 1980). Maunder (2002b) showed that the optimal yield can be approximated (usually exactly) by applying a full or partial harvest at a single age. He termed this harvest $\mathrm{MSY_{ref}}$, and suggested that two-thirds of $\mathrm{MSY_{ref}}$ may be an appropriate limit reference point (*i.e.* effort allocation and selectivity patterns should produce MSY that is at or above $^{2}/_{3}\mathrm{MSY_{ref}}$). The two-thirds suggestion was based on analyses in the literature that indicated that the best practical selectivity patterns could produce 70-80% of $\mathrm{MSY_{ref}}$, that the yellowfin assessment at the time (Maunder and Watters 2002a) estimated that the dolphin fisheries produce about this MSY, and that two-thirds is a convenient fraction.

$\mathrm{MSY_{ref}}$ is associated with a SBR ($\mathrm{SBR_{ref}}$) that may also be an appropriate reference point. $\mathrm{SBR_{ref}}$ is not dependent on the selectivity of the gear or the effort allocation among gears. Therefore, $\mathrm{SBR_{ref}}$ may be more appropriate than $\mathrm{SBR_{MSY}}$ for stocks with multiple fisheries and should be more precautionary because $\mathrm{SBR_{ref}}$ is usually higher than $\mathrm{SBR_{MSY}}$. However, when recruitment is assumed to be constant (*i.e.* no stock recruitment relationship), $\mathrm{SBR_{ref}}$ may still be dangerous to the spawning stock because it is possible that $\mathrm{MSY_{ref}}$ occurs before the individuals become fully mature. $\mathrm{SBR_{ref}}$ may be a more appropriate reference point than the generally suggested $\mathrm{SBR_{x\%}}$ (*e.g.* $\mathrm{SBR_{30\%}}$ to $\mathrm{SBR_{50\%}}$ see section 5.1) because $\mathrm{SBR_{ref}}$ is calculated using the biology of the stock. However, $\mathrm{SBR_{ref}}$ may be sensitive to uncertainty in biological parameters such as the steepness of the stock-recruitment relationship, natural mortality, maturity, fecundity, and growth.

$\mathrm{MSY_{ref}}$ is estimated to be 454,980 metric tons and $\mathrm{SBR_{ref}}$ is estimated to be 0.44 (Figure 5.5). If the total effort in the fishery is scaled, without changing the allocation among gears, so that the SBR at equilibrium is equal to SBR_{ref}, the equilibrium yield is estimated to be only 1% less than MSY based on the current effort allocation (Figure 5.3). This indicates that the SBR_{ref} reference point can be maintained without any substantial loss to the fishery. However, MSY at the current effort allocation is only 63% of MSY_{ref}. More research is needed to determine if reference points based on MSY_{ref} and SBR_{ref} are useful.

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 most of 2000-2002. The current effort level is estimated to be above the level required to produce AMSY (Figure A.4, Table 5.1), 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 moderately reduced if effort is increased beyond the level required for AMSY. The analysis without a stock-recruitment relationship has a relative yield curve equal to the relative yield-per-recruit curve because recruitment is constant. The yield curve bends over slightly more rapidly when the stock-recruitment relationship is included (Figure A.4). 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 19 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 would 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 greater 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 (excluding the end of 2002 and 2003).

The current average weight of yellowfin in the catch is much less than the critical weight, and, therefore, from a yield-per-recruit standpoint, yellowfin in the EPO are probably growth 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 was conducted to gain further understanding as to how, in the future, hypothetical changes in the amount of fishing effort exerted by the surface fleet might simultaneously affect the stock of yellowfin 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.

A new method based on the normal approximation to the likelihood profile has been applied. The previously-used method (Maunder and Watters 2001) does not take parameter uncertainty into consideration. It considers only uncertainty about future recruitment. A substantial part of the total uncertainty in predicting future events is caused by uncertainty in the estimates of the model parameters and current status. This uncertainty should be considered in any forward projections. Unfortunately, the appropriate methods are often not applicable to models as large and computationally intense as the yellowfin stock assessment model. Therefore, we have used a normal approximation to the likelihood profile that allows for the inclusion of both parameter uncertainty and uncertainty about future recruitment. This method is implemented by extending the assessment model an additional 5 years with effort data equal to thje effort for 2003, by quarter scaled by the effort weighted average catchability for 2001 and 2002.. No catch or length-frequency data are included for these years,. The recruitments for the five years are estimated as in the assessment model with a lognormal penalty with a standard deviation of 0.6. Normal approximations to the likelihood profile are generated for SBR, surface catch, and longline catch. We also use the Maunder and Watters (2001) method to compare alternative effort scenarios to the base case assumptions.

6.1. Assumptions about fishing operations

6.1.1. Fishing effort

Several future projection studies were carried out to investigate the influence of different levels of fishing effort on the stock biomass and catch. All methods assumed that catachability is equal to the average catchability, by quarter, in 2001 and 2002. the average was weighted by the effort to ensure that extreme values of catchability from years where effort was restricted due to managem,ent did not overly influence the catchability used in the future projections.

The scenarios investigated were:

1. Effort for each year in the future equal to the effort in 2003 by quarter;
2. The same as (1) except that effort for the third quarter was reduced by 50% (a six week closure) for all surface fisheries except pole and line;
3. The same as (1) except that effort for the third quarter was reduced by 50% (a six week closure) for all floating object fisheries and the southern unassociated fishery, and effort for the forth quarter was reduced by 50% (a six week closure) for all dolphin associated fisheries and the northern unassociated fishery;
4. The same as (3) except that effort for the forth quarter was reduced by 66% (a eight week closure) for all dolphin associated fisheries and the northern unassociated fishery;
5. The same as (1) except the effort for the floating object fisheries is reduced by 50%, 75%, and 100%;
6. The same as (1) except no unassociated fishing effort;
7. The same as (1) except no dolphin associated fishing effort;
8. The same as (1) except no longline fishing effort.

9. Simulation results

Under 2003 levels of effort the biomass is predicted to increase during 2004, but then decrease in the following years (Figure 6.1). SBR is predicted to be above the level that will produce MSY at the start of 2005, but drop below that level in the future (Figure 6.2). The confidence intervals are much larger in the future than for the historic period due to uncertainty in the dynamics, current status, and uncertainty about future levels of recruitment. Due to the large confidence intervals and despite that the best prediction of SBR is lower than the level that would produce MSY, there is a moderate probability that the SBR is above this level.

Both surface and lone line catches are predicted to reduce substantially in 2004 compared to 2003 and then decrease slightly over the following years (Figure 6.3).

The six week closure in the third quarter for surface fisheries (50% reduction in effort for that quarter) is predicted to slightly increase the biomass and SBR (Figures 6.5 and 6.5; Table 6.1). The best prediction of SBR is still declines below the level which would produce MSY at the end of the projection period. Changing the dolphin and northern unassociated closure to the forth quarter causes a smaller increase in biomass (Figure 6.6; Table 6.1). Changing the dolphin and northern unassociated closure in the forth quarter from 6 weeks to 8 weeks had little effect on biomass (Figure 6.6; Table 6.1). There is only a slight difference in catch among these three scenarios, which all give smaller catch and much more quarterly variation in catch (Figure 6.7; Table 6.1).

Restrictions in the floating object fishery only causes a small increase in biomass even when the floating object fishery is completely closed (Figure 6.8; Table 6.1). This only causes a small decrease in total surface fishery catch (Figure 6.9; Table 6.1). Closing the dolphin fishery causes the largest increase in biomass (Figure 6.10; Table 6.1). Closing the unassociated fishery has about the same effect as the floating object fishery (Figure 6.10; Table 6.1). Closing the longline fisheries has essentially no impact (Figure 6.10; Table 6.1).

6.4. Summary of the simulation results

Under 2003 levels of effort the biomass is predicted to increase during 2004, but then decrease in the following years. SBR is predicted to be above the level that will produce MSY at the start of 2005, but drop below that level in the future. The catch in 2004 is predicted to be much less than that in 2003. Closing the surface fisheries for six weeks is predicted to only slightly increase the biomass levels. Larger restrictions on the floating object fishery only cause a small increase in biomass even when the floating object fishery is completely closed. Closing the dolphin fishery causes the largest increase in biomass.

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 2004 and updated data for previous years will be incorporated into the next stock assessment.

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 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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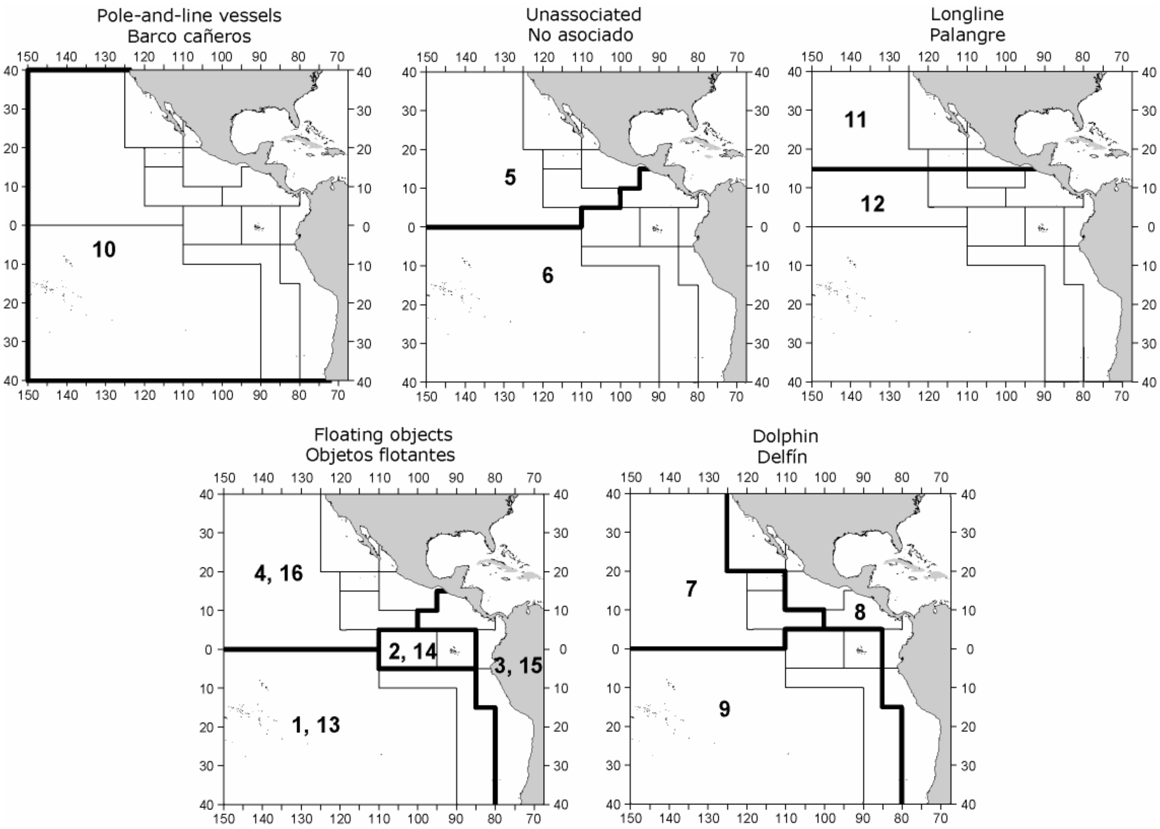

FIGURE 2.1. Spatial extents of the fisheries defined by the IATTC staff for the stock assessment of yellowfin tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the heavy lines the boundaries of each fishery defined for the stock assessment, and the bold numbers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

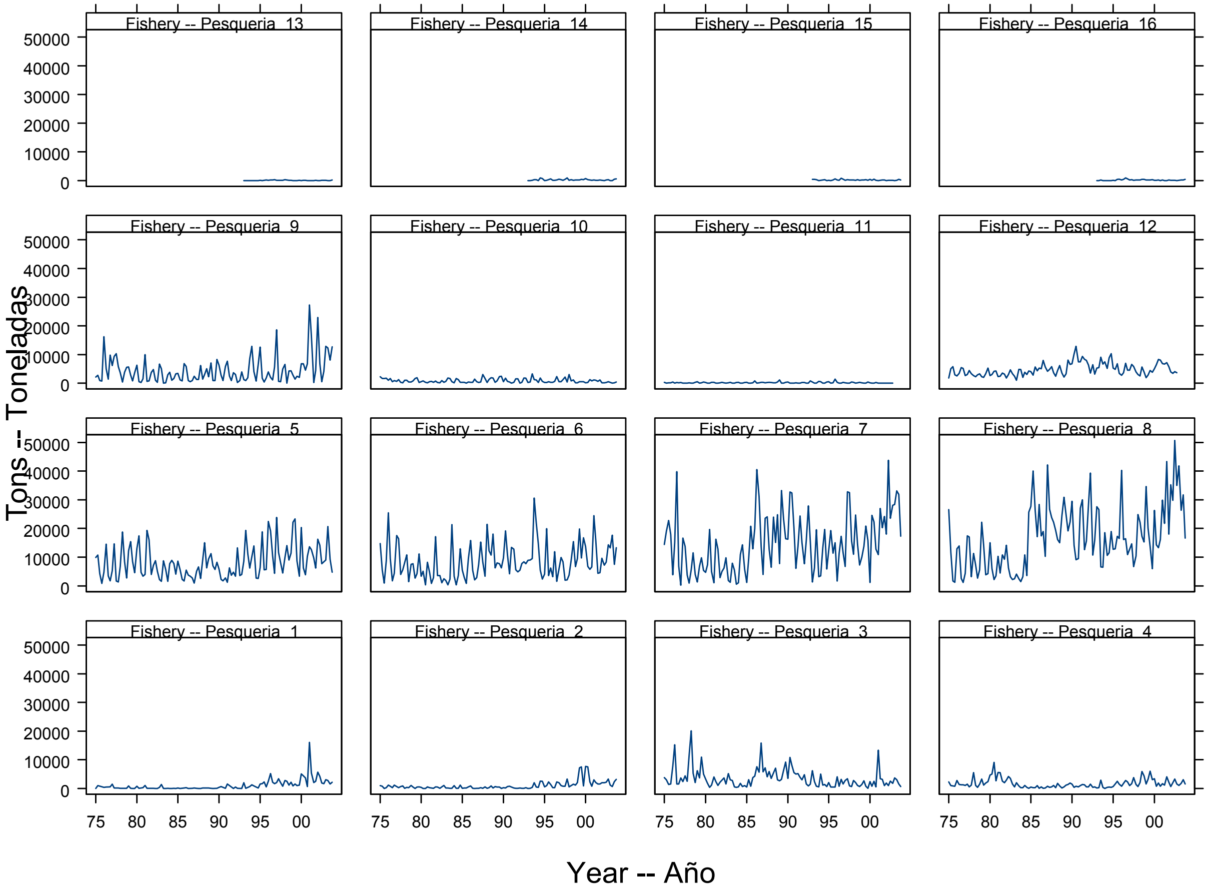

FIGURE 2.2. Catches by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were analyzed on a quarterly basis, there are four observations of catch for each year. Although all the catches are displayed as weights, the stock assessment model uses catch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

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.

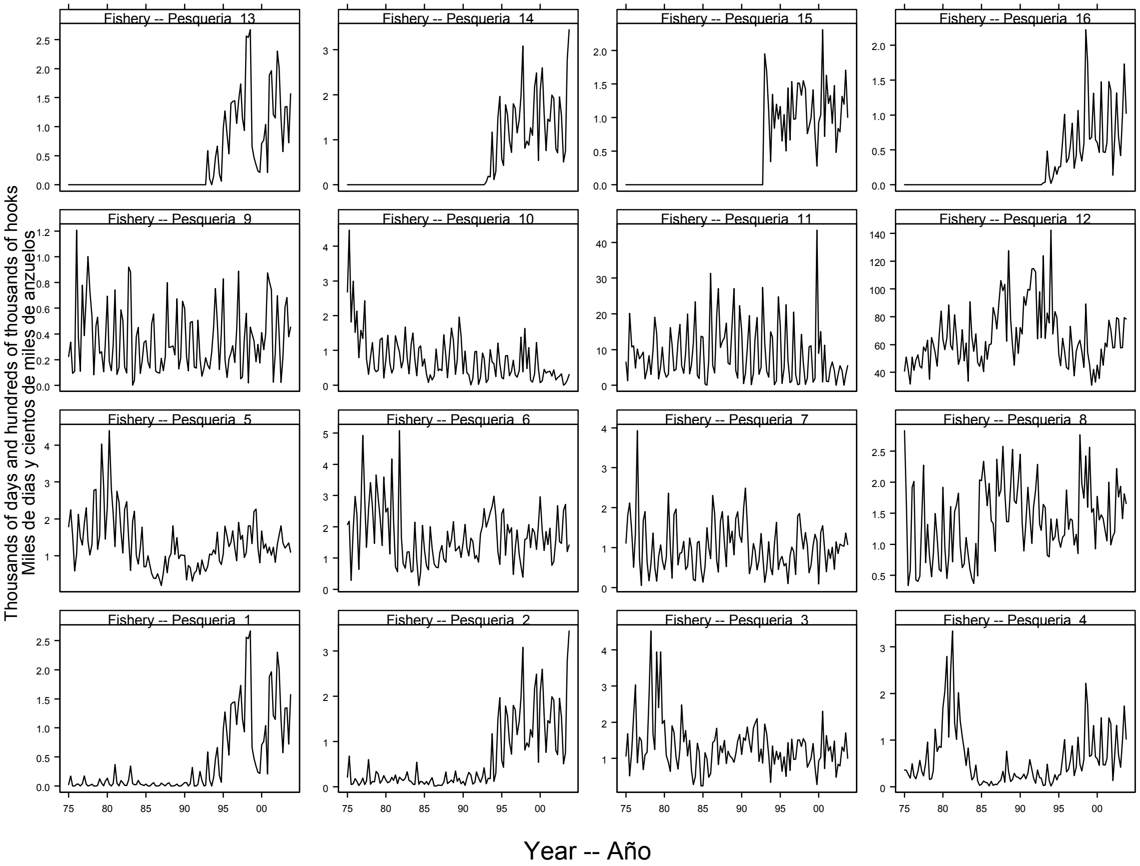

FIGURE 2.3. Fishing effort exerted by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of effort for each year. The effort for Fisheries 1-10 and 13-16 is in days fished, and that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

FIGURA 2.3. Esfuerzo de pesca ejercido por las pesquerías definidas para la evaluación del stock de atún aleta amarilla en el OPO (Tabla 2.1). Ya que se analizaron los datos por trimestre, hay cuatro observaciones de esfuerzo para cada año. Se expresa el esfuerzo de las Pesquerías 1-10 y 13-16 en días de pesca, y el de las Pesquerías 11 y 12 en número estandardizado de anzuelos. Nótese que las escalas verticales de los recuadros son diferentes.

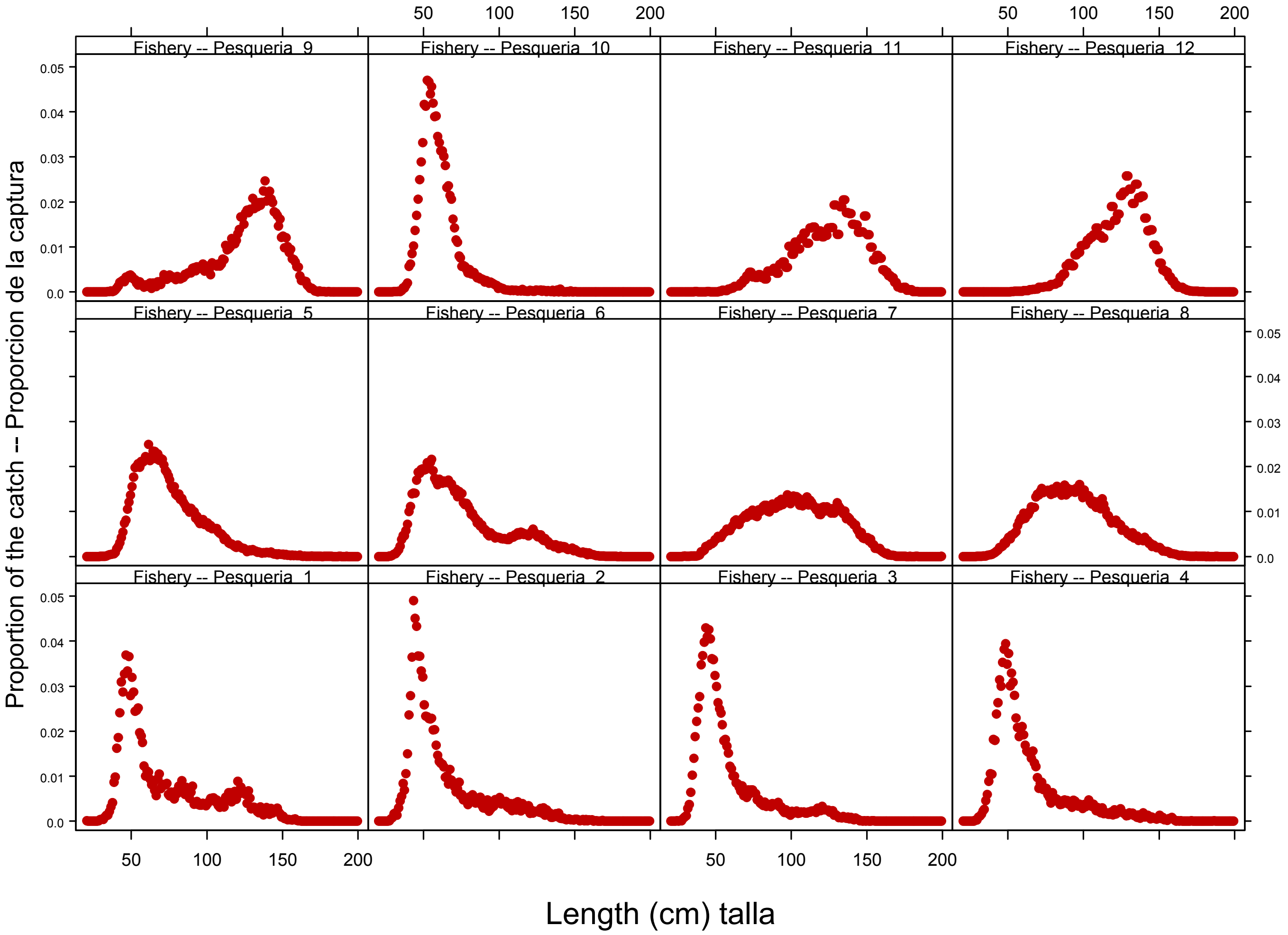

FIGURE 2.4. Average size compositions of the catches made by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). The data cover the period of January 1975 through December 2002.

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 2002.

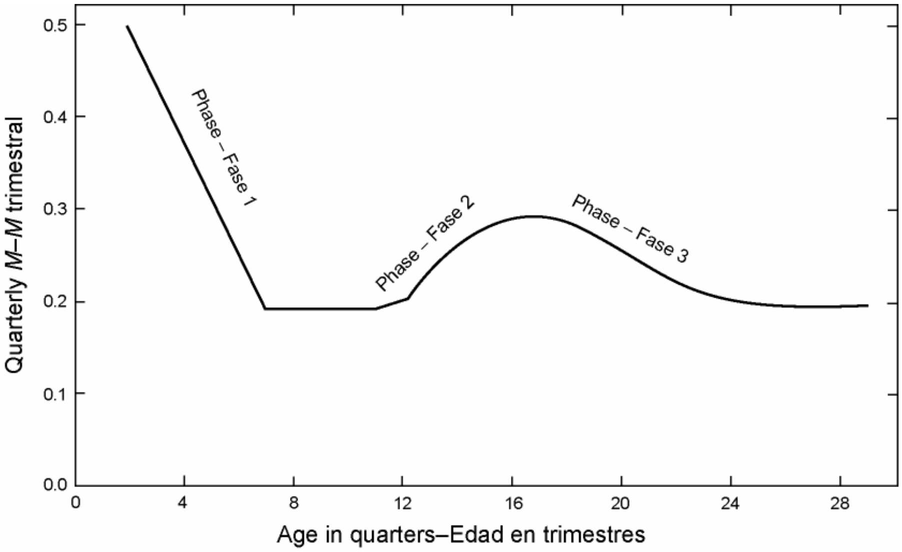

FIGURE 3.1. Natural mortality (*M*) rates, at quarterly intervals, used for the assessment of yellowfin tuna in the EPO. Descriptions of the three phases of the mortality curve are provided in Section 3.1.4.
FIGURA 3.1. Tasas de mortalidad natural (*M*), a intervalos trimestrales, usadas para la evaluación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

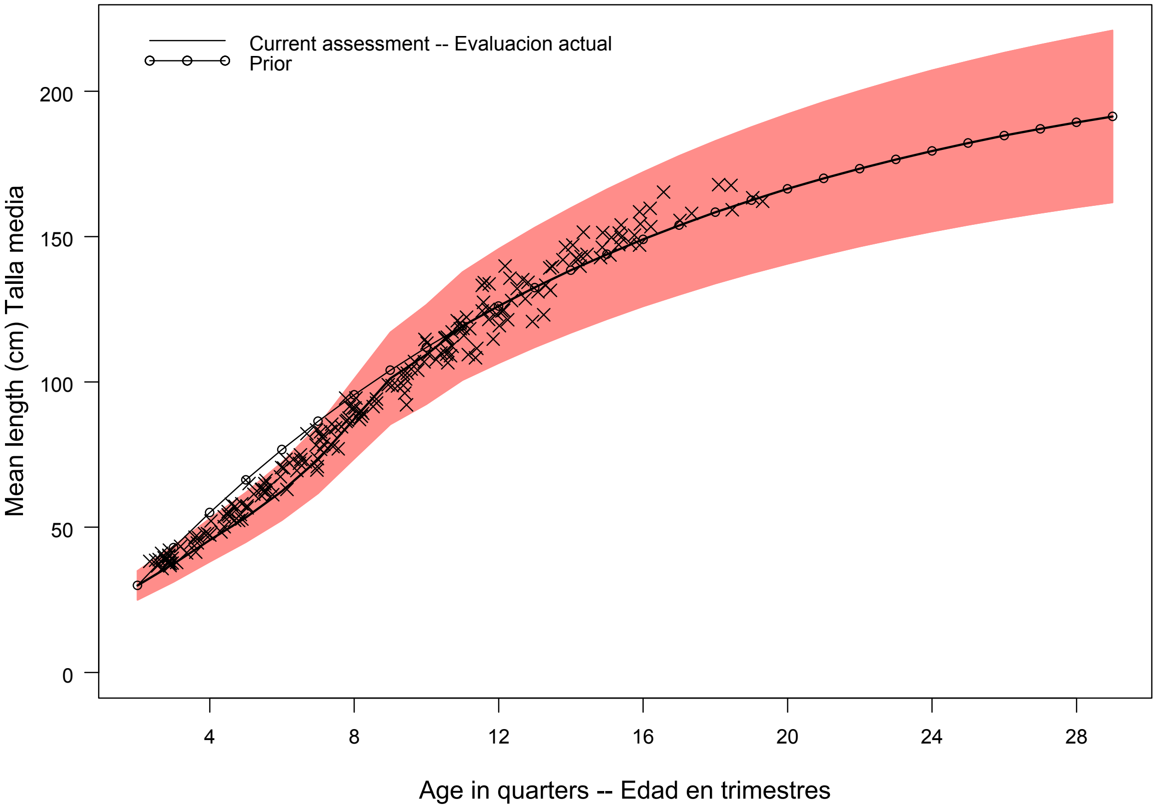

FIGURE 3.2. Growth curve estimated for the assessment of yellowfin tuna in the EPO (solid line). The connected points represent the mean length-at-age prior used in the assessment. The crosses represent length-at-age data from otoliths (Wild 1986). The shaded region represents the variation in length at age (± 2 sd)

FIGURA 3.2. Curva de crecimiento usada para la evaluación del atún aleta amarilla en el OPO (línea sólida). Los puntos conectados representan la distribución previa (*prior*) de la talla a edad usada en la evaluación. Las cruces representan datos de otolitos de talla a edad (Wild 1986). La región sombreada representa la variación de la talla a edad (± 2 de).

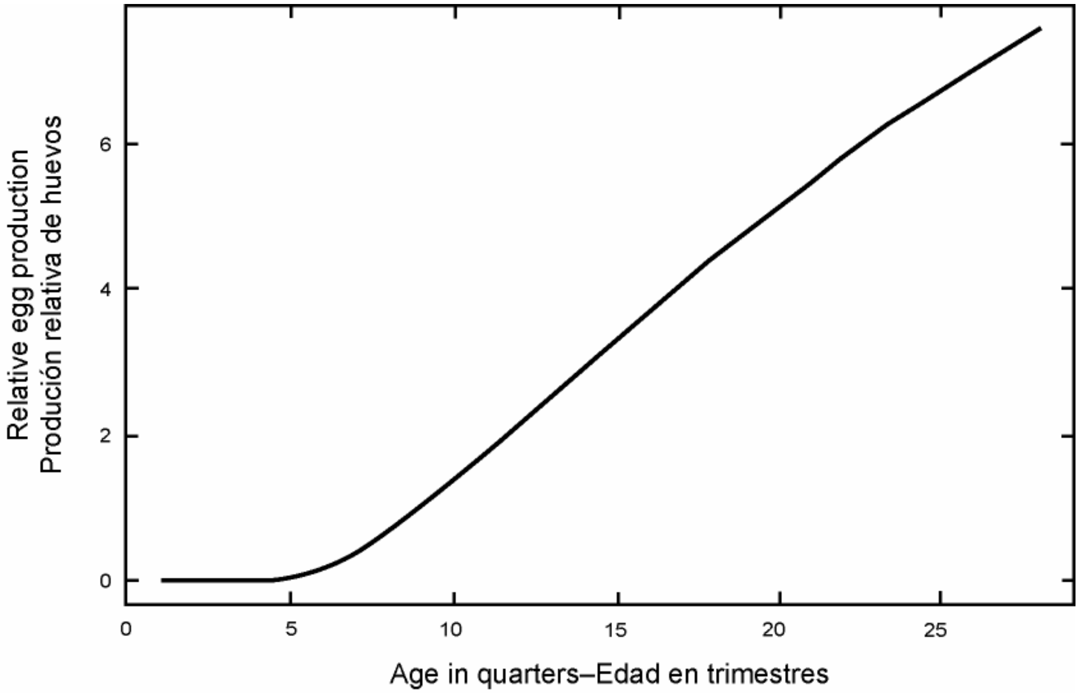

FIGURE 3.3. Relative fecundity-at-age curve (from Schaefer 1998) used to estimate the spawning biomass of yellowfin tuna in the EPO.
FIGURA 3.3. Curva de madurez relativa a edad (de Schaefer 1998) usada para estimar la biomasa reproductora de atún aleta amarilla en el OPO.

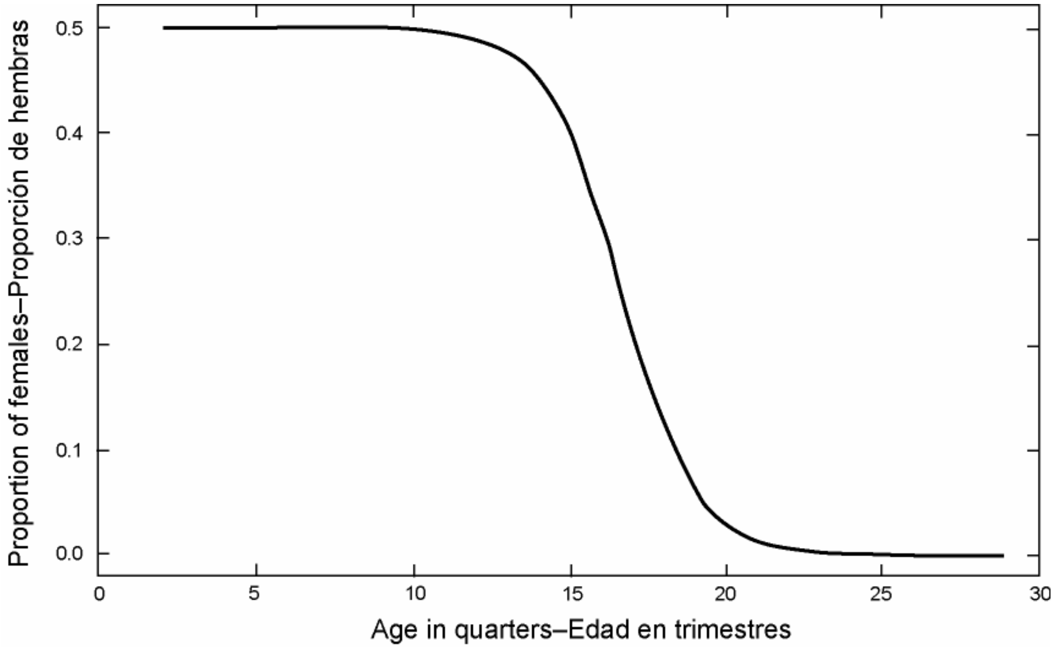

FIGURE 3.4. Sex ratio curve (from Schaefer 1998) used to estimate the spawning biomass of yellowfin tuna in the EPO.
FIGURA 3.4. Curva de proporciones de sexos (de Schaefer 1998) usada para estimar la biomasa reproductora de atún aleta amarilla en el OPO.

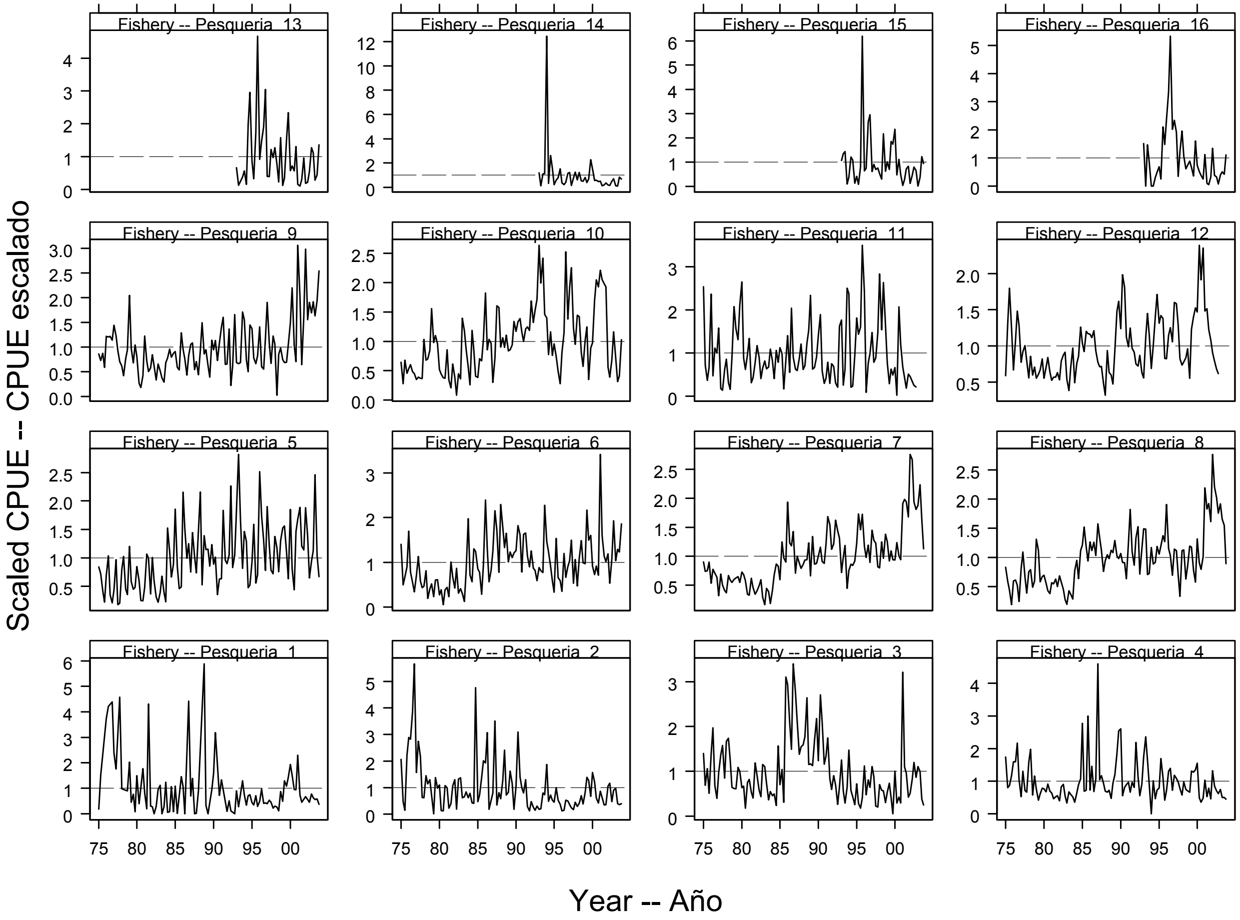

FIGURE 4.1. CPUEs for the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of CPUE for each year. The CPUEs for Fisheries 1-10 and 13-16 are in kilograms per day fished, and those for Fisheries 11 and 12 are standardized units based on numbers 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 unidades estandarizadas basadas en número de anzuelos. Se ajustaron los datos para que el promedio de cada serie de tiempo equivalga a 1,0. Nótese que las escalas verticales de los recuadros son diferentes.

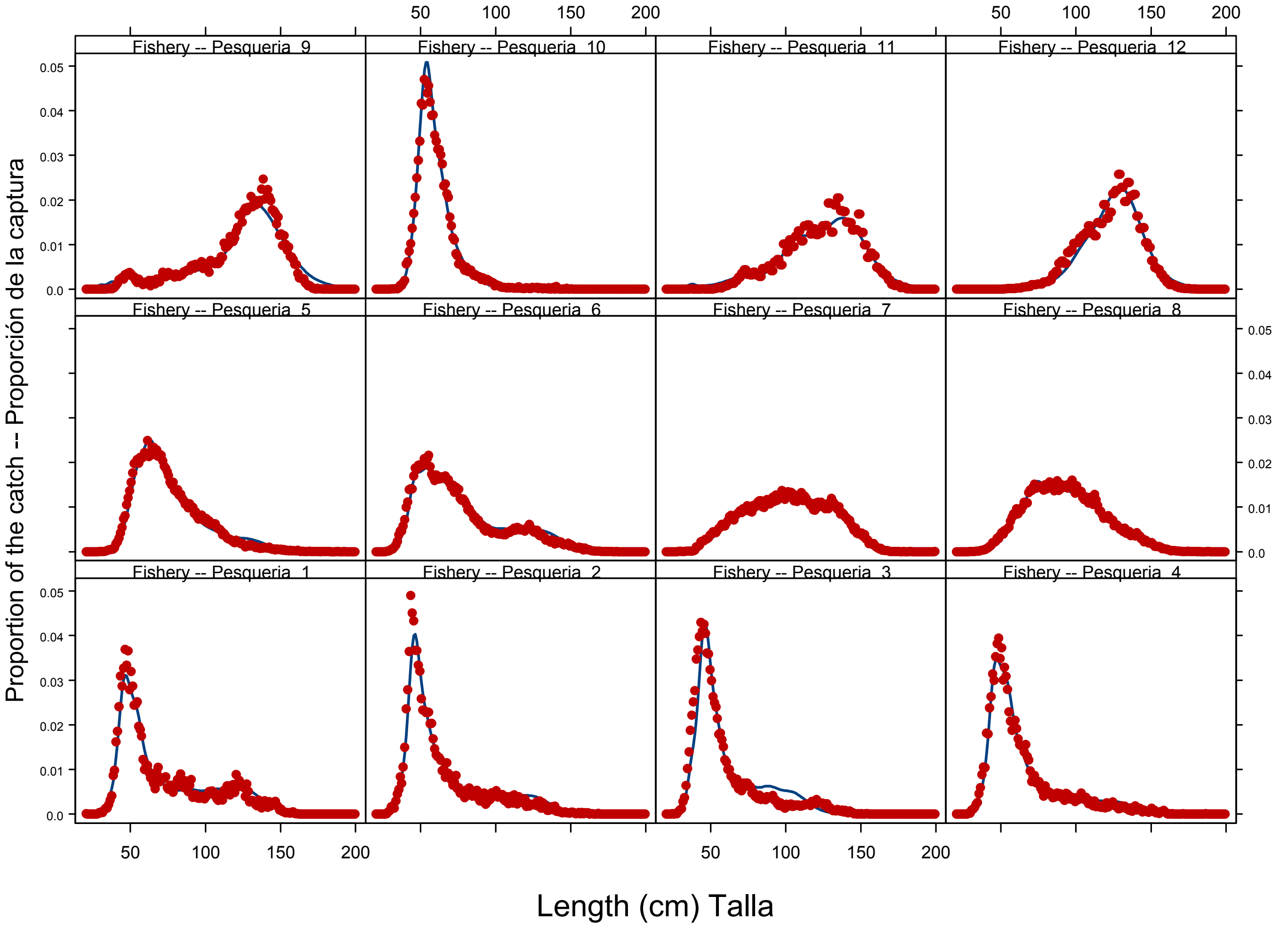

FIGURE 4.2. Average observed (dots) and predicted (curves) size compositions of the catches taken by the fisheries defined for the stock assessment of yellowfin tuna in the EPO.

FIGURA 4.2. Composición media por tamaño observada (puntos) y predicha (curvas) de las capturas realizadas por las pesquerías definidas para la evaluación de la población de atún aleta amarilla en el OPO.

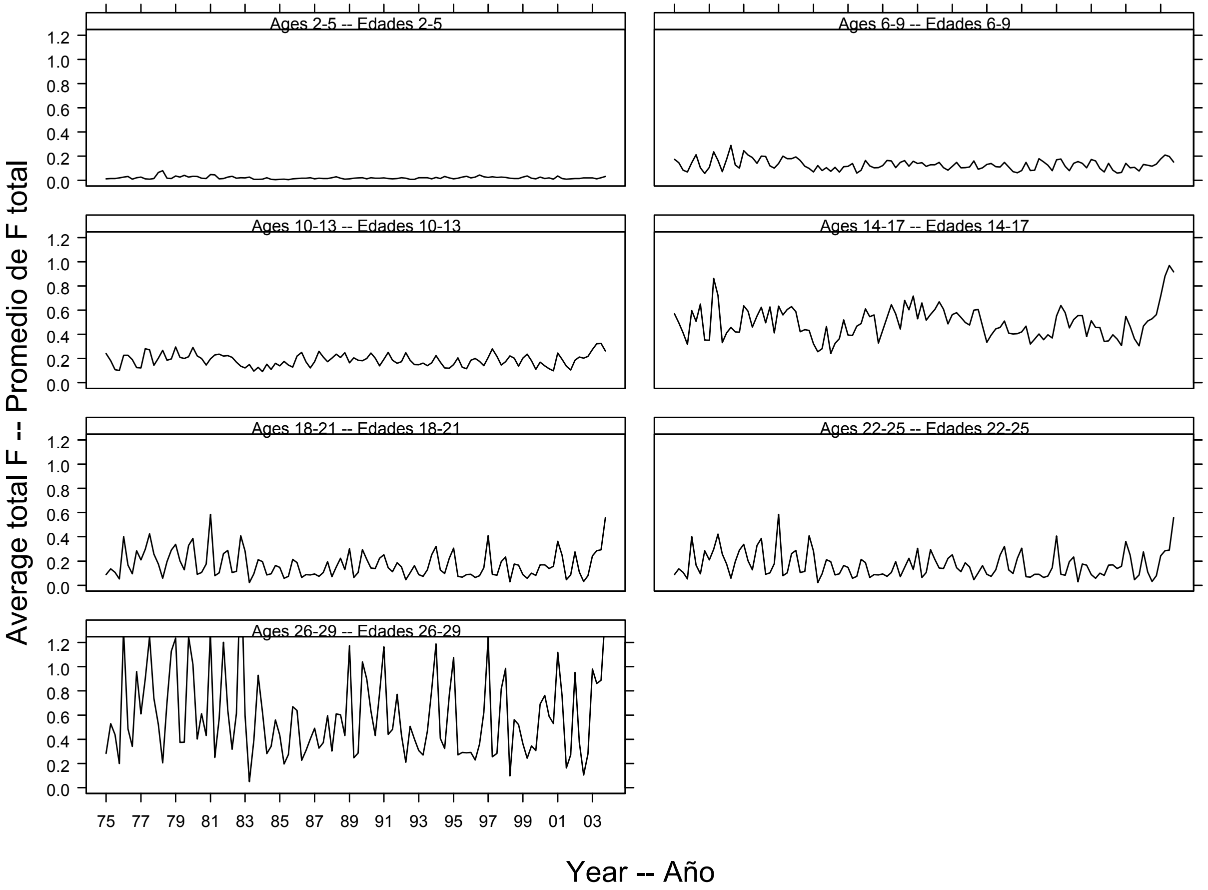

FIGURE 4.3a. Time series of average total quarterly fishing mortality of yellowfin tuna that have been recruited to the fisheries of the EPO. Each panel illustrates an average of four quarterly fishing mortality vectors that affected the fish within the range of ages indicated in the title of each panel.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

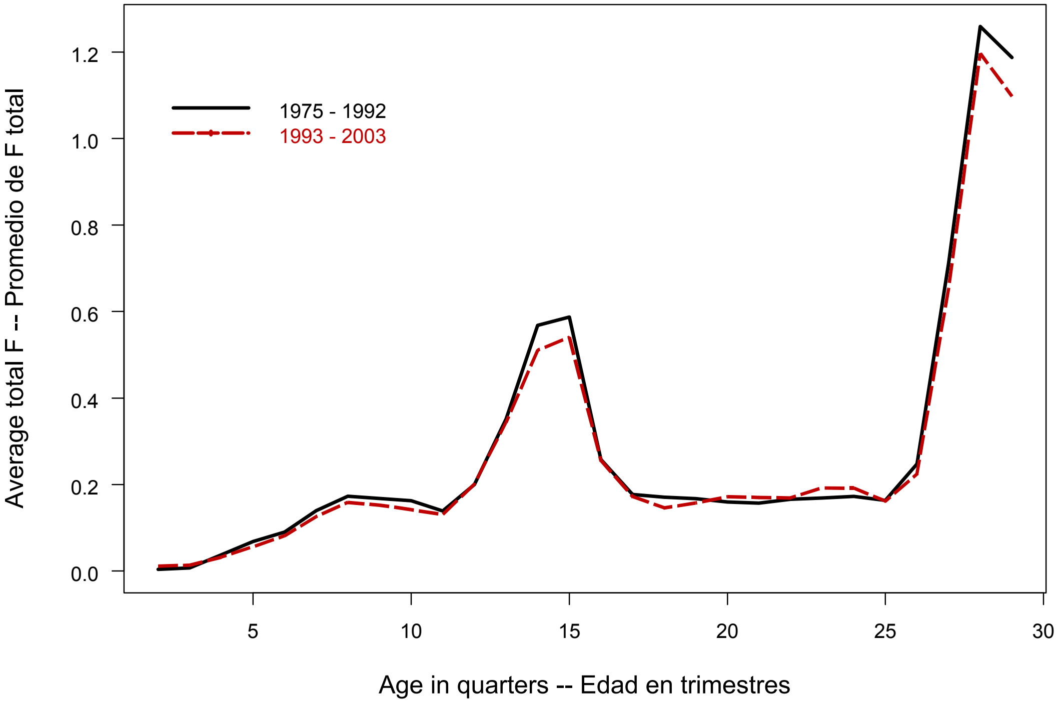

FIGURE 4.3b. Average total quarterly fishing mortality by age of yellowfin tuna that have been recruited to the fisheries of the EPO. The estimates are presented for two periods, the latter period relating to the increase in effort associated with floating objects.

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.

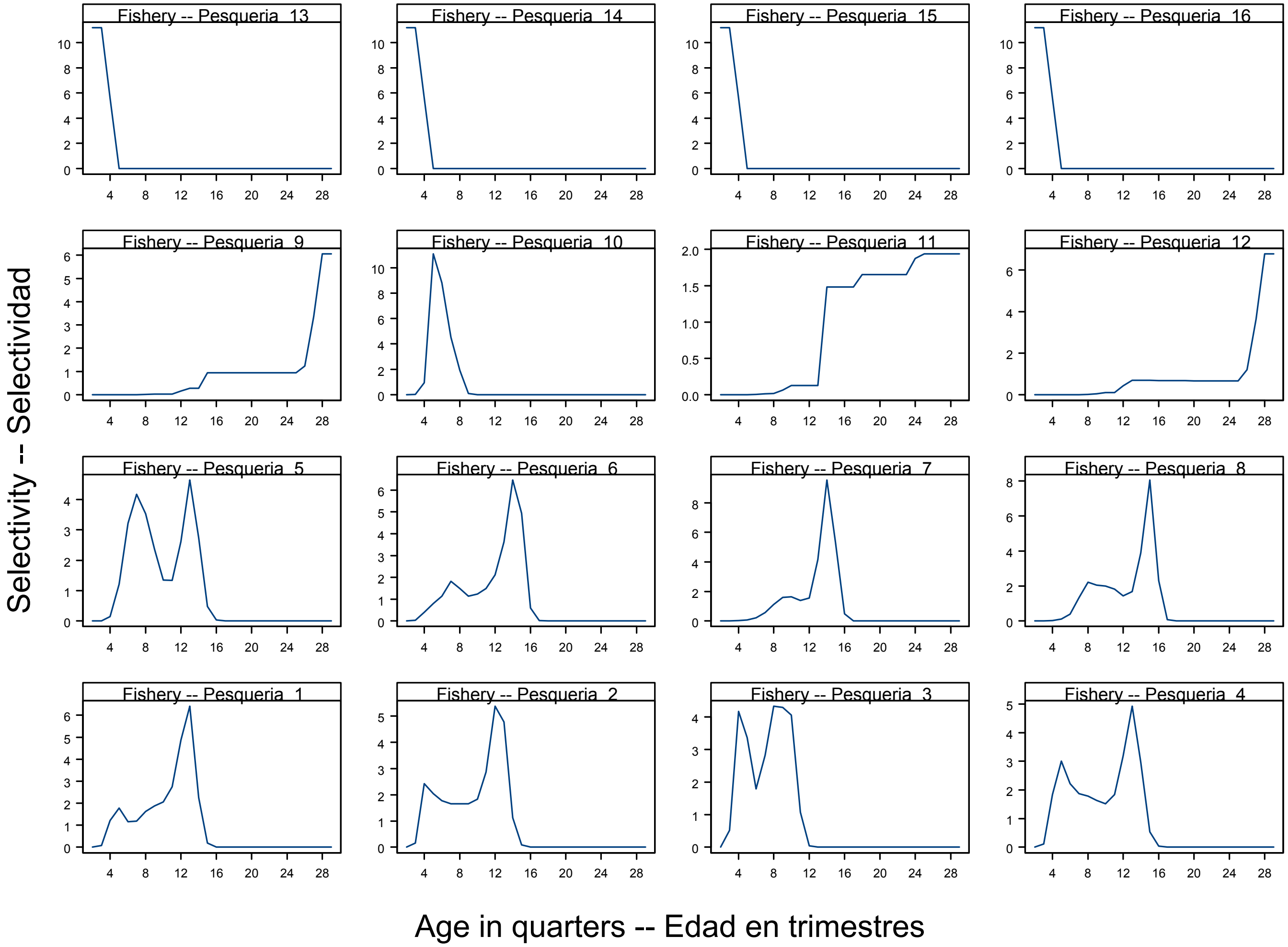

FIGURE 4.4. Selectivity curves for the 16 fisheries that take yellowfin tuna in the EPO. The curves for Fisheries 1-12 were estimated with the A-SCALA method, and those for Fisheries 13-16 are based on assumptions. Note that the vertical scales of the panels are different.

FIGURA 4.4. Curvas de selectividad para las 16 pesquerías que capturan atún aleta amarilla en el OPO. Se estimaron las curvas de las Pesquerías 1-12 con el método A-SCALA, y las de la Pesquerías 13-16 se basan en supuestos. Nótese que las escalas verticales de los recuadros son diferentes.

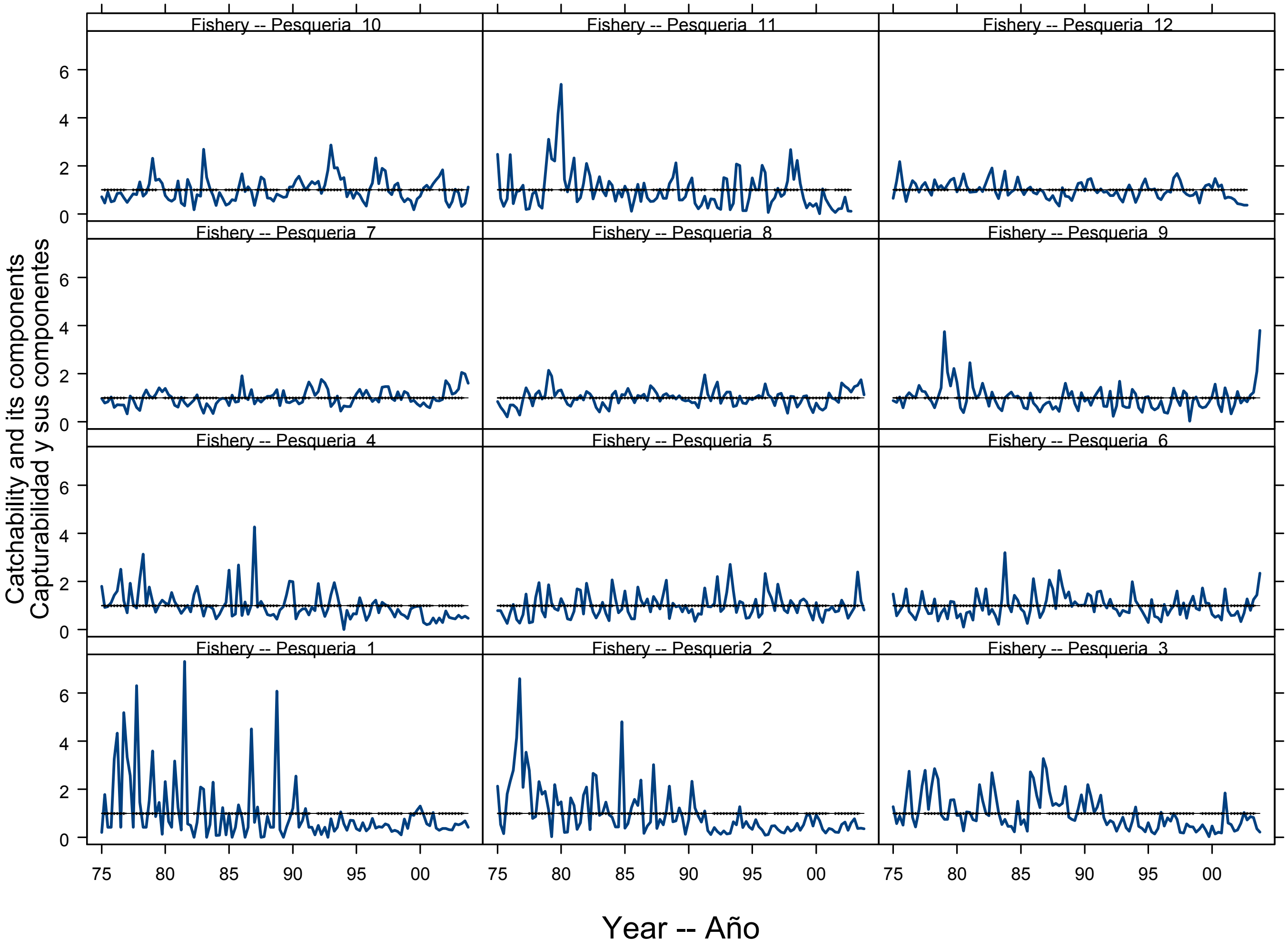

FIGURE 4.5a. Trends in catchability (*q*) for the 12 retention fisheries that take yellowfin tuna in the EPO. The estimates are scaled to average 1.
FIGURA 4.5a. Tendencias en capturabilidad (*q*) para las 12 pesquerías de retención que capturan atún aleta amarilla en el OPO. Se escalan las estimaciones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

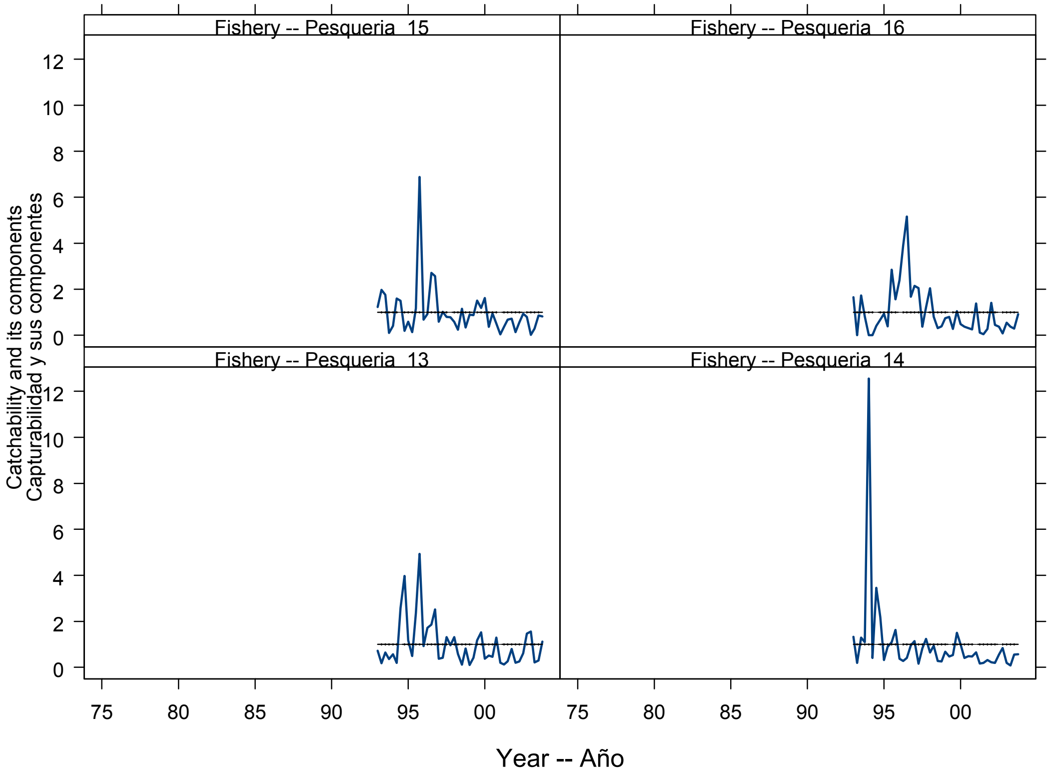

FIGURE 4.5b. Trends in catchability (*q*) for the four discard fisheries that take yellowfin tuna in the EPO. The estimates are scaled to average 1.

FIGURA 4.5b. Tendencias en capturabilidad (*q*) para las cuatro pesquerías de descarte que capturan atún aleta amarilla en el OPO. Se escalan las estimaciones a un promedio de 1.

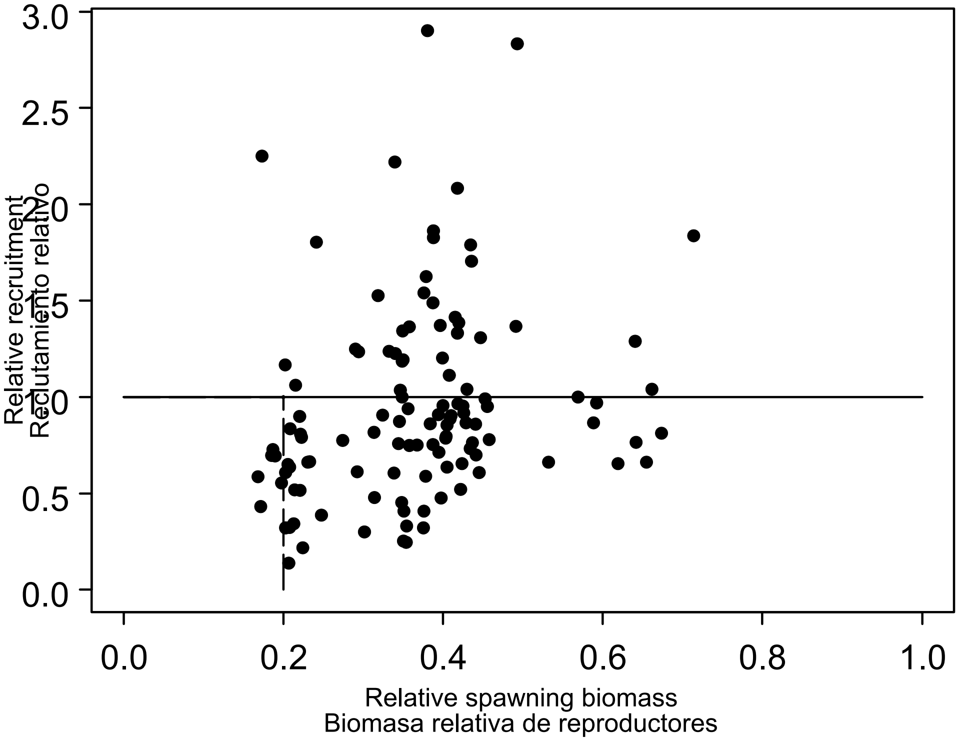

FIGURE 4.6. Estimated relationship between recruitment of yellowfin tuna and spawning biomass. The recruitment is scaled so that the average recruitment is equal to 1.0. The spawning biomass is scaled so that the average unexploited spawning biomass is equal to 1.0.
FIGURA 4.6. Relación estimada entre 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.

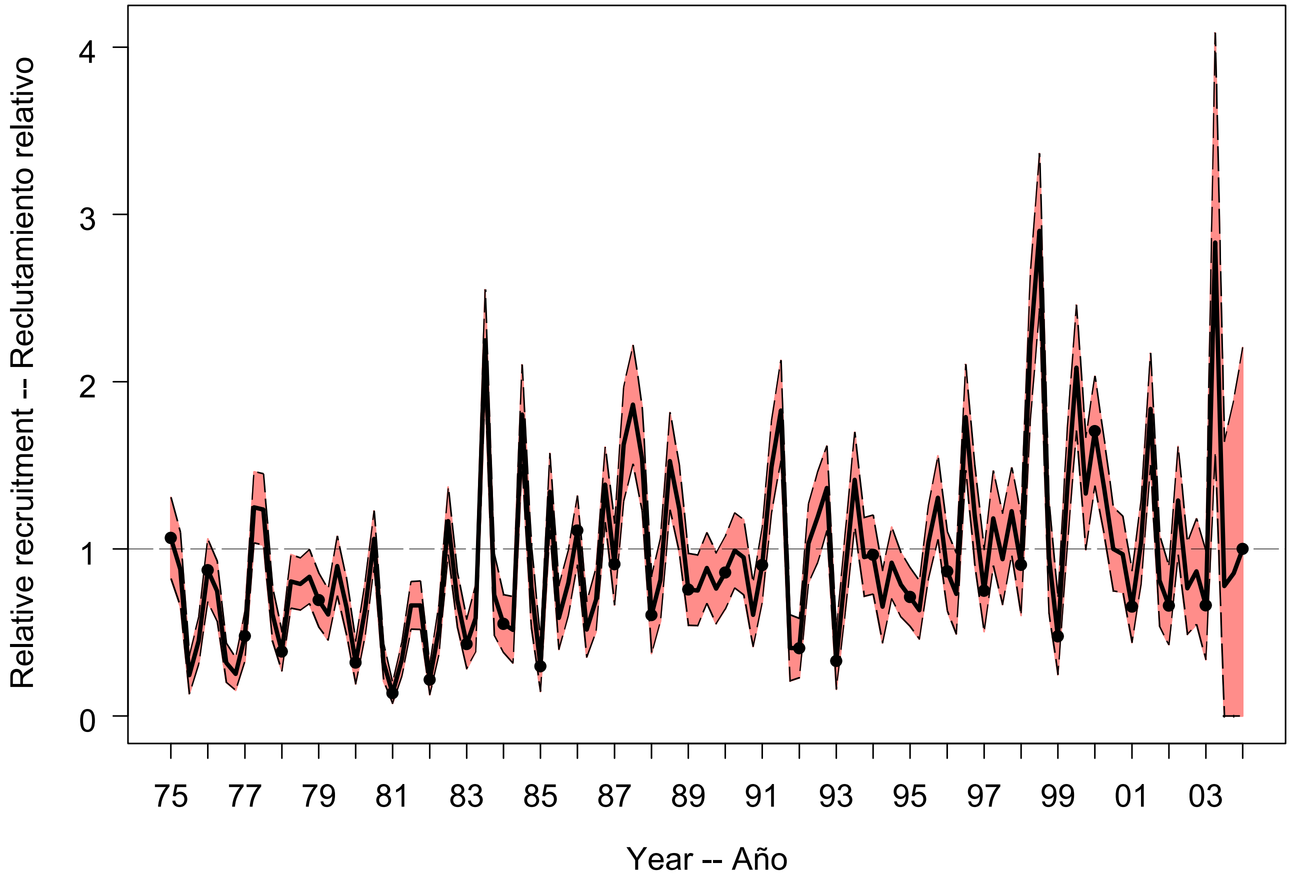

FIGURE 4.7. Estimated recruitment of yellowfin tuna to the fisheries of the EPO. The estimates are scaled so that the average recruitment is equal to 1.0. The heavy line illustrates the maximum likelihood estimates of recruitment, and the shaded area indicates the approximate 95% confidence intervals around those estimates. The labels on the time axis are drawn at the start of each year, but, since the assessment model represents time on a quarterly basis, there are four estimates of recruitment for each year.

FIGURA 4.7. Reclutamiento estimado de atún aleta amarilla a las pesquerías del OPO. Se escalan las estimaciones para que el reclutamiento medio equivalga a 1,0. La línea gruesa ilustra las estimaciones de probabilidad máxima del reclutamiento, y el área sombrada 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.

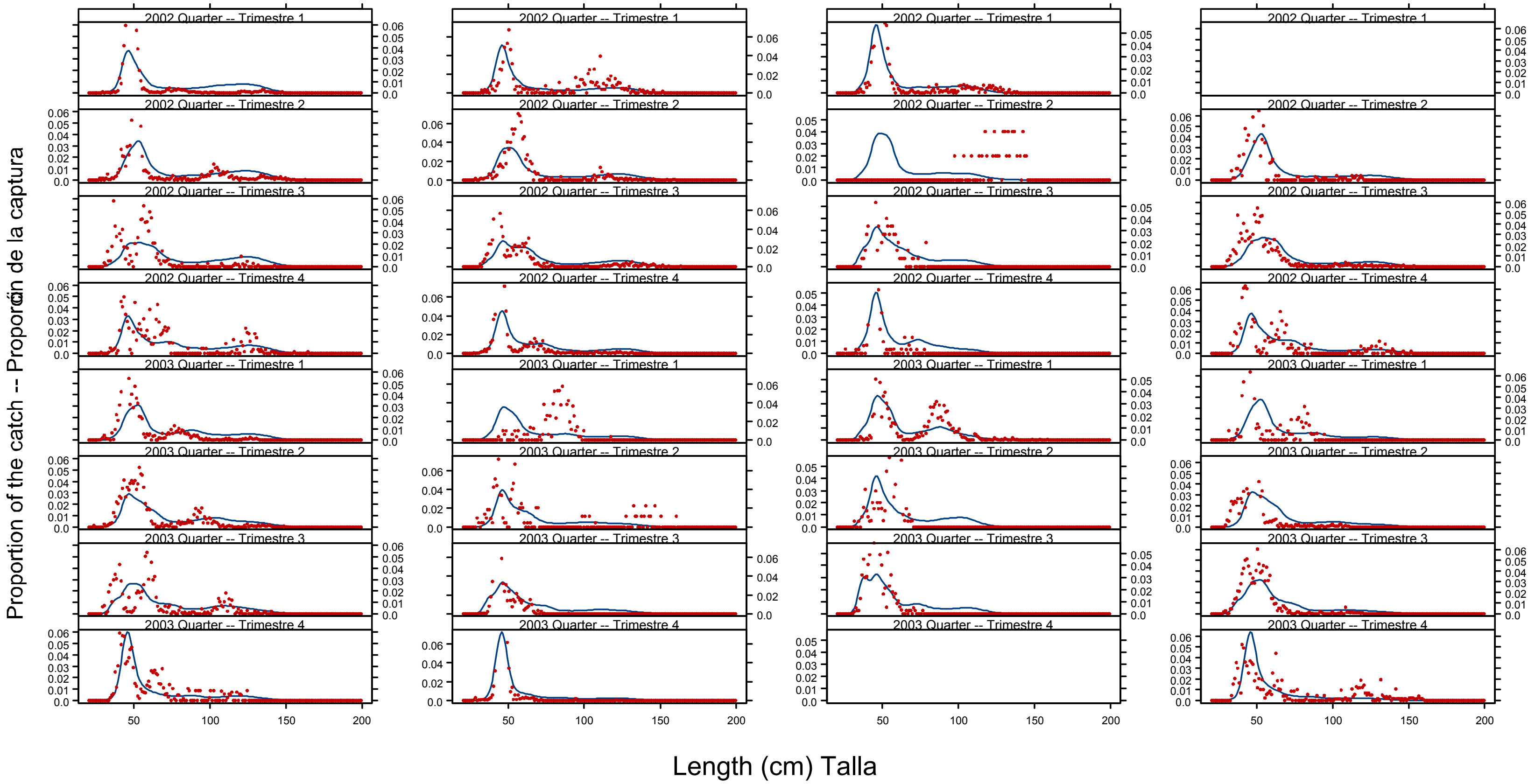

FIGURE 4.8a. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin by the fisheries that take tunas in association with floating objects (Fisheries 1-4).

FIGURA 4.8a. Composiciones por tamaño observadas (puntos) y predichas (curvas) de las capturas recientes de aleta amarilla por las pesquerías que capturan atún en asociación con objetos flotantes (Pesquerías 1-4).

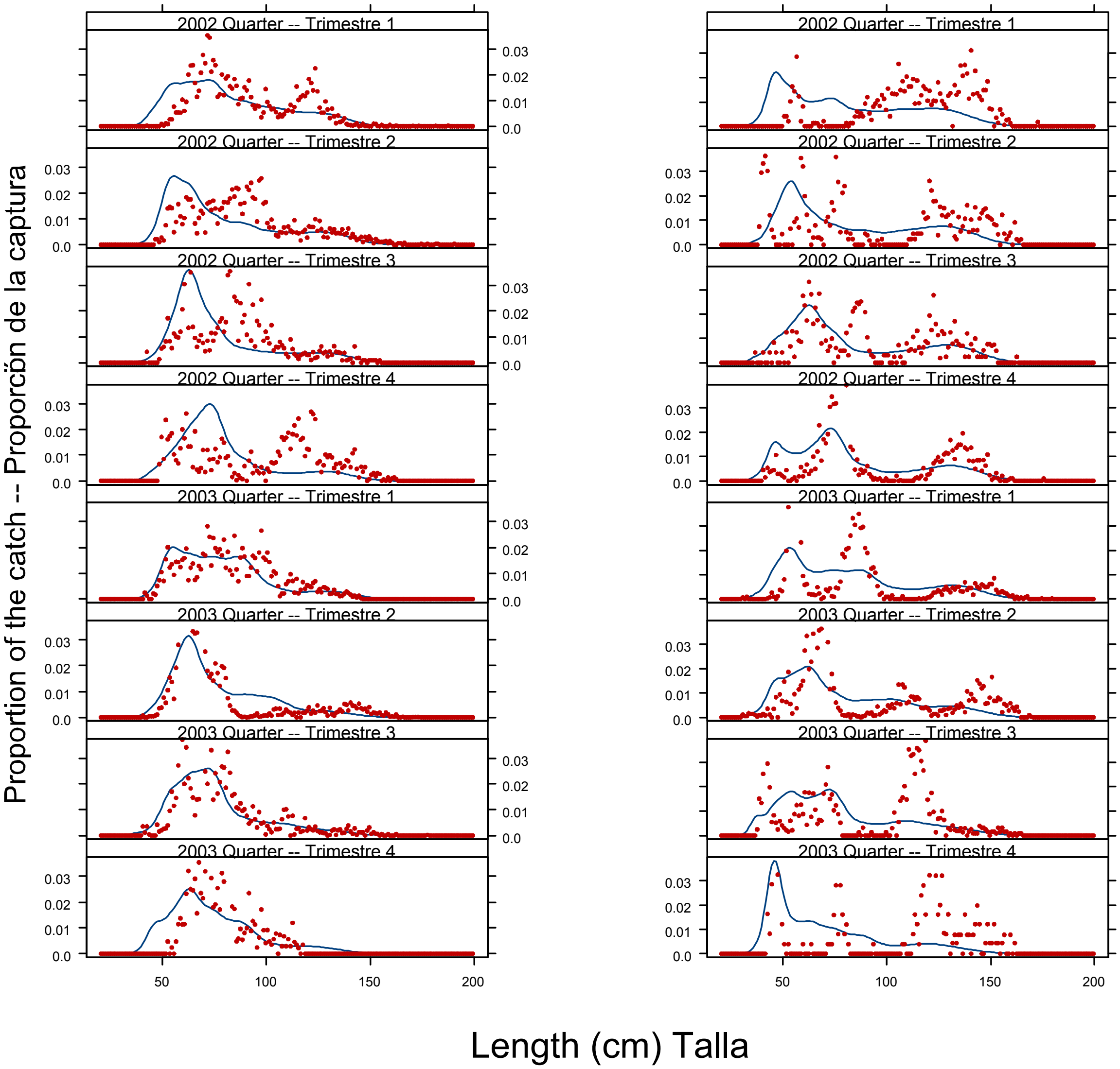

FIGURE 4.8b. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin tuna by the fisheries that take tunas in unassociated schools (Fisheries 5 and 6).

FIGURA 4.8b. Composiciones por tamaño observadas (puntos) y predichas (curvas) de las capturas recientes de atún aleta amarilla por las pesquerías que capturan atún en cardúmenes no asociados (Pesquerías 5 y 6).

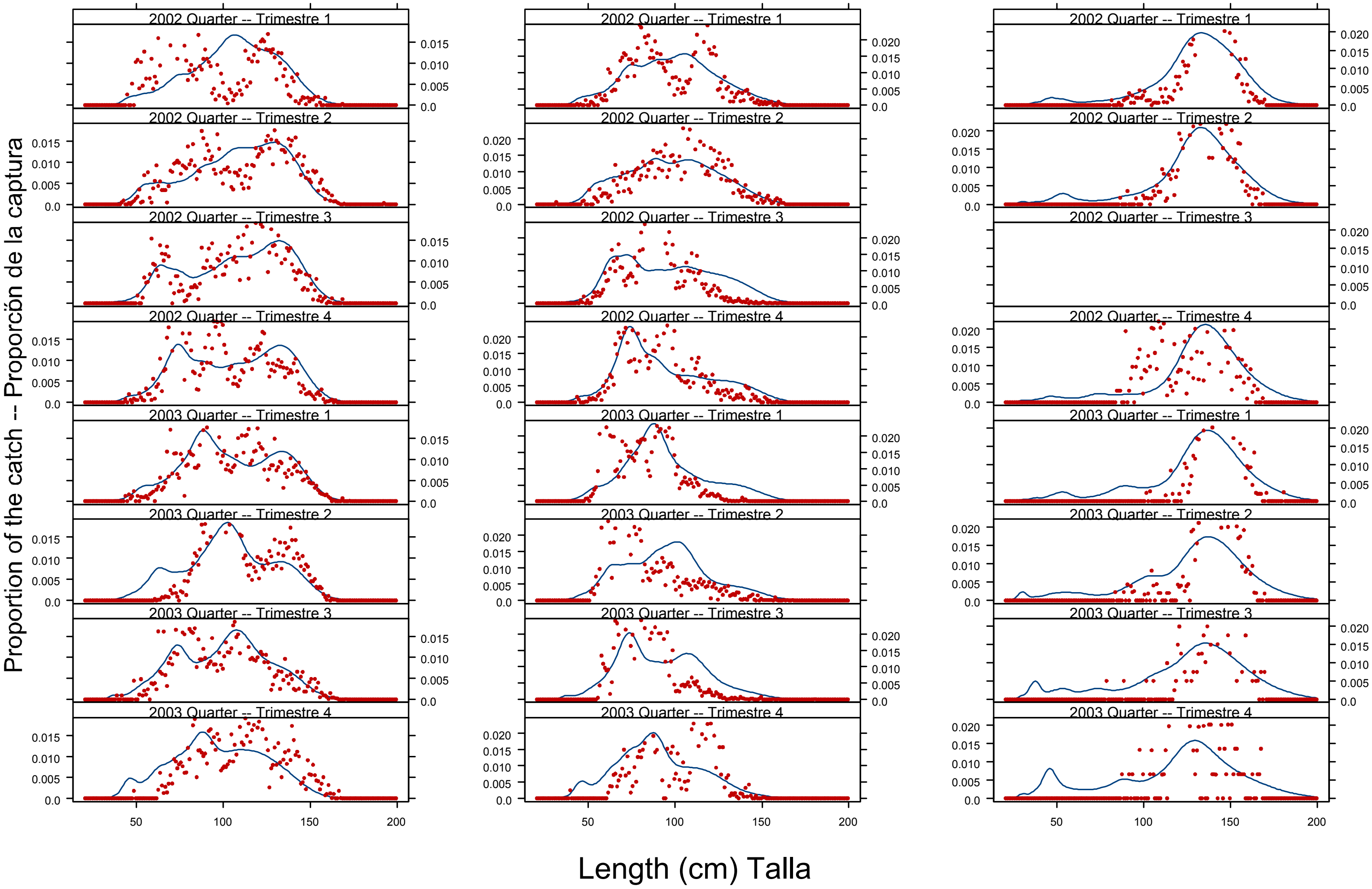

FIGURE 4.8c. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin tuna by the fisheries that take tunas in association with dolphins (Fisheries 7-9).

FIGURA 4.8c. Composiciones por tamaño observadas (puntos) y predichas (curvas) de las capturas recientes de atún aleta amarilla por las pesquerías que capturan atún en asociación con delfines (Pesquerías 7-9).

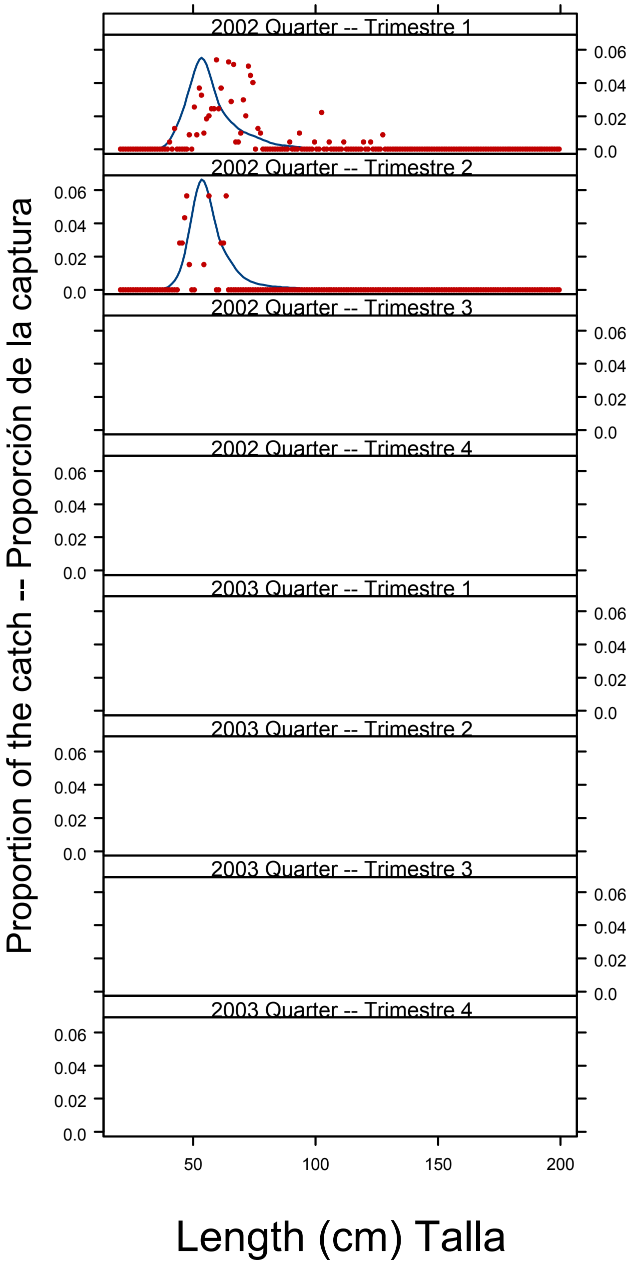

FIGURE 4.8d. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin tuna by the pole-and-line fishery (Fishery 10).

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

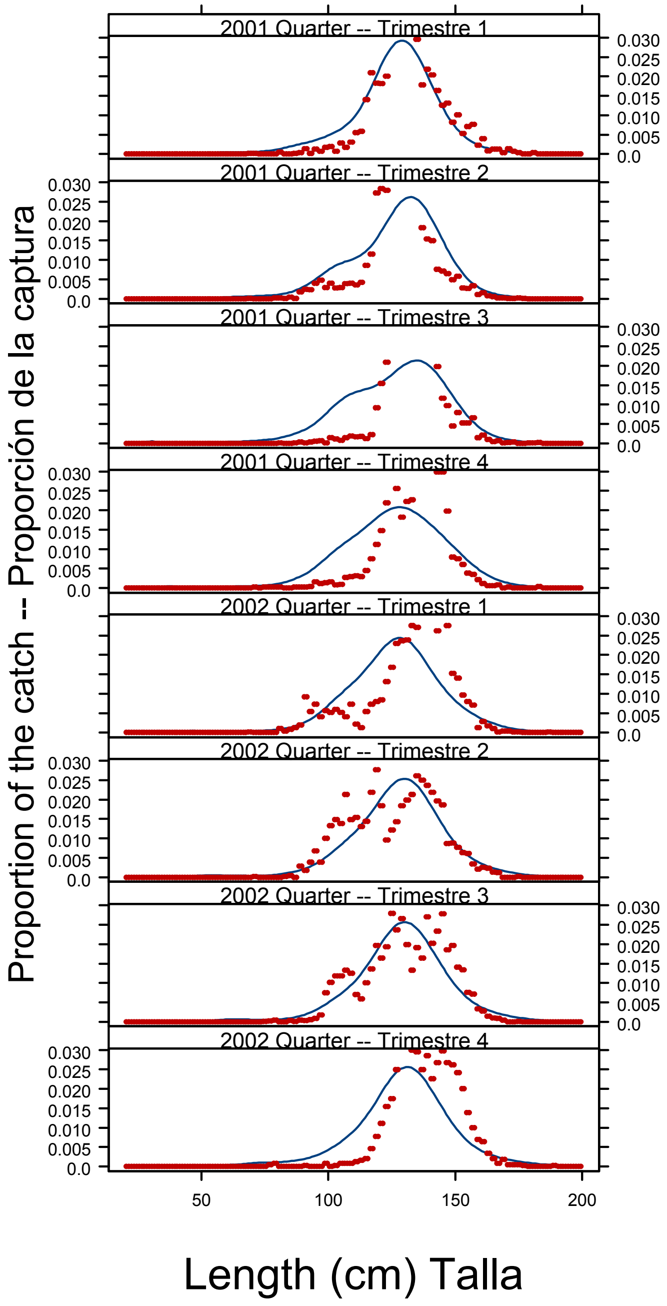

FIGURE 4.8e. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin tuna by the longline fisheries (Fisheries 11 y 12).

FIGURA 4.8e. Composiciones por tamaño observadas (puntos) y predichas (curvas) de las capturas recientes de atún aleta amarilla por las pesquerías palangreras (Pesquerías 11 y 12).

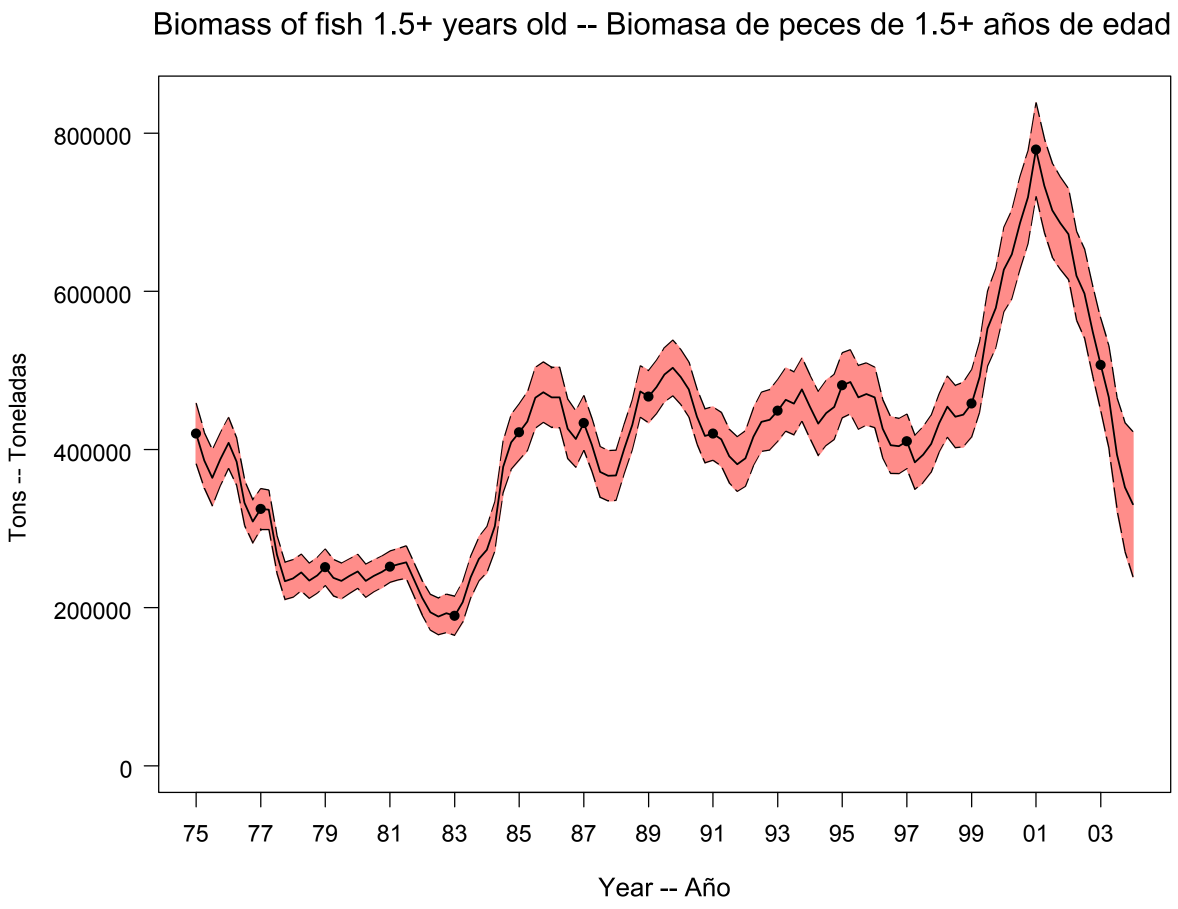

FIGURE 4.9a. Estimated biomass of yellowfin tuna in the EPO. The heavy lines illustrate the maximum likelihood estimates of the biomass, and the thin dashed lines the approximate 95% confidence intervals around those estimates. Since the assessment model represents time on a quarterly basis, there are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

FIGURA 4.9. Biomasa estimada de atún aleta amarilla en el OPO. Las líneas gruesas ilustran las estimaciones de probabilidad máxima de la biomasa, y las líneas delgadas de trazos los límites de confianza de 95% aproximados de las estimaciones. Ya que el modelo de evaluación representa el tiempo por trimestres, hay cuatro estimaciones de biomasa para cada año.

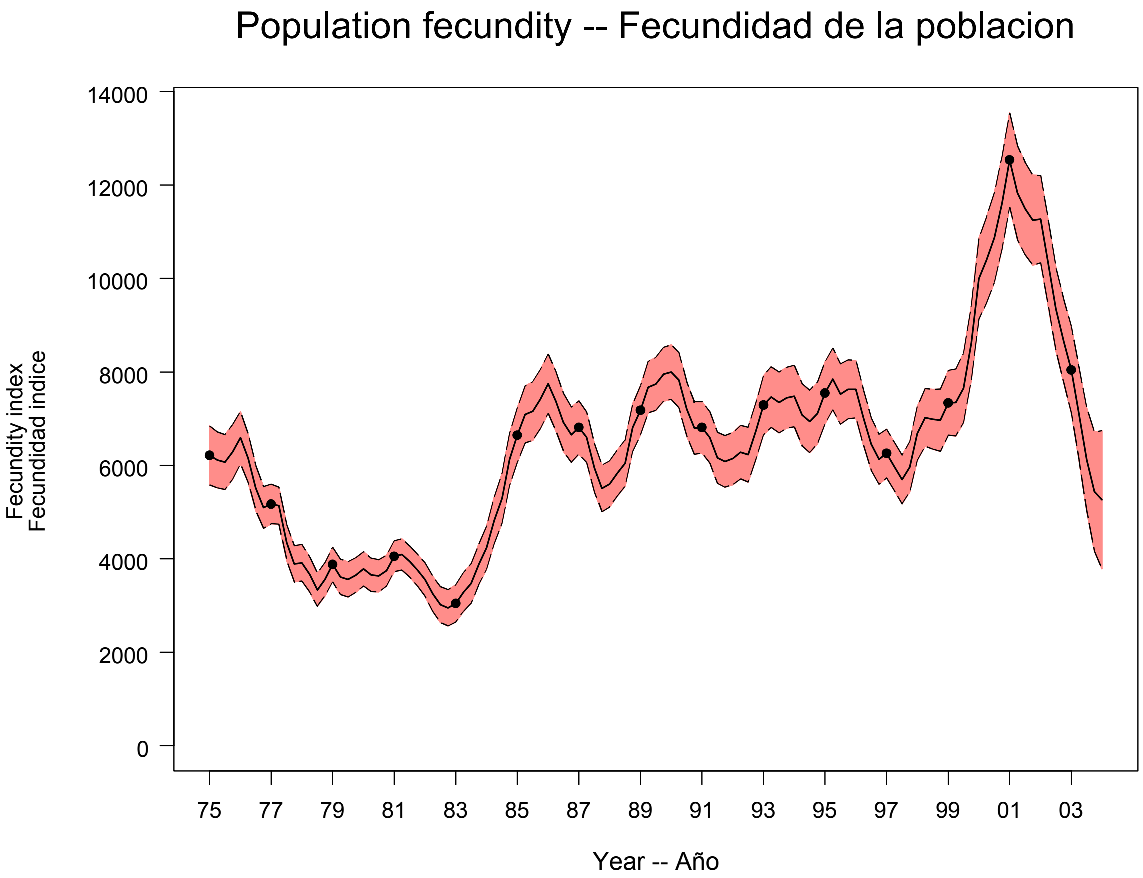

FIGURE 4.9. Estimated relative spawning biomass of yellowfin tuna in the EPO. The heavy lines illustrate the maximum likelihood estimates of the biomass, and the thin dashed lines the approximate 95% confidence intervals around those estimates. Since the assessment model represents time on a quarterly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

FIGURA 4.9. Biomasa relativa estimada de reproductores de atún aleta amarilla en el OPO. Las líneas gruesas ilustran las estimaciones de probabilidad máxima de la biomasa, y las líneas delgadas de trazos los límites de confianza de 95% aproximados de las estimaciones. Ya que el modelo de evaluación representa el tiempo por trimestres, hay cuatro estimaciones de biomasa para cada año.

FIGURE 4.10a. Biomass trajectory of a simulated population of yellowfin tuna that was not exploited during 1975-2003 ("no fishing") and that predicted by the stock assessment model ("fishing").

FIGURA 4.10a. Trayectoria de biomasa de una población simulada de atún aleta amarilla no explotada durante 1975-2003 ("sin pesca") y la predicha por el modelo de evaluación de la población ("con pesca").

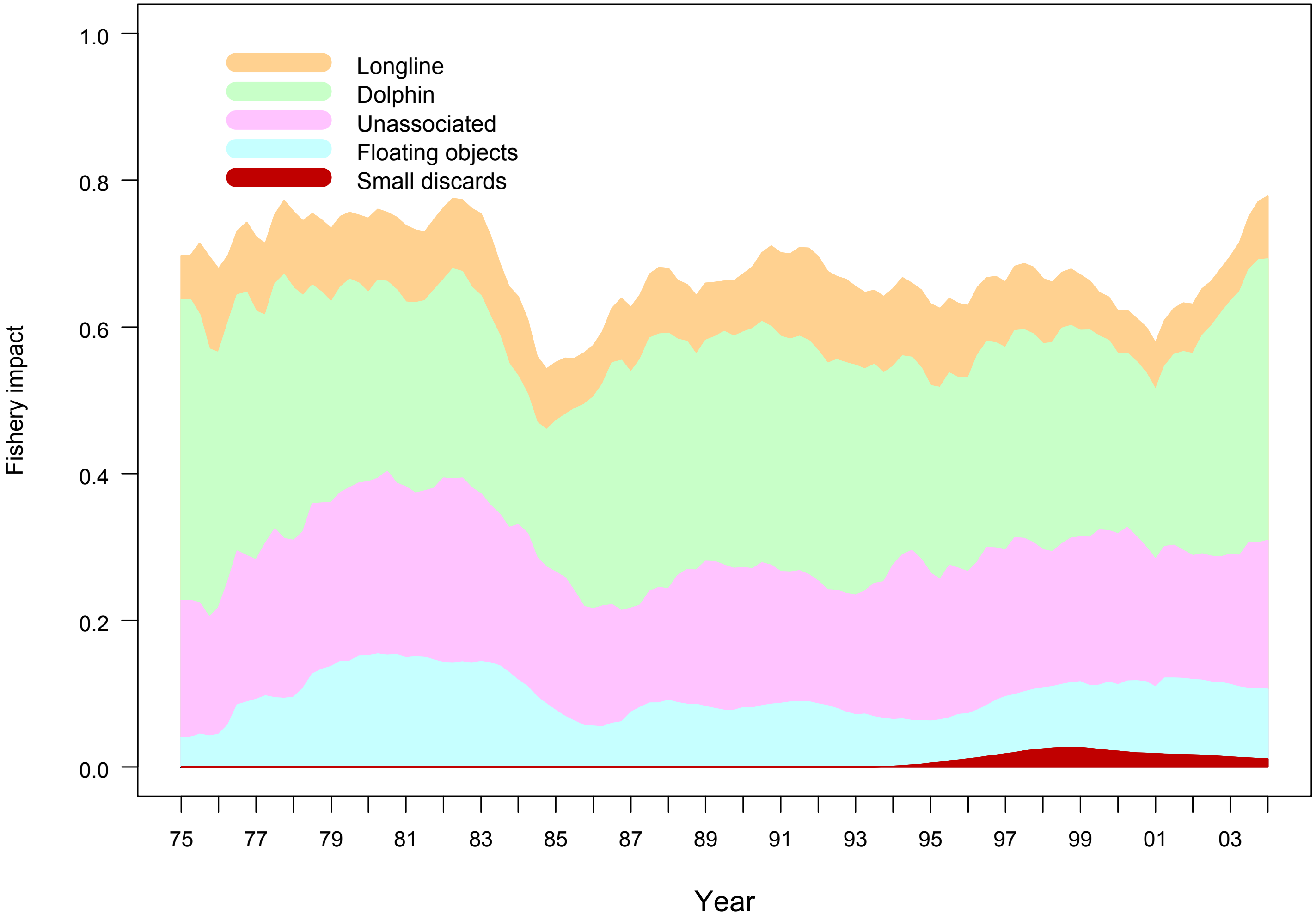

FIGURE 4.10b. Fishery impacts.
FIGURA 4.10b. Efecto de las pes querías

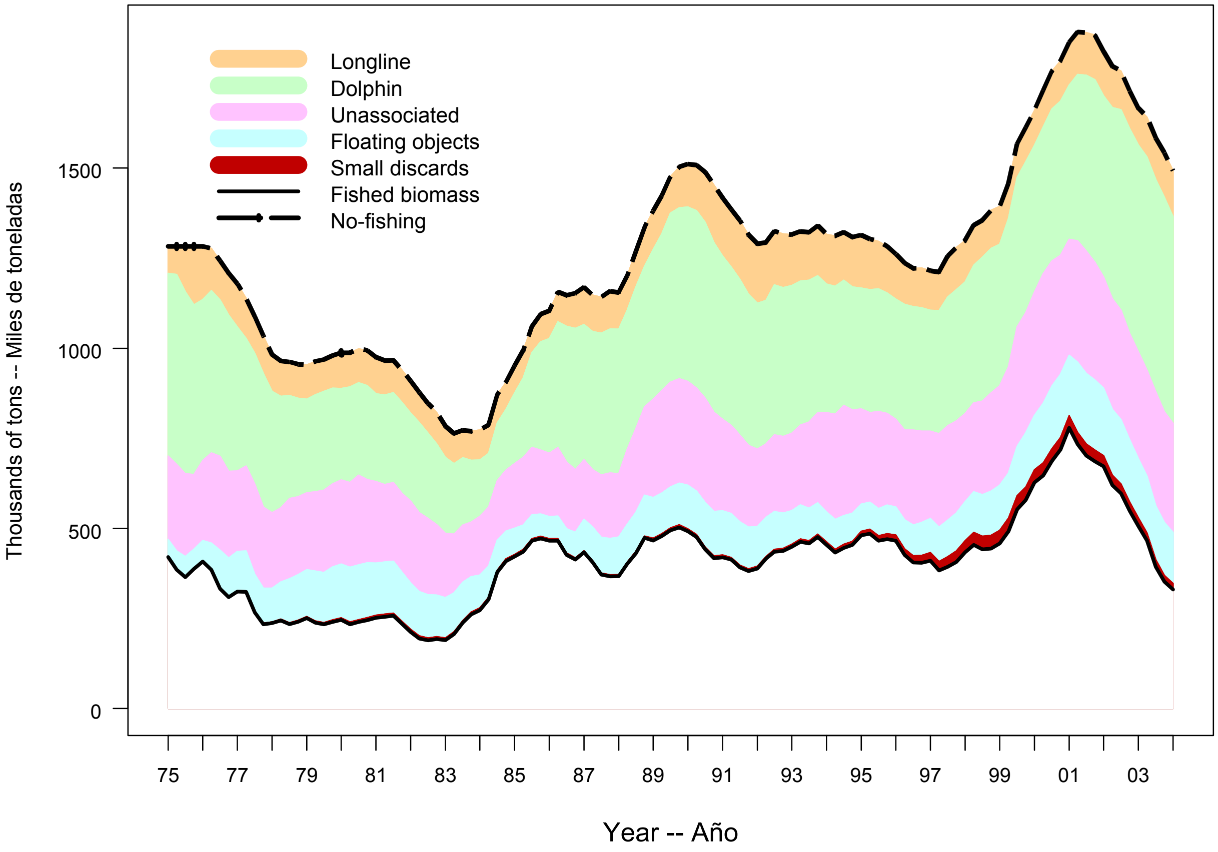

FIGURE 4.10c. Biomass trajectory of a simulated population of yellowfin tuna that was not exploited during 1975-2002 ("Biomass with no fishing") and that predicted by the stock assessment model ("Biomass with fishing"). The shaded areas between the two lines show the portion of the fishery impact attributed to each fishing method.

FIGURA 4.10c. Trayectoria de la biomasa de una población simulada de atún aleta amarilla no explotada durante 1975-2002 ("Biomasa sin pesca") y la que predice el modelo de evaluación ("Biomasa con pesca"). Las áreas sombreadas entre las dos líneas muestran la proporción del efecto de la pesqería por cada métedo de pesca.

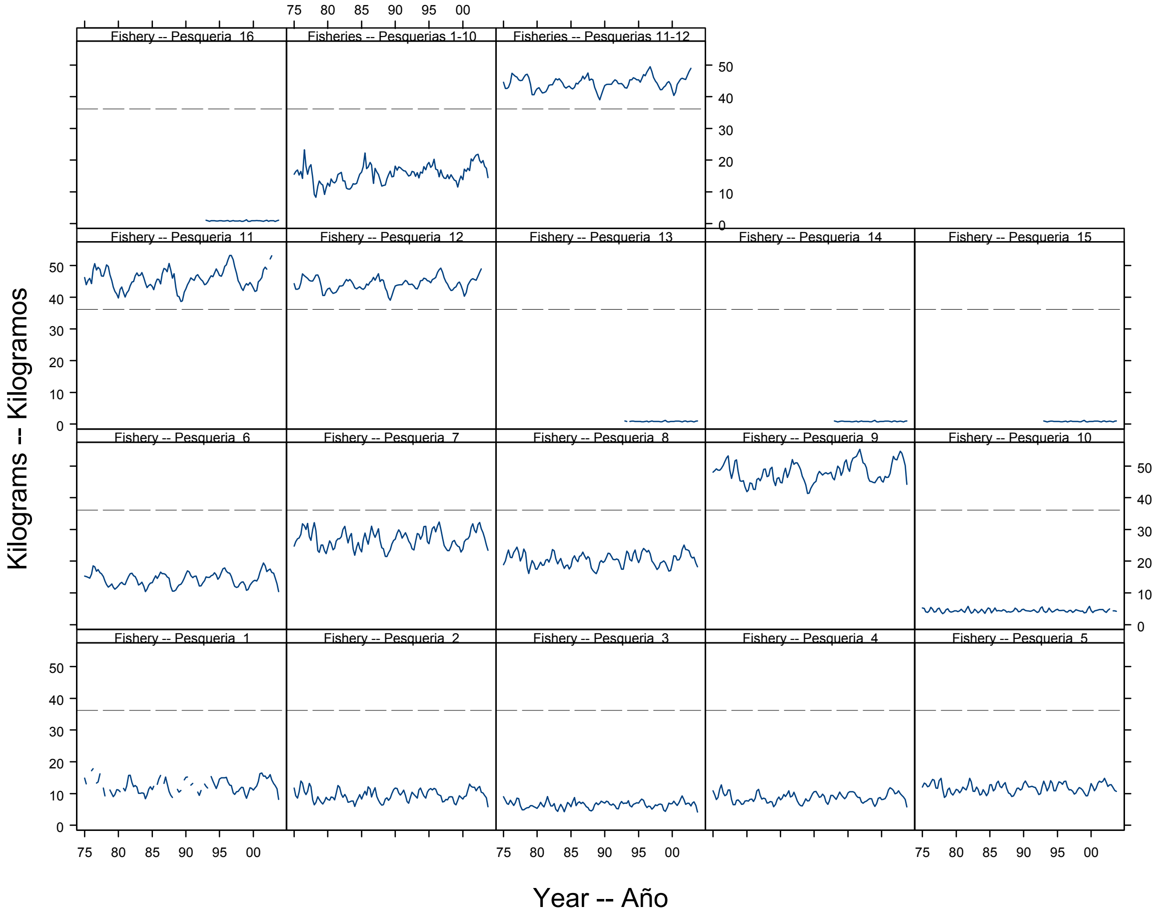

FIGURE 4.11. Estimated average weights of yellowfin tuna caught by the fisheries of the EPO. The time series for "Fisheries 1-10" is an average of Fisheries 1 through 10, and that for "Fisheries 11-12" is an average of Fisheries 11 and 12. The dashed line identifies the critical weight (36.2 kg).

FIGURA 4.11. Peso medio estimado de atún aleta amarilla capturado en las pesquerías del OPO. La serie de tiempo de "Pesquerías 1-10" es un promedio de las Pesquerías 1 a 10, y la de "Pesquerías 11-12" un promedio de las Pesquerías 11 y 12. La línea de trazos identifica el peso crítico (36,2 kg).

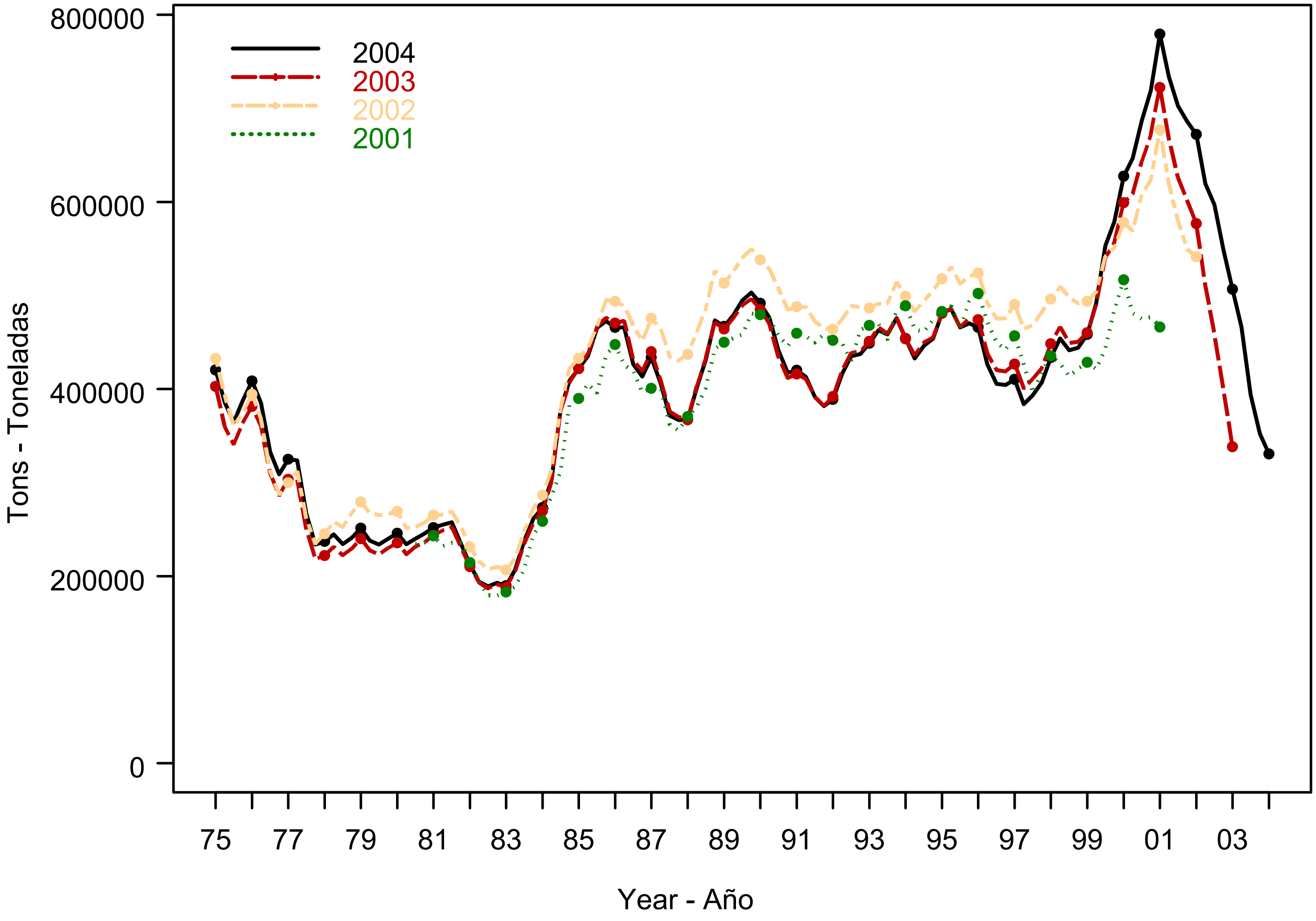

FIGURE 4.12a. Comparison of estimated biomasses of yellowfin tuna in the EPO from previous assessments and the current assessment.
FIGURA 4.12a. Comparación de la biomasa estimada de atún aleta amarilla en el OPO de evaluaciones previas y de la evaluación actual.

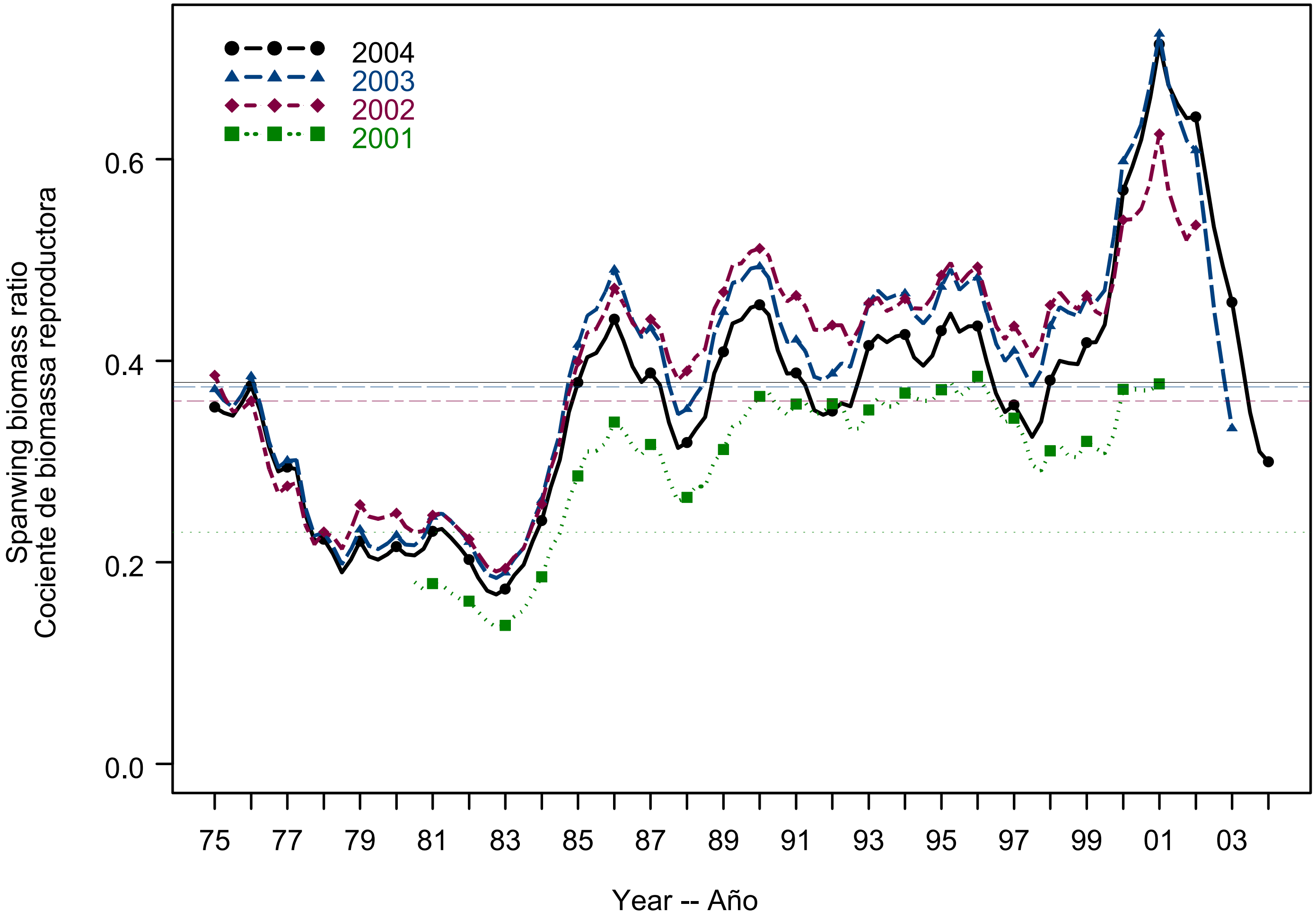

FIGURE 4.12b. Comparison of estimated spawning biomass ratios (SBRs) of yellowfin tuna from previous assessments and the current assessment. The horizontal lines identify the SBRs at AMSY.

FIGURA 4.12b. Comparación de cociente estimado de biomasa reproductora (SBR) de atún aleta amarilla de evaluaciones previas y de la evaluación actual. La línea horizontal identifica el SBR en RMSP.

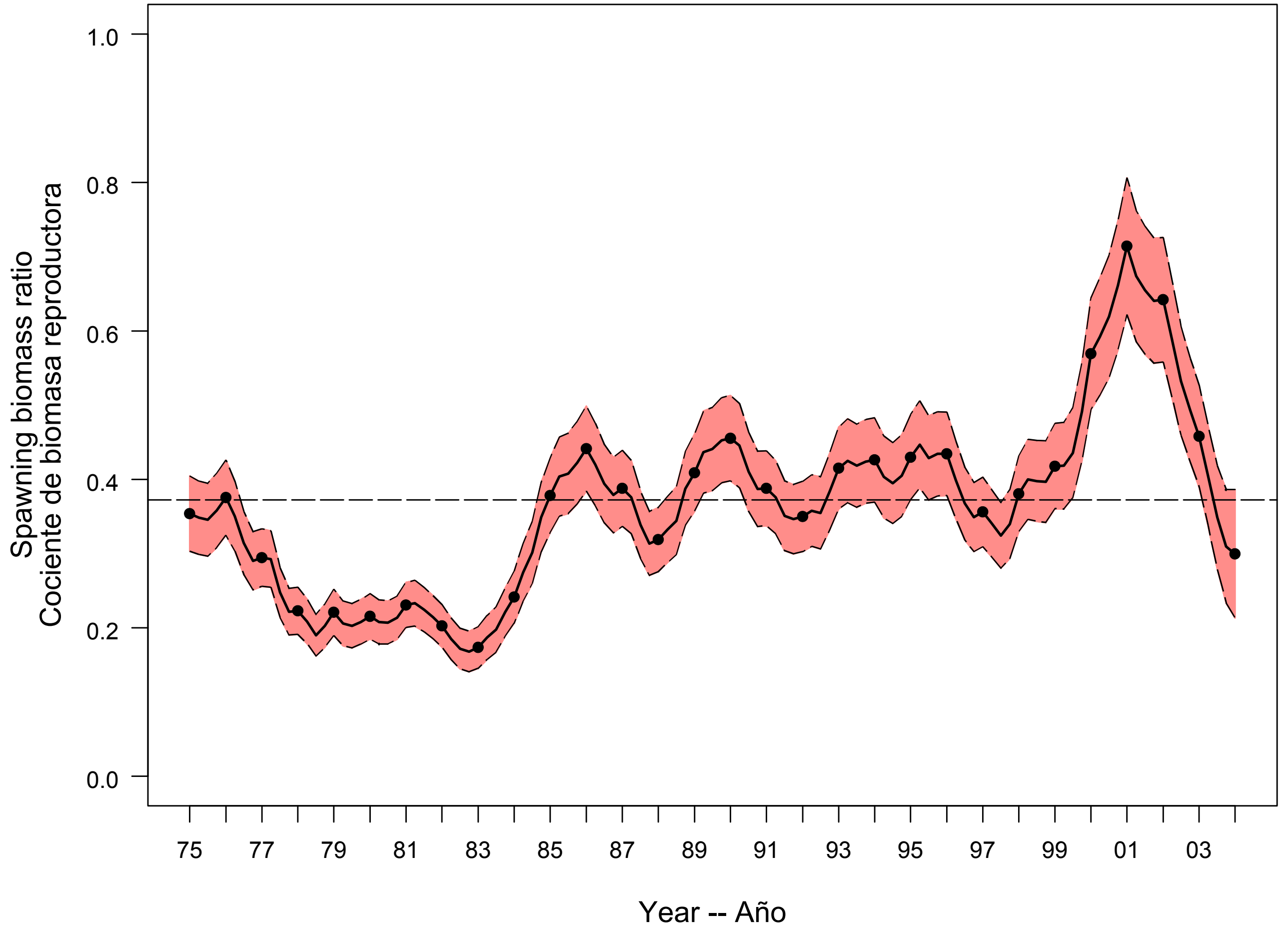

FIGURE 5.1. Estimated time series of spawning biomass ratios (SBRs) for yellowfin tuna in the EPO. The dashed extension to the solid line represents the projected SBR under current effort and average recruitment. The thin dashed lines represent approximate 95% confidence intervals. The dashed horizontal line (at about 0.38) 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 de trazos representan los intervalos de confianza de 95% aproximados. La línea de trazos horizontal (en aproximadamente 0,38) identifican el SBR en RMSP.

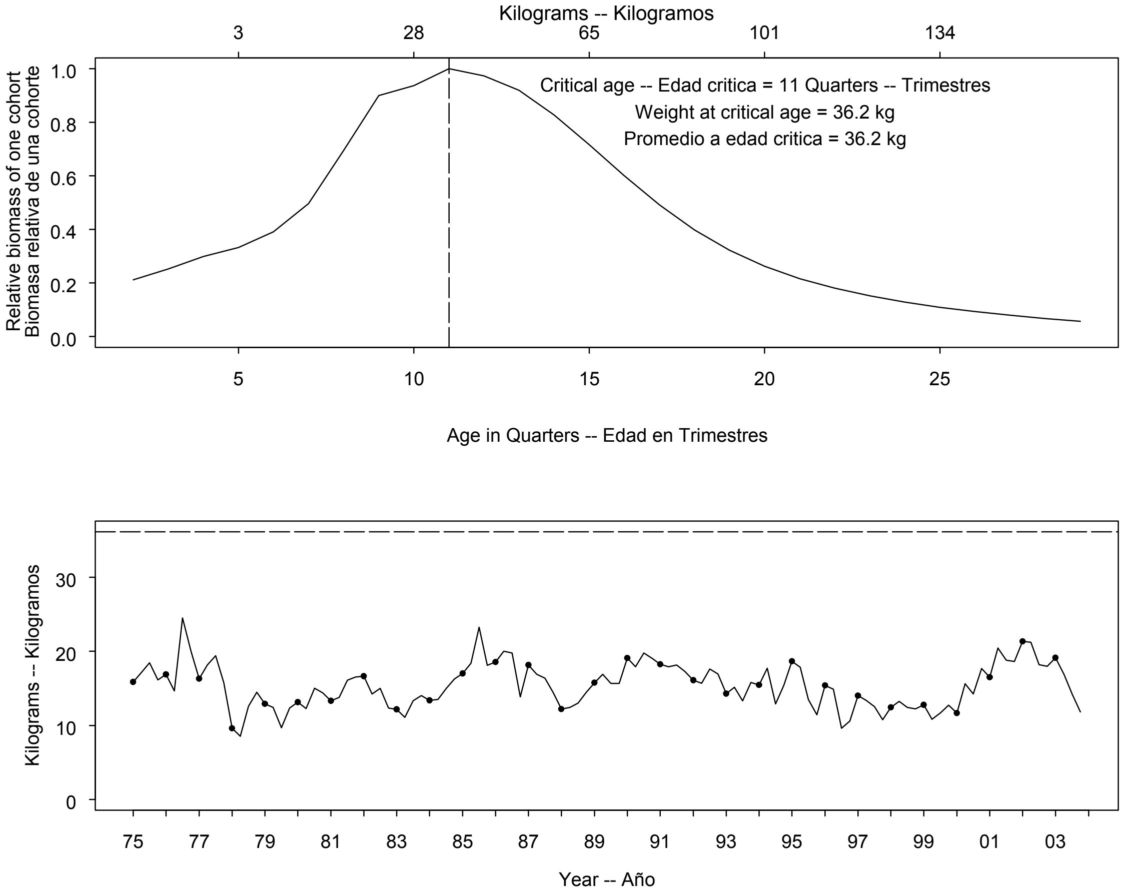

FIGURE 5.2. Combined performance of all fisheries that take yellowfin tuna in the EPO at achieving the maximum yield per recruit. The upper panel illustrates the growth (in weight) of a single cohort of yellowfin, and identifies the "critical age" and "critical weight" (Section 5). The lower panel illustrates the estimated average weight of yellowfin tuna caught in all fisheries combined. The critical weight is drawn as the dashed horizontal 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.

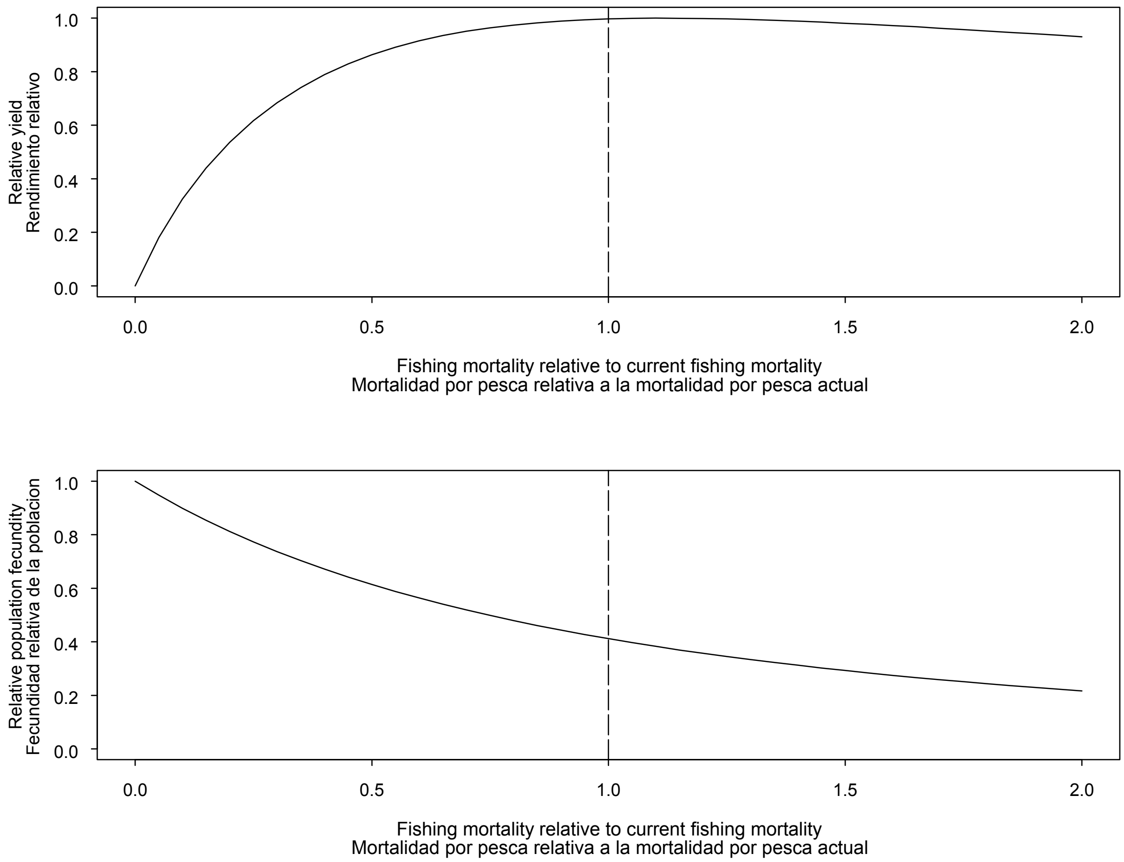

FIGURE 5.3. Predicted effects of long-term changes in fishing effort on the yield (upper panel) and spawning biomass (lower panel) of yellowfin tuna under average environmental conditions, constant recruitment, and the current age-specific selectivity pattern of all fisheries combined. The yield estimates 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 RMSP esté en 1,0, y las de biomasa reproductora para que ésta equivalga a 1,0 en ausencia de explotación.

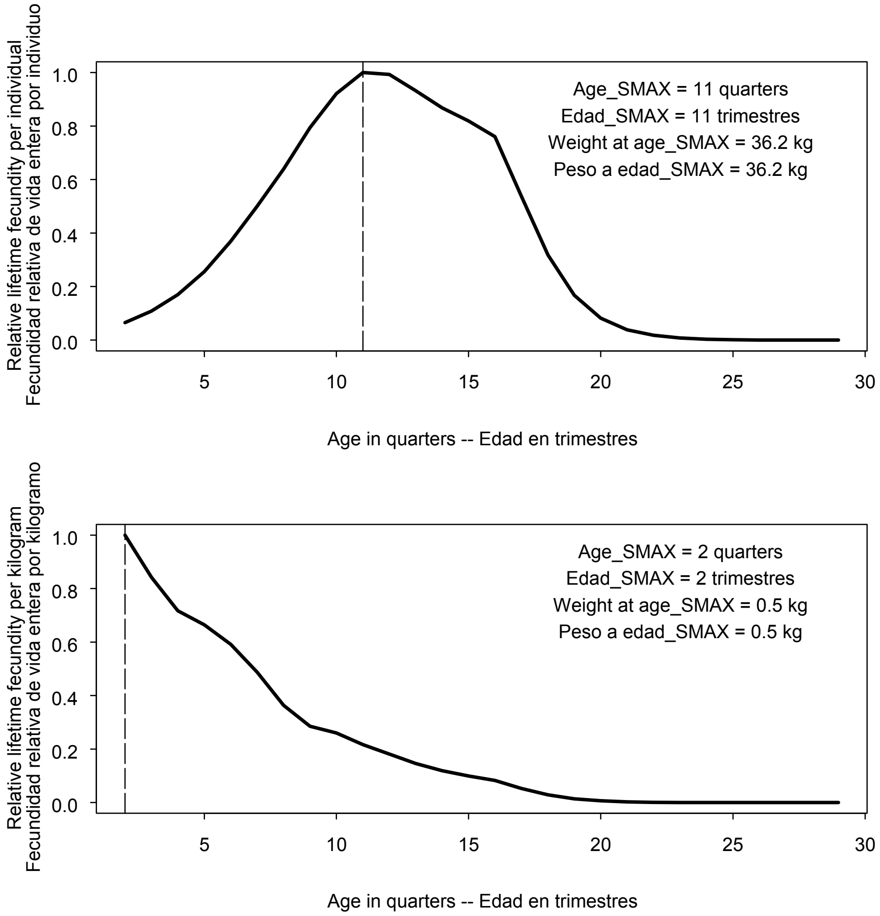

FIGURE 5.4. Marginal relative lifetime reproductive potential of yellowfin tuna at age based on individuals (upper panel) and weight (lower panel). $\mathrm{Age}_{\mathrm{SMAX}}$ is the age at which the maximum marginal relative lifetime reproductive potential is realized. The vertical lines indicate the locations of $\mathrm{Age}_{\mathrm{SMAX}}$.
FIGURA 5.4. Potencial de reproducción relativo marginal de atún aleta amarilla a edad basado en individuos (recuadro superior) y peso (recuadro inferior). $\mathrm{Edad}_{\mathrm{SMAX}}$ es la edad a la cual se logra el potencial de reproducción relativo marginal máximo. Las líneas verticales señalan la posición de $\mathrm{Edad}_{\mathrm{SMAX}}$

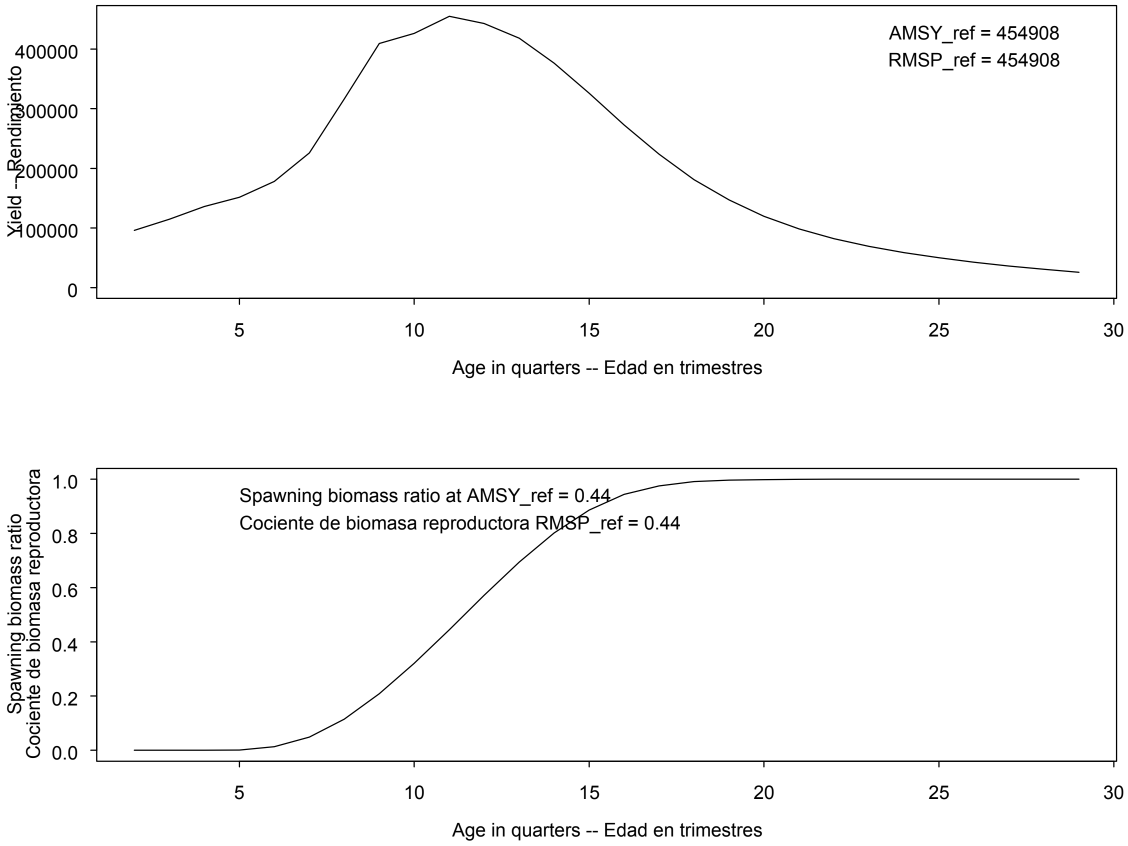

FIGURE 5.5. Yield calculated when catching only individual yellowfin tuna at a single age (upper panel) and the associated spawning biomass ratio (lower panel).

FIGURA 5.5. Rendimiento calculado si se capturaran atunes aleta amarilla individuales de una edad solamente (recuadro superior) y el cociente de biomasa reproductora asociado (recuadro inferior).

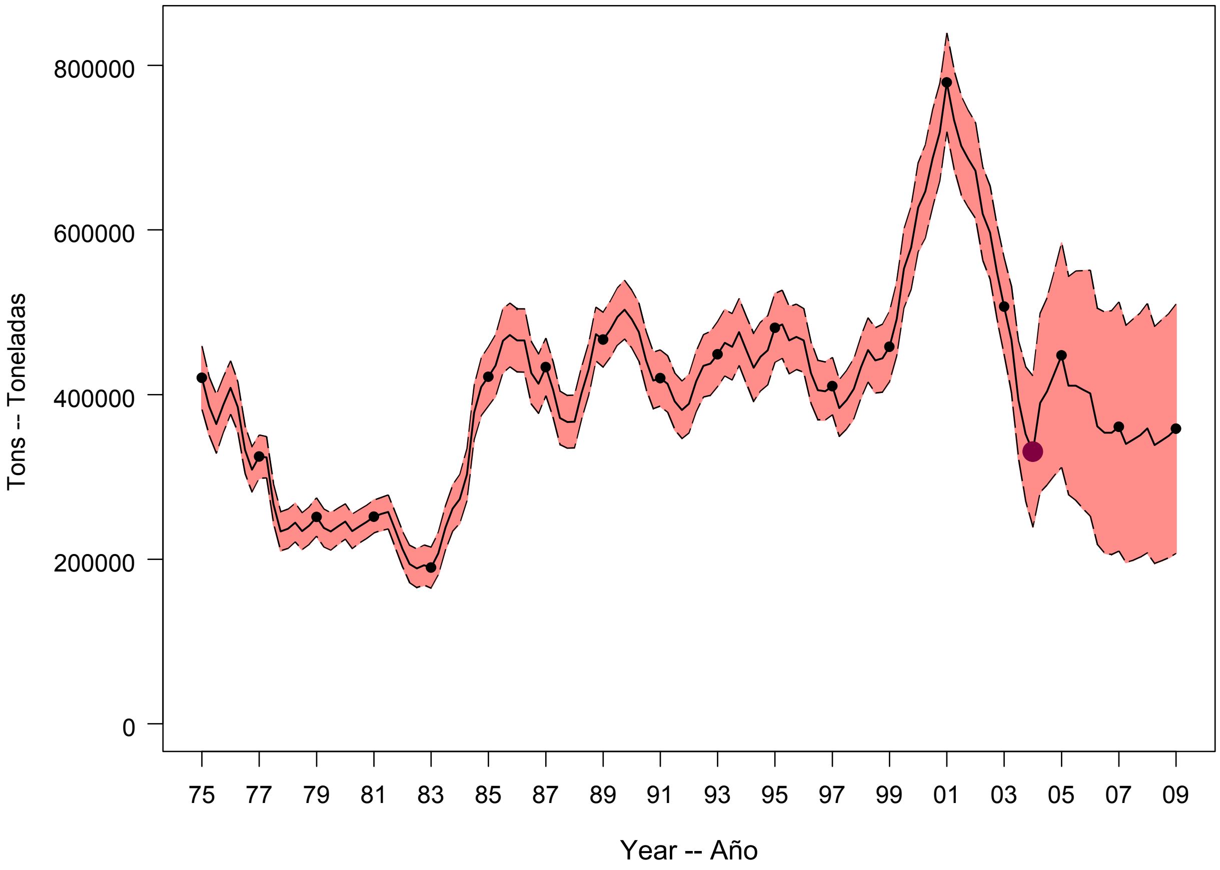

FIGURE 6.1. Biomass projected during 2004-2008 for yellowfin tuna in the EPO under current effort. The shaded area represents the 95% confidence intervals.

FIGURA 6.1. Biomasa predicha durante 2004-2008 de atún aleta amarilla con esfuerza corriente. El área sombreada representa los intervales de confianza de 95%.

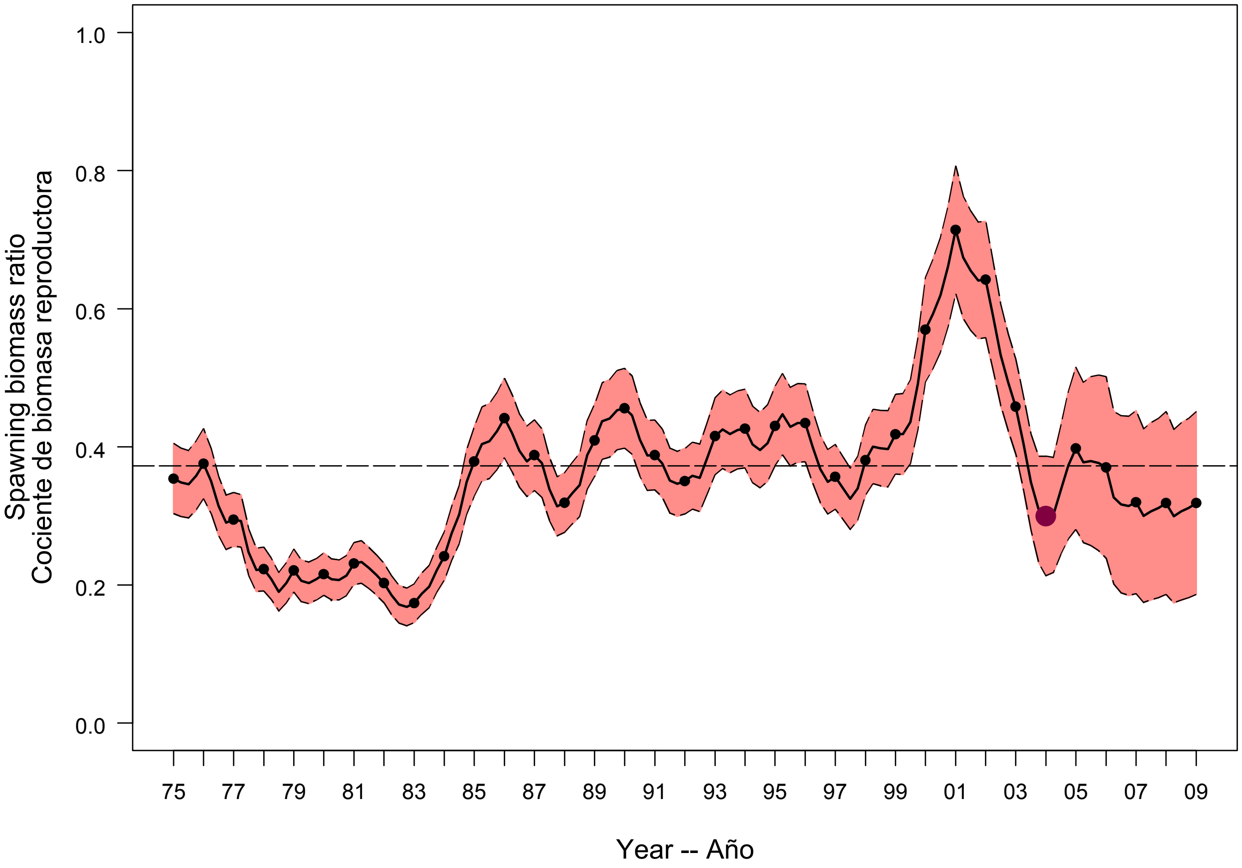

FIGURE 6.2. Spawning biomass ratios (SBRs) projected during 2004-2008 for yellowfin tuna in the EPO under current effort. The dashed horizontal line (at 0.38) identifies SBR_{AMSY} (Section 5.3) and the shaded area represents the 95% confidence intervals.

FIGURA 6.2. Cocientes be biomas reproductora (SBR) proyectados durante 2003-2008 para el atún aleta amarilla en el OPO bajo esfuerza corriente. La línea de trazos horizontal (en 0.38) identifica SBR_{RMSP} (Sección 5.3), y área sombreada representa los intervalos de confianza de 95%.

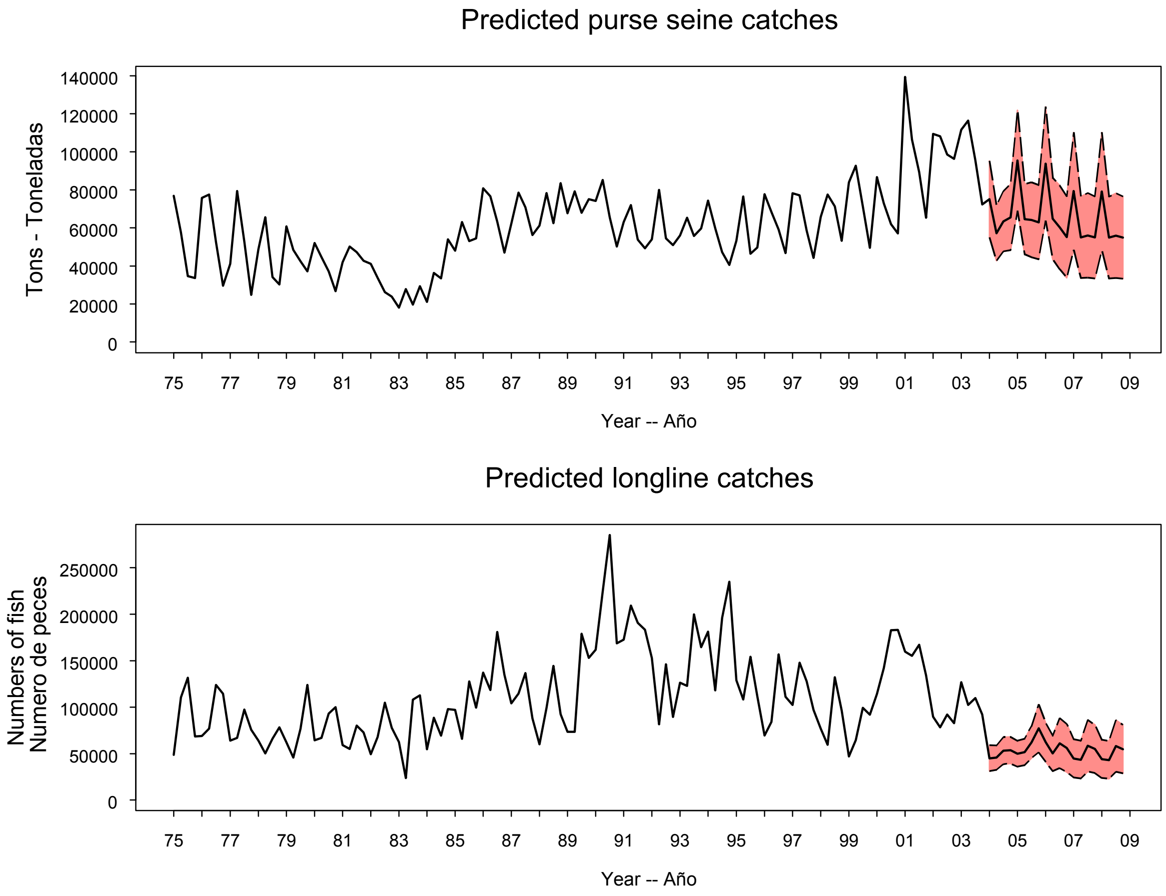

FIGURE 6.3. Simulated catches of yellowfin tuna taken by the primary surface fleet (Fisheries 1-10; upper panel) and the the longline fleet (Fisheries 11 and 12, lower panel) during 2004-2008 under current effort. The shaded area represents the estimated 95% confidence limits of the estimates.

FIGURA 6.3b. Capturas simuladas de atún aleta amarilla por la flota primaria de superficie (Pesquerías 1-10, recuadro superior) y la flota palangrera (Pesquerías 11 y 12, recuadro inferior) durante 2003-2008, bajo esfuerza corriente. El área sombrada representa los intervalos de confianza de 95% estimados des las estimaciones.

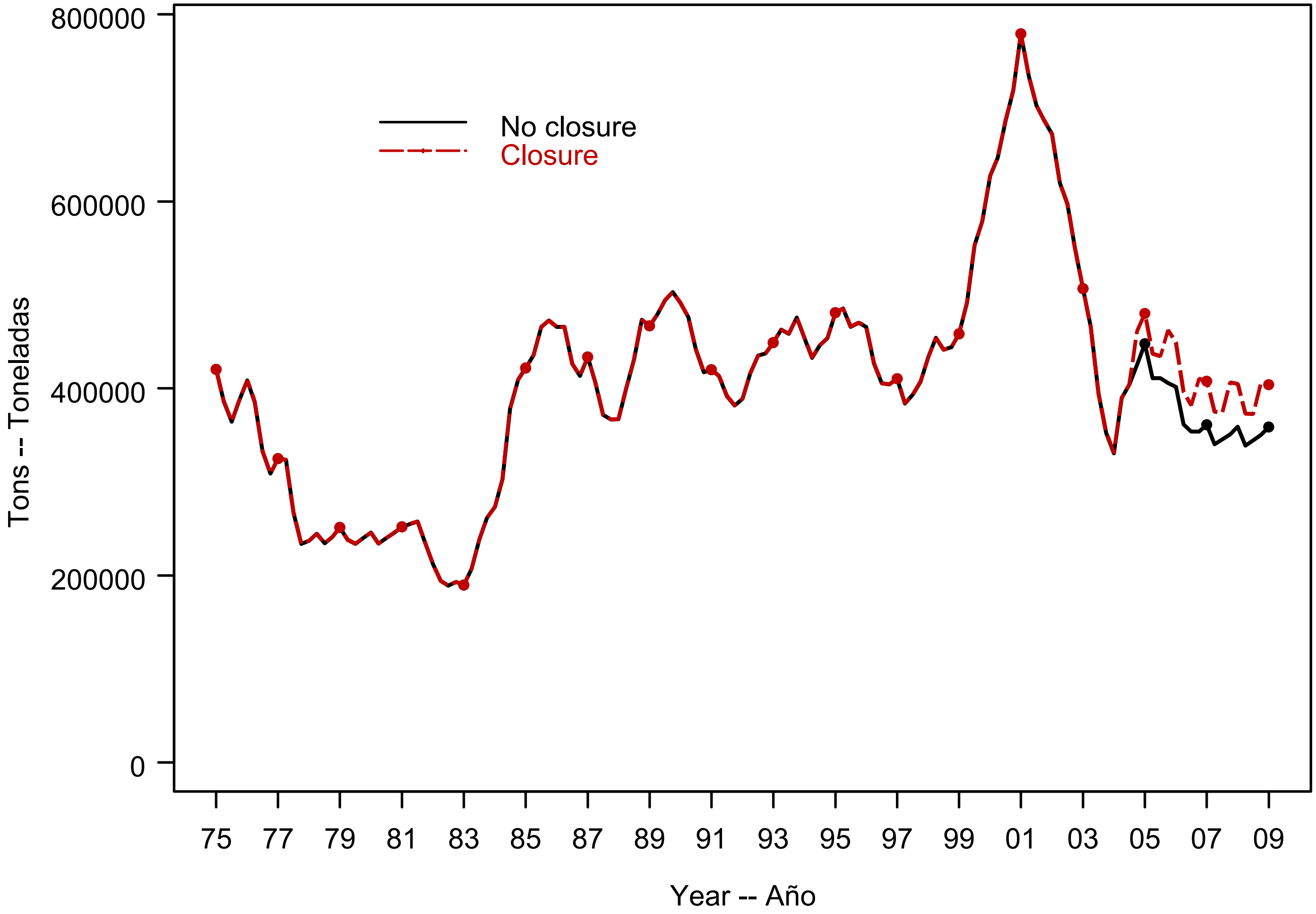

FIGURE 6.4. Biomass projected during 2004-2008 for yellowfin tuna in the EPO under current effort and under a closure of the surface fishery for six weeks in the third quarter.

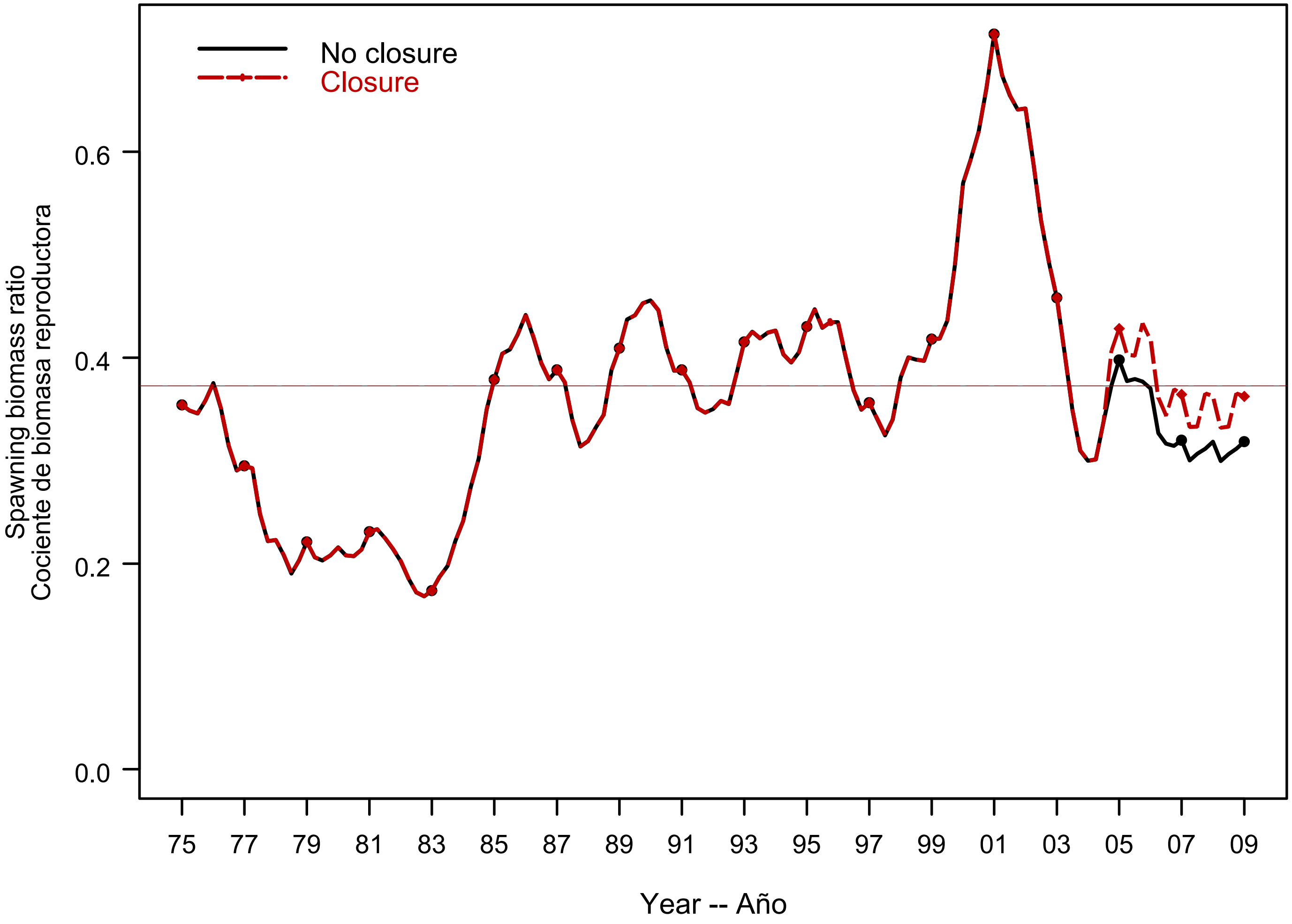

FIGURE 6.5. Spawning biomass ratios (SBRs) projected during 2004-2008 for yellowfin tuna in the EPO under current effort and under a closure of the surface fishery for six weeks in the third quarter. The dashed horizontal line (at 0.38) identifies SBR_{AMSY} (Section 5.3).

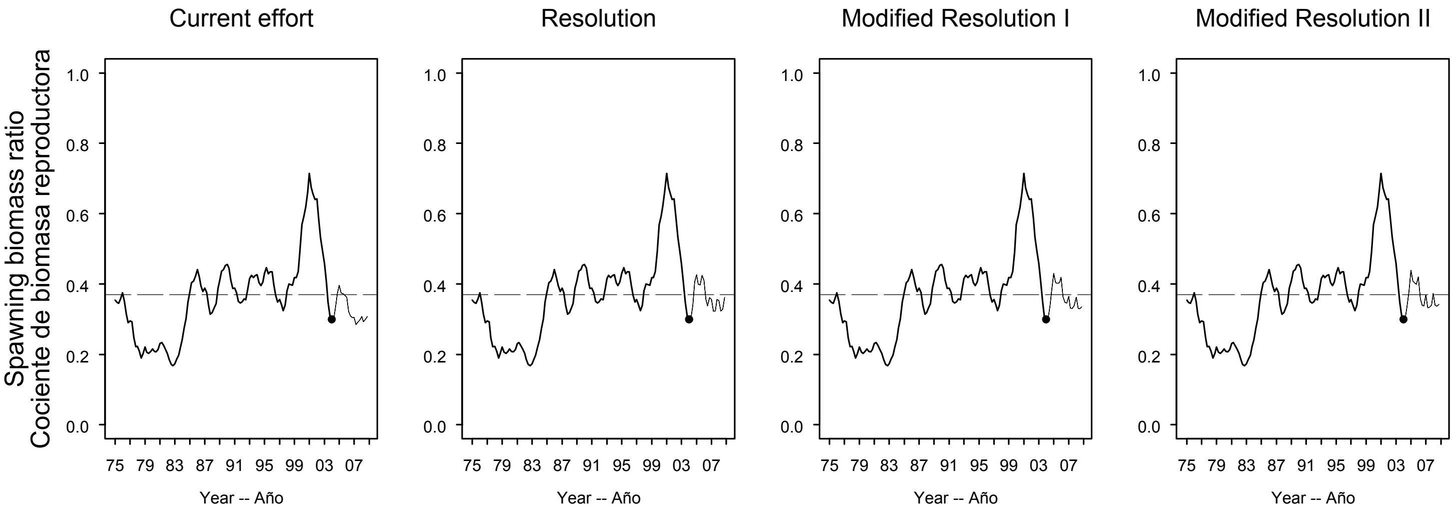

FIGURE 6.6. Spawning biomass ratios (SBRs) projected during 2004-2008 for yellowfin tuna in the EPO under current effort and under three six week closure scenarios for the surface fishery. The dashed horizontal line (at 0.38) identifies SBR_{AMSY} (Section 5.3).

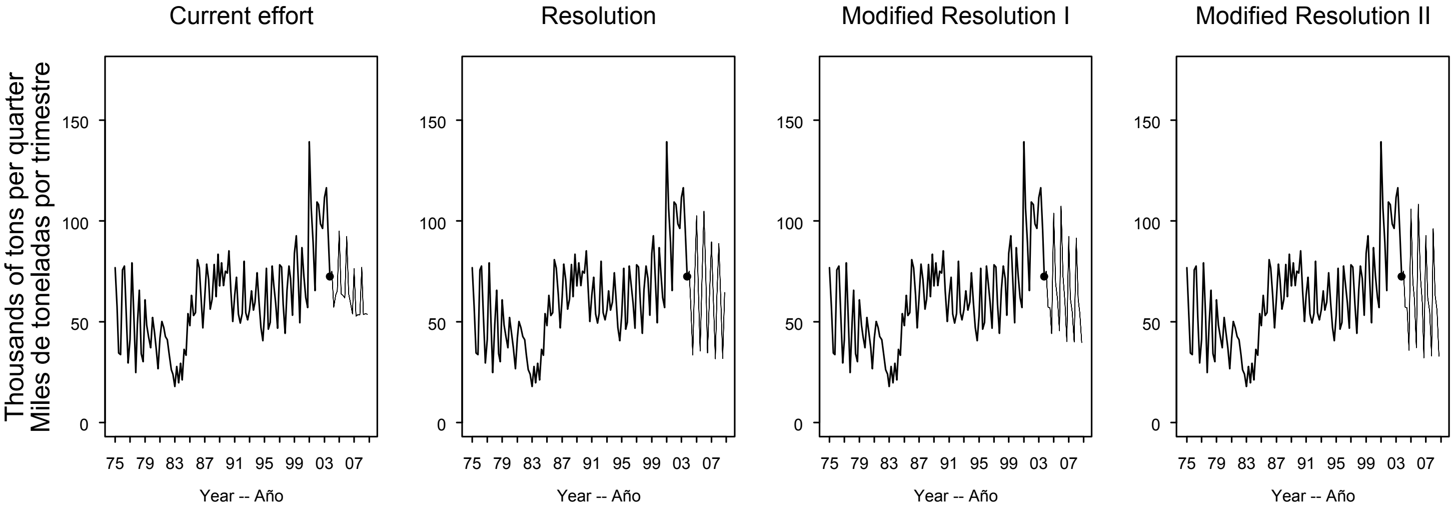

FIGURE 6.7. Surface fishery catch projected during 2004-2008 for yellowfin tuna in the EPO under current effort and under three six week closure scenarios for the surface fishery.

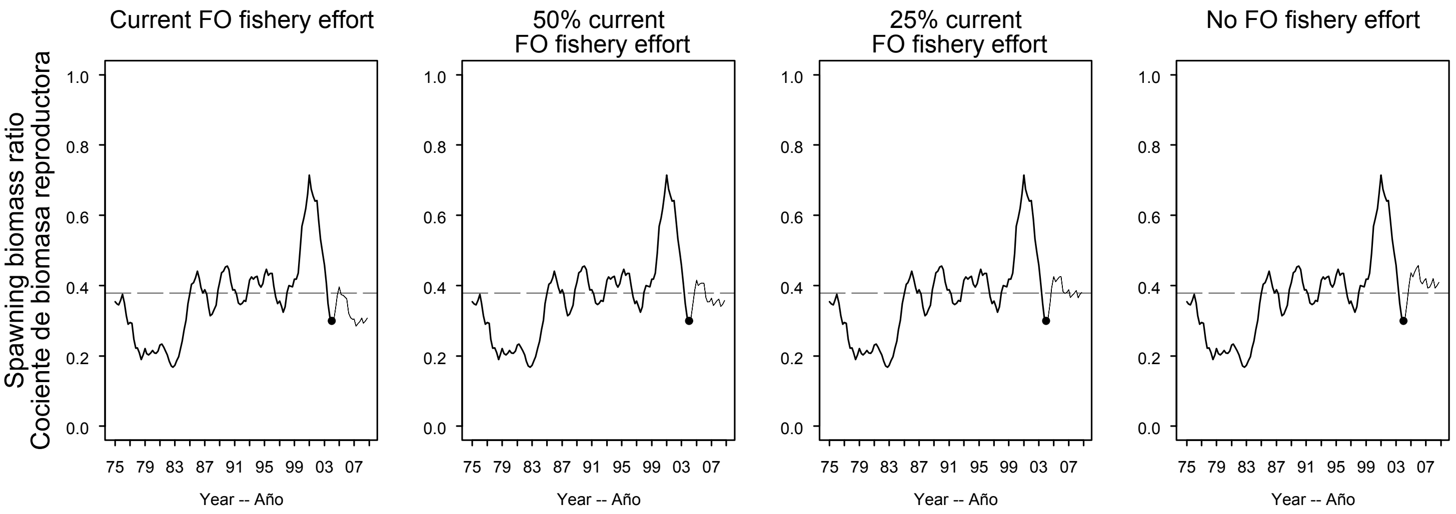

FIGURE 6.8. Spawning biomass ratios (SBRs) projected during 2004-2008 for yellowfin tuna in the EPO under current effort and under three scenarios for the floating object fishery effort. The dashed horizontal line (at 0.38) identifies SBR_{AMSY} (Section 5.3).

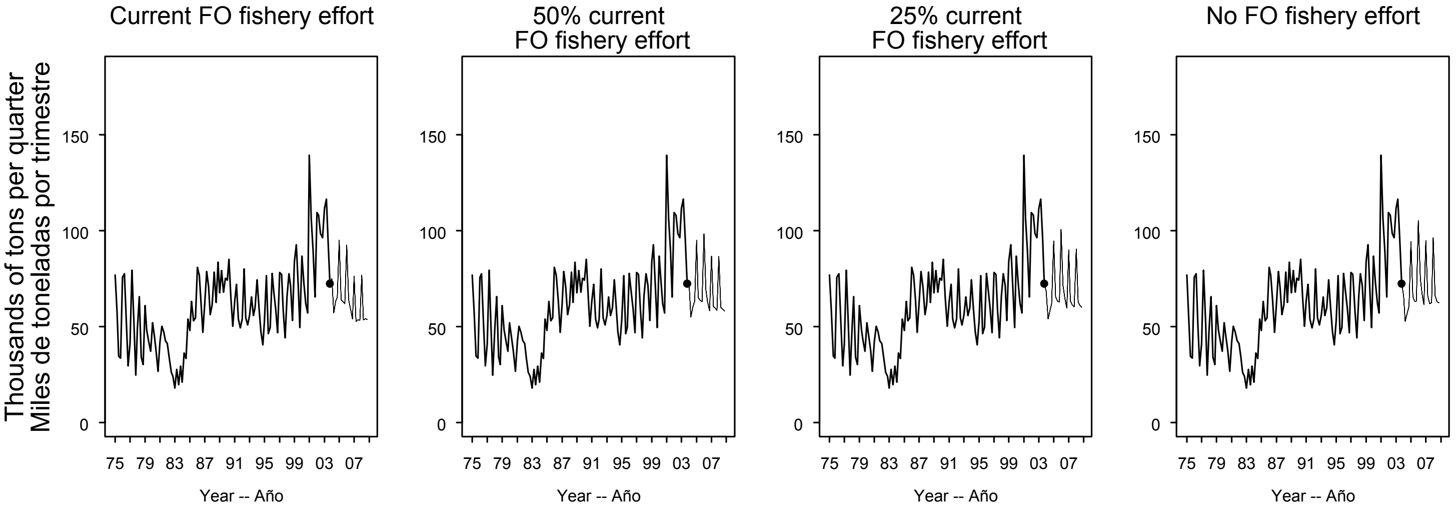

FIGURE 6.9. Surface fishery catch projected during 2004-2008 for yellowfin tuna in the EPO under current effort and under three scenarios for the floating object fishery effort.

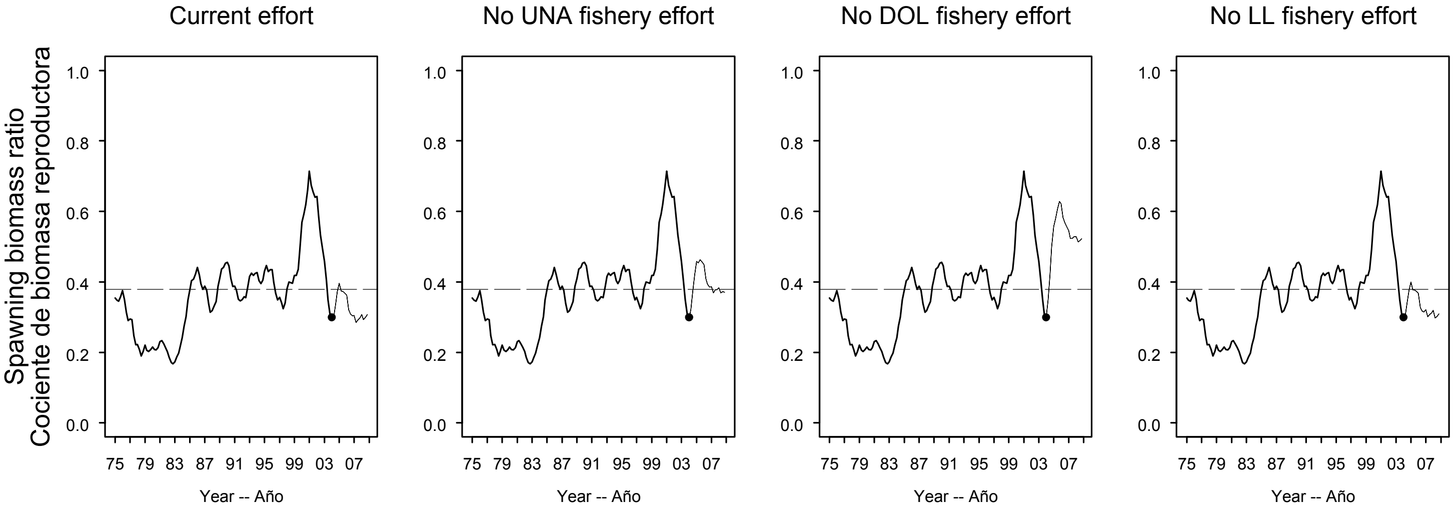

FIGURE 6.10. Spawning biomass ratios (SBRs) projected during 2004-2008 for yellowfin tuna in the EPO under current effort and under three scenarios eliminating effort from three different fisheries. The dashed horizontal line (at 0.38) identifies SBR_{AMSY} (Section 5.3).

TABLE 2.1. Fisheries defined by the IATTC staff for the stock assessment of yellowfin tuna in the EPO. PS = purse seine; LP = pole and line; LL = longline; 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; LP = caña; 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	1975-2003	11-12	retained catch + discards from inefficiencies in fishing process–captura retenida + descartes de ineficacias en el proceso de pesca
2	PS	FLT	1975-2003	7, 9	
3	PS	FLT	1975-2003	5-6, 13	
4	PS	FLT	1975-2003	1-4, 8, 10	
5	PS	UNA	1975-2003	1-4, 8, 10	retained catch + discards–captura retenida + descartes
6	PS	UNA	1975-2003	5-7, 9, 11-13	
7	PS	DOL	1975-2003	2-3, 10	
8	PS	DOL	1975-2003	1, 4-6, 8, 13	
9	PS	DOL	1975-2003	7, 9, 11-12	
10	LP		1975-2003	1-13	retained catch only— captura retenida solamente
11	LL		1975-2003	N of-de 15°N	
12	LL		1975-2003	S of-de 15°N	
13	PS	FLT	1993-2003	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	1993-2003	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	1993-2003	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	1993-2003	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	123,673	420,221	0.50
1976	102,685	408,505	0.53
1977	167,206	324,748	0.41
1978	131,854	236,936	0.31
1979	133,423	251,177	0.31
1980	109,395	245,830	0.30
1981	84,409	251,722	0.32
1982	121,619	212,484	0.28
1983	186,828	189,763	0.24
1984	170,650	273,211	0.34
1985	141,581	421,751	0.53
1986	173,790	465,952	0.62
1987	277,832	433,507	0.54
1988	195,762	367,199	0.45
1989	147,841	466,751	0.57
1990	159,314	491,540	0.64
1991	216,657	420,006	0.54
1992	187,045	388,838	0.49
1993	166,492	449,084	0.58
1994	155,463	454,069	0.60
1995	172,859	481,024	0.60
1996	214,747	465,978	0.61
1997	191,831	410,421	0.50
1998	326,672	433,409	0.53
1999	246,208	458,197	0.59
2000	235,814	627,310	0.80
2001	203,151	779,125	1.00
2002	167,508	672,115	0.90
2003	239,943	506,698	0.64
2004		330,693	0.42

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	149.06	72.01
3	37.37	1.01	17	153.86	79.42
4	45.54	1.86	18	158.34	86.76
5	53.34	3.03	19	162.50	94.00
6	62.38	4.90	20	166.39	101.11
7	73.30	8.06	21	170.00	108.04
8	87.26	13.80	22	173.37	114.78
9	101.22	21.82	23	176.51	121.32
10	109.42	27.75	24	179.43	127.62
11	119.22	36.15	25	182.16	133.69
12	126.11	43.00	26	184.69	139.52
13	132.50	50.08	27	187.06	145.11
14	138.39	57.27	28	189.26	150.44
15	143.91	64.61	29	191.31	155.53

TABLE 5.1. AMSY and related quantities for the base case and the stock-recruitment relationship sensitivity analysis.

TABLA 5.1. RMSP y cantidades relacionadas para el caso base y los análisis de sensibilidad a la relación población-reclutamiento.

	Base case	**h = 0.75**
	Caso base	**h = 0.75**
AMSY–RMSP	284,979	308,585
B_{ms2} – B_{rm2}	420,895	571,588
S_{ms2}—S_{rm2}	6,606	9,055
C_{2002}/AMSY—C_{2002}/RMSP	1.47	1.36
B_{2003}/B_{AMSY} – B_{2003}/B_{RMSP}	0.79	0.60
S_{2003}/S_{AMSY} – S_{2003}/S_{RMSP}	0.80	0.60
$S_{AMSY}/S_{F=0}$ – $S_{RMSP}/S_{F=0}$	0.38	0.42
F multiplier—Multiplicador de *F*	1.12	0.83

TABLE 5.2. Estimates of the AMSY 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 and B_{AMSY} are expressed in metric tons.

TABLA 5.2. Estimaciones del RMSP 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 RMSP y B_{RMSP} en toneladas métricas.

Fishery	**AMSY**	B_{AMSY}	S_{AMSY}	$B_{\text{AMSY}}/B_{F=0}$	$S_{\text{AMSY}}/S_{F=0}$	***F* multiplier**
Pesquería	**RMSP**	B_{RMSP}	S_{RMSP}	$B_{\text{RMSP}}/B_{F=0}$	$S_{\text{RMSP}}/S_{F=0}$	**Multiplicador de *F***
All Gears	284,979	420,895	6,606	0.33	0.38	1.12
FO	194,055	304,007	4,345	0.24	0.25	8.65
UNA	242,816	341,494	5,032	0.27	0.29	5.71
DOL	320,250	435,804	6,810	0.34	0.39	2.20
LL	386,114	493,213	7,745	0.39	0.44	68.08

TABLE 5.2b. Estimates of the AMSY and its associated quantities, obtained by assuming that each fishery maintains its current pattern of age-specific selectivity (Figure 4.4) and that one fishery is not operating in the EPO. The estimates of the AMSY and B_{AMSY} are expressed in metric tons.

TABLA 5.2. Estimaciones del RMSP 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 RMSP y B_{RMSP} en toneladas métricas.

Fishery	**AMSY**	B_{AMSY}	S_{AMSY}	$B_{\text{AMSY}}/B_{F=0}$	$S_{\text{AMSY}}/S_{F=0}$	***F* multiplier**
Pesquería	**RMSP**	B_{RMSP}	S_{RMSP}	$B_{\text{RMSP}}/B_{F=0}$	$S_{\text{RMSP}}/S_{F=0}$	**Multiplicador de *F***
All Gears	284,979	420,895	6,606	0.33	0.38	1.12
No FO	299,345	429,884	6,747	0.34	0.39	1.36
No UNA	295,658	434,025	6,856	0.34	0.39	1.45
No DOL	238,765	370,156	5,651	0.29	0.32	2.67
No LL	281,573	414,217	6,477	0.33	0.37	1.17

TABLE 6.1. Predicted average quarterly catch (mt) in 2008 and average SBR in 2008 for the different future management scenarios

Resolution				
	Current	Resolution	Modified Resolution I	Modified Resolution II
SBR	0.3	0.34	0.34	0.35
Surface catches	57780	62176	57959	59534
FO fishery reductions				
	None	50%	75%	100%
SBR	0.3	0.35	0.38	0.41
Surface catches	57780	63944	65707	69458
Remove each fishery				
	Current	No UNA	No DOL	No LL
SBR	0.3	0.38	0.52	0.31
Surface catches	57780	60195	32390	60028

APPENDIX A: SENSITIVITY ANALYSIS FOR THE STOCK-RECRUITMENT RELATIONSHIP

ANEXO A: ANALISIS DE SENSIBILIDAD A LA RELACIÓN POBLACIÓN-RECLUTAMIENTO

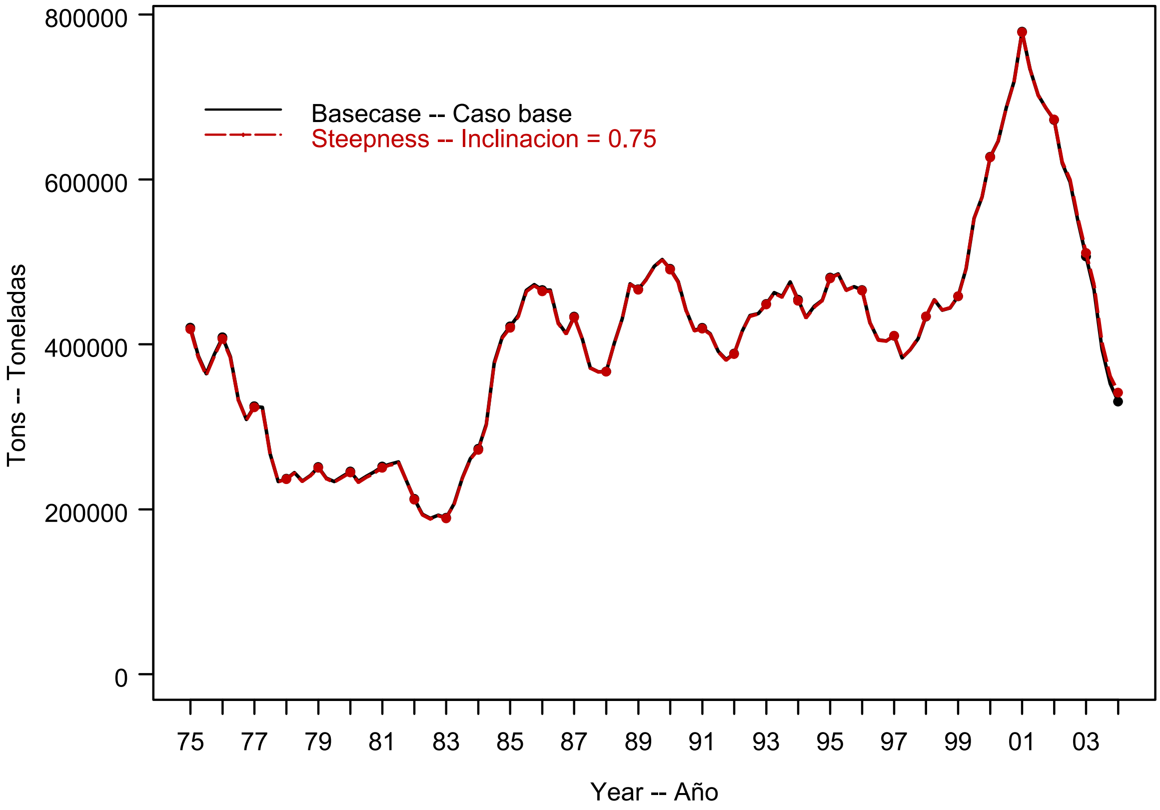

FIGURE A.1. Comparison of estimates of biomass of yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).

FIGURA A.1. Comparación de las estimaciones de biomasa de atún aleta amarilla del análisis sin relación población-reclutamiento (caso base) y con relación población-reclutamiento (inclinación = 0,75).

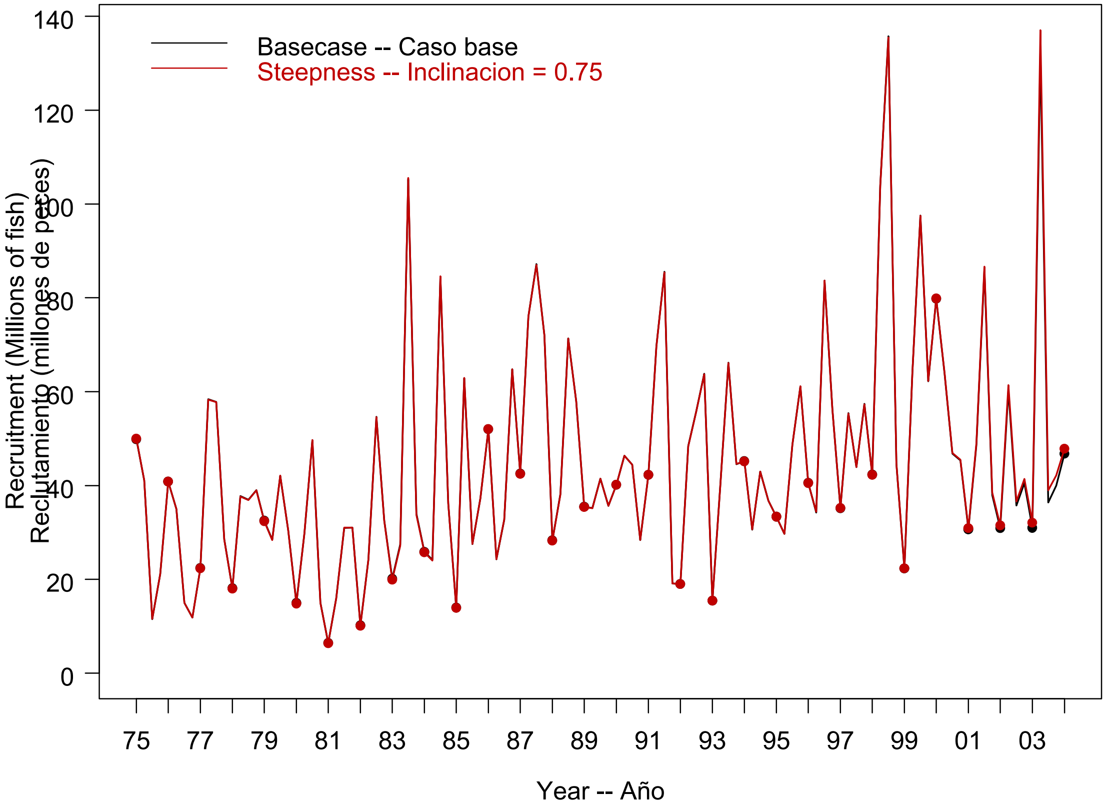

FIGURE A.2. Comparison of estimates of recruitment of yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).

FIGURA A.2. Comparación de las estimaciones de reclutamiento de atún aleta amarilla del análisis sin relación población-reclutamiento (caso base) y con relación población-reclutamiento (inclinación = 0,75).

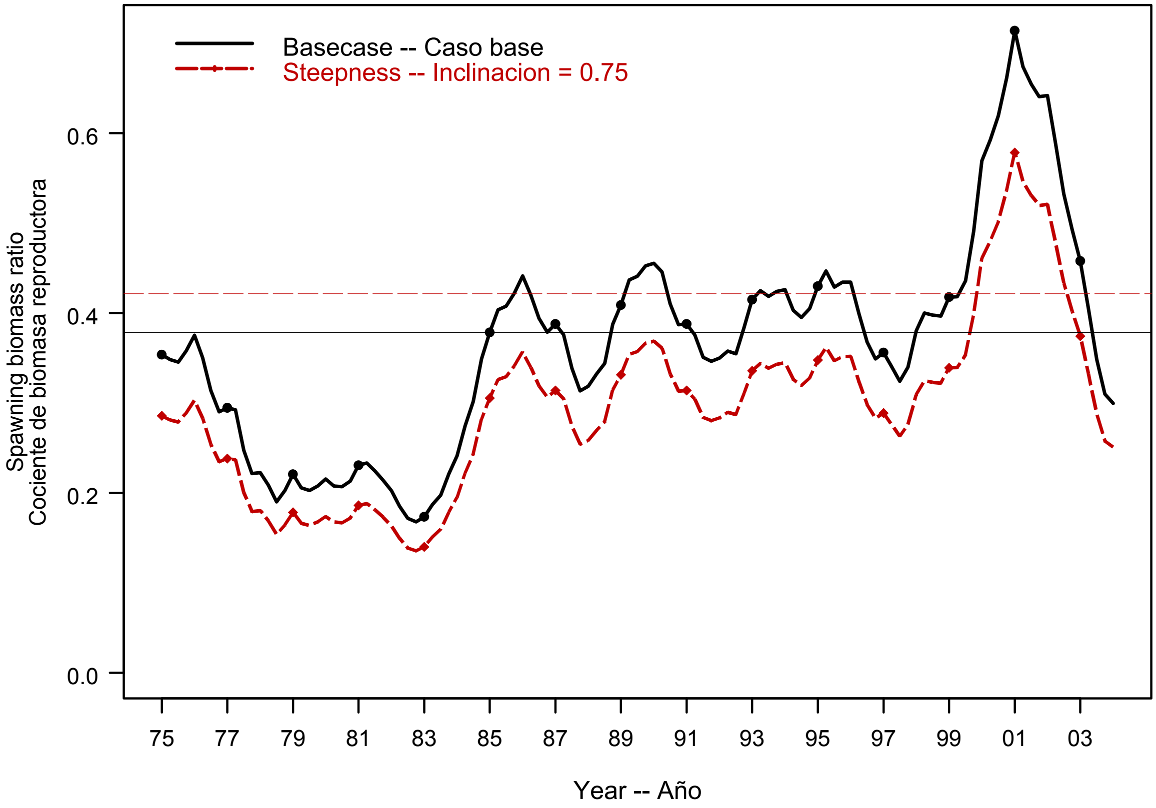

FIGURE A.3. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). The horizontal lines represent the SBRs associated with AMSY for the two scenarios.

FIGURA A.3. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún aleta amarilla del análisis sin (caso base) y con relación población-reclutamiento (inclinación = 0,75). Las líneas horizontales representan el SBR asociado con el RMSP para los dos escenarios.

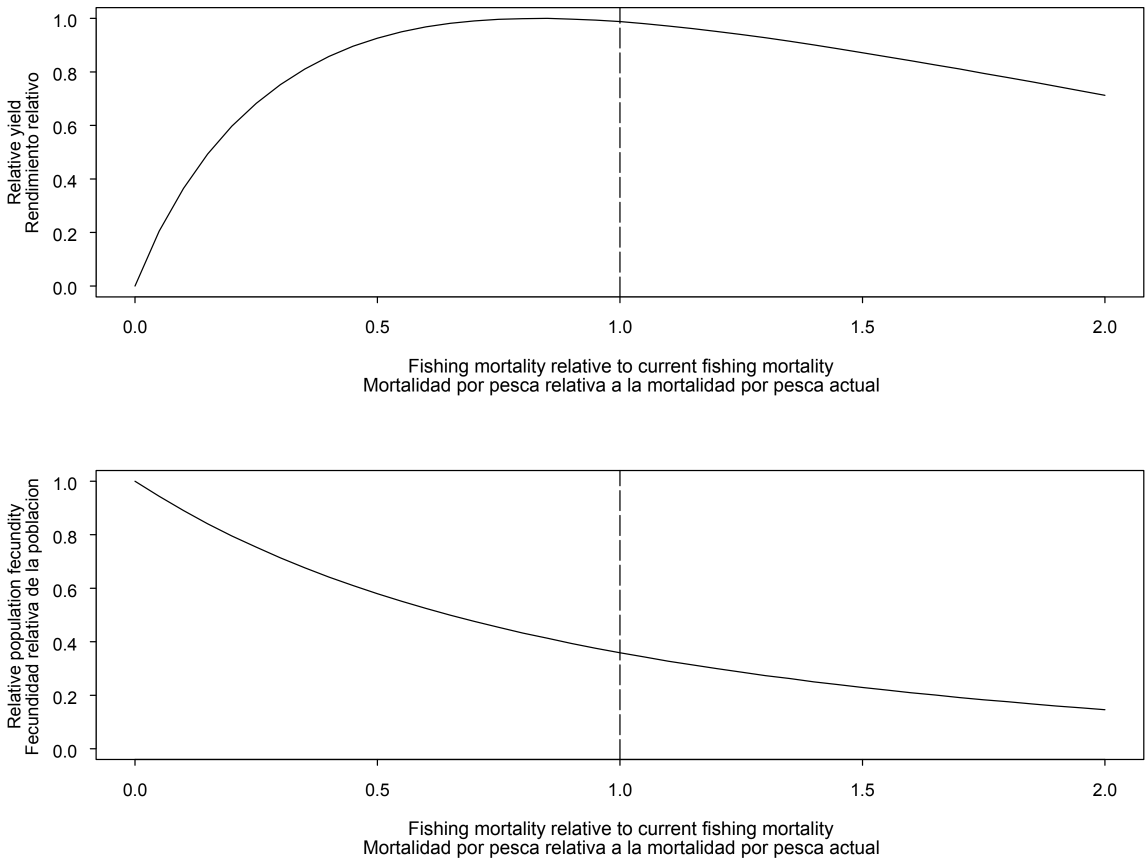

FIGURE A.4. Relative yield (upper panel) and the associated spawning biomass ratio (lower panel) of yellowfin tuna when the stock assessment model has a stock-recruitment relationship (steepness = 0.75).

FIGURA A4. Rendimiento relativo (recuadro superior) y el cociente de biomasa reproductora asociado (recuadro inferior) de atún aleta amarilla cuando el modelo de evaluación de la población incluye una relación población-reclutamiento (inclinación = 0.75).

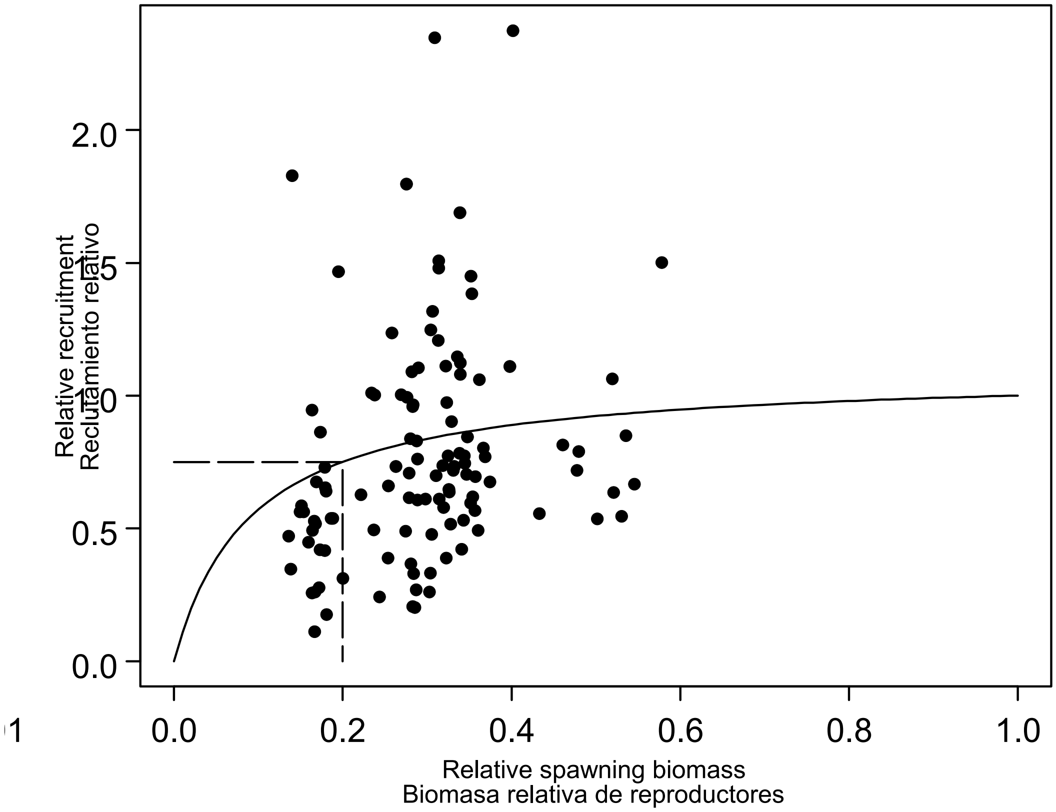

FIGURE A.5. Recruitment plotted against spawning biomass of yellowfin tuna when the analysis has a stock-recruitment relationship (steepness = 0.75).

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

APPENDIX C: ADDITIONAL RESULTS FROM THE BASE CASE ASSESSMENT

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

ANEXO C: 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.

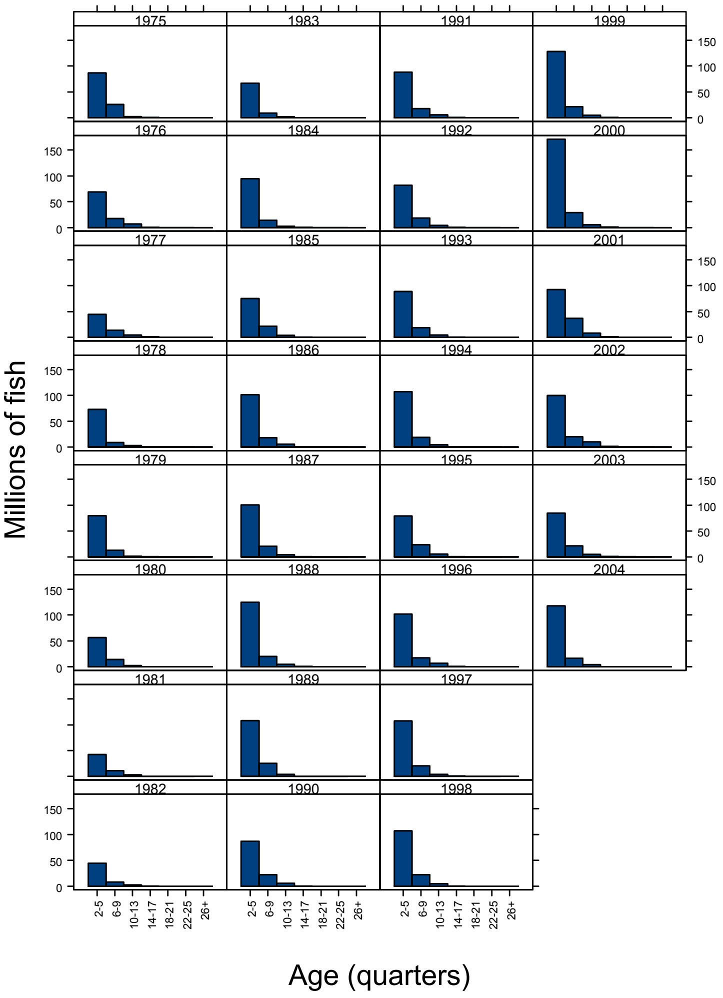

FIGURE C.1. Estimated numbers of yellowfin tuna present in the EPO on 1 January of each year.
FIGURA C.1. Número estimado de atunes aleta amarilla presentes en el OPO el 1 de enero de cada año.

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

Year	Age in quarters—Edad en trimestres						
Año	2-5	6-9	10-13	14-17	18-21	22-25	26+
1975	0.0942	0.5654	1.1533	1.6660	0.3953	0.4989	2.1372
1976	0.1704	0.6423	1.0745	1.7652	1.1226	1.3197	4.8292
1977	0.1975	0.6970	0.9873	1.9592	1.0919	1.3475	4.0333
1978	0.4039	0.8832	1.0449	1.4340	0.6428	1.0775	2.6610
1979	0.2744	0.9164	1.3112	2.1857	1.0706	1.3515	4.8107
1980	0.2324	0.7407	1.3672	1.8115	0.9676	0.9891	3.6029
1981	0.3484	0.7224	1.1835	1.8123	1.4512	1.6177	4.4482
1982	0.2221	0.6852	1.1163	1.8019	0.8976	1.2492	2.9732
1983	0.1703	0.3819	0.8360	0.8866	0.6889	0.9912	2.3865
1984	0.1301	0.4092	0.8010	0.7664	0.5711	0.7008	2.5508
1985	0.0988	0.5307	0.8987	1.2360	0.4718	0.6692	2.0541
1986	0.1339	0.6428	1.1270	1.6884	0.4852	0.7003	2.4331
1987	0.1458	0.6529	1.2439	1.4069	0.4124	0.6386	2.3792
1988	0.2172	0.7095	1.2045	1.4414	0.5151	0.7421	2.7404
1989	0.1542	0.6381	1.0078	1.8480	0.8191	1.1560	4.0979
1990	0.1412	0.5844	1.2073	1.9661	0.7242	1.0216	3.7731
1991	0.1468	0.5838	1.1076	1.7922	0.7619	0.9548	4.4857
1992	0.1803	0.6062	1.0769	1.5993	0.4581	0.5478	2.0307
1993	0.1920	0.5556	0.9146	1.2083	0.4528	0.7605	2.1757
1994	0.1241	0.5082	1.0823	1.5462	0.8868	1.1104	4.3319
1995	0.1172	0.4446	0.9202	1.1415	0.7071	0.7662	3.4508
1996	0.1613	0.6445	0.9565	1.0917	0.3512	0.5268	1.7314
1997	0.1699	0.6950	1.2296	1.7459	1.0005	1.2849	4.1832
1998	0.1791	0.6266	1.0271	1.6853	0.6401	0.8743	3.4815
1999	0.2105	0.6523	1.0653	1.5014	0.3199	0.4492	1.8078
2000	0.1219	0.4600	0.8322	1.1606	0.6417	0.7761	3.2079
2001	0.1641	0.5042	1.0901	1.7117	1.0135	1.0650	4.2669
2002	0.1624	0.6342	1.0576	1.2638	0.6563	0.7191	3.0829
2003	0.2177	0.9095	1.7220	2.7021	1.1666	1.4538	4.6919

APPENDIX D: DIAGNOSTICS

ANEXO D: DIAGNÓSTICOS

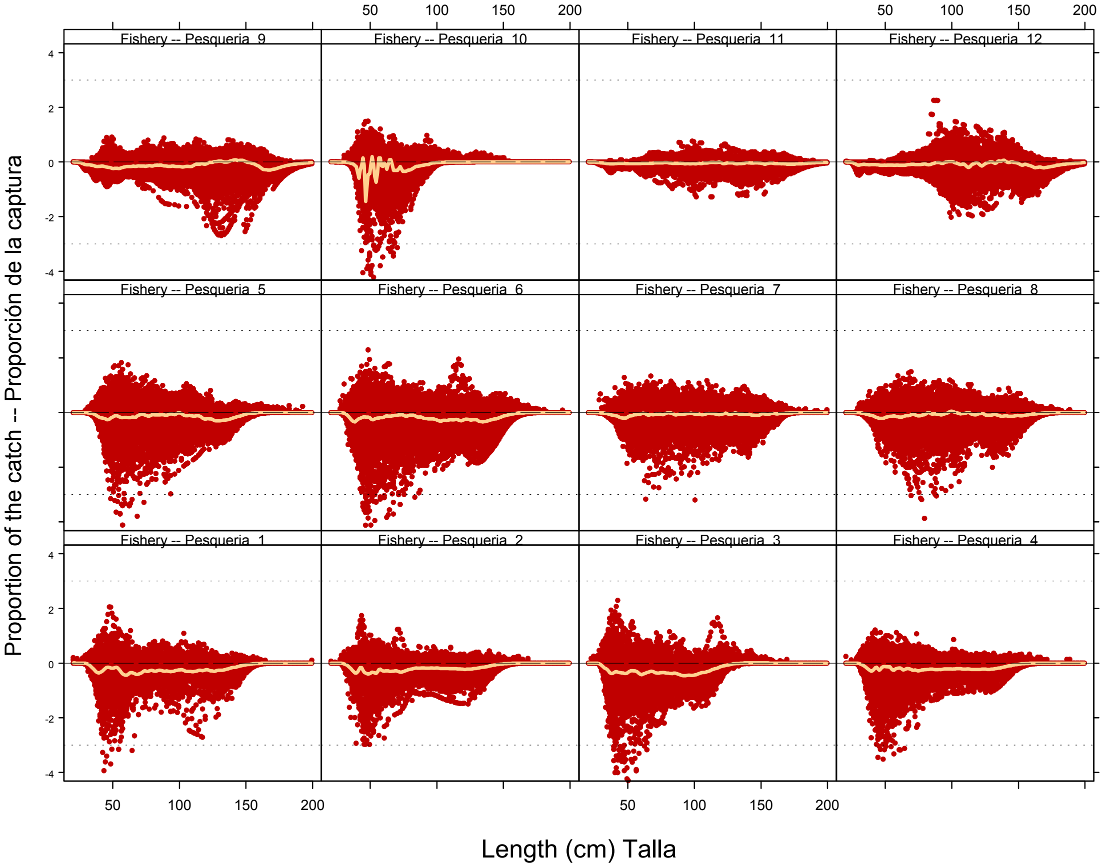

FIGURE D.1. Standardized residuals for the length-frequency data of yellowfin tuna by length. The dotted horizontal lines represent plus and minus 3 standard deviations.

FIGURA D.1. Residuales estandarizados para los datos de frecuencia de talla de atún aleta amarilla, por talla. Las líneas horizontales de trazos representan 3 desviaciones estándar positivas y negativas.

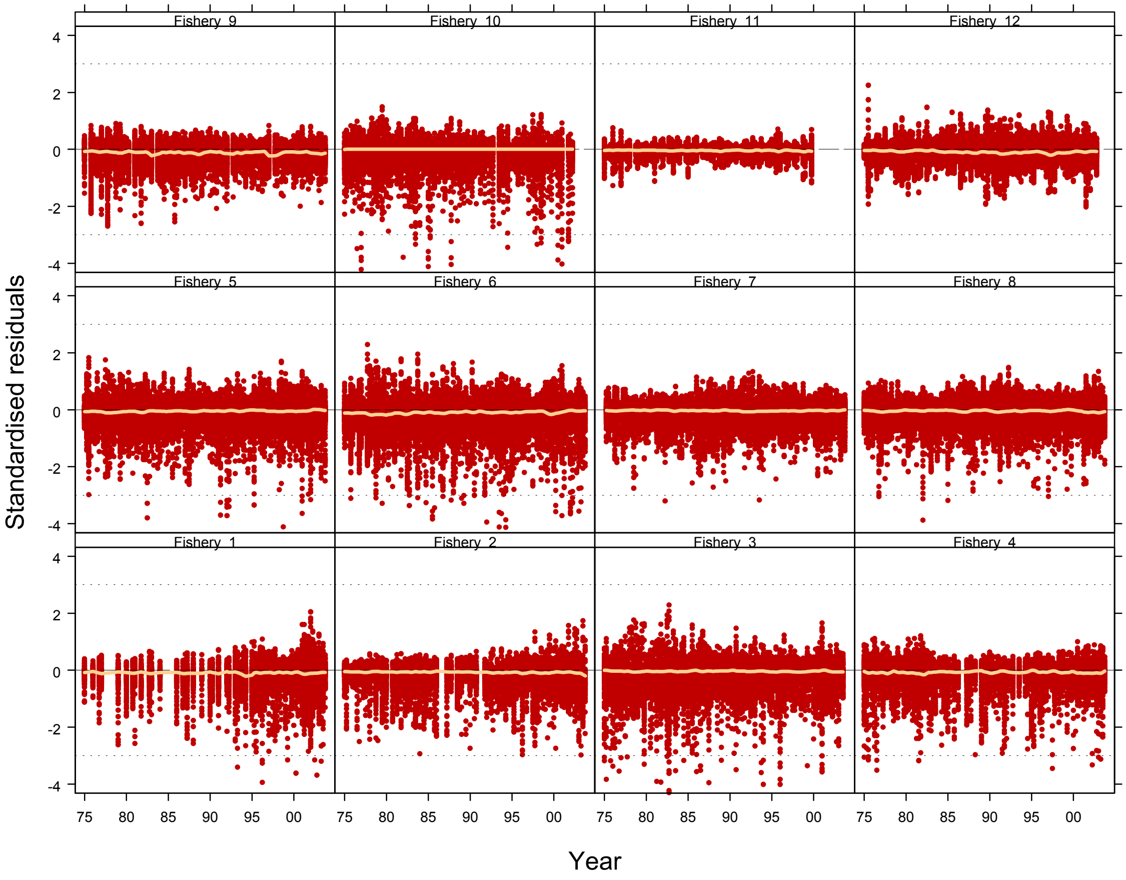

FIGURE D.2. Standardized residuals for the length-frequency data of yellowfin tuna by time. The dotted horizontal lines represent plus and minus 3 standard deviations.

FIGURA D.2. Residuales estandarizados para los datos de frecuencia de talla de atún aleta amarilla, por año. Las líneas horizontales de trazos representan 3 desviaciones estándar positivas y negativas.

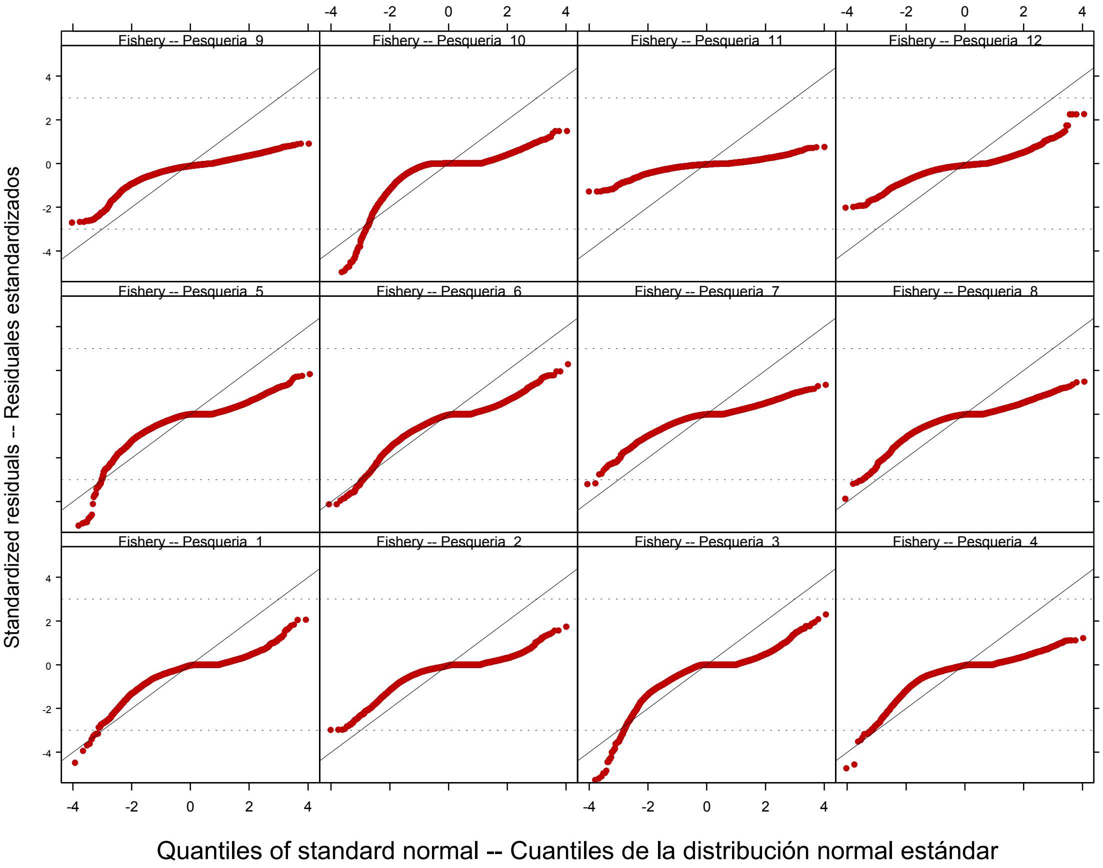

FIGURE D.3. Q-Qnorm plots for the length-frequency data for yellowfin tuna. The diagonal lines indicate the expectations for the residuals following normal distributions. The dotted horizontal lines represent three standard deviations on either side of the mean.

FIGURA D.3. Gráficas de Q-Qnorm para los datos de frecuencia de talla para atún aleta amarilla. Las líneas diagonales indican las expectativas de los residuales siguiendo distribuciones normales. Las líneas con puntos representan tres desviaciones estándar en cualquier lado del medio.