STATUS OF YELLOWFIN TUNA IN THE EASTERN PACIFIC OCEAN IN 2002 AND OUTLOOK FOR 2003

by

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CONTENTS

1. EXECUTIVE SUMMARY

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

A mid-year technical meeting on diagnostics was held in La Jolla, October 2-4. 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 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 2002 differs in several from the previous assessment carried out in 2001:

1. Catch, effort, and length-frequency data for the surface fisheries have been updated to include new data for 2002 and revised data for 2000 and 2001.
2. Catch data for the Japanese longline fisheries have been updated to include new data for 2001 and updated data for 1998 and 2000.
3. Catch data for the Taiwan longline fisheries have been updated for 1998 and new data added for 1999.
4. Longline effort data are based on neural-network-standardization of CPUE.
5. Longline catch-at-length data was included for 1975-1980.
6. Growth is constrained to equal the prior for more ages than in the previous assessment
7. The smoothness penalties for selectivity were chosen using cross-validation.
8. The years used to average catchability for the projections and management quantities were calculated using retrospective analysis.
9. Iterative reweighting was used to determine the sample size for catch-at-length data in a sensitivity analysis.

10. Diagnostics including residual plots, correlation plots, and retrospective analysis were carried out.

Significant levels of fishing mortality have been observed in the yellowfin tuna fishery in the EPO. These levels are highest for middle aged yellowfin (except for the estimates for the oldest yellowfin, which is an artifact of the model). Both recruitment and exploitation have had substantial impacts on the yellowfin biomass trajectory. It appears that the yellowfin population has experienced two different productivity regimes (1975-1983 and 1984-2001), with greater recruitment during the second than the first. The two recruitment regimes correspond to two regimes in biomass, the high-recruitment regime producing greater biomasses. The spawning biomass ratio (the ratio of spawning biomass to that for the unfished stock; SBR) of yellowfin in the EPO was below the level that will support the average maximum sustainable yields (AMSYs) during the low-recruitment regime, but above that level during the high-recruitment regime. The two different productivity regimes may support two different levels of AMSY and associated SBRs. The current SBR is slightly below the SBR level at AMSY. The effort levels are estimated to be less than the levels that will support the AMSY (based on the current distribution of effort among the different fisheries). However, due to the large recruitment that entered the fishery in 1998, the catch levels are greater than the corresponding values at the AMSY. Because of the flat yield curve, current effort levels are estimated to produce, under average conditions, catch that is only slightly less than AMSY. Future projections under the current effort levels and average recruitment indicate that the population will increase to an SBR level more than the current level and above that which will support the 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 higher.

The analysis indicates that strong cohorts entered the fishery in 1998 through 2000 and that these cohorts increased the population biomass during 1999 and 2000. However, they have now moved through the population, and the biomass decreased in 2001 and 2002.

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 directed toward the fisheries that catch yellowfin closest to the critical weight (longlining and purse-seine sets on yellowfin associated with dolphins, particularly in the southern area). This would also increase the SBR levels.

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

A sensitivity analysis was carried out to determine the effect of a stock-recruitment relationship. The results suggest that the model with a stock-recruitment relationship fits the data slightly better than the base case. The results from the analysis with a stock-recruitment relationship are more pessimistic, and they suggest that the effort level is greater than that which would produce AMSY; however the yield at this effort level is only slightly less than AMSY. The biomass is estimated to have been less than the biomass that would give rise to AMSY for most of the modeling period, except for most of the 1999-2002 period.

The assessment results are very similar to the results from the previous assessments. The major differences occur, as expected, in the most recent years. The current assessment and the 2002 assessment estimates 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 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 2002 were used to conduct the stock assessment of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean (EPO). The data for 2002, which are preliminary, include records that had been entered into the IATTC databases as of the end of March 2002. 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 mix of flotsam and FADs (Fisheries 3 and 15).

2.2. Catch and effort data

To conduct the stock assessment of yellowfin tuna, the catch and effort data in the IATTC databases are stratified according to the fishery definitions described in Section 2.1 and presented in Table 2.1. The three definitions relating to catch data used throughout 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 IATTC terminology used in other 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 data for 2000 and 2001 have been updated, and those for 2002 are new (compared to those presented by Maunder (2002) in the previous assessment of yellowfin from the EPO). New data on catch for the longline fisheries (Fisheries 11 and 12) during 2001 for Japan and 1999 for Taiwan have been incorporated into the current assessment. Data for Japan was updated for 1998-2000 and data for Taiwan was updated for 1998.

2.2.1. Catch

For this assessment, the Japanese longline data are available through 2001. This includes one additional year compared to the previous assessment. However, detailed effort data available to standardize the CPUE were only available through 2000. For the assessment it is assumed that the total longline effort (scaled to include nations other than Japan) in 2002 is equal to the standardised longline effort in 2000. The total 2002 longline catch is thus a function of the 2000 effort, the estimated numbers in 2002, and the estimated selectivities and catchabilities for the longline fisheries.

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

Compared to 2001, surface fishery catches in 2002 increased in Fisheries 2 (by 12%), 5 (by 10%), 7 (by 38%), and 8 (by 33%), and decreased in Fisheries 1 (by 48%), 3 (by 65%), 4 (by 18%), 6 (by 20%), and 9 (by 29%),. Compared to 2000, longline fishery catches in 2001 decreased in Fisheries 11 (by 82%) and 12 (by 22%).

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

2.2.2. Effort

New effort for this assessment includes 2002 effort data for the surface fisheries and updated effort includes 2000 and 2001 effort data for the surface fisheries.

A complex algorithm, described by Maunder and Watters (2001), was used to estimate the amount of fishing effort in days fished exerted by purse-seine vessels. The longlining effort data for yellowfin have been calculated from standardized CPUE using neural networks. Effort data used in the previous assessment (Maunder 2002) was provided by the SPC (Bigelow *et al*. 2002) and based on standardization using the habitat-based method (Hinton and Nakano 1996). The most reliable, consistent, and complete effort data are available for the Japanese longline fleet, and these are used in the standardization. To enable the inclusion of catch data from the other nations into the assessment, the Japanese effort data are scaled by the ratio of the Japanese catch to the total catch. This allows the inclusion of all the longline catch data into the assessment, while using only the Japanese effort data to provide information on abundance.

The following is a brief description of the neural network effort standardization method (see Maunder and Hinton submitted). The effectiveness of longline effort with respect to yellowfin tuna is strongly affected by the fishing depth of the gear, due to the preferences of the species with regard to habitat characteristics (*e.g*. temperature and oxygen levels). Since the mid-1970s, longlines have fished at greater depths in attempts to increase catches of bigeye. Therefore, it is important that standardized longline effort, which is used with catch to provide information on abundance, take into consideration the depth of the longline and the relationship between this depth and the habitat preference of yellowfin. Analyses using several different methods to standardize CPUE (habitat based methods, statistical habitat based methiods, GLMs, and neural networks) indicated that neural networks performed best based on cross-validation. The neural networks takes multiple explanatory variables and develops a nonlinear relationship between these variables and the catch. Time in quarters is integrated with the neural network as a categorical variable and this is used to represent the standardized CPUE. The variables included in the neural network were hooks per basket (a measure of depth), latitude, longitude, and the water temperature and oxygen level at a series of depths. Only Japanese catch and effort data is used in the CPUE analysis, because it includes information on the number of hooks per basket, provides the only consistent large area coverage of the distribution of yellowfin, and represents the majority of the effort. The effort data is calculated by dividing the total catch for a fishery and time period by the corresponding CPUE.

The IATTC databases do not contain catch and effort information from longlining operations conducted in the EPO during 2002 and detailed data required to apply the CPUE standardization was not available for 2001. To conduct the stock assessment of yellowfin tuna, it is assumed that the amount of longlining effort exerted during each quarter of 2001 was calculated using CPUE for the corresponding quarter for 2000 and the amount of effort exerted during each quarter of 2002 was equal to the effort exerted during the corresponding quarter of 2000.

Trends in the amount of fishing effort exerted by the 16 fisheries defined for the stock assessment of yellowfin tuna in the EPO are plotted in Figure 2.3. Fishing effort for surface gears (Fisheries 1-10 and 13-16) is in days fishing. It is assumed that the fishing effort in Fisheries 13-16 is equal to that in Fisheries 1-4 (Figure 2.3) because the catches taken by Fisheries 13-16 are derived from those taken by Fisheries 1-4 (see Section 2.2.3). Fishing effort for longliners (Fisheries 11 and 12) is in standardised units. Maunder and Watters (2001, 2002) and Maunder (2002) discuss the historic fishing effort.

Compared to 2000, surface fishery effort in 2001 increased in Fisheries 1 (by 8%), 5 (by 25%), 6 (by 7%), 7 (by 5%), and 8 (by 19%), and decreased in Fisheries 2 (by 11%), 3 (by 8%), 4 (by 15%), 9 (by 41%), and 10 (by 36%). The changes in effort may be in part due to the fishing regulations implemented in 2001 and 2002.

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 (2003a). 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. Purse seine length-frequency data was updated for 2000 and 2001 and new data was added for 2002. Longline length-frequency data was updated for 1998-2000, new data added for 2001, and data included for 1975-1980.

The length frequencies of the catch during 2002 from the 4 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 an additional large mode at about 120-130cm. 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. A large cohort of yellowfin tuna about 125 cm in length was evident in the length-frequency data for the first quarter of 2001 in the southern surface fisheries (Fisheries 1, 3, 6, and 9), but was not seen in any other quarters until 2002. However, a mode in the southern longline fishery seen during 2000 may be the same cohort (Figure 4.8e). The appearance, disappearance, and subsequent reappearance of strong cohorts in the length-frequency data is a common phenomena for yellowfin tuna in the EPO. This may indicate spatial movement of cohorts or fishing effort, or inefficiencies in the length-frequency sampling.

The length frequencies of the catch during 2000 and 2001 for the longline fisheries were only available for the southern fishery. This data showed a mode moving through the longline fishery starting at about 90cm in the first quarter of 2000. This cohort was not predicted by the model, but it may be consistent with the strong cohort seen in the southern surface fisheries length-frequency data during the first quarter of 2001.

2.4. Auxiliary data

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

3. ASSUMPTIONS AND PARAMETERS

3.1. Biological and demographic information

3.1.1. Growth

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

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

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

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

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

3.1.2. Recruitment and reproduction

The A-SCALA method allows a Beverton-Holt (1957) stock-recruitment relationship to be specified. The Beverton-Holt curve is parameterized so that the relationship between spawning biomass and recruitment is determined by estimating the average recruitment produced by an unexploited population (virgin recruitment) and a parameter called steepness. Steepness is defined as the fraction of virgin recruitment that is produced if the spawning stock size is reduced to 20% of its unexploited level, and it controls how quickly recruitment decreases when the spawning stock size is reduced. Steepness can vary between 0.2 (in which case recruitment is a linear function of spawning stock size) and 1.0 (in which case recruitment is independent of spawning stock size). In practice, it is often difficult to estimate steepness because the spawning stock may not have been reduced to less than 20% of its unexploited level and because there are other factors (*e.g.* environmental influences) that cause recruitment to be extremely variable. The base-case assessment assumes that there is no relationship between stock size and recruitment. This assumption is the same as that used in the 2000, 2001, and 2002 assessments (Maunder and Watters 2001, 2002, Maunder 2002). The influence of a Beverton-Holt stock-recruitment relationship is investigated in a sensitivity analysis.

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

An assumption is made about the way that recruitment can vary around its expected level, as determined from the stock-recruitment relationship. It is assumed that recruitment should not be less than 25% 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). 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*., and it appears that the mixing of fish between the EPO and the areas to the west of it is not extensive. Therefore, for the purposes of the current stock assessment, it is assumed that there are two stocks, one in the EPO and the other in the western and central Pacific.

3.2. Environmental influences

Previous stock assessments have included the assumption that oceanographic conditions might influence recruitment of yellowfin tuna in the EPO (Maunder 2001, 2002; 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. However, because the model has been extended back to 1975, the environmental time series does not cover the same period (the environmental data start in 1980). The previous assessments (Maunder and Watters 2001, 2002) showed that estimates of recruitment were essentially identical with or without the inclusion of the environmental data. 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 change in the period of the model and the use of standardised longline CPUE, environmental effects on catchability were not investigated in this assessment.

4. STOCK ASSESSMENT

A-SCALA, an age-structured statistical catch-at-length analysis model (Maunder and Watters, 2003a) and information contained in catch, effort, 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 this assessment are 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 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 2002 (this includes estimation of recruitment anomalies, and a seasonal effect);
2. quarterly catchability coefficients for the 16 fisheries that take yellowfin from the EPO (this includes estimation of random effects);
3. selectivity curves for 12 of the 16 fisheries (Fisheries 13-16 have an assumed selectivity curve);
4. initial population size and age-structure;
5. mean length at age (Figure 3.2);
6. amount of variation in length at age.

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

1. natural mortality at age (Figure 3.1);
2. fecundity of females at age (Figure 3.3);
3. sex ratio at age (Figure 3.4);
4. selectivity curves for the discard fisheries (Fisheries 13-16);
5. steepness of the stock-recruitment relationship (steepness = 1 for the basecase assessment).

The weighting factors for the selectivity smoothness penalties (see Maunder and Watters 2003a) in the previous assessment were 1, 0, 1, and -1, for the first, second, and third differences, and the length-based penalty, respectively. A weighting factor of 1000 was also applied to a monotonic penalty on the southern longline fishery selectivity. Cross validation (setting aside 20% of the length-frequency data as a test data set) using last years bigeye tuna assessment (Maunder and Harley 2002) indicated that weighting factors of 1 on the third difference was appropriate for domed shaped selectivities (fisheries 1-8, and 10) and a weighting factor of 0.1 on the first difference with a length-based penalty of -1 and a monotonic penalty of 1000 are appropriate for asymptotic selectivity curves (fisheries 9, 11, and 12).

In previous assessments two methods were used to determine what fishing mortality or effort was used in yield calculations and forward projections: 1) fishing mortality averaged over the most recent two years for yield calculations and effort averaged over the most recent two years multiplied by catchability averaged over the most recent two years for forward projections, and 2) effort averaged over the last two years multiplied by average catchability over the whole time frame. These two methods produced substantially different results for the bigeye tuna assessment (Maunder and Harley 2002). The reason for the difference is that bigeye tuna catchability has been estimated to have increased for the floating object fisheries over the last few years. However, using the most recent catchabilty may not be the best choice because estimates of recent catchability are the most uncertain. We have used retrospective analysis for the 2002 bigeye tuna assessment (Maunder and Harley 2002) to determine the most appropriate years to average catchability and effort. Retrospective analysis, where one year of catch and length-frequency data is removed in consecutive analyses, was carried out but while still including effort data for the full time frame of the stock assessment. The effort used for the periods where data was removed was generated using several different years to average the catchability and effort. The estimated catch for these periods was then compared to the actual catch. From this analysis we decided that the best method for yellowfin tuna, which does not show substantial trends in catchability, is for projections to use effort averaged over the last two years (2001 and 2002) and catchability averaged not over the last two years but over the two years prior to those (1999 and 2000). For yield calculations we used average fishing mortality not over the last two years but over the two years prior to those (1999 and 2000).

4.1. Indices of abundance

Catches per unit of effort (CPUEs) have been used as indices of abundance in previous assessments of yellowfin tuna from the EPO (*e.g.* Anonymous 1999). It is important to note, however, that trends in the CPUE will not always follow trends in the biomass or abundance. There are many reasons why this could be the case. For example, if fishermen become more or less efficient at catching fish while the biomass is not changing the CPUEs would increase or decrease despite the lack of trend in biomass. The CPUEs of the 16 fisheries defined for the current assessment of yellowfin in the EPO are illustrated in Figure 4.1. Trends in longline CPUE are based only on the Japanese data. As mentioned in section 2.2.2, CPUE for the longline fisheries was standardized using neural networks this year. A discussion of historical catch rates can be found in Maunder and Watters (2001, 2002) and Maunder (2002), but trends in CPUE should be interpreted with caution. Trends in estimated biomass are discussed in Section 4.2.3.

On average, CPUE was less in 2002 than it was in 2001 for Fisheries 1 (by 52%), 3 (by 63%) , 4 (by 4%), 5 (by 12%), 6 (by 25%) and 10 (by 63%) and greater for Fisheries 2 (by 26%), 7 (by 31%), 8 (by 12%), and 9 (by 21%).

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 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 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 latter two effects are discussed in the following paragraphs; the first effect (changes in effort) was addressed in Section 2.2.1 (also see Figure 2.3).

Selectivity curves estimated for the 16 fisheries defined in the stock assessment of yellowfin tuna are shown in Figure 4.4. Purse-seine sets on floating objects select mostly yellowfin that are about 4 to 14 quarters old (Figure 4.4, Fisheries 1-4). Purse-seine sets on unassociated schools of yellowfin select fish of similar size to those caught by sets on floating objects (about 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 (Fishery 10) select small yellowfin (about 4 to 7 quarters old). The southern dolphin associated and longline fisheries have a very high selectivity 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 yellowfin recruited to the fishery for 3 quarters or less (aged 2-4 quarters, Figure 4.4, Fisheries 13-16). (Additional information regarding the treatment of discards is given in Section 2.2.2.)

The ability of purse-seine vessels to capture yellowfin tuna in association with floating objects has generally declined over time (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 and 2002.

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

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. Another characteristic of the recruitment that was also apparent in previous assessments is the regime change in the recruitment levels, starting during the last quarter of 1983. The recruitment was, on average, greater after than before 1983. This change in recruitment levels produces a similar change in biomass (Figure 4.9). 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 0.15. 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 timeframe 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) suggest that the fishing mortality affects the total biomass. The simulated biomass trajectory without fishing and the biomass trajectory estimated from the stock assessment model are overlaid in Figure 4.10. The large difference in biomass indicates that fishing has a large impact on the biomass of yellowfin in the EPO. The large increase in biomass during 1984-1985 was caused by an increase in average recruitment (Figure 4.7) and an increase in the average size of the fish caught (Anonymous, 1999), but increased fishing pressure prevented the biomass from increasing further during the 1986-1990 period.

4.2.4. Average weights of fish in the catch

The overall average weights of the yellowfin tuna caught in the EPO predicted by the analysis have been consistently around 10-20 kg for most of the period from 1975 to 2001, but have differed considerably among fisheries (Figures 4.10 and 5.2). The average weight was greatest during the 1985-1992 period (Figure 5.2) when the effort from the floating-object and unassociated fisheries was lower (Figure 2.3). The average weight was also higher in 1975-1977 and in the most recent two 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, 10kg 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, October 2-4. 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 assessment. We present these is three sections; a) residual plots, b) parameter correlations, and c) retrospective analysis.

4.4.1. Residual plots

Residual plots show the difference between the observations and the model predictions. The residuals should show similar characteristics 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 are one type of residual in the assessment and are shown versus time in Figure 4.5. These residuals are assumed to be normally distributed (the residual is exponentiated before multiply 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 (sd = 0.2) while the dolphin associate 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 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 southen longline fishery effort deviations, however there is some consecutive residuals that are all above or all below the average. The standard deviation of the residuals is 0.88 which is much higher than the 0.2

assumed for this fishery. For the other fisheries, the standard deviations of the residuals are all higher than those assumed, except for the discard fisheries. These results indicates that the assessment gives more weight to the CPUE information than it should (see below and section 4.5 for additional indication that less weight should be given to the CPUE information and more to the length-frequency data). The effort residuals for the floating object fisheries have a declining trend over time while the effort residuals for the dolphin associate and unassociated fisheries have a slight increasing trend over time. These trends may be related to true trends in catchability.

The observed proportion of fish caught in a length-class is assumed to be normally distributed around the predicted proportion with the standard deviation equal to the binomial variance, based on the observed proportions, divided by the square of the sample size (Maunder and Watters 2003a). The length-frequency residuals appear to be smaller than the assumed standard deviation (Figure 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 that implies that a range of alternative states of nature have a similar likelihood.

The is negative correlation between the current estimated effort deviates for each fishery and estimated recruitment deviates lagged to represent cohorts entering each fishery (Figures D5, D6, and D7). The negative correlation is most obvious for the discard fisheries (around -0.6). Less recent effort deviates are positively correlated with these recruitment deviates.

Current spawning biomass is positively correlated (around 0.4) with recruitment deviates lagged to represent cohorts entering the spawning biomass population (Figure D8). This correlation is greater than for less recent spawning biomass estimates. Similar correlations are seen for recruitment and spawning biomass (Figure D9).

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 shoes the estimated biomass from the most recent 3 assessments compared to 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 bias. Retrospective analysis and the assumption that more data improves the estimates, can be used to determine if there are consistent biases in the estimates.

We present two retrospective analyses, 1) removing the catch and length-frequency data for 2002, and 2) removing the catch and length-frequency data for 2002 and 2001. For both these analyses we continued to model the population to the start of 2003 using the same effort data, but without estimating recruitment or effort deviations. This allows the prediction of abundance conditioned on known effort. Results show that the biomass "converged" in the third to last year of data (Figure D11). The peak in biomass in 2001 has been consistently under estimated (Figure D11). Results show that recruitment takes an additional year to “converge” (Figure D10).

4.5. Sensitivity to assumptions

Several; sensitivity analyses were carried out including: 1) inclusion of a Beverton-Holt stock-recruitment relationship with a steepness of 0.75, 2) iterative reweighting of the length-frequency sample size, 3) species composition catch estimates, and 4) selectivity smoothness penalty weights used in previous assessments. The estimates of management quantities for these sensitivities are presented in Table 5.1. The sensitivities do not differ much from the base case except for the stock-recruitment relationship sensitivity. We discuss this sensitivity and the iterative reweighting of the length-frequency sample size sensitivity in more detail below.

A sensitivity analysis was carried out to determine the effect of the stock-recruitment relationship. The basecase analysis was carried out with no stock-recruitment relationship. An alternative analysis was carried out with the steepness of the Beverton-Holt stock-recruitment relationship fixed at 0.75. This implies that when the population is reduced to 20% of its unexploited level, the expected recruitment is 75% of the recruitment from an unexploited population. Previous results (Maunder and Watters 2002) suggest that the analysis with a stock-recruitment relationship fits the data better than the analysis without the stock-recruitment relationship, but, given the amount of data used in the analysis, the difference is probably not statistically significant (see Maunder and Watters 2002: Table 4.3). When a Beverton-Holt stock recruitment relationship (steepness = 0.75) is included, the estimated biomass (Figure A.1) and recruitment (Figure A.2) are almost identical to the base case.

A sensitivity analysis was carried out to determine the influence of the length-frequency sample size. McAllister and Ianelli (1997) used an analytical method to determine the effective sample size for catch-at-age data based on the observed and predicted proportional catch-at-age. They used a method of iteratively modifying the sample size based on this calculation until the change in sample size was only small. We use this method to determine new sample sizes for each set (fishery and time period) of length-frequency data. The original sample size used in the basecase was based on number of wells sample for the surface gears. For the longline gears we modified the sample size so that the average sample size for the southern longline fishery was equal to the average sample size for the surface fishery that had the maximum average sample size (Fishery 7). This involved dividing the longline sample size by 25,143 for each length-fequency time-fishery data set. Table B.1 gives the average sample size by fishery for the basecase and for the iterative reweighting sensitivity, Figures B.1 and B.2 show the frequency distributions for the basecase sample size for each fishery. The reweighting sensitivity has on average higher sample sizes than the basecase for all fisheries (Figures B.3 and B.4). The sample size is increased on average between about 5 and 15 times for all fisheries except for the northern longline fishery that increased by 88 times. This indicates that the purse seine effective sample size is still less than the number of fish measured (about 50 per well) and that the longline effective sample size is still substantially less than the number of fish measured. The results from the reweighting sensitivity are similar to the basecase (Table 5.1, Figure B.5), but the confidence intervals are much smaller (Figure B.6). The average CV for the recruitment, biomass, and spawning biomass are 0.08, 0.02, and 0.02, respectively.

4.6. Comparison to previous assessments

The estimated biomass trajectory is very 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 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

The catch rates of yellowfin decreased for the surface fisheries that catch smaller yellowfin (floating object and unassociated fisheries) in 2002 relative to 2001.

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 18 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 and 2002.

The average weights of yellowfin taken from the fishery have been fairly consistent over time, but vary substantially among the different fisheries. In general, the floating-object (Fisheries 1-4), unassociated (Fisheries 5 and 6), and 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} as a target reference point.
2. F_{MSY} as a limit reference point
3. S_{min}, the minimum spawning biomass seen in the model period, as a limit reference point.

Maintaining tuna stocks at levels capable of producing the AMSY is the current management objective specified by the IATTC Convention. The S_{min} reference point is based on the observation that the population has recovered from this population size in the past (*e.g* the levels estimated in 1983). Development of reference points that are consistent with the precautionary appoach to fisheries management will continue.

5.1. Assessment of stock status based on spawning biomass

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

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

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

The SBR has been used to define reference points in many fisheries. Various studies (*e.g.* Clark 1991, Francis 1993, Thompson 1993, Mace 1994) suggest that some fish populations can produce the AMSY when the SBR is somewhere in the range 0.3 to 0.5, and that some fish populations are not able to produce the AMSY if the spawning biomass during a period of exploitation is less than about 0.2. Unfortunately, the types of population dynamics that characterize tuna populations have generally not been considered in these studies, and their conclusions are sensitive to assumptions about the relationship between adult biomass and recruitment, natural mortality, and growth rates. In the absence of simulation studies that are designed specifically to determine appropriate SBR-based reference points for tunas, estimates of SBR_t can be compared to an estimate of SBR for a population that is producing the AMSY ($SBR_{AMSY} = S_{AMSY}/S_{F=0}$). S_{AMSY} is the spawning biomass at AMSY (see Section 5.3 for details regarding calculation of AMSY and related quantities).

Estimates of quarterly SBR_t for yellowfin in the EPO have been computed for every quarter represented in the stock assessment model (the first quarter of 1975 to the first quarter of 2003). Estimates of the spawning biomass during the period of harvest (S_t) are presented in Section 4.2.2. The equilibrium spawning biomass after a long period with no harvest ($S_{F=0}$) was estimated by assuming that recruitment occurs at an average level expected from an unexploited population. The SBR level that would give rise to AMSY (SBR_{AMSY}) is estimated to be about 0.37.

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 0.33, with lower and upper 95% confidence limits of 0.23 and 0.44, respectively. It is important to note that the estimate of the upper confidence limit is greater than the estimate of SBR_{AMSY} (0.37), 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 high 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) and Maunder (2002) (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 has increased compared to 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 required to produce AMSY has increased compared to Maunder and Watters (2002) because of differences in the estimates of growth. The estimates of SBR and SBR required to produce AMSY have increased compared to Maunder and Watters (2001) because of differences in fecundity, growth, and recent fishing mortality.

Retrospective analysis shows that SBR converges quickly and only the estimates for the most recent two years change as new data is added (Figure D12). The analysis suggests that the peak in SBR in 2001 was under estimated by earlier assessments, which is also indicated by comparing estimates from the previous assessments (Figure 4.12b).

In general, the SBR estimates for yellowfin in the EPO are reasonably precise; the average CV of these estimates is about 0.05. 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 0.37 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 the previous estimate (Maunder 2002) because 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 16 kg at the end of 2002 (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 above the critical weight (Figure 4.11). All the remaining fisheries catch yellowfin of average sizes that are less than the critical weight. Of the fisheries that catch the majority of yellowfin (unassociated and dolphin-associated fisheries, Fisheries 5-8), the dolphin-associated fisheries perform better under the critical-weight criterion.

5.3. Assessment of stock status based on AMSY

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

At the start of 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 level of fishing effort that is estimated to produce the AMSY is greater than the current level of effort, as the effort at AMSY is 120% of the current level of effort. It is important to note, however, that the curve relating the average sustainable yield to the long-term fishing mortality is very flat around the AMSY level. Therefore changes in the long-term levels of effort will only marginally change the catches, while considerably changing the biomass. The spawning stock biomass changes substantially with changes in the long-term fishing mortality (Figure 5.3). Decreasing the effort, which will increase CPUE and thus may also reduce the cost of fishing, would provide only a marginal decrease in the long-term average yield, with the benefit of a relatively large increase in the spawning biomass.

The apparent regime shift in productivity that began in 1984 may require a different approach to estimating the AMSY. Different regimes will give rise to different values for the AMSY. This is discussed by Maunder and Watters (2001). If average recruitment from the 1975-1983 period is used, AMSY is 23% less than when the whole period is used. If the 1984-2002 period is used AMSY is 13% greater.

The estimation of the AMSY, and its associated quantities, is sensitive to the age-specific pattern of selectivity that is used in the calculations. To illustrate how AMSY might change if the effort is reallocated among the various fisheries (other than the discard fisheries) that catch yellowfin tuna in the EPO, the previously-described calculations were repeated, using the age-specific selectivity pattern estimated for each fishery. If the management objective is to maximize the AMSY, the longline fisheries (Fisheries 11 and 12) and the southern dolphin-associated fishery (Fishery 9) will perform the best, followed by the northern and coastal dolphin-associated fisheries (Fisheries 7 and 8), and then the southern unassociated fishery (Fisheries 6) and the southern floating-object fishery (Fishery 1) (Table 5.2). The fisheries that catch yellowfin by making purse-seine sets on floating objects (except in the southern region, Fisheries 2-

4), the northern unassociated fishery (Fishery 5), and the pole and line fishery (Fishery 10) will perform the worst (Table 5.2). If an additional management objective is to maximize the S_{AMSY}, the southern dolphin-associated fishery (Fishery 9) will perform the best, followed by the northern and southern longline fisheries (Fisheries 11 and 12). Of the fisheries that catch the majority of yellowfin (unassociated and dolphin-associated fisheries, Fisheries 5-8), the dolphin-associated fisheries perform better under both the AMSY and S_{AMSY} objectives. Maunder and Watters (2002) present results that are restricted to each type of fishery. It is not known, however, whether the fisheries that would produce greater AMSYs would be efficient enough to catch the full AMSYs predicted.

5.4. Lifetime reproductive potential

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

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

The lifetime reproductive potential for each quarterly age class was calculated, using the average fishing mortality at age over 1999 and 2000. 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 MSYref and SBRref

Section 5.3 discusses how MSY and the SBR at MSY are dependent on the selectivity of the different fisheries and the effort distribution among these fisheries. MSY can be increased or deceased applying more effort to one fishery or another. 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. Maunder (2002b) termed this harvest MSY_{ref} and suggested that two thirds of MSY_{ref} may be an appropriate limit reference point (e.g. effort allocation and selectivity patterns should produce MSY that is at or above $\frac{2}{3}MSY_{ref}$). The two thirds suggestion was based on analyses in the literature that indicated the best practical selectivity patterns could produce 70-80% of 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.

MSY_{ref} is associated with a SBR (SBR_{ref}) that may also be an appropriate reference point. SBR_{ref} is not dependent on the selectivity of the gear or the effort allocation among gears. Therefore, SBR_{ref} may be more appropriate than SBR_{MSY} for stocks with multiple fisheries and should be more precautionary because SBR_{ref} is usually higher than SBR_{MSY}. However, when recruitment is assumed to be constant (i.e. no stock recruitment relationship), SBR_{ref} may still be dangerous to spawning stock because it is possible that MSY_{ref} occurs before the individuals become fully mature. Although, it may be possible that a general life history pattern where growth is reduced or natural mortality is increased when individuals become mature may provide a growth and natural mortality tradeoff after the age at maturity that is protective of SBR. This is observed for about 90% of the stocks presented in Maunder (2002b). SBR_{ref} may be a more appropriate reference point than generally suggested $SBR_{x\%}$ (e.g. $SBR_{30\%}$ to $SBR_{50\%}$ see section 5.1) because SBR_{ref} is calculated using the biology of the stock. However, 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.

MSY_{ref} is estimated to be 416,610 metric tons and 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 61% of MSY_{ref}. More research is needed to determine if reference points based on MSY_{ref} and SBR_{ref} are appropriate.

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 1999-2002. 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 slightly bends over faster 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 18 years. The increase in the SBR is attributed to a regime change in the productivity of the population. The two different productivity regimes may support two different

AMSY levels and associated SBR levels. The effort levels are estimated to be less than those that will support the AMSY (based on the current distribution of effort among the different fisheries). However, due to the large number of recruits entering the fishery in 1998 to 2000, the catch levels are higher than the corresponding values at AMSY. Because of the flat yield curve, the average equilibrium yield at current effort levels is only slightly less than AMSY.

If a stock-recruitment relationship is assumed, the results are more pessimistic, and current biomass is estimated to be below the level that would support AMSY for most of the model period, except for the last few years (excluding the end of 2002).

The current average weight of yellowfin in the catch is much less than the critical weight, and therefore, from the yield-per-recruit standpoint, yellowfin in the EPO are 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, using the method described by Maunder and Watters (2001), was conducted to gain further understanding of how, in the future, hypothetical changes in the amount of fishing effort exerted by the surface fleet might simultaneously affect the stock of yellowfin tuna in the EPO and the catches of yellowfin by the various fisheries. Several scenarios were constructed to define how the various fisheries that take yellowfin in the EPO would operate in the future and also to define the future dynamics of the yellowfin stock. The assumptions that underlie these scenarios are outlined in Sections 6.1 and 6.2.

In addition to the method used in previous assessments, a new method has been applied based on the normal approximation to the likelihood profile. The previously used method does not take parameter uncertainty into consideration. It only considers 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 which 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 based on the average over 2001 and 2002, by quarter. No catch or length-frequency data is included for these years and the projections are based on the average catchability estimated (within the projection model) over the period 1975-2002. The recruitment for the 5 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. The descriptions below only refer to the method used in previous assessments.

6.1. Assumptions about fishing operations

6.1.1. Fishing effort

The following scenarios have been specified to describe the hypothetical amount of fishing effort that might be exerted by the surface fleet during 2003-2007.

1. The surface fleet will exert an amount of effort that is equal to 75% of the average amount of effort it exerted during 2001-2002.
2. The surface fleet will exert an amount of effort that is equal to the average amount of effort it exerted during 2001-2002.
3. The surface fleet will exert an amount of effort that is equal to 125% of the average amount of effort it exerted during 2001-2002.

These scenarios are based on quarterly levels of fishing effort. For example, in the first scenario, the effort during the fourth quarters of 2003, 2004, 2005, 2006, and 2007 is equal to 75% of the average effort exerted during the fourth quarters of 2001 and 2002.

All of the simulations were conducted under the assumption that, from 2003 through 2007, the longline fleet will exert an amount of effort equal to the amount of effort it exerted during 2000 (again by quarter). Assumptions about selectivity, catchability, discards, and population dynamics are the same as these in the assessment model (Maunder and Watters 2001).

It was assumed that the catchability of yellowfin tuna for each fishery included in the simulation study does not change during the course of the simulation. Future levels of catchability for each fishery were assumed to be equal to the average catchability for that fishery during 1999 and 2000. (These averages are computed on a quarterly basis.)

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

The recruitment during 2003 through 2007 was assumed to vary randomly around the same expected level from the stock-recruitment relationship (*i.e.* average recruitment in the base case because it does not assume a stock-recruitment relationship) and to be as variable as the recruitment during 1975-2002. It should be noted that the estimates of recruitment from the stock assessment model appear to be autocorrelated (Figure 4.7), but in the simulation study the recruitment was not autocorrelated. Adding autocorrelation to the simulated time series of recruitment would cause the simulation results to be more variable.

6.2. Assumptions about population dynamics

The simulation study was conducted using the same assumptions about population dynamics used during the period 1975-2002 (*see* Maunder and Watters, 2001). Stochasticity is added to each simulation by randomly sampling from a distribution of recruitment anomalies. These anomalies are assumed to come from the same distribution as those estimated for 1975-2002.

6.3. Simulation results

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

6.3.1. Predicted SBRs

Within the range of scenarios specified for the simulation study, future changes in the amount of fishing effort exerted by the surface fleet are predicted to have substantial effects on the SBR (Figure 6.1 and Table 6.1). Increasing the surface effort to 125% of its recent, average level is predicted to decrease the median estimate of the SBR by about 16% by the end of 2007 compared to predictions using average effort (Table 6.1; compare 50% quantiles for “average surface effort” to those for “125% surface effort”). Decreasing the surface effort to 75% of its recent average is predicted to increase the median estimate of the SBR by about 21% (Table 6.1; compare 50% quantiles for “average surface effort” to those for “75% surface effort”). Under current effort levels, it is predicted that at the end of 2007 the SBR would remain, on average, higher than SBR_{AMSY} (Table 6.1; compare the 20% quantiles for the SBR to the estimated SBR_{AMSY} of 0.37). This result is consistent with the previous estimate that, under average conditions, current levels of fishing effort should be increased to achieve the AMSY (Section 5.3).

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

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

The average weight of individuals in the catch is expected to increase in the next few years as the large recruitments to the fishery that occurred during 1998 to 2000 increase in size. Within the range of scenarios specified for the simulation study, future changes in the amount of fishing effort exerted by the surface fleet are predicted to have moderate effects on the average weight of fish caught by fisheries operating in the EPO (Figure 6.2 and Table 6.1). Increasing the surface effort to 125% of its recent average would, after 5 years, decrease the average weight of fish in the combined catch by about 12% compared to predictions using average effort (Table 6.1; compare 50% quantiles for "average surface effort" to those for "125% surface effort"). Decreasing the surface effort to 75% of its recent average would increase the average weight of fish in the catch by about 15% (Table 6.1; compare 50% quantiles for "average surface effort" to those for "75% surface effort"). Under all of the simulated effort scenarios, the average weight of fish in the combined catch taken during 2005 would be substantially less than the critical weight (compare the estimated critical weight of about 36.2 kg to the 80% quantiles in Table 6.1). Thus, it appears that it will not be possible to maximize the yield per recruit without substantially reducing the amount of fishing effort exerted by the surface fleet. This conclusion could change if, in the future, the surface fleet is able to catch larger (older) yellowfin.

If the fisheries that catch yellowfin in association with floating objects continue to exert an average amount of effort, preventing the capture of fish vulnerable to the discard fisheries (or ensuring that discarded fish survive) would moderately increase (24%) the average weight of fish in the combined catch during 2007 (Figure 6.1 and Table 6.1). This result is to be expected because the discard fisheries (Fisheries 13-16) catch large numbers of small fish, and this influences the estimates of the average weight.

6.3.3. Predicted catches taken by the primary surface fisheries

Since the simulation study was conducted under the assumptions that the catchability will remain constant for every fishery continuing to operate in the EPO (see Section 6.1.2) and that recruitment will vary randomly around the average, increases in future levels of surface fishing effort would cause short-term increases in the catches taken by these fisheries (Fisheries 1-10). The reverse is also true; decreases in the future level of surface fishing effort would cause short-term decreases in the catch. It is also important to note that if the future level of effort increases (or decreases) by 25%, the catch would not necessarily increase (or decrease) by the same percentage. If the future level of effort increases by 25%, the quarterly catches taken by the surface fleet during 2007 would increase by only 3% compared to that predicted under average levels of effort (Table 6.1; compare 50% quantiles from "average surface effort" to those from "125% surface effort). Similarly, if the future level of effort decreases by 25%, the quarterly catches taken by the surface fleet during 2007 would decrease by about 7% (Table 6.1; compare 50% quantiles from "average surface effort" to those from "75% surface effort"). This lack of sensitivity of the future catch by the surface fishery to increases in the effort of the surface fishery is consistent with the fact that the curve relating average sustainable yield to fishing effort is nearly flat at the top and that the current amount of fishing effort being exerted in the EPO produces an average yield that is very close to the AMSY (see Section 5.3 and Figure 5.3).

If the fisheries that catch yellowfin tuna in association with floating objects continue to exert an average amount of effort, preventing the capture of unmarketable fish (or ensuring that the discarded fish survive) would increase the future catches of the surface fleet by 4% (Figure 6.3 and Table 6.1; compare 50% quantiles from "average surface effort" to those from "average, no discards").

6.3.4. Predicted catches taken by the longline fleet

The results from the simulation study suggest that future changes in the amount of effort exerted by the surface fleet would substantially affect the catches by the longline fleet (Figure 6.4 and Table 6.1). The quarterly longline catch during 2007 would increase by about 31% if the surface effort were reduced to 75% of its recent average for the next 5 years compared to predictions using average effort (Table 6.1; compare 50% quantiles from "average surface effort" to those from "75% surface effort"). Similarly, the quarterly longline catch during 2007 would decrease by about 22% if the surface fishing effort were increased to 125% of its recent average (Table 6.1; compare 50% quantiles from "average surface effort" to those from "125% surface effort").

The future catch taken by longline vessels is predicted to be only slightly sensitive to whether the surface fleet continues to catch unmarketable yellowfin around floating objects (Figure 6.4 and Table 6.1). Preventing catches of unmarketable yellowfin would increase the quarterly longline catch during 2007 by about 5% (Table 6.1; compare 50% quantiles from "average surface effort" to those from "average, no discards"). This result is consistent with prediction that the SBR would increase only slightly if the catches of unmarketable fish are prevented.

6.3.4. Results using the normal approximation to the likelihood profile

In general the estimates from the normal approximation to the likelihood profile are the same as the estimates using the previous method (Figures 6.1b and 6.3b). The difference occurs in the confidence intervals which are much larger for the likelihood profile method, particularly for the first year of the projections. These estimates of the confidence intervals are more realistic because they include parameter uncertainty.

6.4. Summary of the simulation results

It is predicted that the SBR will increase in the next few years to a level above the level required to produce AMSY.

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

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

The results from these simulations have been calculated, using the average recruitment for the 1975-2002 period. As was mentioned in Section 4, it appears that yellowfin have been in a higher productivity regime for the last 15 years. If the simulations were repeated, using an average recruitment based on the 1985-2001 period, it is likely that the estimates would be different.

New simulations using the normal approximation to the likelihood profile method show that there is considerable uncertainty in the predictions of future levels of SBR and catch that is attributed to parameter uncertainty.

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 2003 and updated data for 2002 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 that the IATTC staff has conducted over the years can be incorporated into the A-SCALA analyses. The staff also intends to reinvestigate indices of yellowfin abundance from the CPUEs of purse seiners fishing in the EPO. If this work is successful, the results will, as far as possible, be integrated into future stock assessments.

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

A likelihood function that conditions otolith data on the population length-frequency to give unbiased estimates of variation in length-at-age will be developed.

The likelihood profile method for performing projections will be further developed in an effort to replace the method used in previous assessments.

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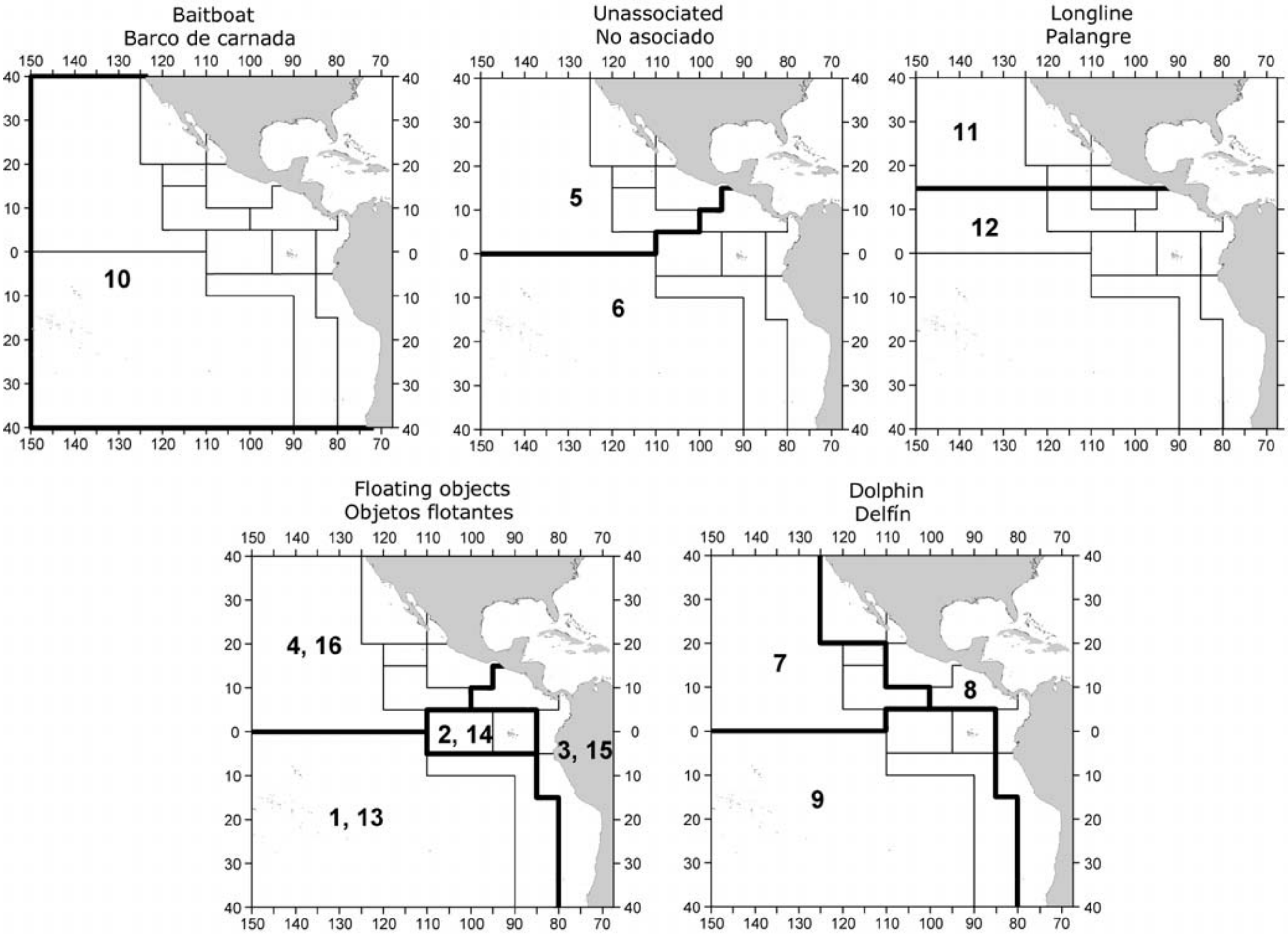

FIGURE 2.1. Spatial extents of the fisheries defined by the IATTC staff for the stock assessment of yellowfin tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the bold numbers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

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

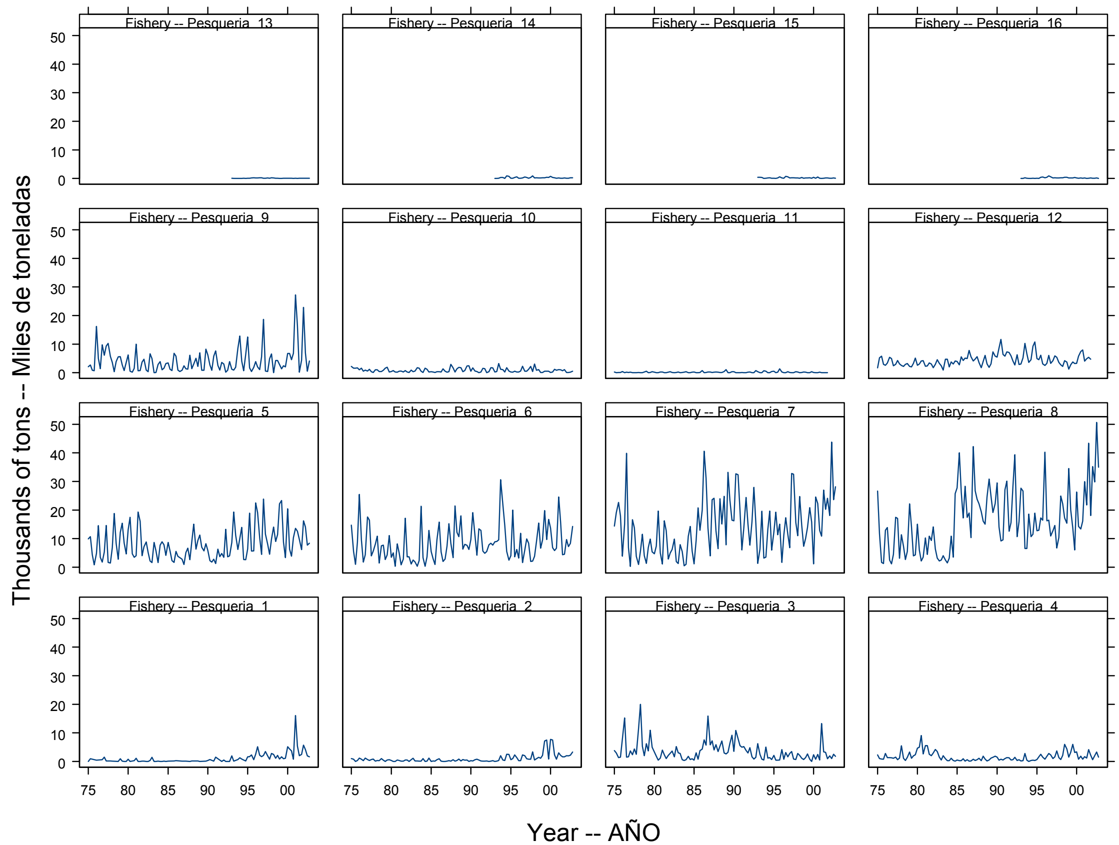

FIGURE 2.2. Catches by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were analyzed on a quarterly basis, there are four observations of catch for each year. Although all the catches are displayed as weights, the stock assessment model uses catch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

FIGURA 2.2. Capturas de las pesquerías definidas para la evaluación del stock de atún aleta amarilla en el OPO (Tabla 2.1). Ya que se analizaron los datos por trimestre, hay cuatro observaciones de captura para cada año. Se expresan todas las capturas en peso, pero el modelo de evaluación del stock usa captura en número de peces para las Pesquerías 11 y 12. Se estiman las capturas de las Pesquerías 11 y 12 en peso multiplicando las capturas en número de peces por estimaciones del peso promedio.

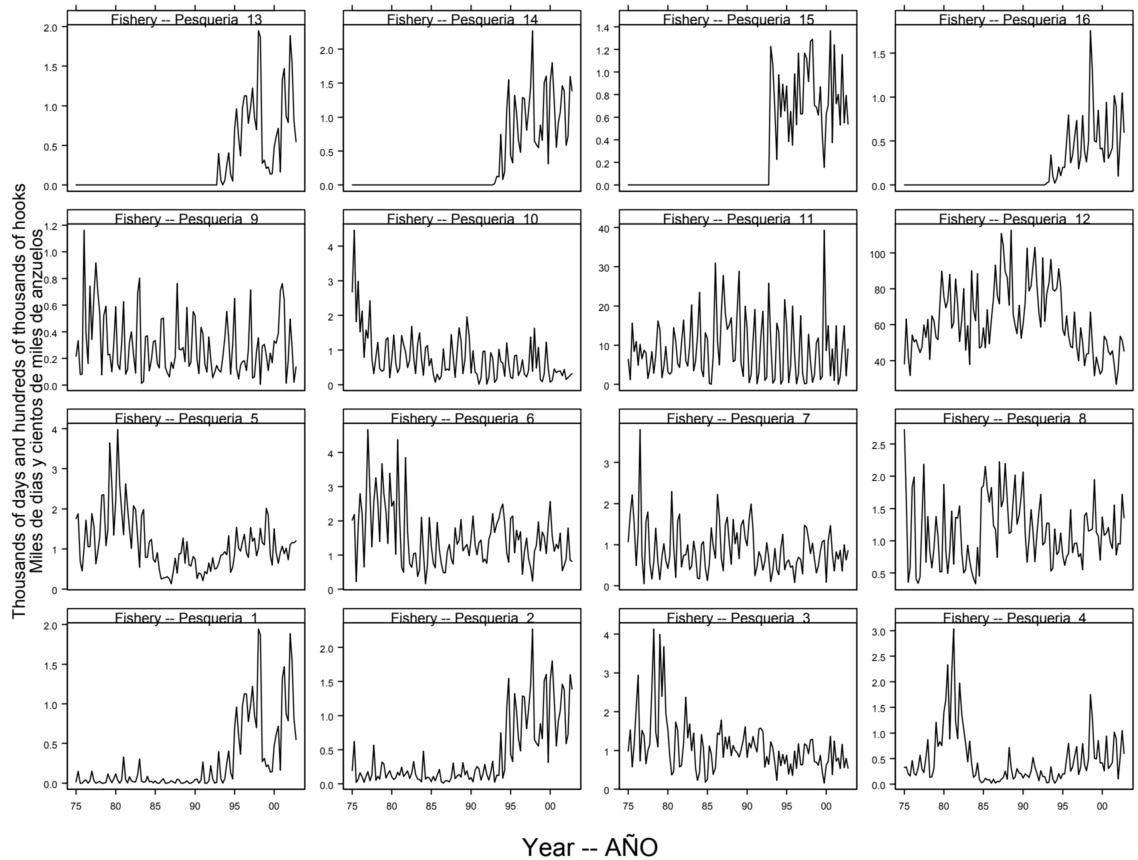

FIGURE 2.3. Fishing effort exerted by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of effort for each year. The effort for Fisheries 1-10 and 13-16 is in days fished, and that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

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

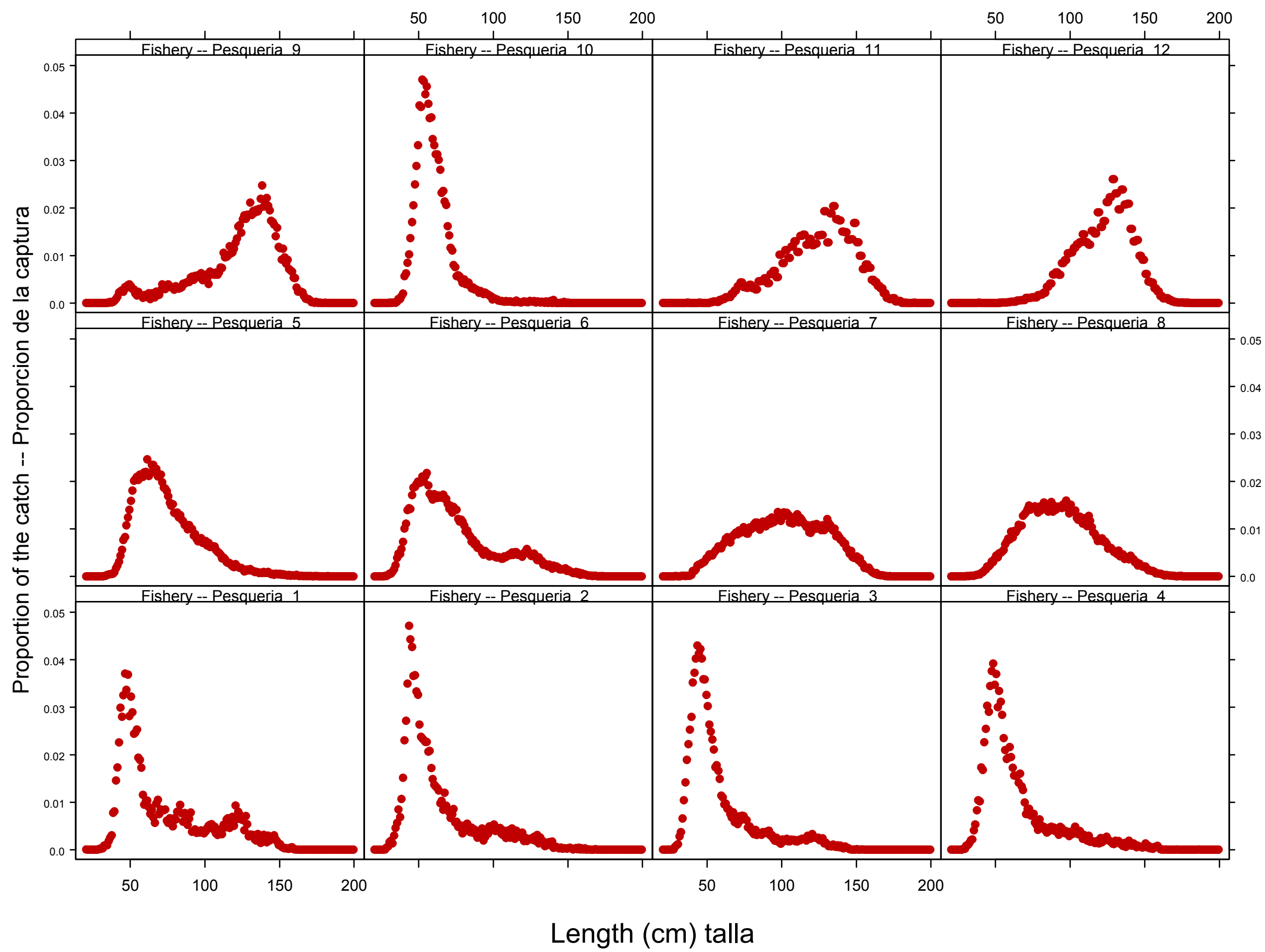

FIGURE 2.4. Average size compositions of the catches made by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). The data cover the period of January 1975 through December 2002.

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 2001.

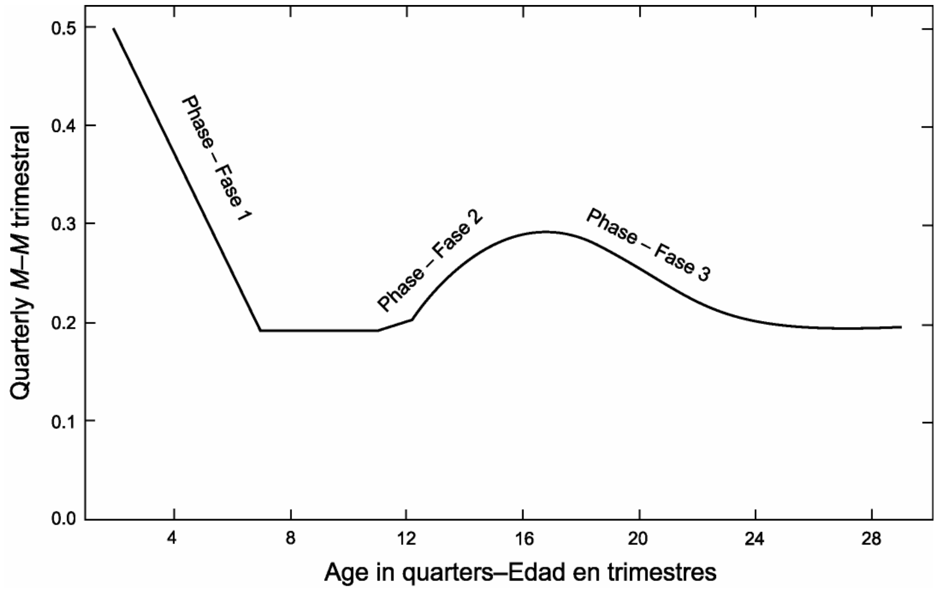

FIGURE 3.1. Natural mortality (*M*) rates, at quarterly intervals, used for the assessment of yellowfin tuna in the EPO. Descriptions of the three phases of the mortality curve are provided in Section 3.1.4.
FIGURA 3.1. Tasas de mortalidad natural (*M*), a intervalos trimestrales, usadas para la evaluación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

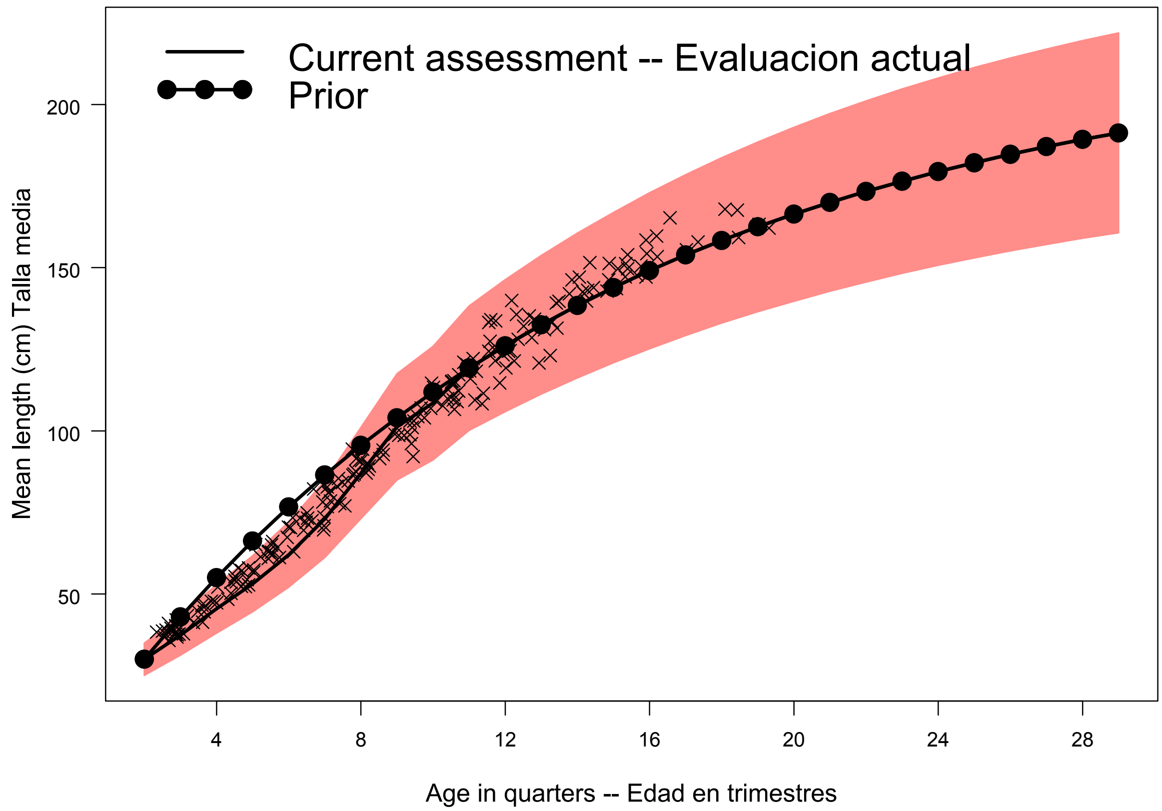

FIGURE 3.2. Growth curve estimated for the assessment of yellowfin tuna in the EPO (solid line). The dashed line is the mean length-at-age prior used in the assessment. The circles represent length-at-age data from otoliths (Wild 1986). The shaded region represents the variance of length at age (± 2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

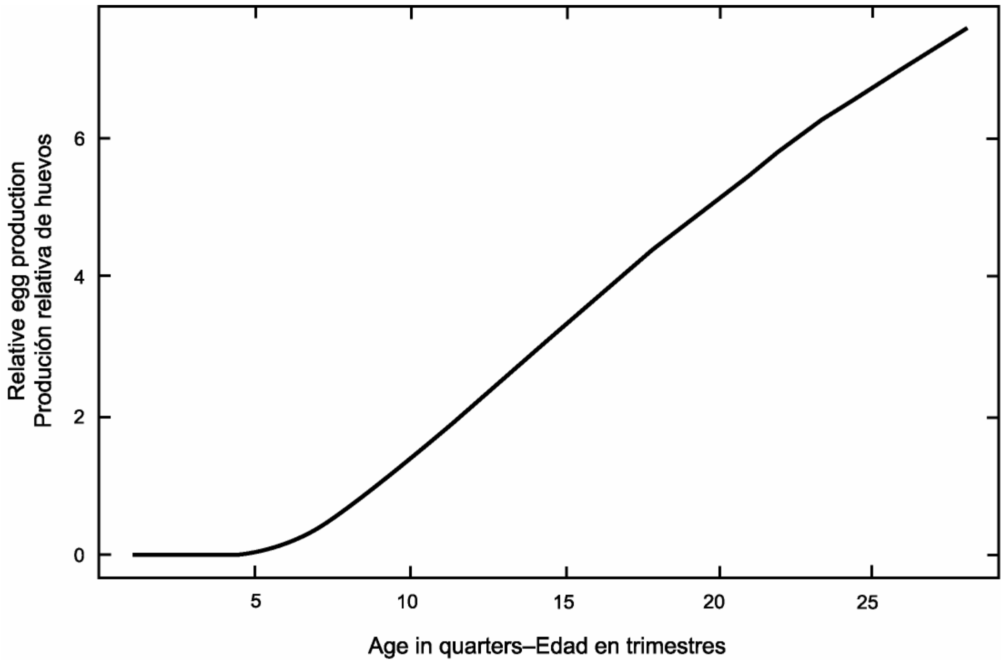

FIGURE 3.3. Relative fecundity-at-age curve (from Schaefer 1998) used to estimate the spawning biomass of yellowfin tuna in the EPO.
FIGURA 3.3. Curva de madurez relativa a edad (de Schaefer 1998) usada para estimar la biomasa reproductora de atún aleta amarilla en el OPO.

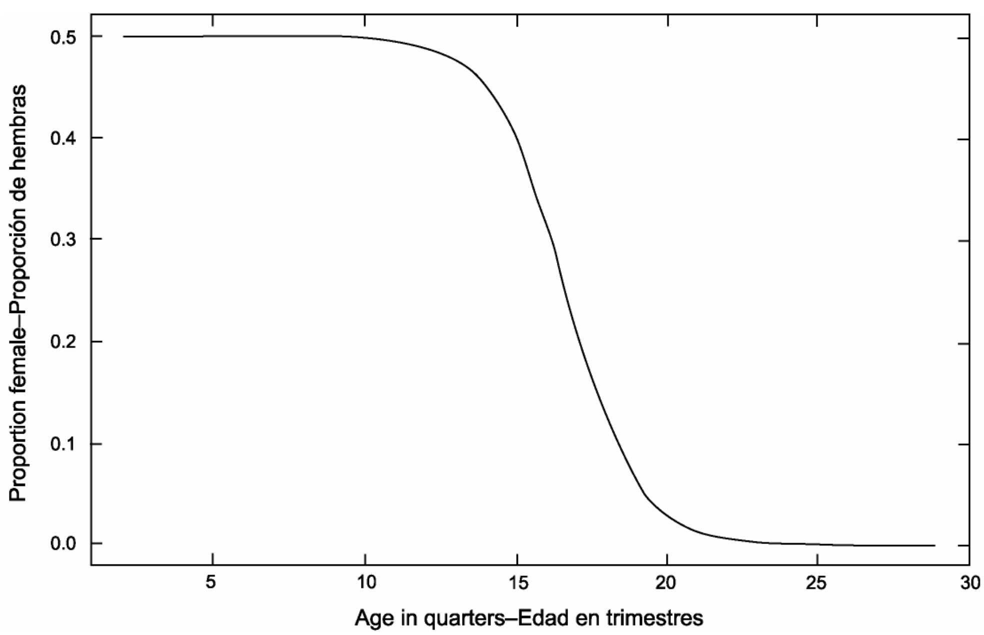

FIGURE 3.4. Sex ratio (from Schaefer 1998) curve used to estimate the spawning biomass of yellowfin tuna in the EPO.
FIGURA 3.4. Curva de proporciones de sexos (de Schaefer 1998) usada para estimar la biomasa reproductora de atún aleta amarilla en el OPO.

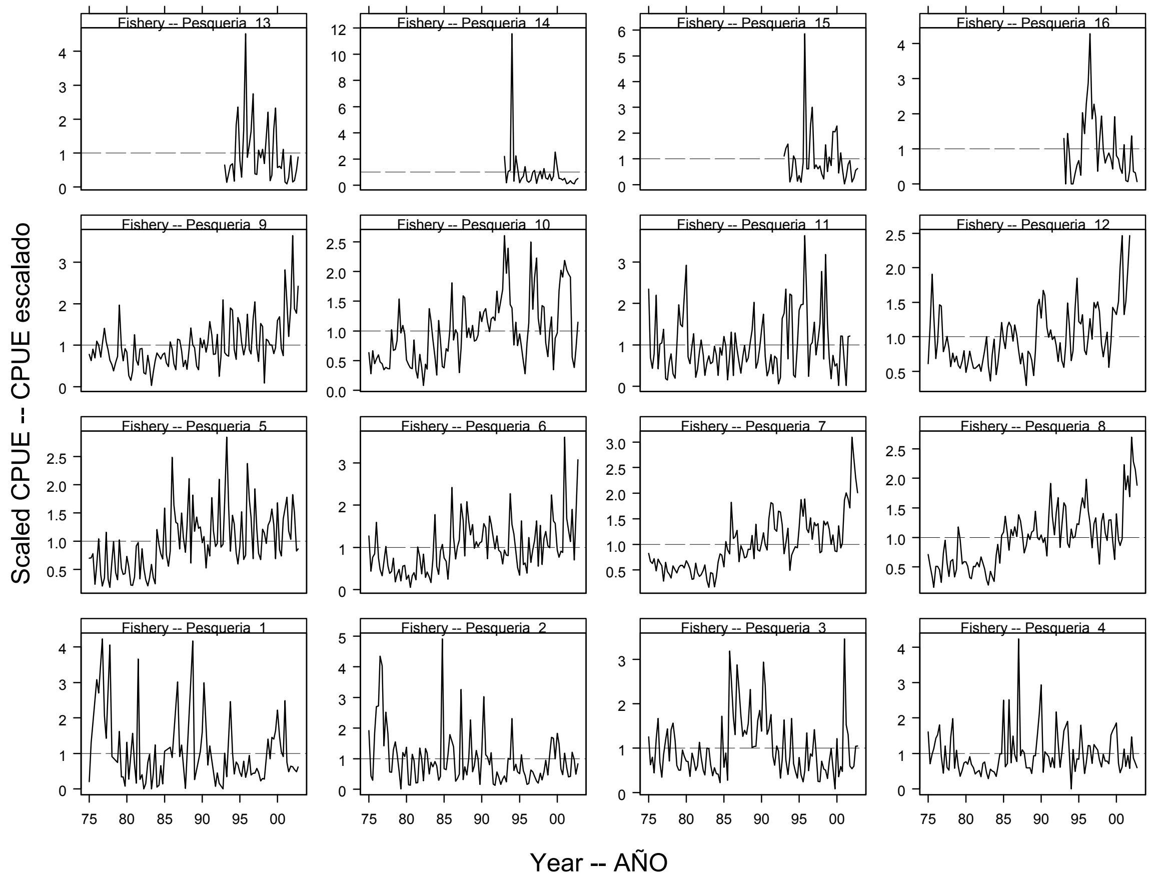

FIGURE 4.1. CPUEs for the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of CPUE for each year. The CPUEs for Fisheries 1-10 and 13-16 are in kilograms per day fished, and those for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

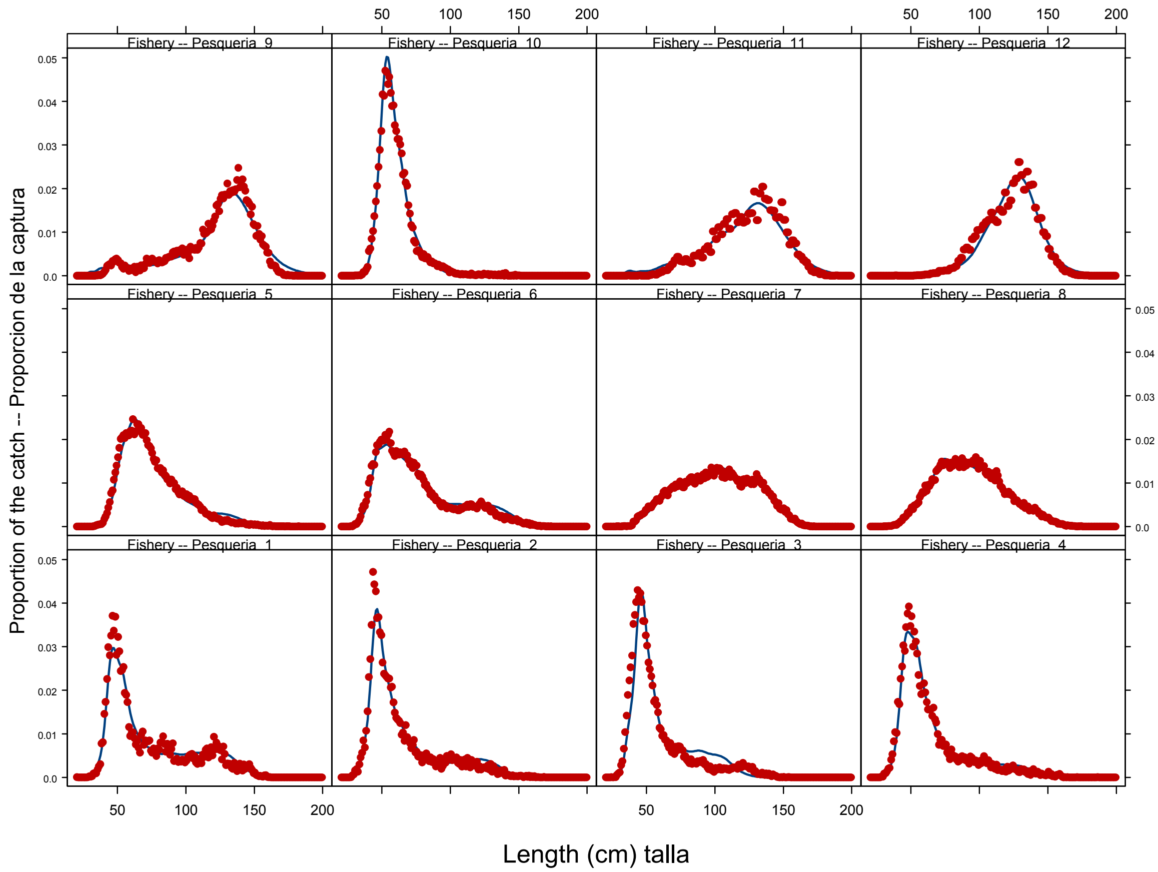

FIGURE 4.2. Average observed (dots) and predicted (curves) size compositions of the catches taken by the fisheries defined for the stock assessment of yellowfin tuna in the EPO.
FIGURA 4.2. Composición media por tamaño observada (puntos) y predicha (curvas) de las capturas realizadas por las pesquerías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

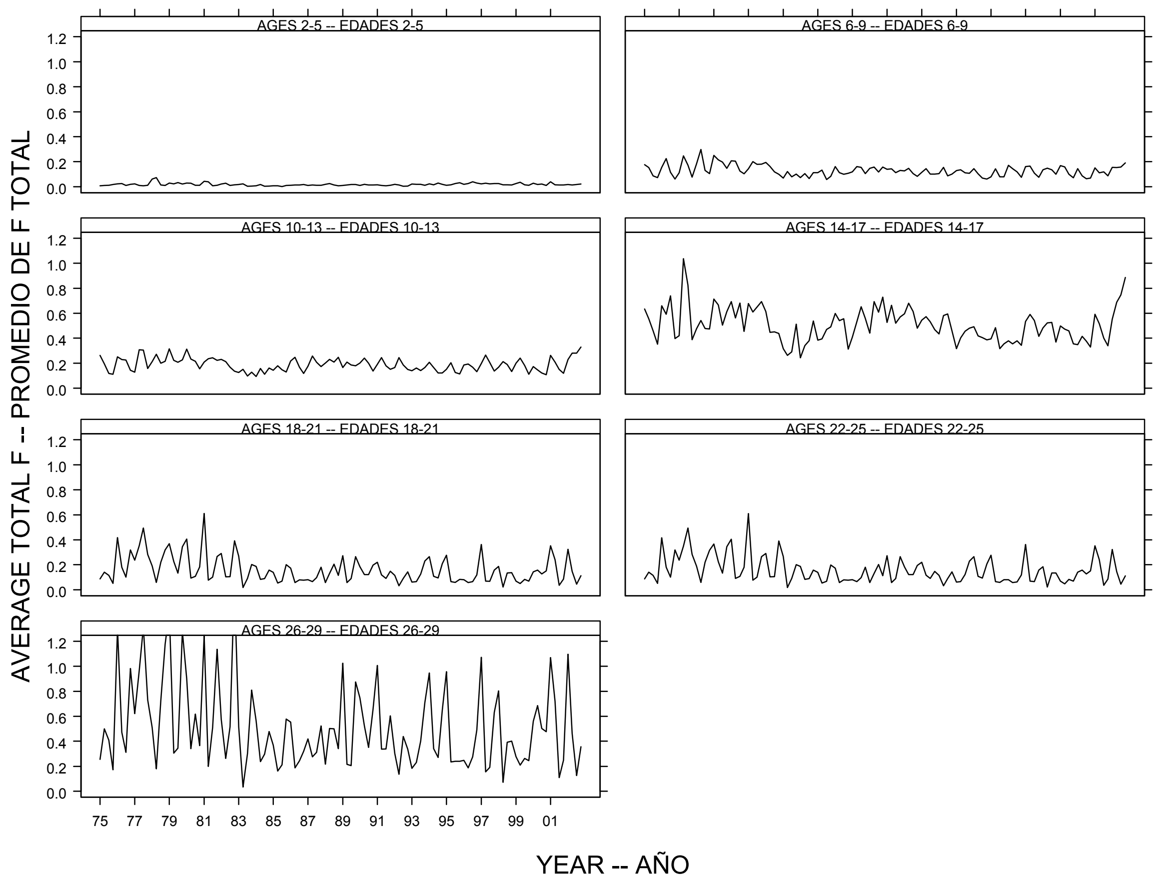

FIGURE 4.3a. Time series of average total quarterly fishing mortality of yellowfin tuna that have been recruited to the fisheries of the EPO. Each panel illustrates an average of four quarterly fishing mortality vectors that affected the fish that were as old as the range of ages indicated in the title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

FIGURA 4.3a. Series de tiempo de la mortalidad por pesca trimestral total media de atún aleta amarilla reclutado a las pesquerías del OPO. Cada recuadro ilustra un promedio de cuatro vectores trimestrales de mortalidad por pesca que afectaron los peces de la edad indicada en el título de cada recuadro. Por ejemplo, la tendencia ilustrada en el recuadro superior izquierdo es un promedio de las mortalidades por pesca que afectaron peces de entre 2 y 5 trimestres de edad.

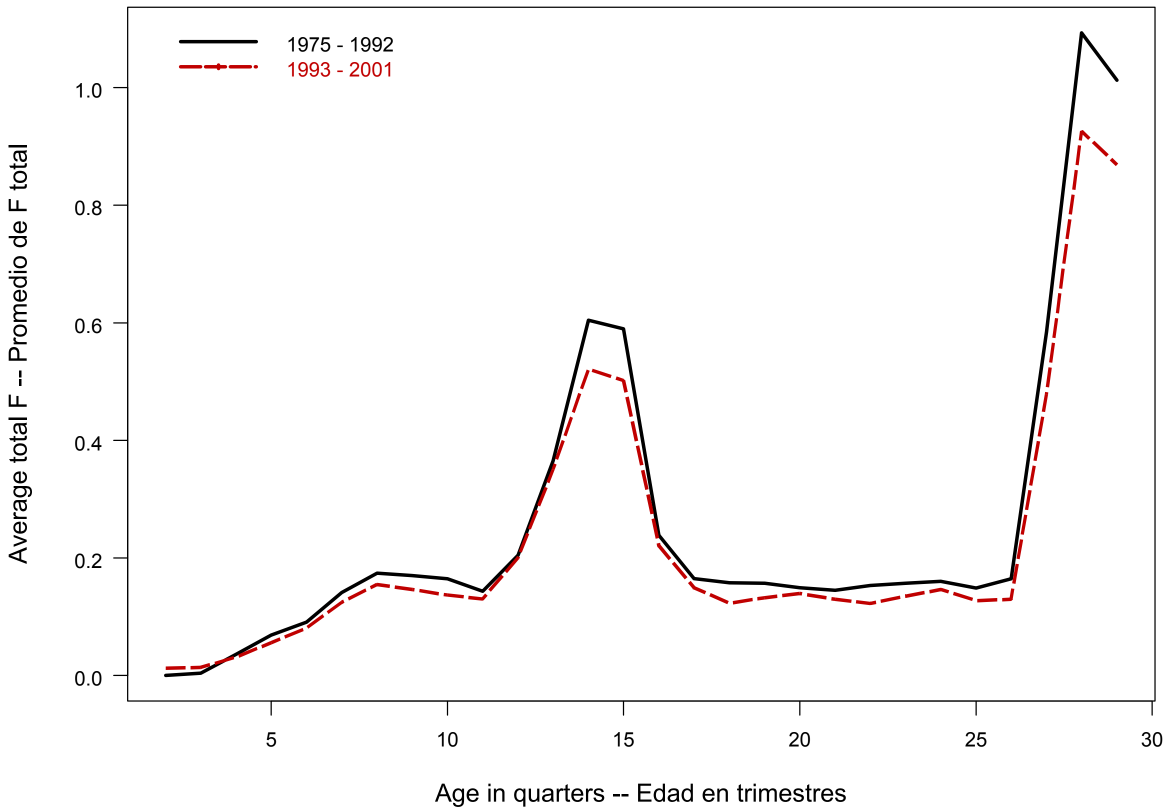

FIGURE 4.3b. Average total quarterly fishing mortality by age of yellowfin tuna that have been recruited to the fisheries of the EPO. The estimates are presented for two periods, the latter period relating to the increase in effort associated with floating objects.
FIGURA 4.3b. Mortalidad por pesca total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

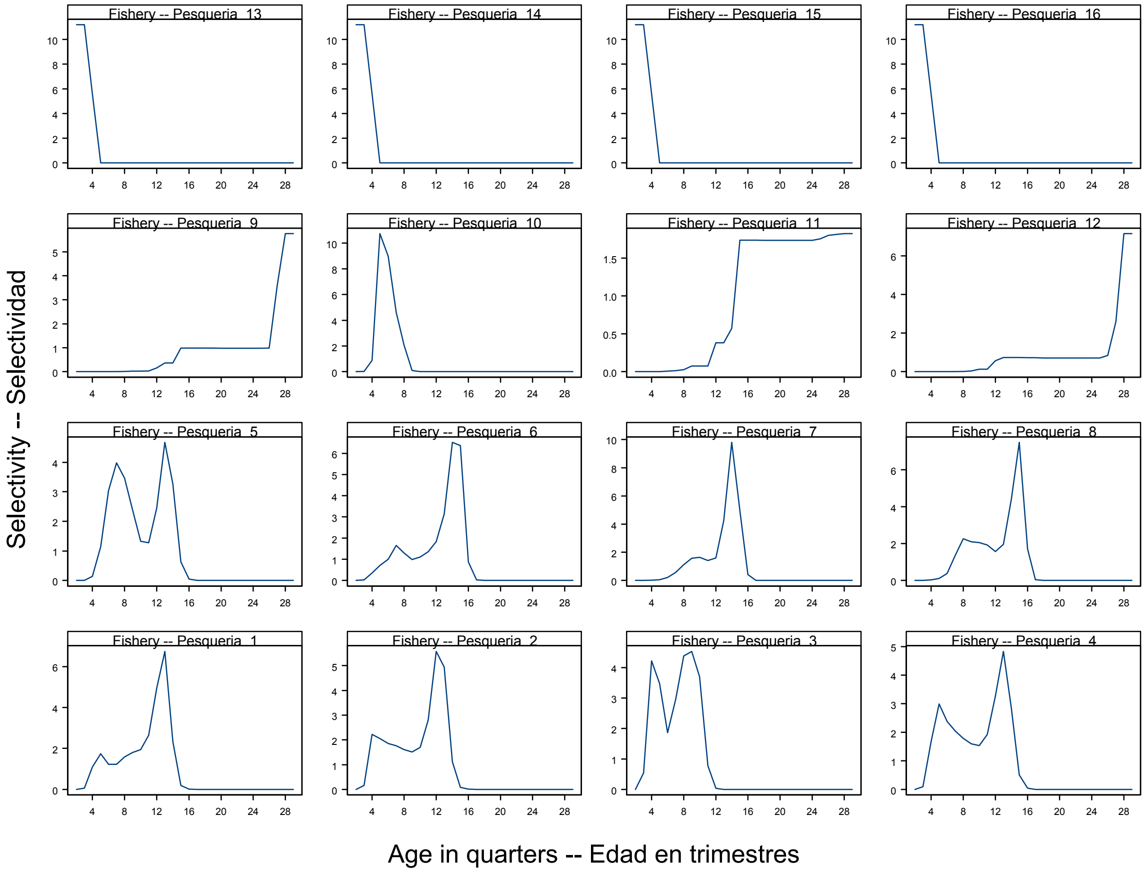

FIGURE 4.4. Selectivity curves for the 16 fisheries that take yellowfin tuna in the EPO. The curves for Fisheries 1-12 were estimated with the A-SCALA method. The curves for Fisheries 13-16 are based on assumptions.

FIGURA 4.4. Curvas de selectividad para las 16 pesquerías que capturan atún aleta amarilla en el OPO. Se estimaron las curvas de las Pesquerías 1-12 con el método A-SCALA; las de la Pesquerías 13-16 se basan en supuestos.

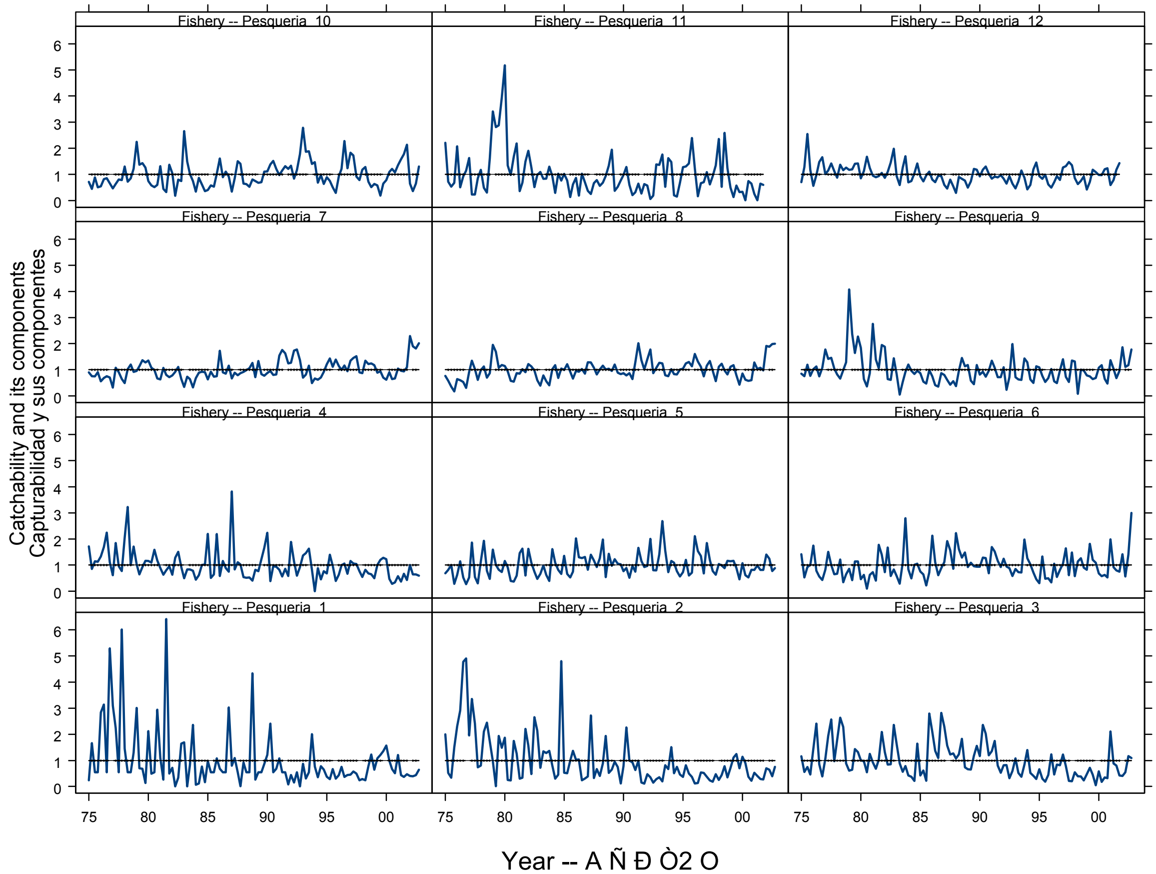

FIGURE 4.5a. Trends in catchability (*q*) for the 16 fisheries that take yellowfin tuna in the EPO. The estimates are scaled to average 1.
FIGURA 4.5a. Tendencias en capturabilidad (*q*) para las 16 pesquerías que capturan atún aleta amarilla en el OPO. Se escalan las estimaciones a un promedio de 1.

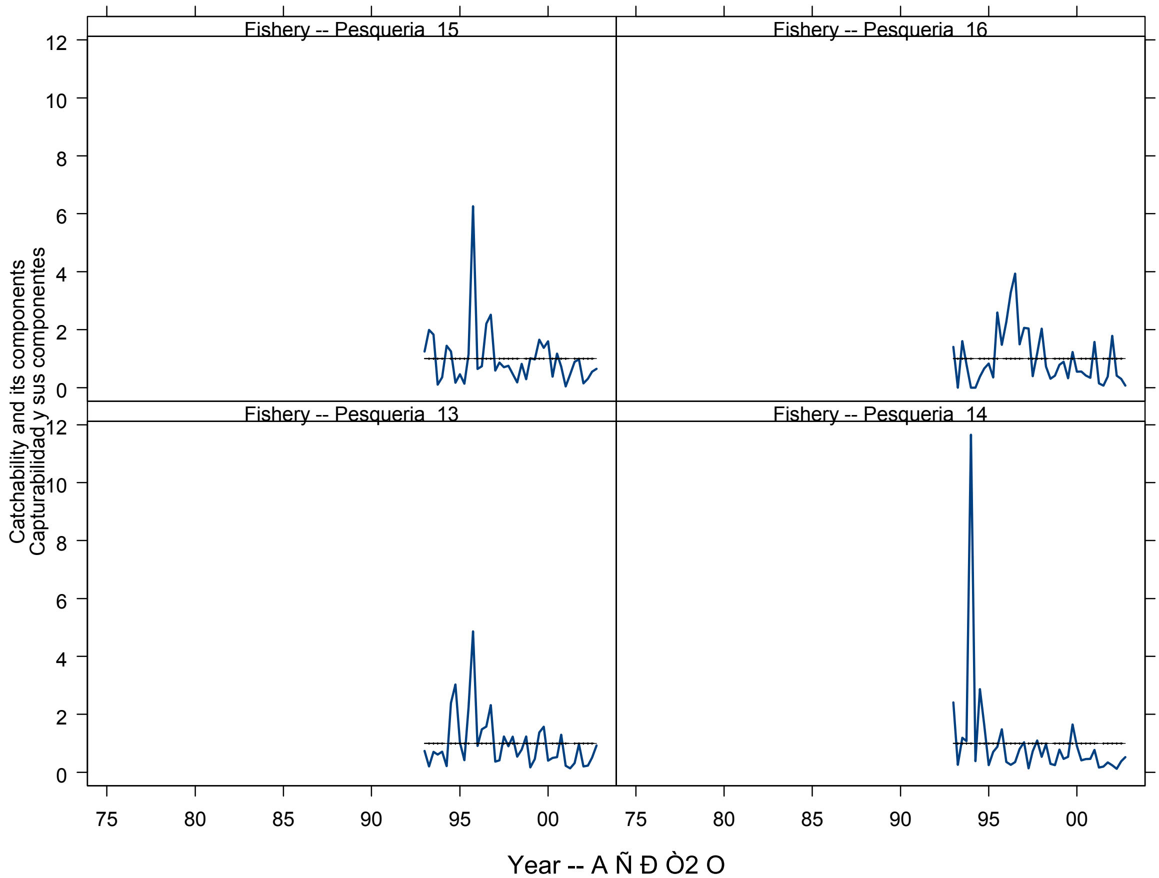

FIGURE 4.5b. Trends in catchability (*q*) for the 16 fisheries that take yellowfin tuna in the EPO. See Figure 4.5a for additional detail.

FIGURA 4.5b. Tendencias en capturabilidad (*q*) para las 16 pesquerías que capturan atún aleta amarilla en el OPO. Ver Figura 4.5a para mayor detalle.

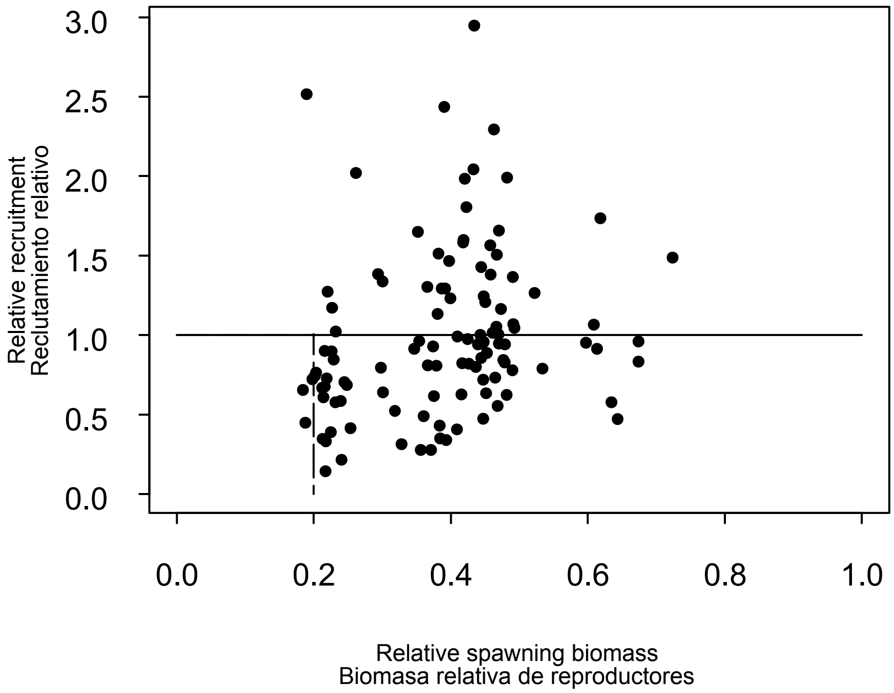

FIGURE 4.6. Estimated relationships between recruitment of yellowfin tuna and spawning biomass. The recruitment is scaled so that the average recruitment is equal to 1.0. The spawning biomass is scaled so that the average unexploited spawning biomass is equal to 1.0.
FIGURA 4.6. Relaciones estimadas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

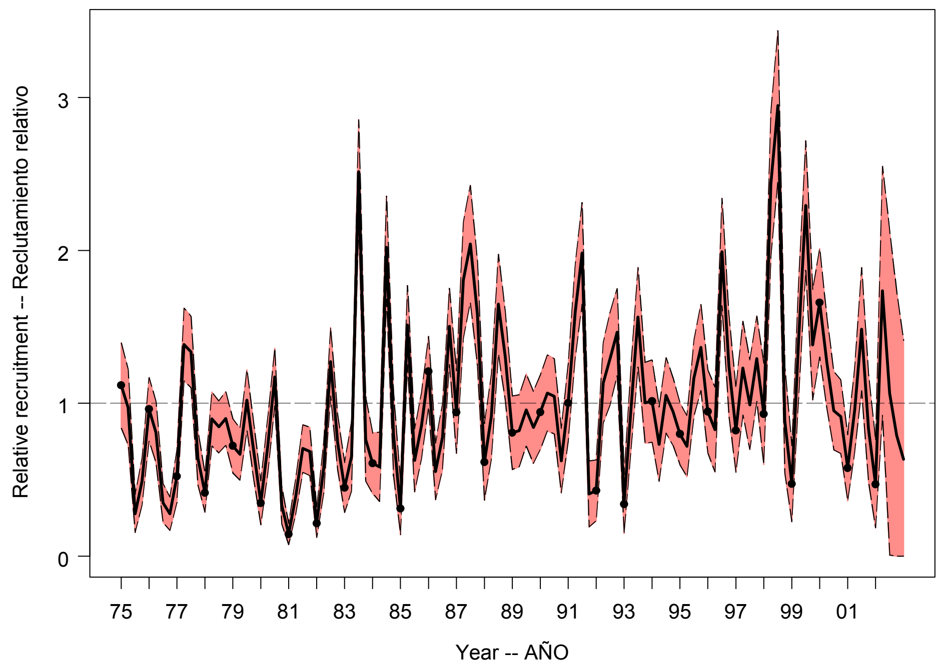

FIGURE 4.7. Estimated recruitment of yellowfin tuna to the fisheries of the EPO. The estimates are scaled so that the average recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the thin lines indicate the approximate 95% confidence intervals around those estimates. The labels on the time axis are drawn at the start of each year, but, since the assessment model represents time on a quarterly basis, there are four estimates of recruitment for each year.
FIGURA 4.7. Reclutamiento estimado de atún aleta amarilla a las pesquerías del OPO. Se escalan las estimaciones para que el reclutamiento medio equivalga a 1,0. La línea gruesa ilustra las estimaciones de probabilidad máxima del reclutamiento, y las líneas delgadas los intervalos de confianza de 95% aproximados de las estimaciones. Se dibujan las leyendas en el eje de tiempo al principio de cada año, pero, ya que el modelo de evaluación representa el tiempo por trimestres, hay cuatro estimaciones de reclutamiento para cada año.

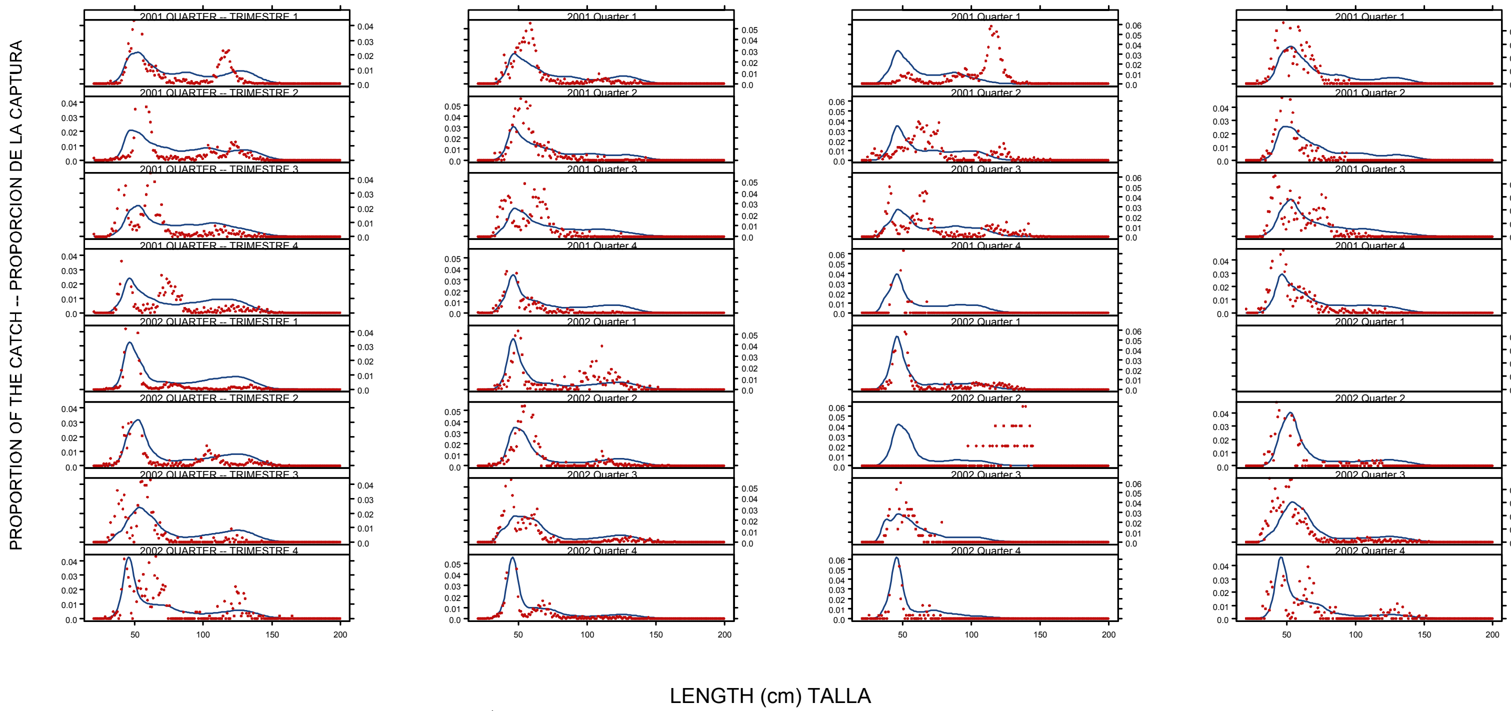

FIGURE 4.8a. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin by the fisheries that take tunas in association with floating objects.

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

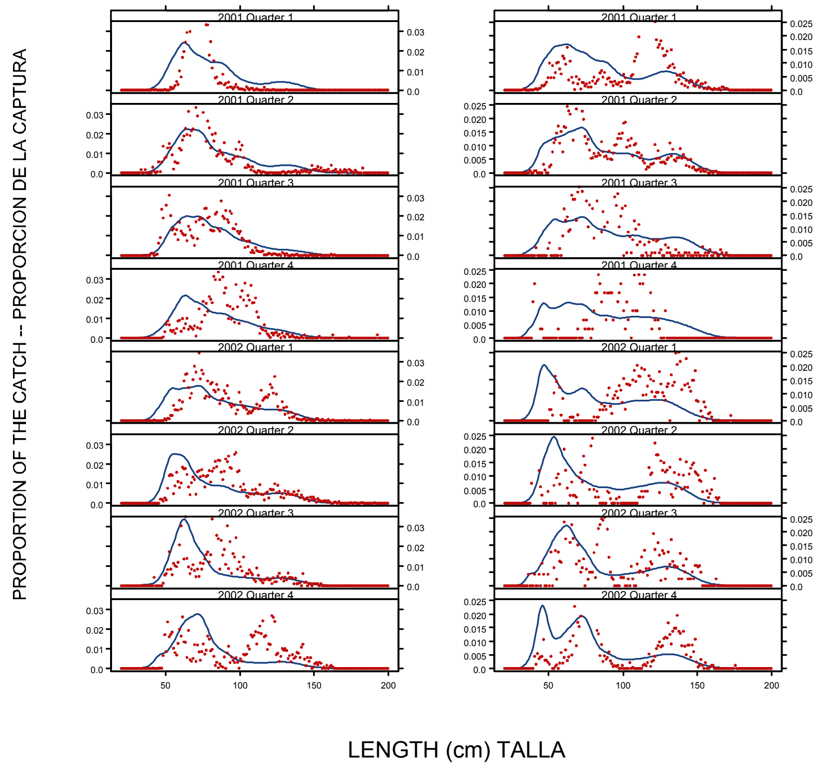

FIGURE 4.8b. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin by the fisheries that take tunas in unassociated schools.
FIGURA 4.8b. Composiciones por tamaño observadas (puntos) y predichas (curvas) de las capturas recientes de aleta amarilla por las pesquerías que capturan atún en cardúmenes no asociados.

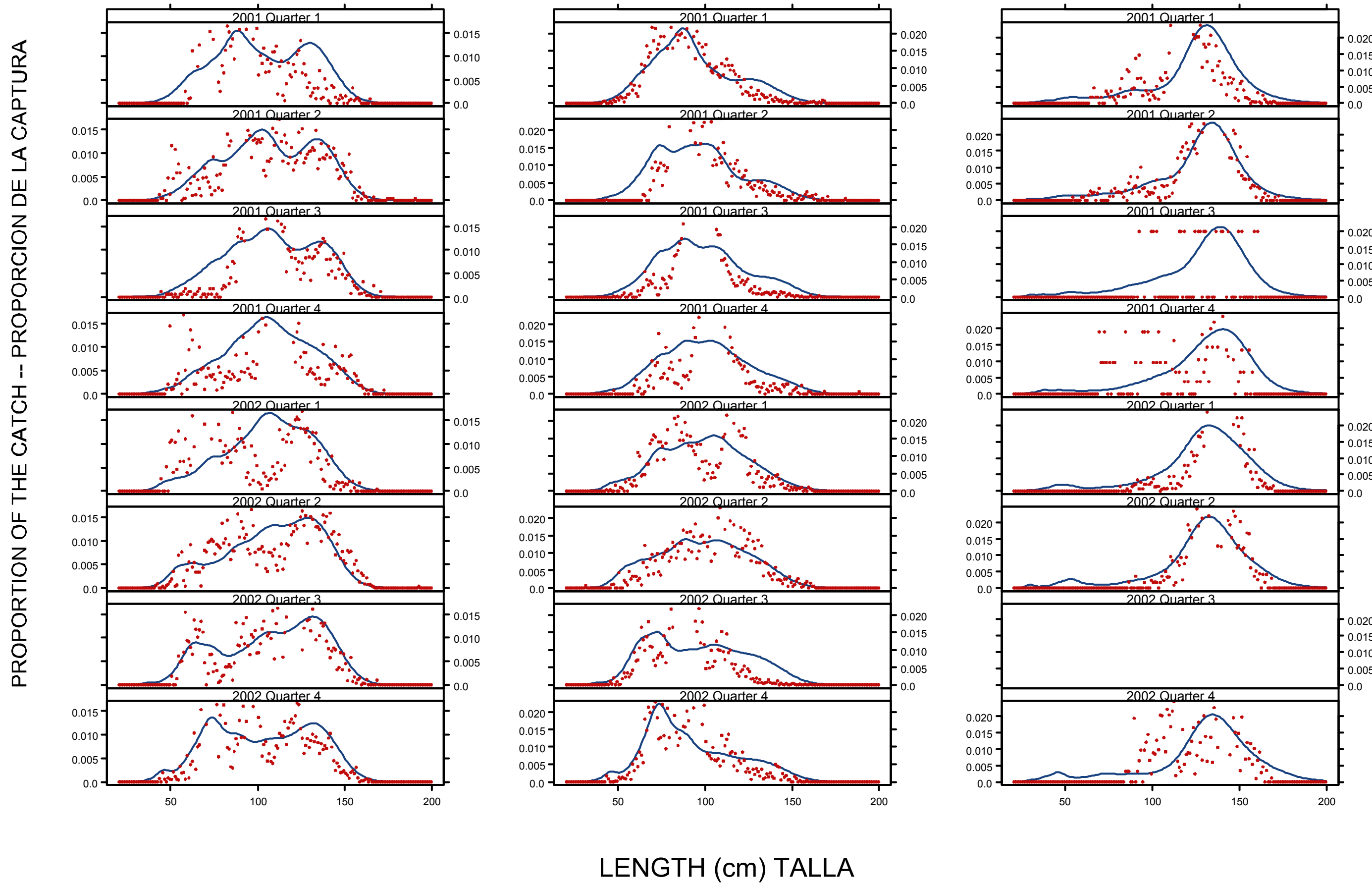

FIGURE 4.8c. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin by the fisheries that take tunas in association with dolphins.

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

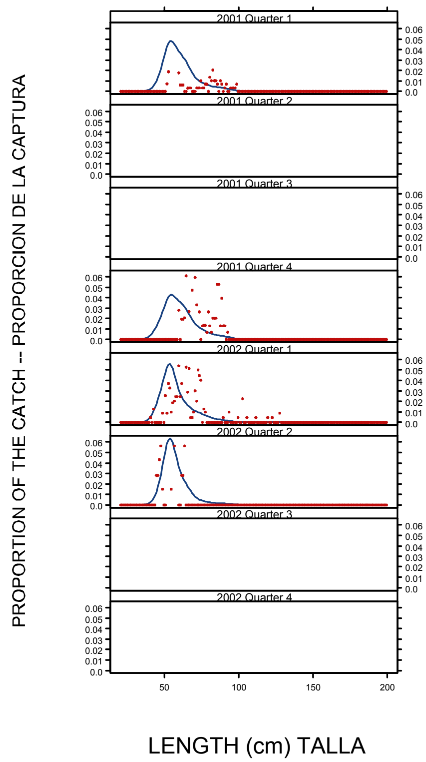

FIGURE 4.8d. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin by the pole and line fishery (Fishery 10).

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

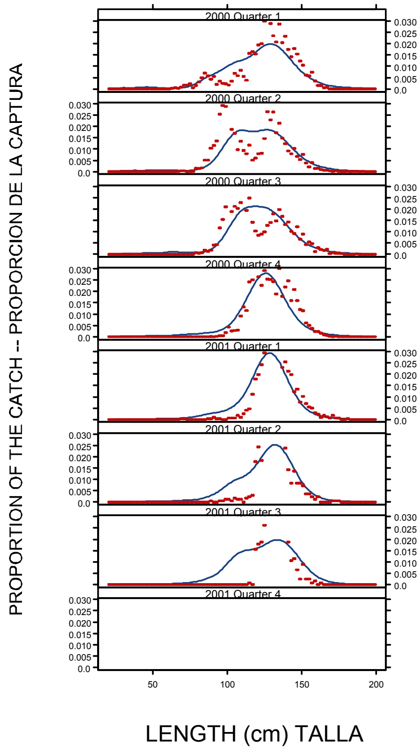

FIGURE 4.8e. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin by the longline fisheries.
FIGURA 4.8e. Composiciones por tamaño observadas (puntos) y predichas (curvas) de las capturas recientes de aleta amarilla por las pesquerías palangreras.

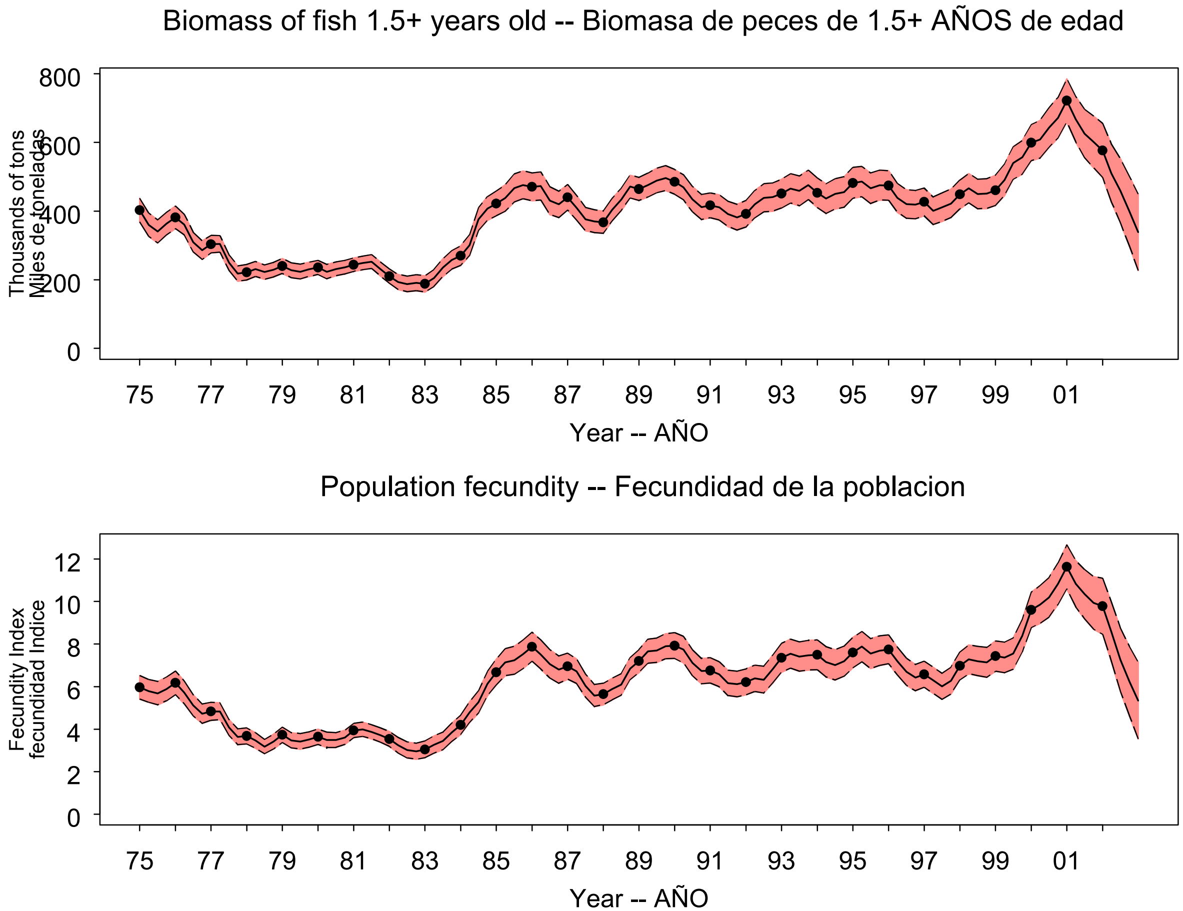

FIGURE 4.9. Estimated biomass and spawning biomass of yellowfin tuna in the EPO. The bold lines illustrate the maximum likelihood estimates of the biomass, and the thin lines the approximate 95% confidence intervals around those estimates. Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year.
FIGURA 4.9. Biomasa estimada y biomasa reproductora de atún aleta amarilla en el OPO. Las líneas gruesas ilustran las estimaciones de probabilidad máxima de la biomasa, y las delgadas los límites de confianza de 95% aproximados de las estimaciones. Ya que el modelo de evaluación representa el tiempo por trimestres, hay cuatro estimaciones de biomasa para cada año.

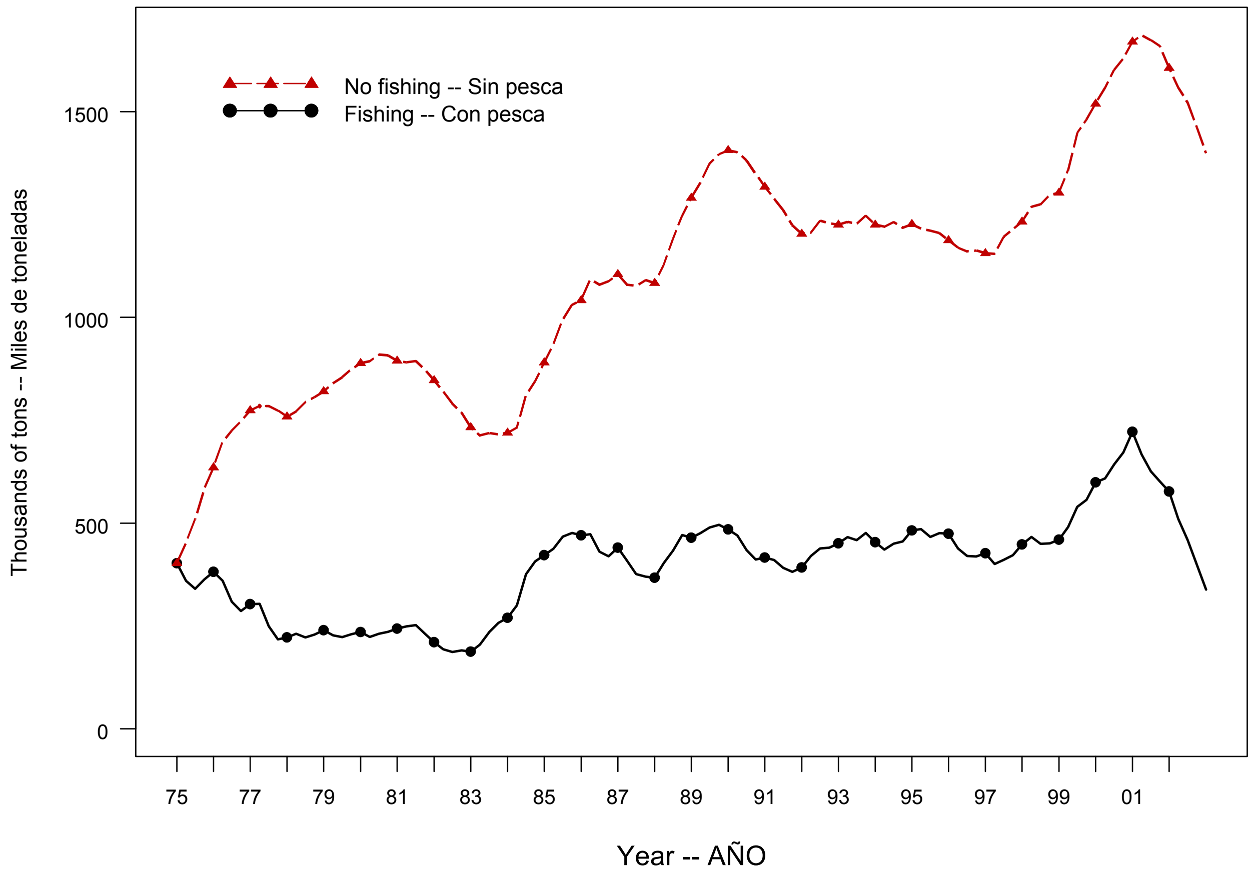

FIGURE 4.10. Biomass trajectory of a simulated population of yellowfin tuna that was not exploited during 1975-2002 ("no fishing") and that predicted by the stock assessment model ("fishing").
FIGURA 4.10. Trayectoria de biomasa de una población simulada de atún aleta amarilla no explotada durante 1975-2001 ("sin pesca") y la predicha por el modelo de evaluación del stock ("con pesca").

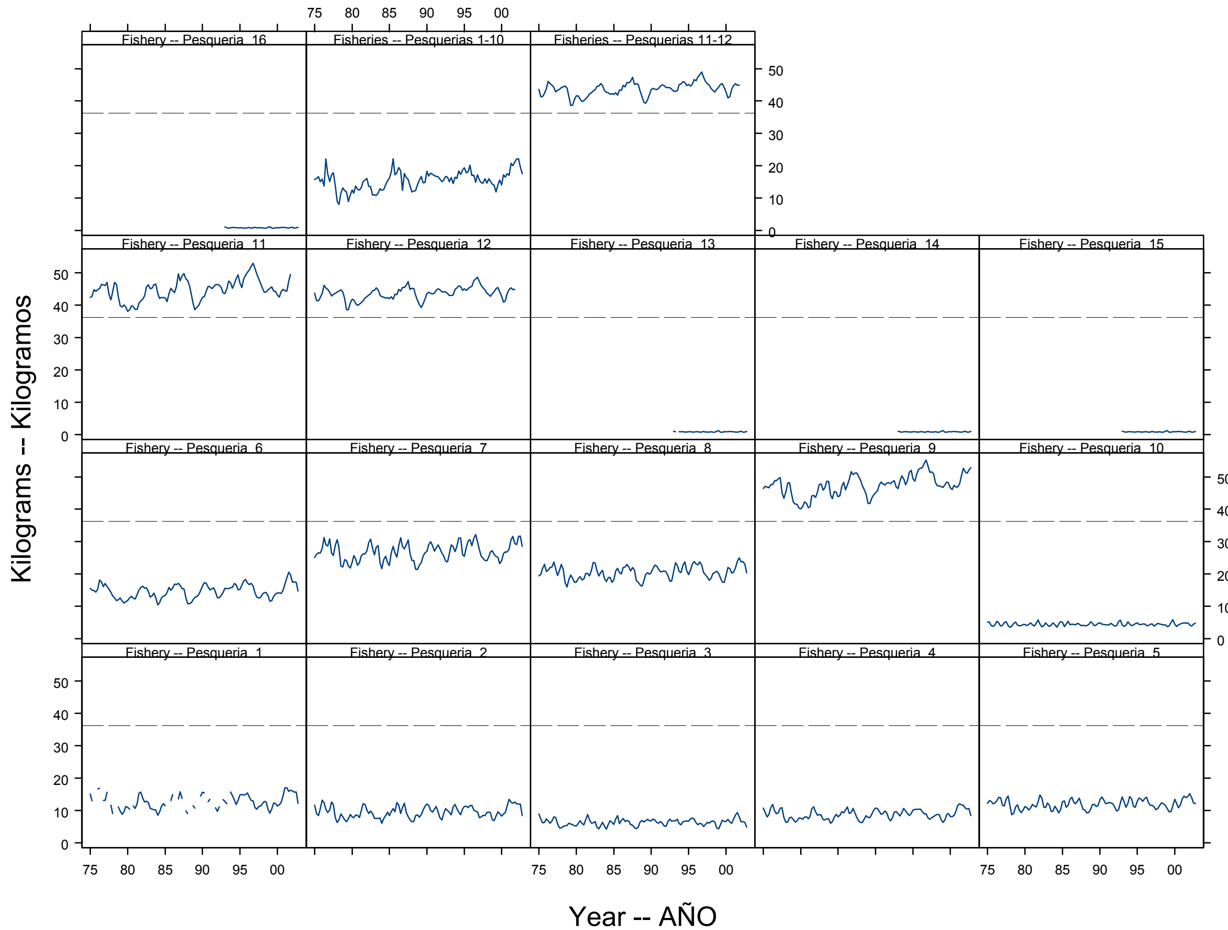

FIGURE 4.11. Estimated average weights of yellowfin tuna caught by the fisheries of the EPO. The time series for "Fisheries 1-10" is an average of Fisheries 1 through 10, and the time series for "Fisheries 11-12" is an average of Fisheries 11 and 12. The dashed line identifies the critical weight.

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

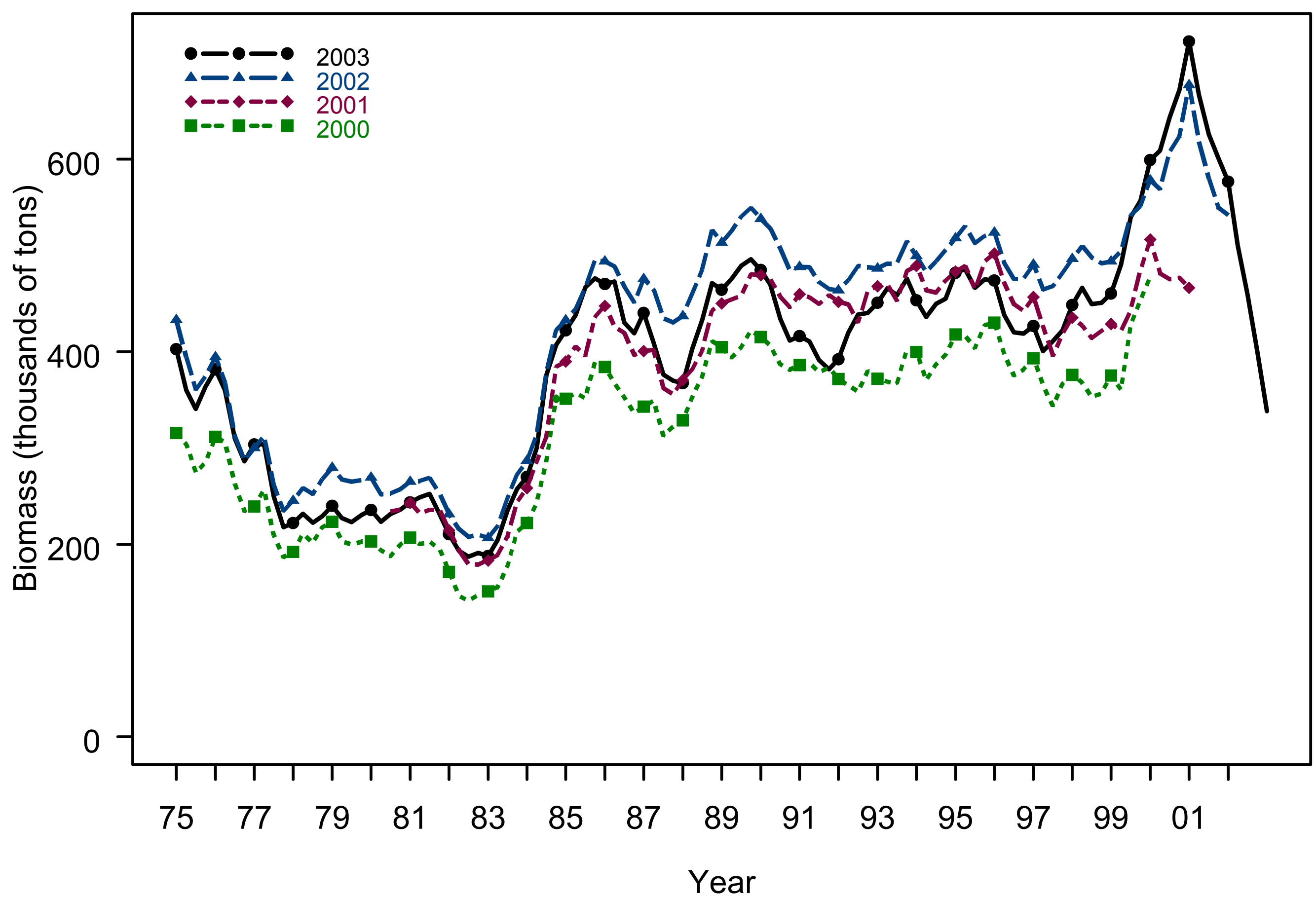

FIGURE 4.12a. Comparison of biomass from previous assessments and the current assessment.
FIGURA 4.12a. Comparación de biomasa (edades de dos años y más) de evaluaciones previas y de la evaluación actual.

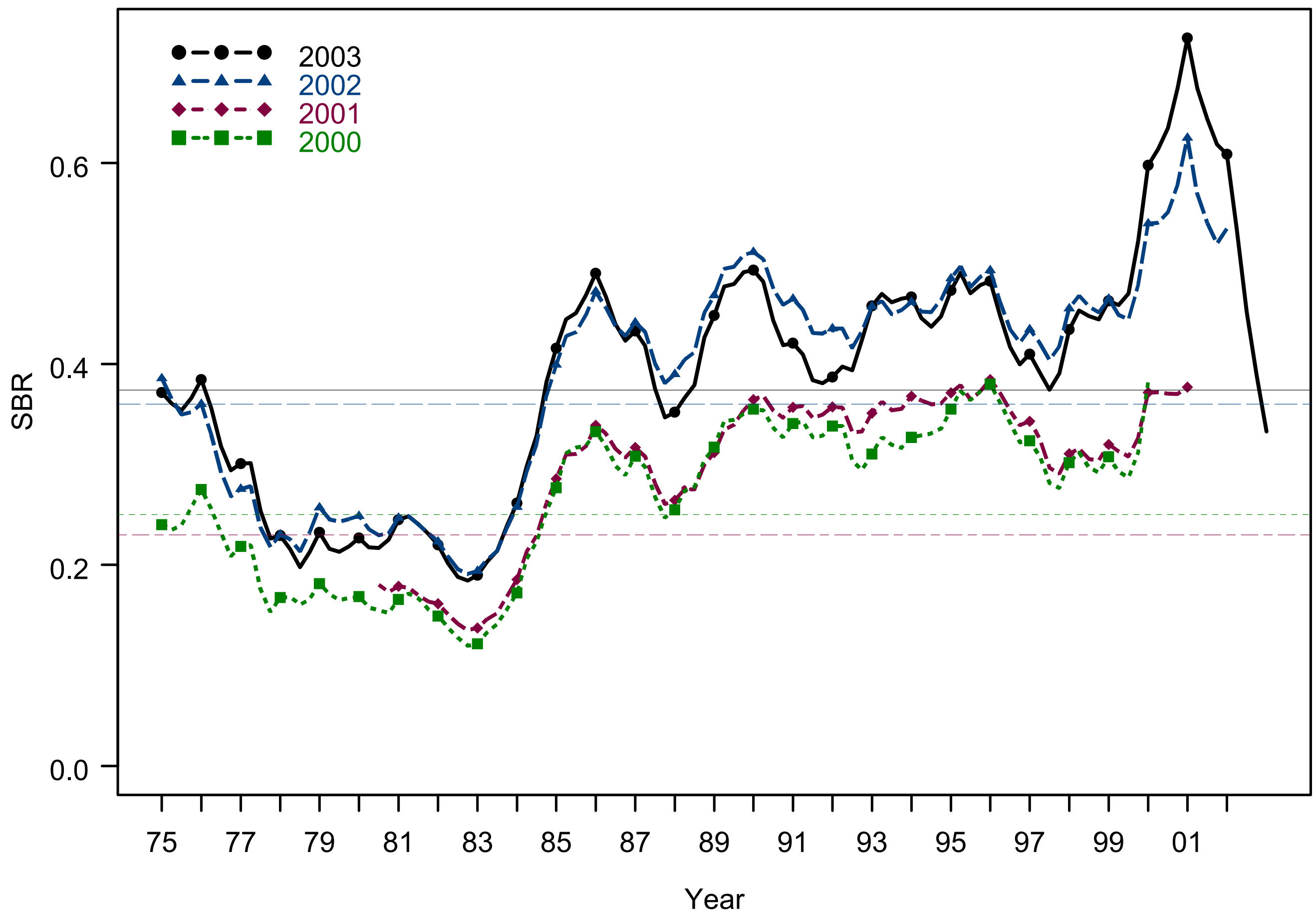

FIGURE 4.12b. Comparison of SBR from previous assessments and the current assessment. The horizontal lines identifies the SBR at AMSY
FIGURA 4.12b. Comparación de biomasa (edades de dos años y más) de evaluaciones previas y de la evaluación actual.

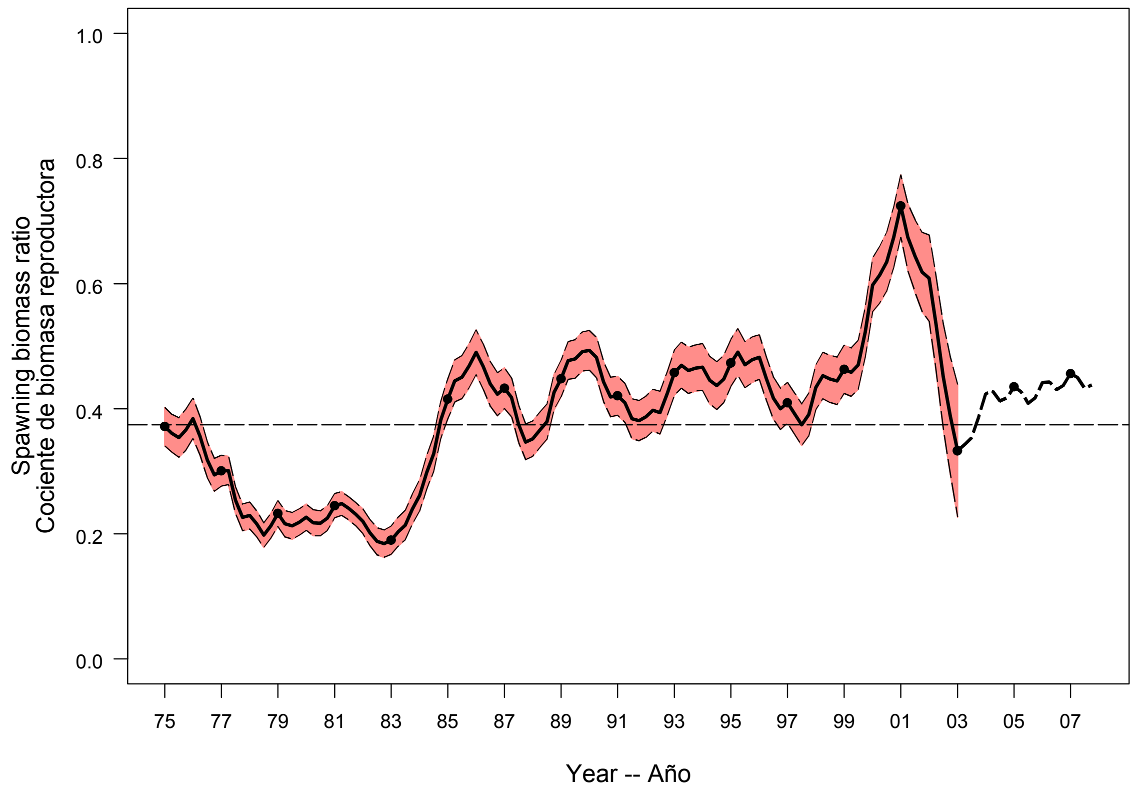

FIGURE 5.1. Estimated time series of spawning biomass ratios (SBRs) for yellowfin tuna in the EPO. The dashed extension to the solid line represents the projected SBR under current effort and average recruitment. The thin lines represent approximate 95% confidence intervals. The dashed horizontal line (at about 0.37) identifies the SBR at AMSY.
FIGURA 5.1. Series de tiempo estimadas de los cocientes de biomasa reproductora (SBR) de atún aleta amarilla en el OPO. La extensión de trazos de la línea sólida representa el SBR proyectado con el esfuerzo y el reclutamiento medio actuales. Las líneas delgadas representan los intervalos de confianza de 95% aproximados. Las líneas de trazos horizontal (en aproximadamente 0,36) identifican el SBR en RPMS.

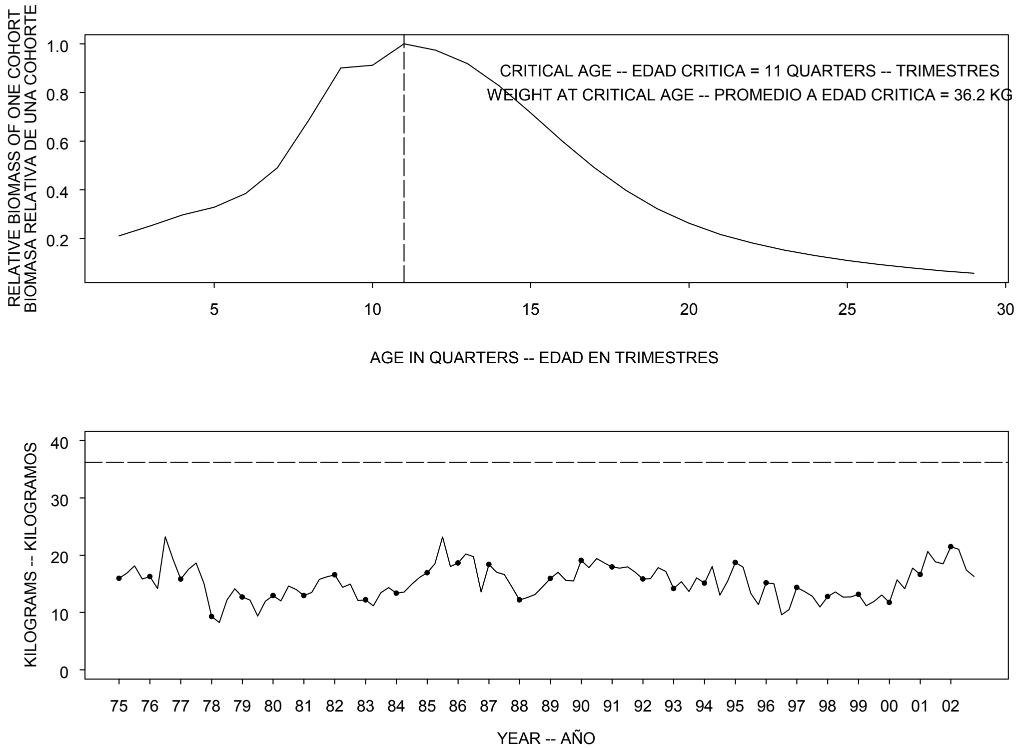

FIGURE 5.2. Combined performance of all fisheries that take yellowfin tuna in the EPO at achieving the maximum yield per recruit. The upper panel illustrates the growth (in weight) of a single cohort of yellowfin, and identifies the “critical age” and “critical weight” (Section 5). The lower panel illustrates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

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

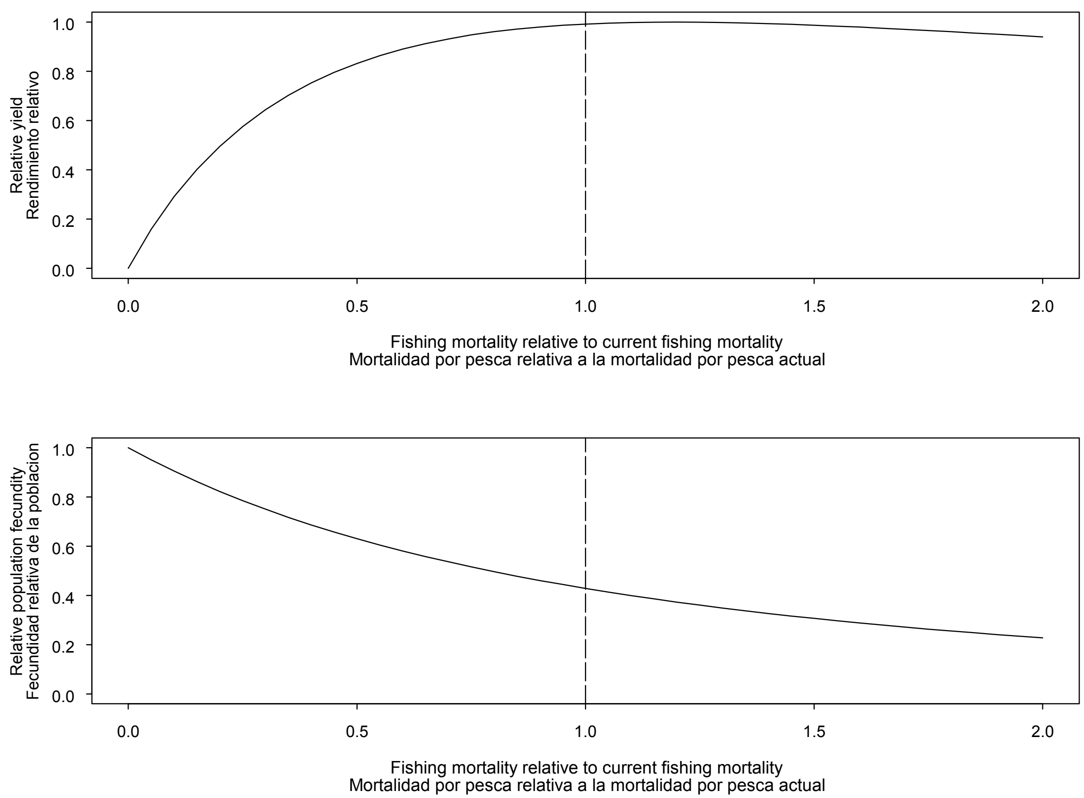

FIGURE 5.3. Predicted effects of long-term changes in fishing effort on the yield (upper panel) and spawning biomass (lower panel) of yellowfin tuna under average environmental conditions, constant recruitment, and the current age-specific selectivity pattern of all fisheries combined. The yield estimates are scaled so that the AMSY is at 1.0, and the spawning biomass estimates so that the spawning biomass is equal to 1.0 in the absence of exploitation.

FIGURA 5.3. Efectos predichos de cambios a largo plazo en el esfuerzo de pesca sobre el rendimiento (recuadro superior) y la biomasa reproductora (recuadro inferior) de atún aleta amarilla bajo condiciones ambientales medias, reclutamiento constante, y el patrón actual de selectividad por edad de todas las pesquerías combinadas. Se escalan las estimaciones de rendimiento para que el RPMS esté en 1,0, y las de biomasa reproductora para que ésta equivalga a 1,0 en ausencia de explotación.

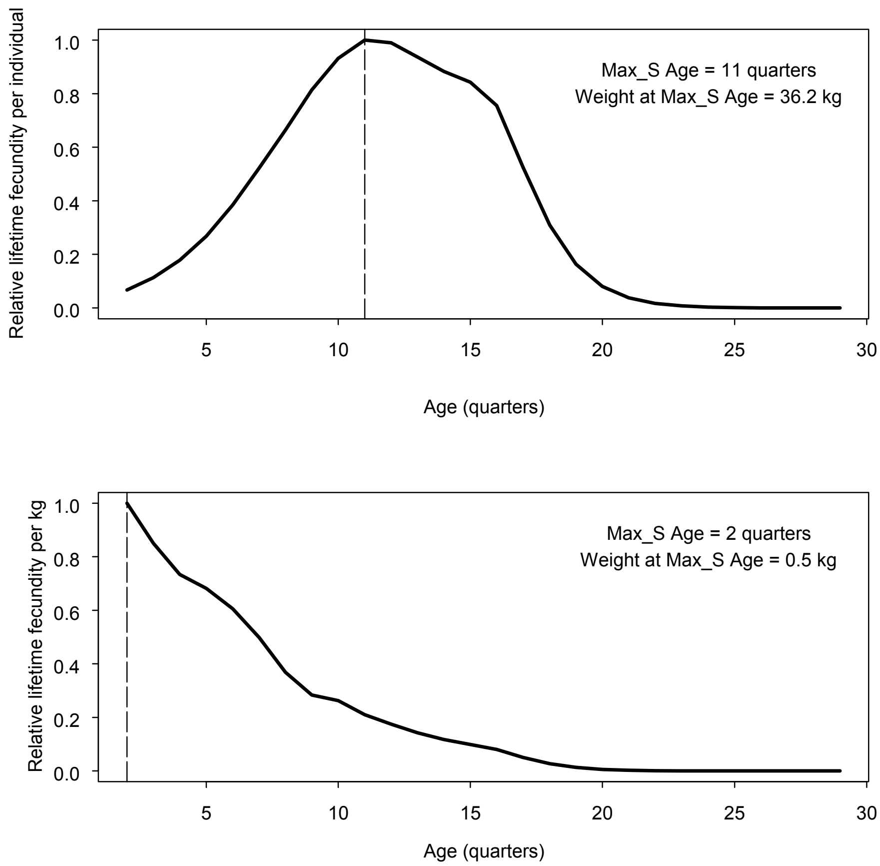

FIGURE 5.4. Marginal relative lifetime reproductive potential at age based on individuals (upper panel) and weight (lower panel). Age_{SMAX} is the age at which the maximum marginal relative lifetime reproductive potential is realized. The vertical lines indicate the locations of Age_{SMAX} .

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

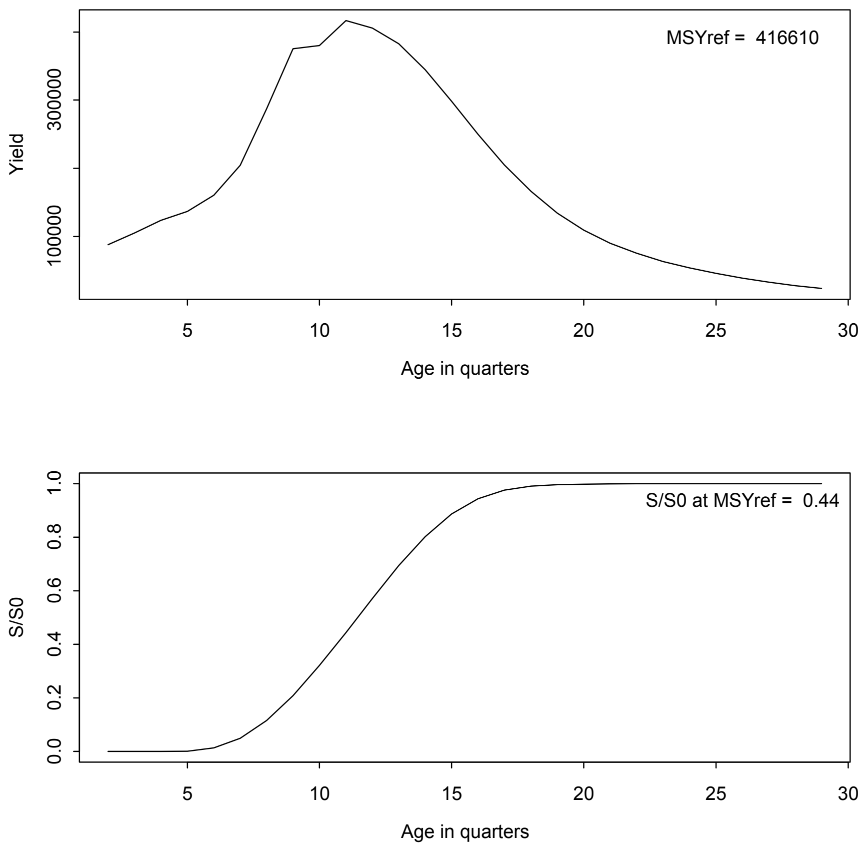

FIGURE 5.5. Yield calculated when only catching individuals at a single age (top panel) and the associated SBR (lower panel)

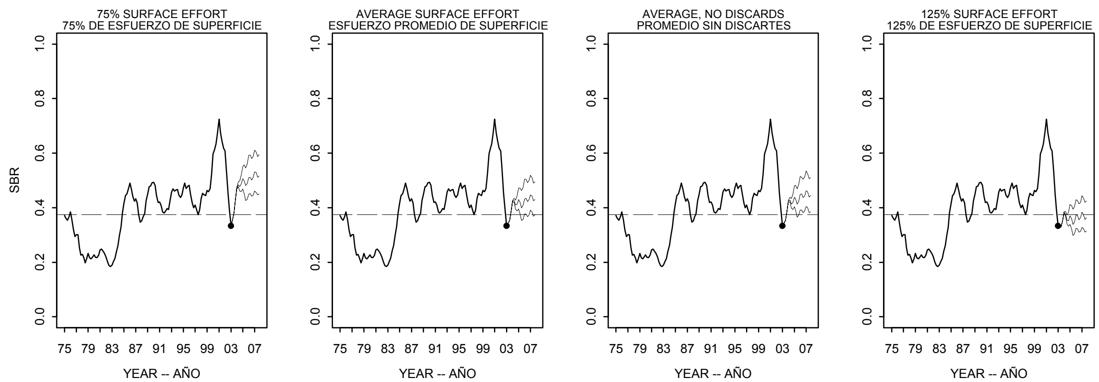

FIGURE 6.1a. Simulated SBRs during 2003-2007 for yellowfin tuna in the EPO. Each panel illustrates the results of 1001 simulations using different scenarios described in Sections 6.1 and 6.2. The thin lines to the right of the each dot represent the median and 20% and 80% quantiles of the simulated SBRs. The dashed horizontal lines (at 0.37) identify SBR_{AMSY} (Section 5.3).
FIGURA 6.1a. SBR simulados durante 2002-2006 para el atún aleta amarilla en el OPO. Cada recuadro ilustra los resultados de 101 simulaciones usando distintos escenarios descritos en las Secciones 6.1 y 6.2. Las líneas delgadas a la derecha de cada punto representan la mediana y los cuantiles de 20% y 80% de los SBR simulados. Las líneas de trazos horizontales (en 0.36) identifican SBR_{RPMS} (Sección 5.3).

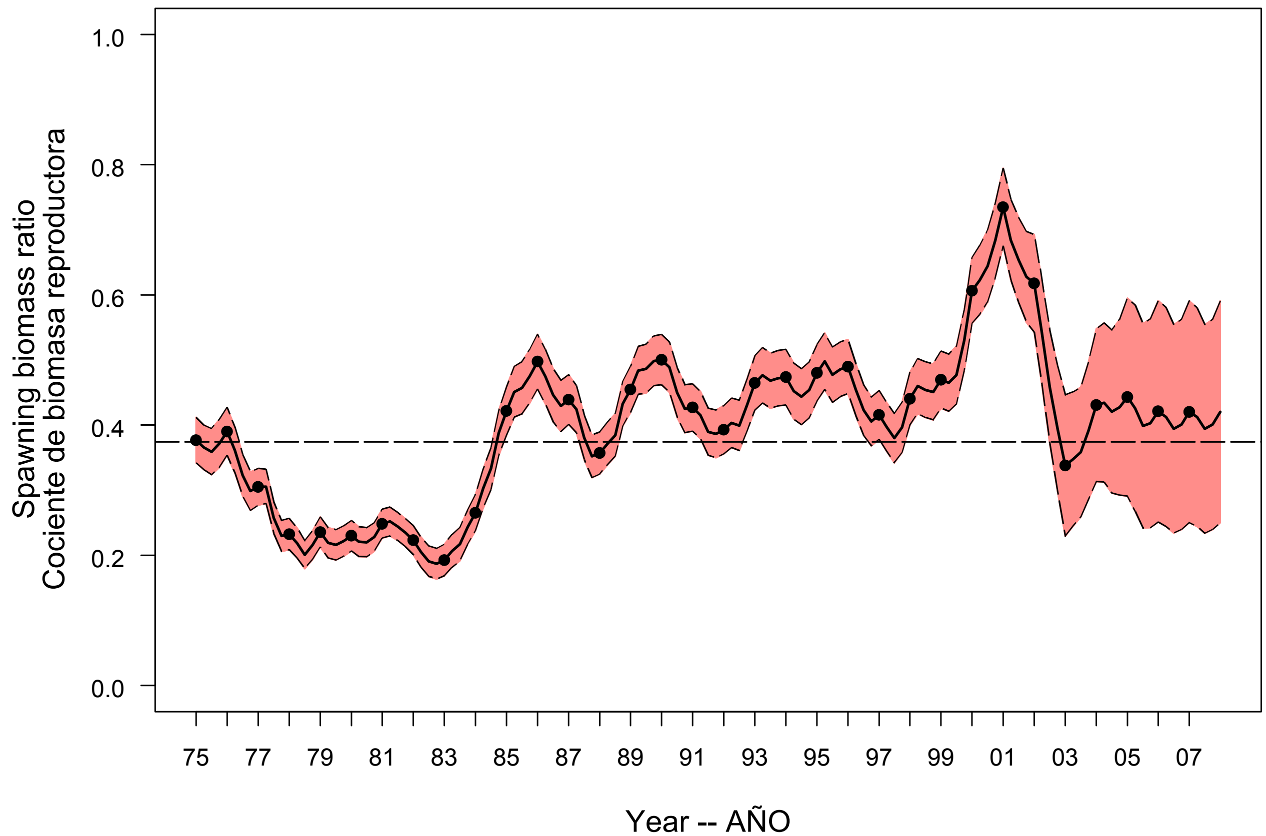

FIGURE 6.1b. SBRs projected during 2003-2007 for yellowfin tuna in the EPO using the likelihood profile approximation method. The dashed horizontal line (at 0.37) identifies SBR_{AMSY} (Section 5.3).

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

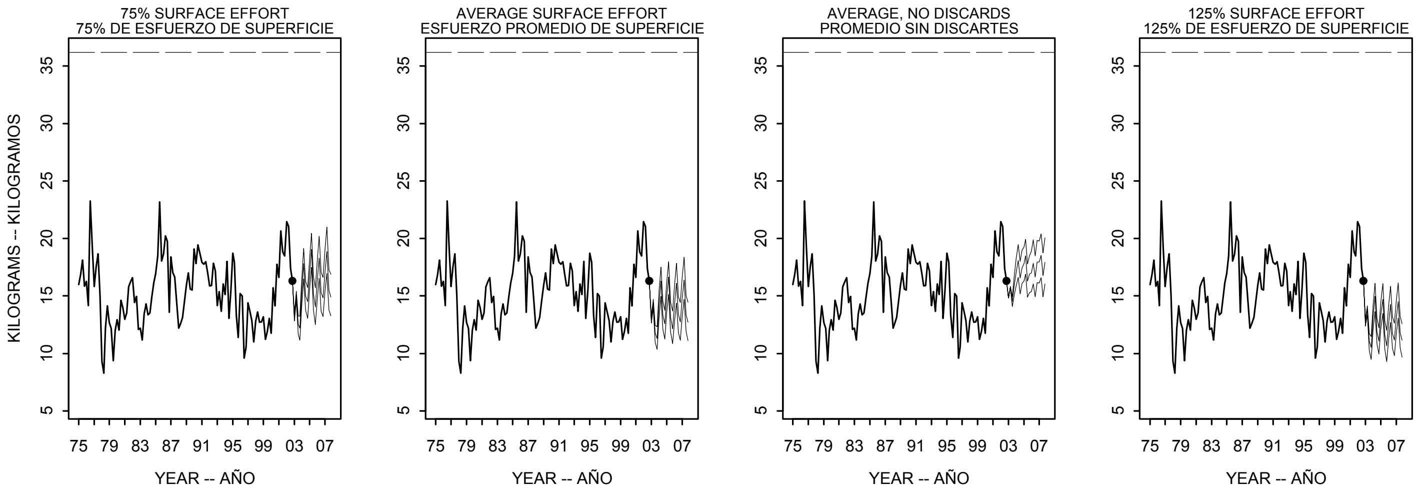

FIGURE 6.2. Simulated estimates of the average weight of yellowfin tuna in the combined catch during 2003-2007. Each panel illustrates the results of 1001 simulations using different scenarios described in Sections 6.1 and 6.2. The thin lines to the right of the each dot represent the median and 20% and 80% quantiles of the simulated average weights. The estimated critical weight is drawn as a horizontal dashed line in each panel.

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

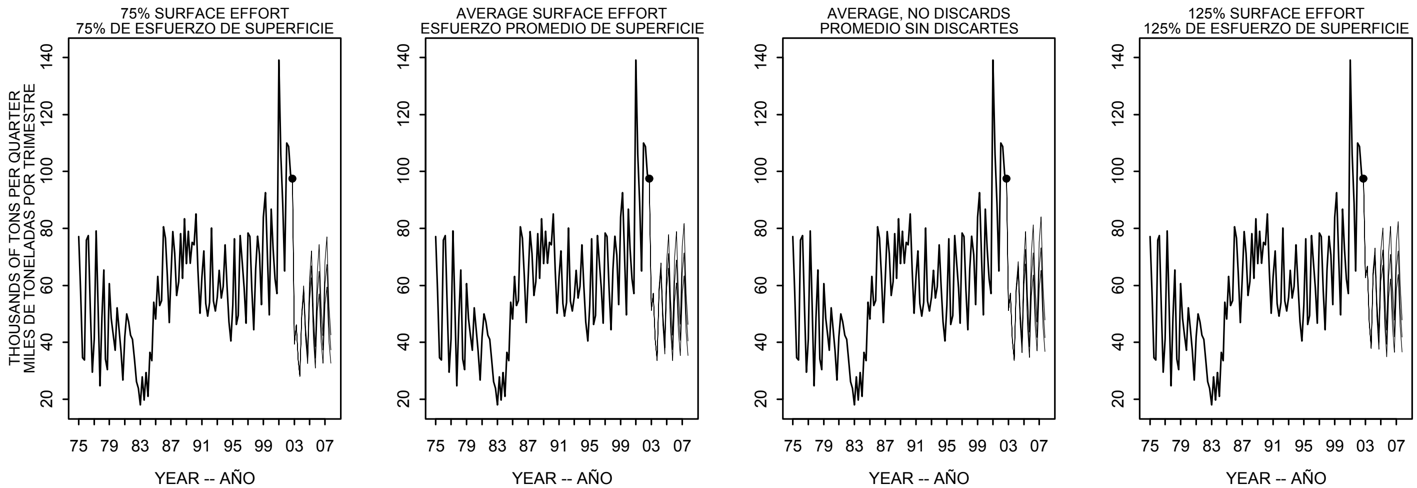

FIGURE 6.3a. Simulated catches of yellowfin tuna taken by the primary surface fleet (Fisheries 1-10) during 2003-2007. Each panel illustrates the results of 1001 simulations using different scenarios described in Sections 6.1 and 6.2. The thin lines to the right of the each dot represent the median and 20% and 80% quantiles of the simulated catches taken by these fisheries.

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

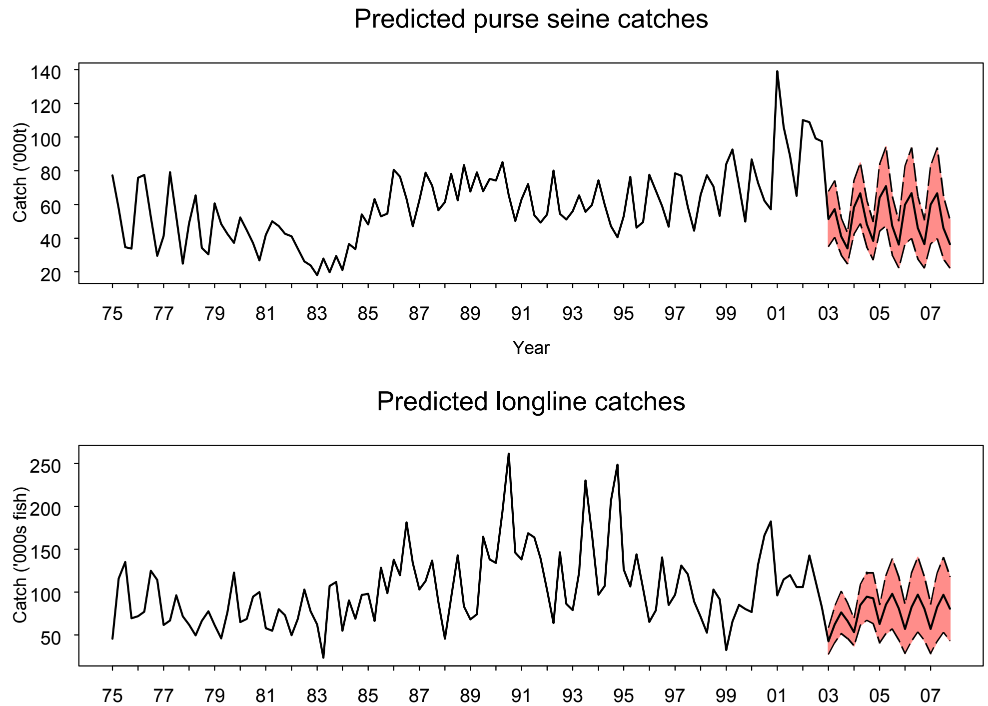

FIGURE 6.3b. Simulated catches of yellowfin tuna taken by the primary surface fleet (Fisheries 1-10; top panel) and the the longline fleet (Fisheries 11 and 12, bottom panel) during 2003-2007 using the likelihood profile method.

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

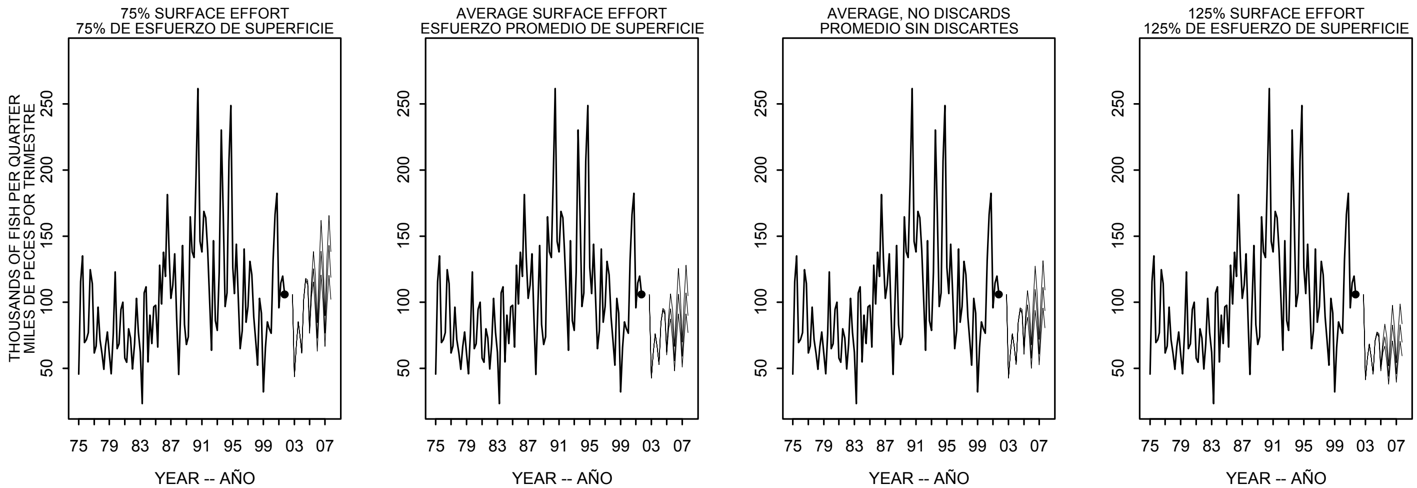

FIGURE 6.4. Simulated catches of yellowfin tuna taken by the longline fleet (Fisheries 11 and 12) during 2003-2007. Each panel illustrates the results of 1001 simulations using different scenarios described in Sections 6.1 and 6.2. The thin lines to the right of the each dot represent the median and 20% and 80% quantiles of the simulated catches of the fish taken by these fisheries.

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

TABLE 2.1. Fisheries defined by the IATTC staff for the stock assessment of yellowfin tuna in the EPO. PS = purse seine; PL = **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; BB = carnada; LL = palangre; FLT = lance sobre objeto flotante; UNA = lance sobre atunes no asociados; DOL = lances sobre delfines. En la Figura 3.1 se ilustran las zonas de muestreo, y en la Sección 2.2.2 se describen los descartes.

Fishery	**Gear type**	**Set type**	**Years**	**Sampling areas**	**Catch data**
Pesquería	**Tipo de arte**	**Tipo de lance**	**Año**	**Zonas de muestreo**	**Datos de captura**
1	PS	FLT	1975-2002	11-12	retained catch + discards from inefficiencies in fishing process–descargas + descartes de ineficacias en el proceso de pesca
2	PS	FLT	1975-2002	7, 9	retained catch + discards from inefficiencies in fishing process–descargas + descartes de ineficacias en el proceso de pesca
3	PS	FLT	1975-2002	5-6, 13	retained catch + discards from inefficiencies in fishing process–descargas + descartes de ineficacias en el proceso de pesca
4	PS	FLT	1975-2002	1-4, 8, 10	retained catch + discards from inefficiencies in fishing process–descargas + descartes de ineficacias en el proceso de pesca
5	PS	UNA	1975-2002	1-4, 8, 10	retained catch + discards–descargas + descartes
6	PS	UNA	1975-2002	5-7, 9, 11-13	retained catch + discards–descargas + descartes
7	PS	DOL	1975-2002	2-3, 10	retained catch + discards–descargas + descartes
8	PS	DOL	1975-2002	1, 4-6, 8, 13	retained catch + discards–descargas + descartes
9	PS	DOL	1975-2002	7, 9, 11-12	retained catch + discards–descargas + descartes
10	PL		1975-2002	1-13	retained catch only—descargas solamente
11	LL		1975-2002	N of-de 15°N	retained catch only—descargas solamente
12	LL		1975-2002	S of-de 15°N	retained catch only—descargas solamente
13	PS	FLT	1993-2002	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	1993-2002	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	1993-2002	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	1993-2002	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	122,312	402,624	0.51
1976	102,680	381,436	0.53
1977	166,286	303,368	0.42
1978	130,918	221,845	0.32
1979	132,116	239,940	0.32
1980	110,434	235,426	0.31
1981	82,343	243,575	0.34
1982	120,188	210,271	0.30
1983	187,574	187,664	0.26
1984	171,567	269,685	0.36
1985	141,582	421,919	0.57
1986	173,086	470,320	0.68
1987	272,812	439,986	0.60
1988	191,943	367,218	0.49
1989	146,722	464,163	0.62
1990	157,495	484,837	0.68
1991	213,576	416,176	0.58
1992	185,088	391,873	0.53
1993	166,163	450,754	0.63
1994	160,269	453,348	0.64
1995	173,290	481,806	0.65
1996	214,440	473,953	0.67
1997	185,649	426,647	0.57
1998	308,268	448,313	0.60
1999	238,744	460,176	0.64
2000	205,006	598,986	0.83
2001	164,961	722,049	1.00
2002	173,927	576,558	0.84
2003		338,109	0.46

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

Age (quarters)	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	72.10
3	37.38	1.01	17	153.86	79.51
4	45.47	1.85	18	158.34	86.87
5	53.15	2.99	19	162.50	94.12
6	62.09	4.83	20	166.39	101.23
7	73.03	7.98	21	170.00	108.18
8	87.03	13.70	22	173.37	114.93
9	101.26	21.86	23	176.51	121.47
10	108.48	27.05	24	179.43	127.79
11	119.22	36.19	25	182.16	133.87
12	126.11	43.04	26	184.69	139.70
13	132.50	50.13	27	187.06	145.30
14	138.39	57.34	28	189.26	150.64
15	143.91	64.69	29	191.31	155.74

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

	Basecase Caso base	**h = 0.75**	**Iterative re-weighting**
AMSY–RPMS	254,723	266,371	250,750
B_{ms2} –B_{rm2}	381,775	502,129	377,686
S_{ms2}—S_{rm2}	6,010	7,946	5,990
C_{2002}/AMSY—C_{2002}/RPMS	1.72	1.64	1.76
B_{2003}/B_{AMSY} –B_{2003}/B_{RMS}	0.89	0.70	0.74
S_{2003}/S_{AMSY} –S_{2003}/S_{RMS}	0.89	0.70	0.74
$S_{AMSY}/S_{F=0}$ –$S_{RPMS}/S_{F=0}$	0.37	0.41	0.38
F multiplier—Multiplicador de *F*	1.20	0.89	1.36

	Last years selectivity smoothness weighting factors	**Species composition based catches**
AMSY–RPMS	254,334	253,594
B_{ms2} –B_{rm2}	379,826	379,913
S_{ms2}—S_{rm2}	5,965	5,983
C_{2002}/AMSY—C_{2002}/RPMS	1.72	1.63
B_{2003}/B_{AMSY} –B_{2003}/B_{RMS}	0.86	0.87
S_{2003}/S_{AMSY} –S_{2003}/S_{RMS}	0.87	0.87
$S_{AMSY}/S_{F=0}$ –$S_{RPMS}/S_{F=0}$	0.37	0.38
F multiplier—Multiplicador de *F*	1.18	1.20

TABLE 5.2. Estimates of the AMSY (value in brackets represents the component of AMSY made up of discards of small tunas), and its associated quantities, obtained by assuming that each fishery maintains its current pattern of age-specific selectivity (Figure 4.4) and that each fishery is the only fishery operating in the EPO. The estimates of the AMSY, B_{AMSY}, and S_{AMSY} are in metric tons.

TABLA 5.2. Estimaciones del RPMS (el valor en paréntesis representa el componente de RPMS compuesto de descartes de atunes pequeños) y sus cantidades asociadas, obtenidas suponiendo que cada pesquería mantiene su patrón actual de selectividad por edad (Figure 4.4) y que cada pesquería es la única operando en el OPO. Se expresan las estimaciones de RPMS, B_{RPMS}, y S_{RPMS} en toneladas métricas.

Fishery	**AMSY**	B_{AMSY}	S_{AMSY}	$B_{\text{AMSY}}/B_{F=0}$	$S_{\text{AMSY}}/S_{F=0}$	***F* multiplier**
Pesquería	**RPMS**	B_{RPMS}	S_{RPMS}	$B_{\text{RPMS}}/B_{F=0}$	$S_{\text{RPMS}}/S_{F=0}$	**Multiplica-dor de *F***
1	231,864	327,754	4,892	0.28	0.30	49.6
2	202,527	302,584	4,435	0.26	0.28	22.6
3	150,827	195,442	2,585	0.17	0.16	86.5
4	191,022	289,545	4,246	0.25	0.26	37.4
5	205,394	270,933	3,820	0.23	0.24	9.1
6	248,065	376,316	5,890	0.32	0.37	8.3
7	304,863	399,641	6,235	0.34	0.39	8.3
8	275,641	344,750	5,193	0.29	0.32	6.4
9	340,926	492,157	8,011	0.42	0.50	61.0
10	123,065	28,889	352	0.02	0.02	397.9
11	338,930	456,281	7,293	0.39	0.45	2106.2
12	354,743	456,265	7,234	0.39	0.45	56.4

TABLE 6.1. Summary of the outcomes from 1001 simulations using the scenarios described in Sections 6.1 and 6.2. "Quantiles" identify the levels at which 20%, 50%, and 80% of the predicted outcomes are less than or equal to the value provided in the table. The 50% quantile is equal to the median.
TABLA 6.1. Resumen de los resultados de 100 simulaciones usando los escenarios descritos en las Secciones 6.1 y 6.2. Los "cuantiles" identifican los niveles a los cuales el 20%, 50%, y 80% de los resultados predichos son menores o iguales al valor en la tabla. El cuantil de 50% equivale a la mediana.

	75% surface effort	**Average surface effort**	**Average surface effort, no discards**	**125% surface effort**
Cuantil	**75% del esfuerzo de superficie**	**Esfuerzo de superficie medio**	**Esfuerzo de superficie medio, sin descartes**	**125% del esfuerzo de superficie**
SBR for fourth quarter of 2007–SBR para el cuarto trimestre de 2007				
20%	0.45	0.37	0.38	0.31
50%	0.52	0.43	0.44	0.36
80%	0.59	0.5	0.51	0.42
Average weight (kg) of fish in the combined catch during 2007–Peso medio (kg) de los peces en la captura combinada durante el cuarto trimestre de 2007				
20%	14.4	12.4	15.9	10.8
50%	16.5	14.3	17.8	12.6
80%	19	16.5	19.8	14.5
Median of quarterly catches (mt) by the primary surface fleet (Fisheries 1-10) during 2007–Mediana de las capturas trimestrales (tm) por la flota primaria de superficie (Pesquerías 1-10) durante 2007				
20%	39,559	42,596	44,199	44,403
50%	52,651	56,507	58,513	58,252
80%	66,571	71,173	72,932	72,334
Median of quarterly catches, in thousands of fish, by the longline fleet (Fisheries 11 and 12) during 2007–Mediana de las capturas trimestrales, en miles de peces, por la flota palangrera (Pesquerías 11 y 12) durante 2007				
20%	86	65	68	51
50%	113	86	90	67
80%	142	108	112	84

APPENDIX A: STOCK RECRUITMENT SENSITIVITY ANALYSIS

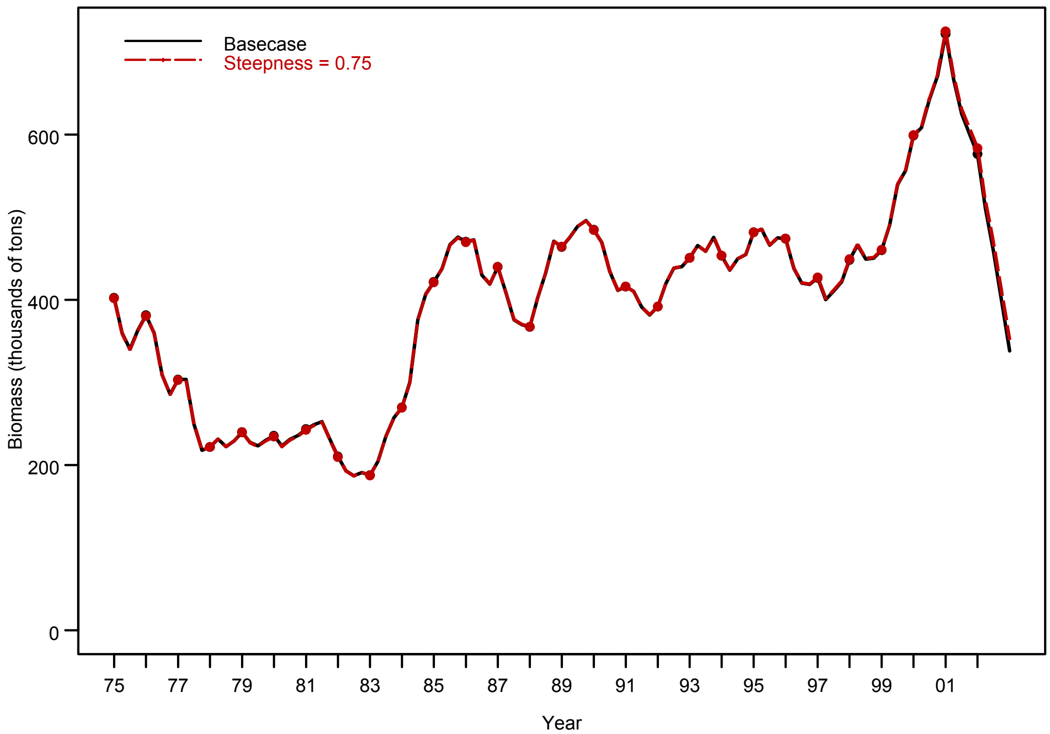

FIGURE A.1. Comparison of estimates of biomass from the analysis without a stock recruitment relationship (base case) and with a stock recruitment relationship (steepness = 0.75).
FIGURA A.1. Comparación de las estimaciones de biomasa del análisis sin relación stock-reclutamiento (caso base) y con (inclinación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

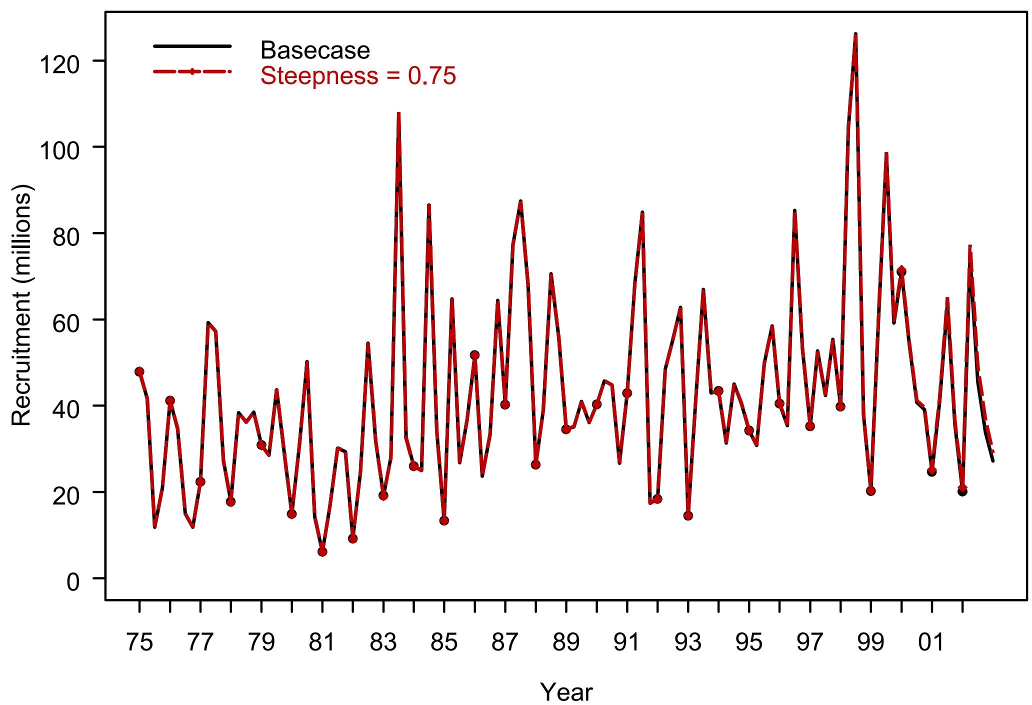

FIGURE A.2. Comparison of estimates of recruitment from the analysis without a stock recruitment relationship (base case) and with a stock recruitment relationship (steepness = 0.75).
FIGURA A.2. Comparación de las estimaciones de reclutamiento del análisis sin relación de reclutamiento de stock (caso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

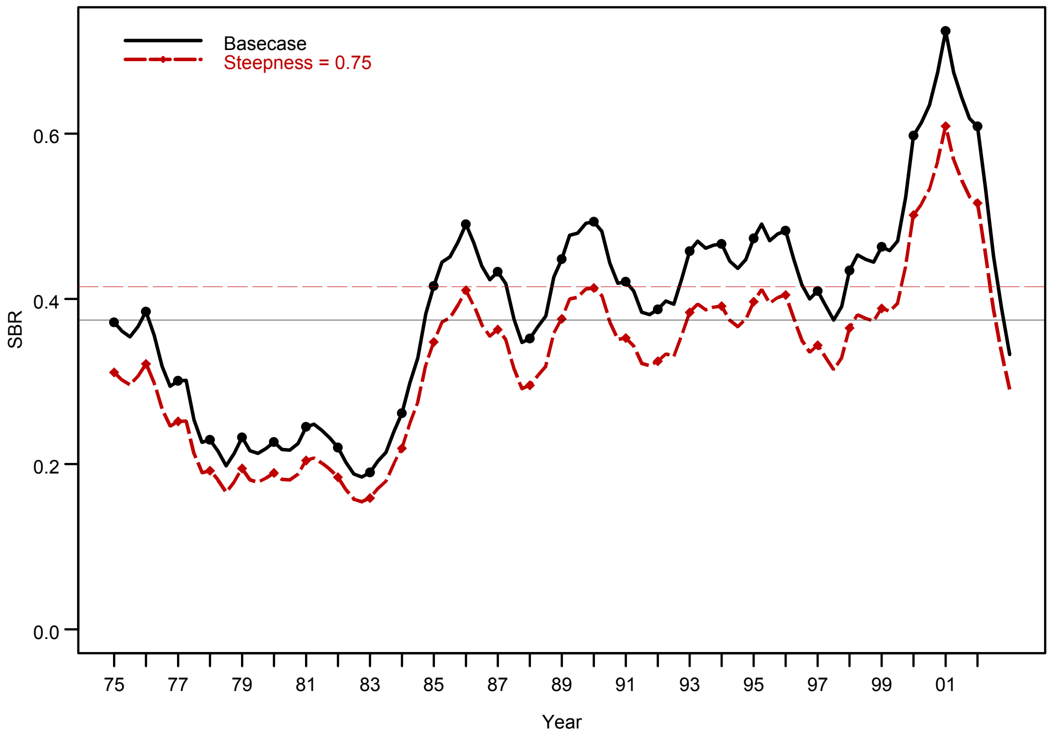

FIGURE A.3. Comparison of estimates of the spawning biomass ratio (SBR) from the analysis without a stock recruitment relationship (base case) and with a stock recruitment relationship (steepness = 0.75). The horizontal lines represent the SBR associated with AMSY.
FIGURA A.3. Comparación de las estimaciones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

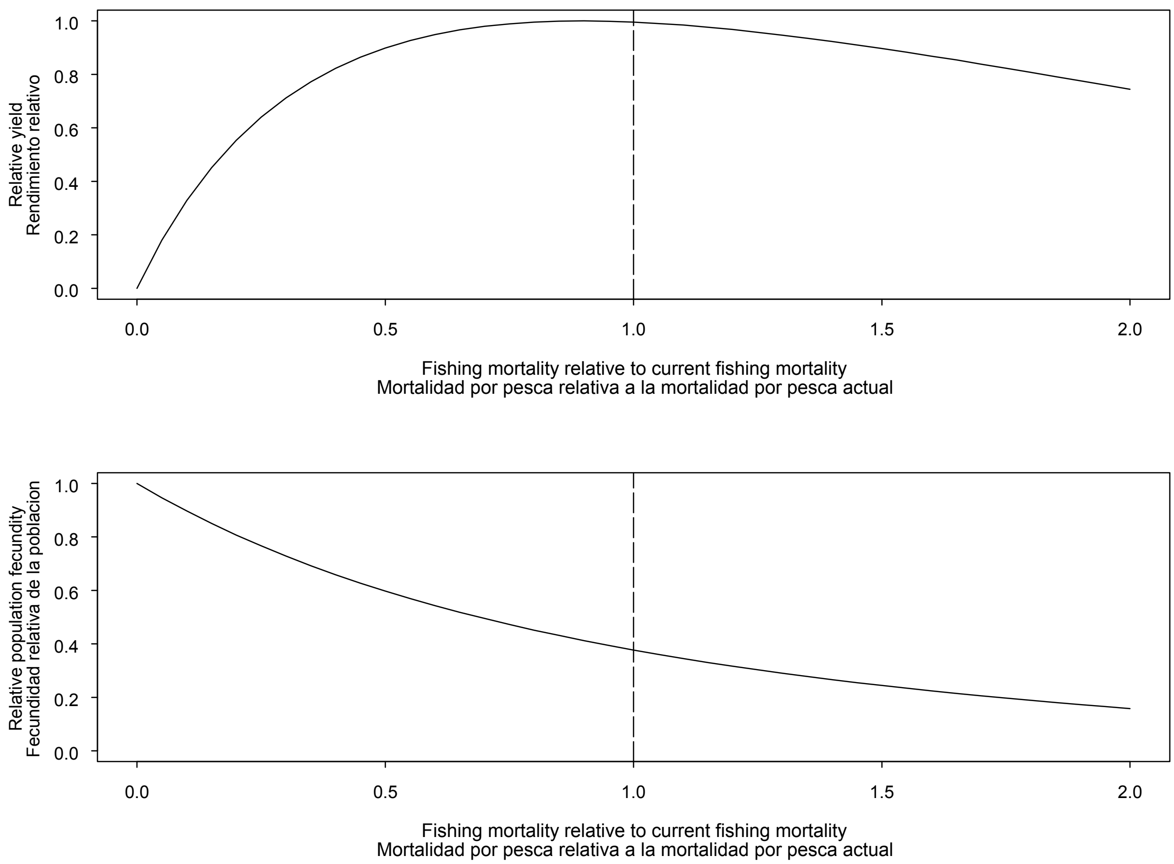

FIGURE A.4. Relative (upper panel) and the associated SBR (lower panel) when the stock assessment model has a stock recruitment relationship (steepness = 0.75).
FIGURA A4. Comparación del rendimiento relativo (línea sólida) con el rendimiento por recluta relativo (línea de trazos) cuando el modelo de evaluación del stock incluye una relación stock-reclutamiento (inclinación = 0.75).

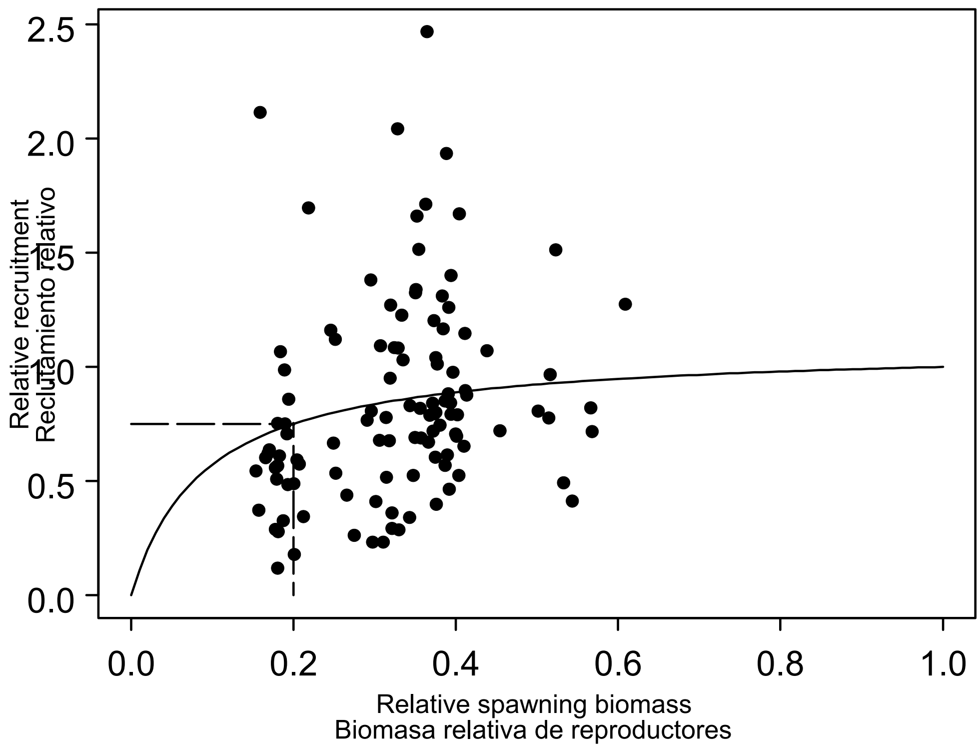

FIGURE A.5. Recruitment plotted against spawning biomass when the analysis has a stock recruitment relationship (steepness = 0.75).

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

APPENDIX B: LENGTH FREQUENCY SAMPLE SIZE SENSITIVITY ANALYSIS

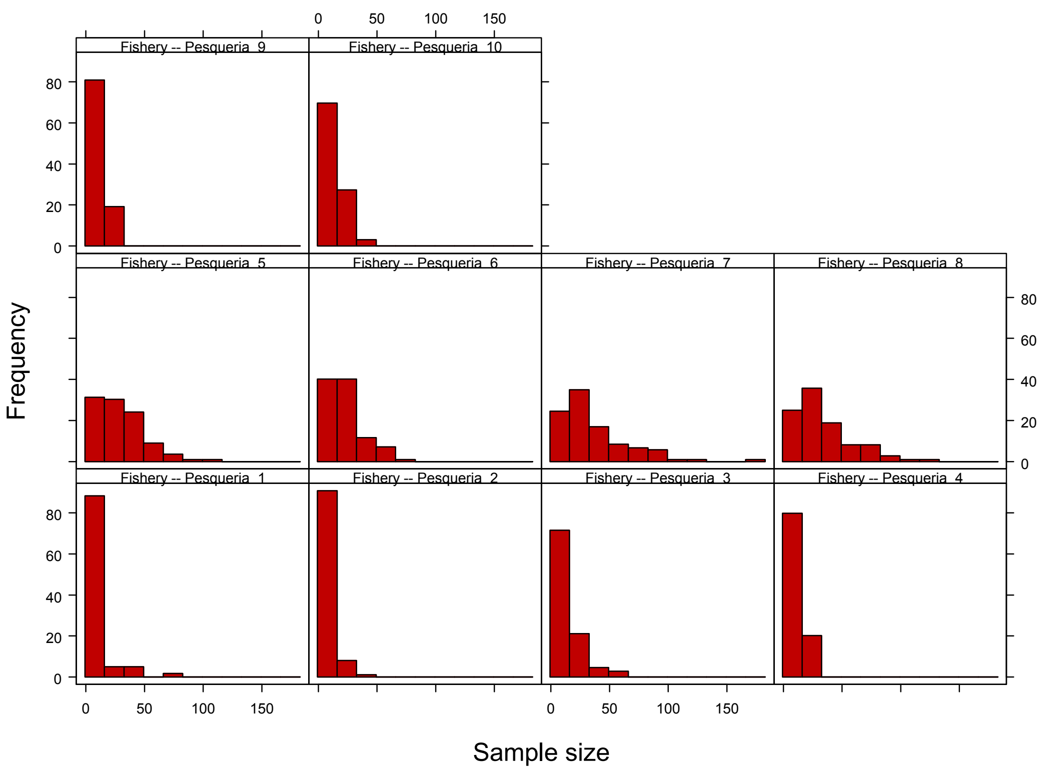

FIGURE B.1. Length-frequency sample size for the surface fisheries used in the basecase.
FIGURA B.1. Comparación de las estimaciones de biomasa del análisis sin relación stock-reclutamiento (caso base) y con (inclinación = 0,75).

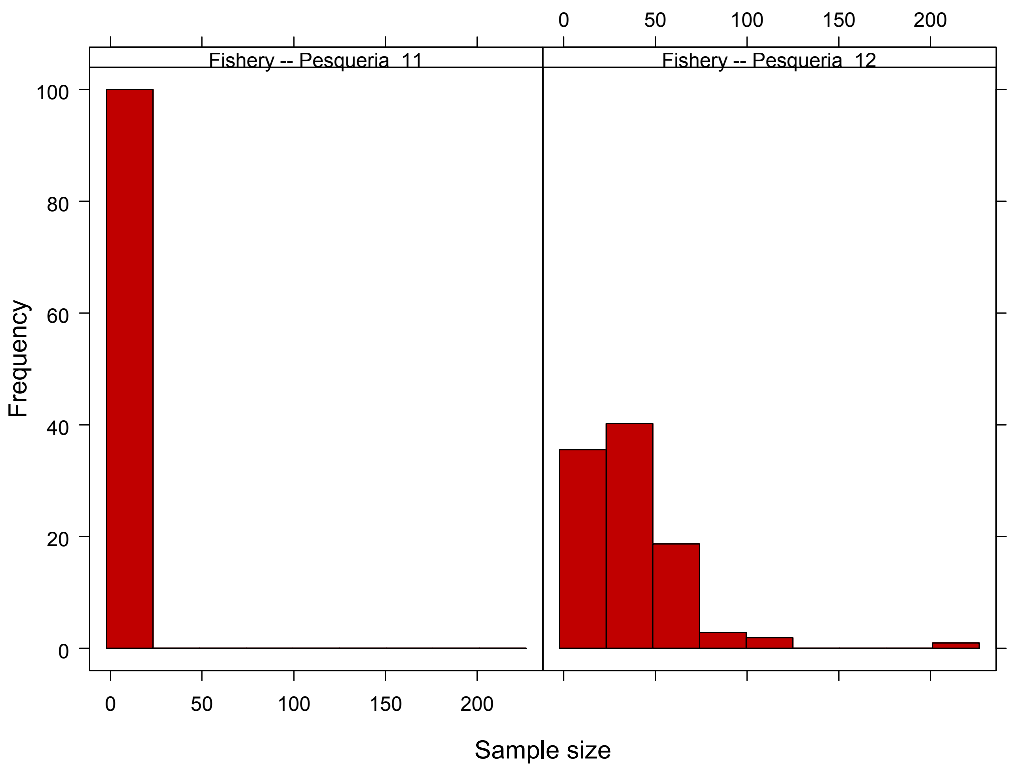

FIGURE B.2. Length-frequency sample size for the longline fisheries used in the basecase.
FIGURA B.2. Comparación de las estimaciones de biomasa del análisis sin relación stock-reclutamiento (caso base) y con (inclinación = 0,75).

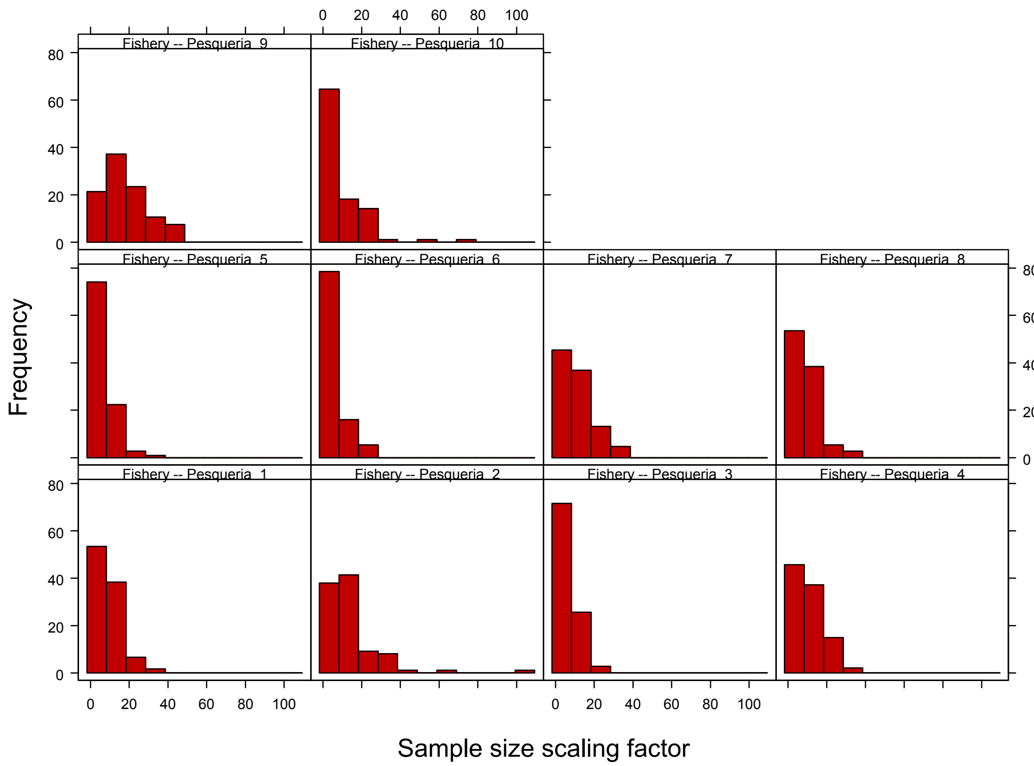

FIGURE B.3. Amont that the length-frequency sample size is scaled in the iterative reweighting sensitivity for the surface fisheries.

FIGURA B.3. Comparación de las estimaciones de biomasa del análisis sin relación stock-reclutamiento (caso base) y con (inclinación = 0,75).

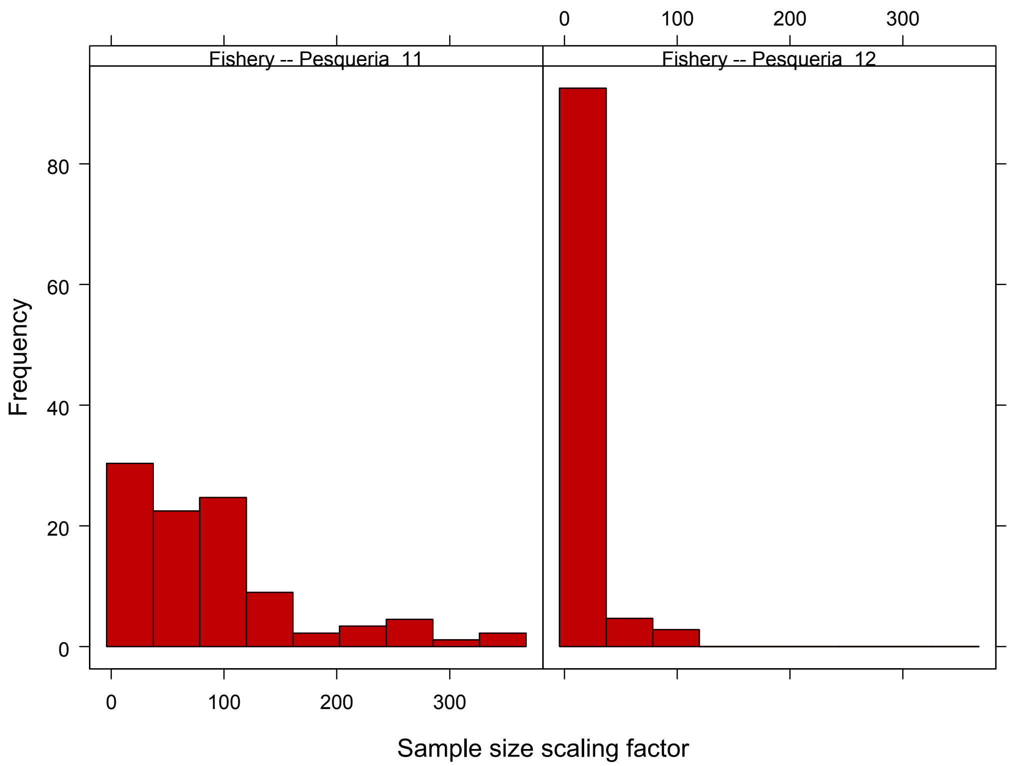

FIGURE B.4. Amont that the length-frequency sample size is scaled in the iterative reweighting sensitivity for the longline fisheries.

FIGURA B.4. Comparación de las estimaciones de biomasa del análisis sin relación stock-reclutamiento (caso base) y con (inclinación = 0,75).

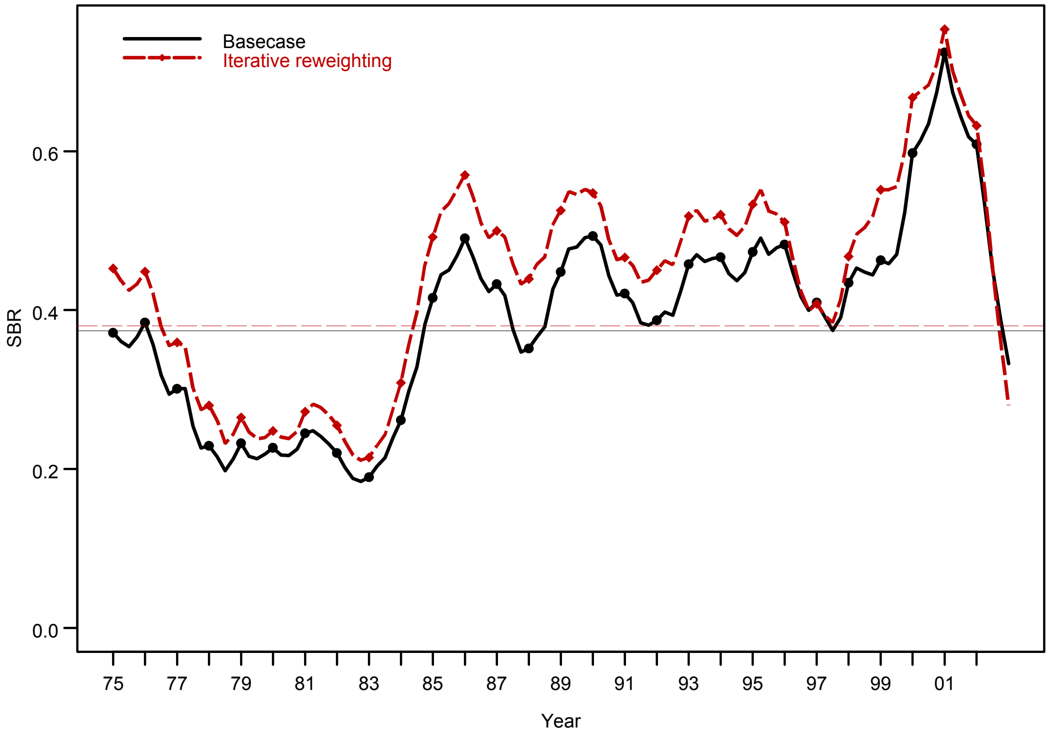

FIGURE B.5. Comparison of SBR from the base case with SBR from the the iterative reweighting sensitivity.
FIGURA B.5. Comparación de las estimaciones de biomasa del análisis sin relación stock-reclutamiento (caso base) y con (inclinación = 0,75).

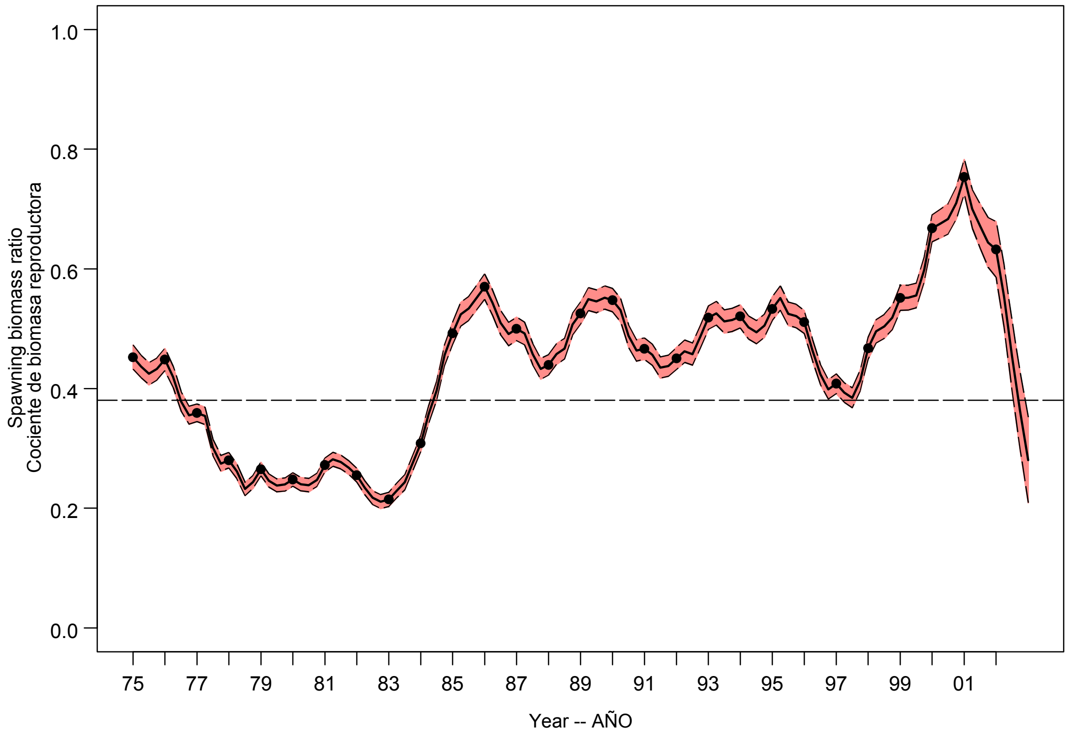

FIGURE B.6. SBR and the associated confidence intervals for the iterative reweighting sensitivity.
FIGURA B.6. Comparación de las estimaciones de biomasa del análisis sin relación stock-reclutamiento (caso base) y con (inclinación = 0,75).

TABLE B.1. The average length-frequency sample size for each fishery for the basecase assessment and the sensitivity using the iterative reweighting. The average scaling factor for the iterative reweighting is also given.

Fishery	Basecase	Reweighted	Scaling factor
1	8.38	41.39	8.72
2	5.54	39.28	14.11
3	12.95	51.77	5.53
4	8.56	63.04	10.64
5	28.68	147.61	6.13
6	21.84	85.80	5.57
7	35.31	287.96	11.08
8	32.59	247.72	9.23
9	8.45	115.36	17.55
10	11.98	76.99	9.24
11	4.06	150.10	88.10
12	35.31	314.03	15.48

APPENDIX C: ADDITIONAL RESULTS FROM THE BASECASE ASSESSMENT

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

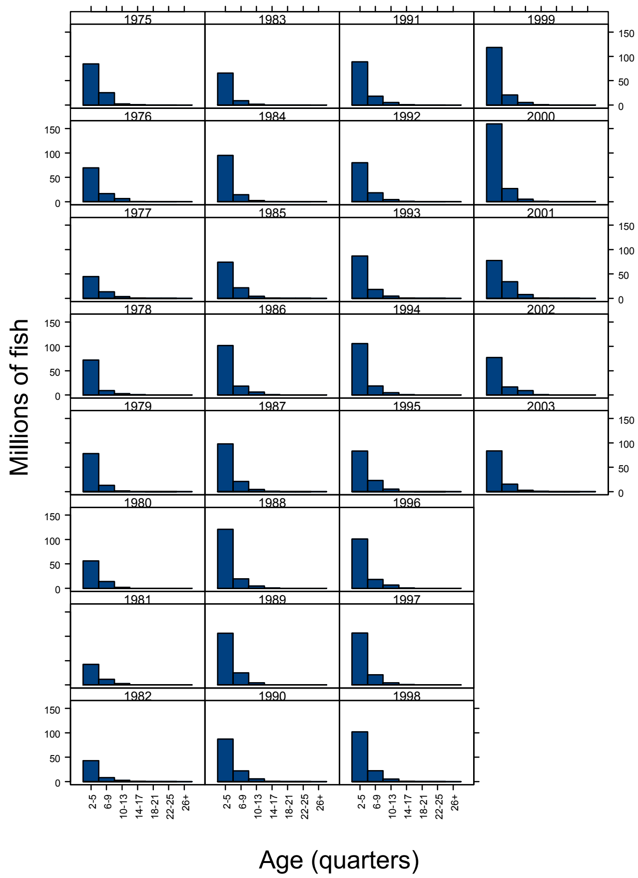

FIGURE C.1. Numbers of yellowfin tuna present in the EPO on 1 January of each calendar year.
FIGURA C.1. Número de atunes aleta amarilla presentes en el OPO el 1 de enero de cada año.

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

	Age (quarters) – Edad (trimestres)						
	2-5	**6-9**	**10-13**	**14-17**	**18-21**	**22-25**	**26+**
1975	0.0887	0.5936	1.3171	1.8580	0.4096	0.4770	2.0940
1976	0.1674	0.6962	1.1788	1.9107	1.1956	1.3659	4.7456
1977	0.1980	0.7390	1.0906	2.3144	1.2546	1.4735	4.2234
1978	0.4086	0.9280	1.1169	1.6718	0.7069	1.1702	2.6819
1979	0.2679	0.9526	1.4095	2.4441	1.1714	1.4085	5.4895
1980	0.2280	0.7735	1.4690	2.0323	1.0147	1.0122	3.2385
1981	0.3441	0.7406	1.2467	1.9315	1.5208	1.6427	4.1391
1982	0.2156	0.6865	1.1474	1.8641	0.8923	1.1853	2.7294
1983	0.1640	0.3835	0.8715	0.8588	0.6556	0.8874	2.1597
1984	0.1253	0.4114	0.8357	0.7501	0.5494	0.6437	2.3101
1985	0.0971	0.5246	0.9227	1.1538	0.4471	0.6005	1.8314
1986	0.1304	0.6276	1.1230	1.6039	0.4463	0.5845	2.1359
1987	0.1415	0.6410	1.2591	1.3038	0.3759	0.5536	2.1095
1988	0.2158	0.7024	1.2126	1.3693	0.4539	0.6125	2.3749
1989	0.1517	0.6378	1.0271	1.7894	0.7354	1.0010	3.5380
1990	0.1359	0.5826	1.2193	1.8950	0.6282	0.8544	3.1982
1991	0.1372	0.5744	1.0919	1.6515	0.6450	0.7837	3.7596
1992	0.1729	0.5918	1.0645	1.4152	0.3679	0.4312	1.6232
1993	0.1905	0.5477	0.9169	1.1418	0.3930	0.6506	1.9045
1994	0.1242	0.4990	1.0542	1.4821	0.7493	0.9231	3.5300
1995	0.1133	0.4386	0.9283	1.0670	0.6339	0.6657	2.9768
1996	0.1573	0.6167	0.9391	0.9901	0.3056	0.4288	1.4600
1997	0.1645	0.6548	1.1692	1.5991	0.8519	1.0564	3.3853
1998	0.1759	0.6002	0.9959	1.4826	0.5061	0.6659	2.7262
1999	0.2164	0.6484	1.0805	1.4400	0.2653	0.3547	1.4712
2000	0.1309	0.4850	0.8810	1.1467	0.5785	0.6855	2.7858
2001	0.1835	0.5542	1.1974	1.8164	0.9758	1.0051	4.0035
2002	0.0887	0.5936	1.3171	1.8580	0.4096	0.4770	2.0940

APPENDIX D: DIAGNOSTICS

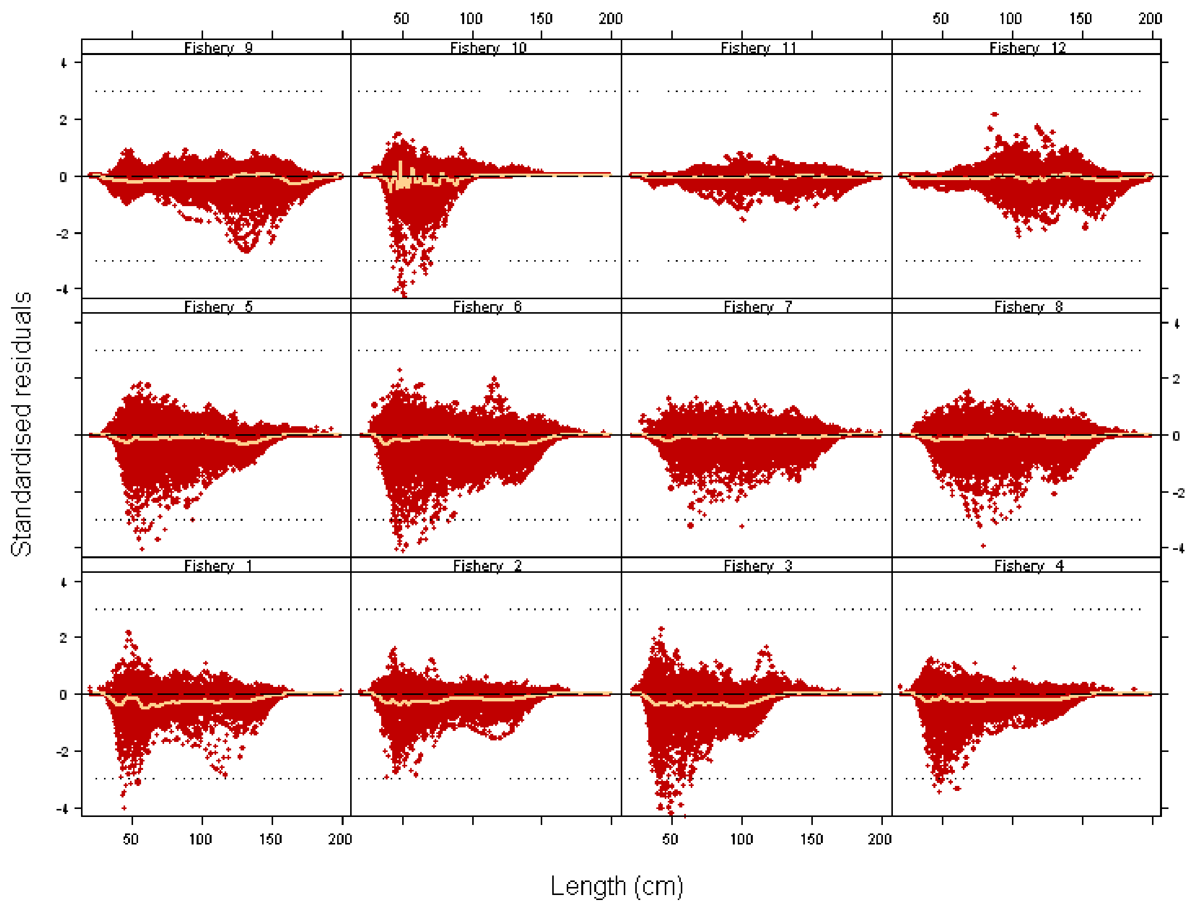

FIGURE D1. Standardised residuals for the length-frequency data by length. The dotted horizontal lines are plus and minus 3 standard deviations.
FIGURA D1. .

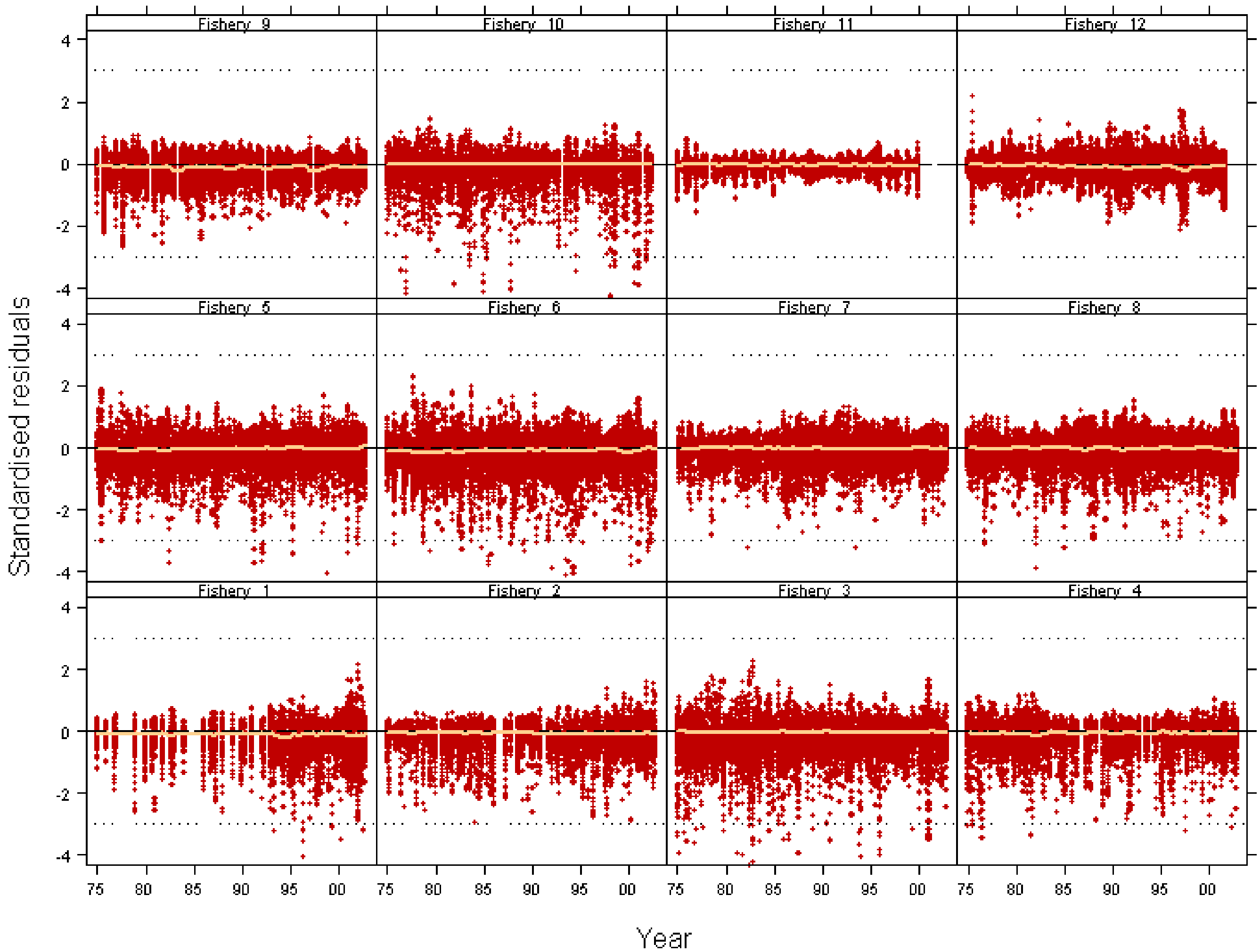

FIGURE D2. Standardised residuals for the length-frequency data by time. The dotted horizontal lines are plus and minus 3 standard deviations.
FIGURA D2. .

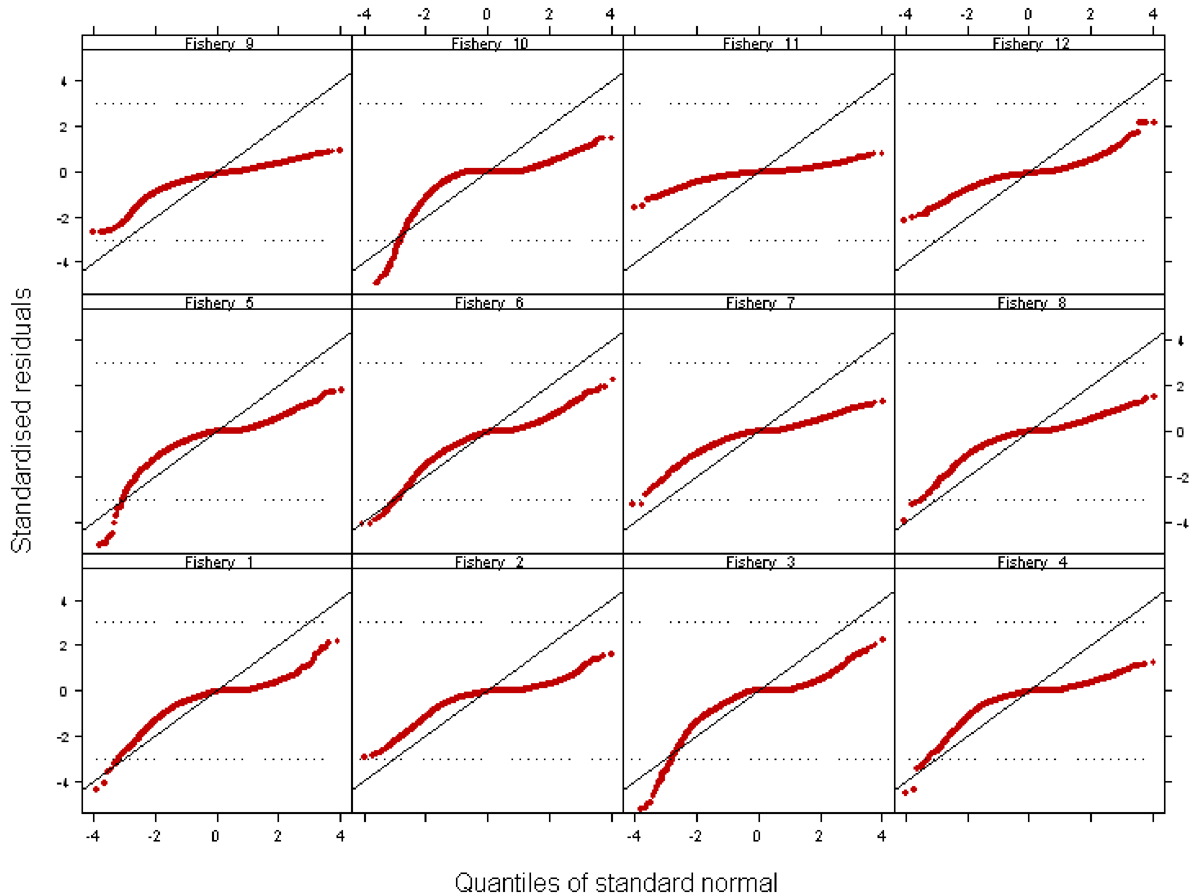

FIGURE D3. QQnorm plots for the length-frequency data.
FIGURA D3. .

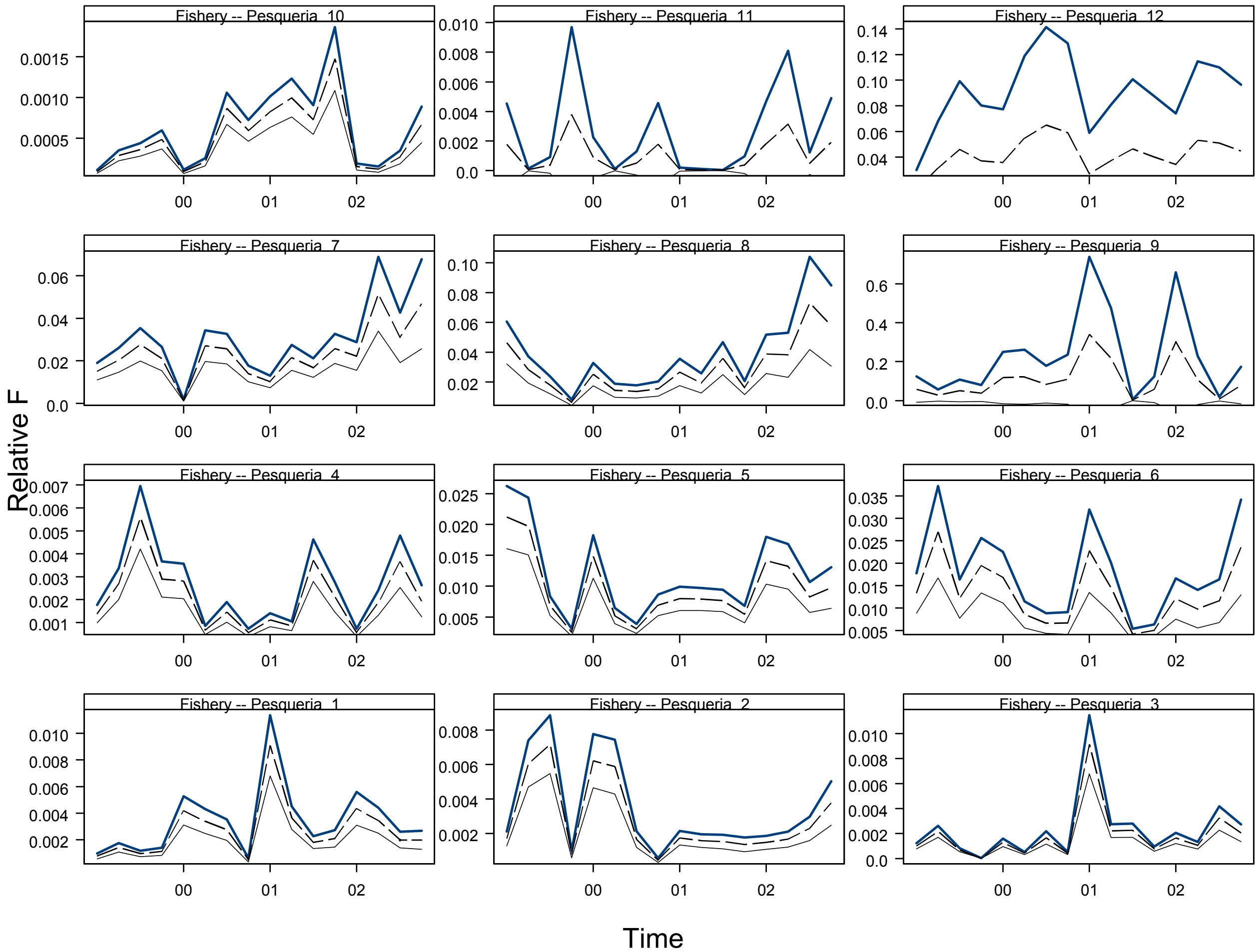

FIGURE D4. Relative fishing mortality (catchability multiplied by the effort deviate) and 95% confidence intervals for the last four years.
FIGURA D4. .

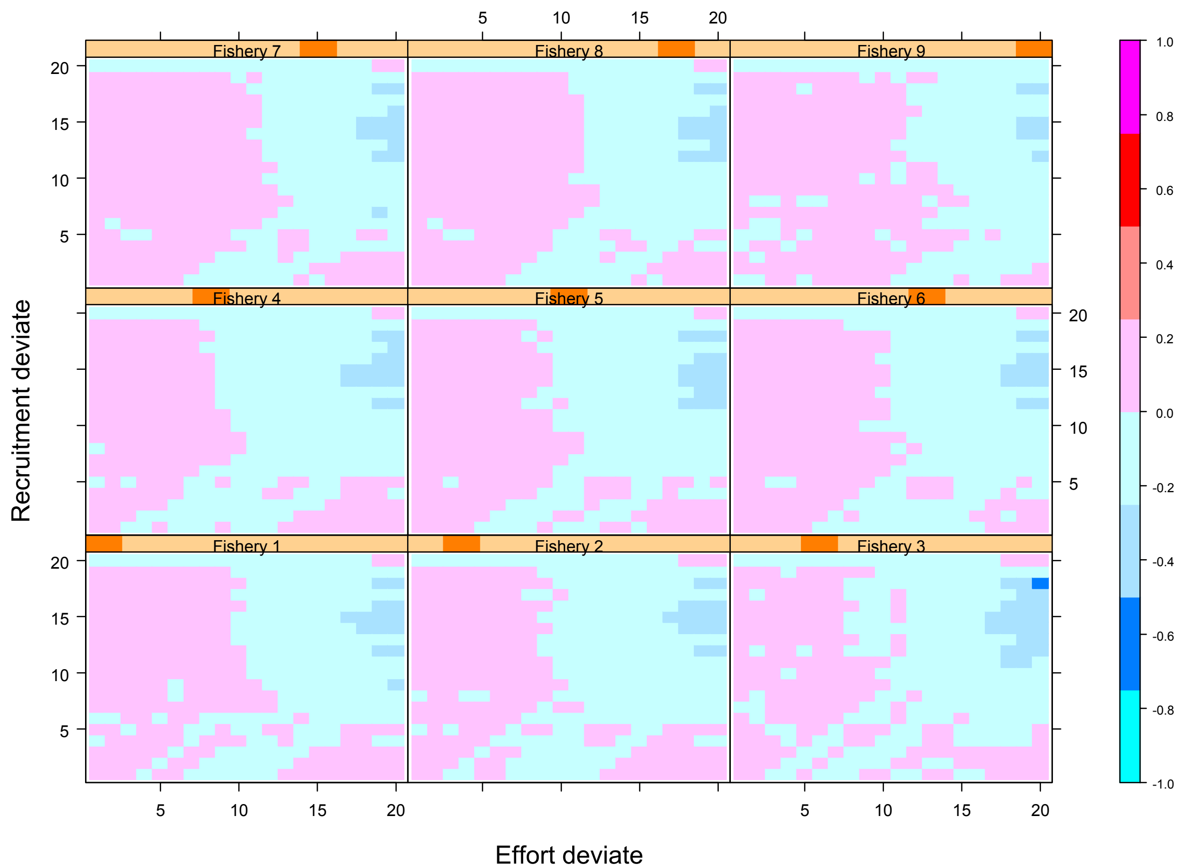

FIGURE D5. Correlation between the estimated effort deviates and recruitment deviates for the most recent 20 quarters for the surface fisheries.
FIGURA D5. .

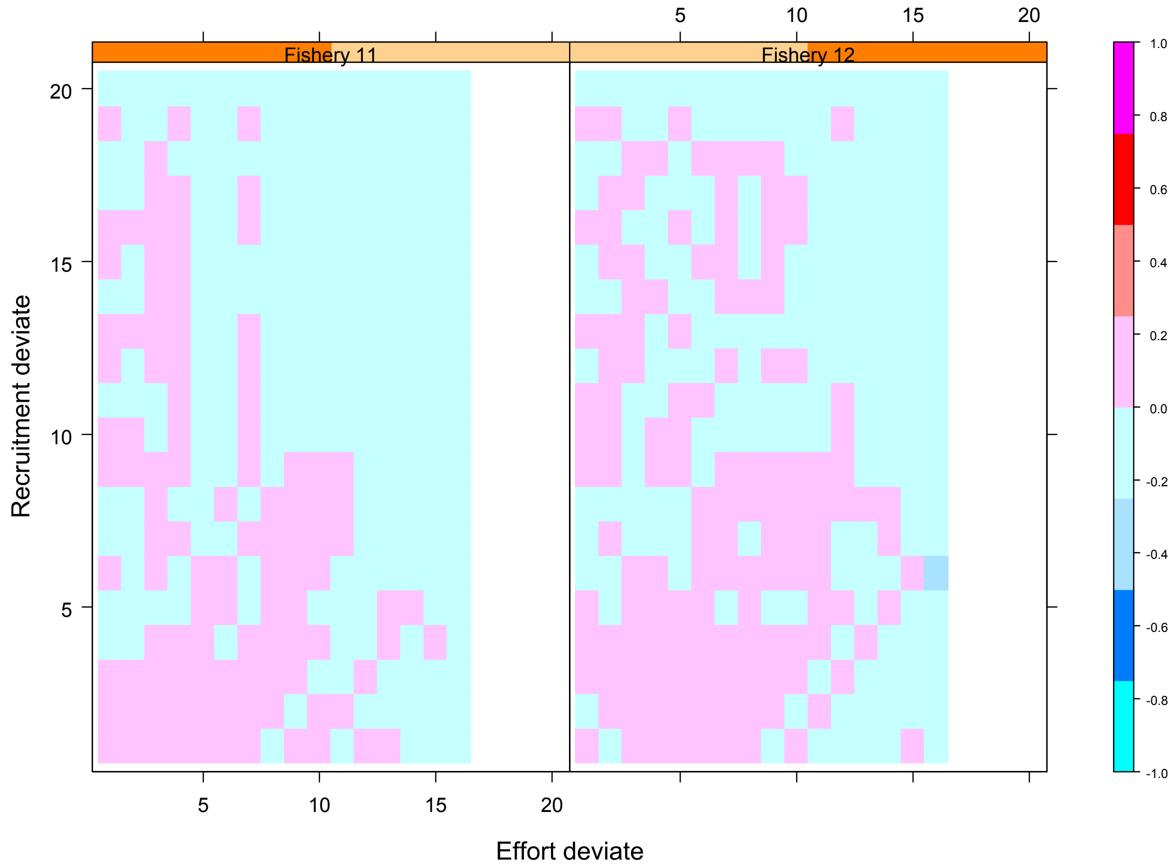

FIGURE D6. Correlation between the estimated effort deviates and recruitment deviates for the most recent 20 quarters for the longline fisheries.
FIGURA D6. .

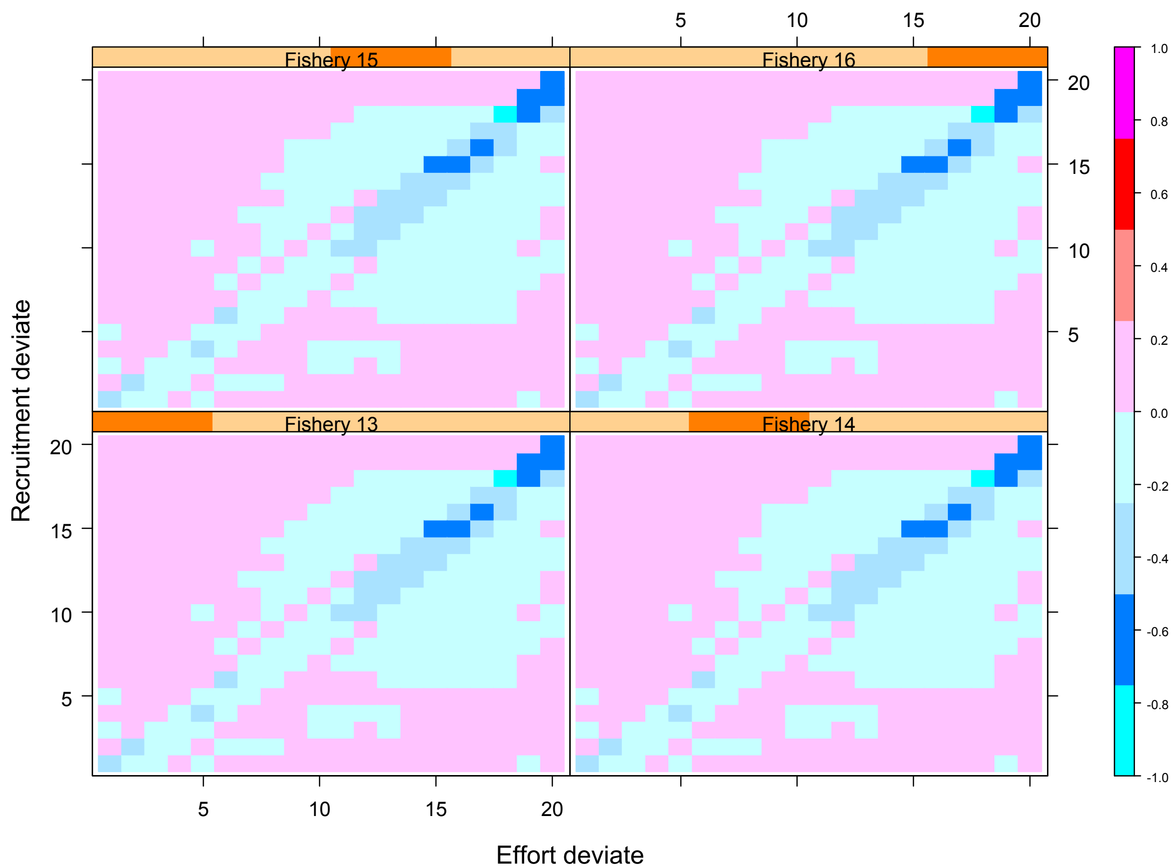

FIGURE D7. Correlation between the estimated effort deviates and recruitment deviates for the most recent 20 quarters for the discard fisheries.
FIGURA D7. .

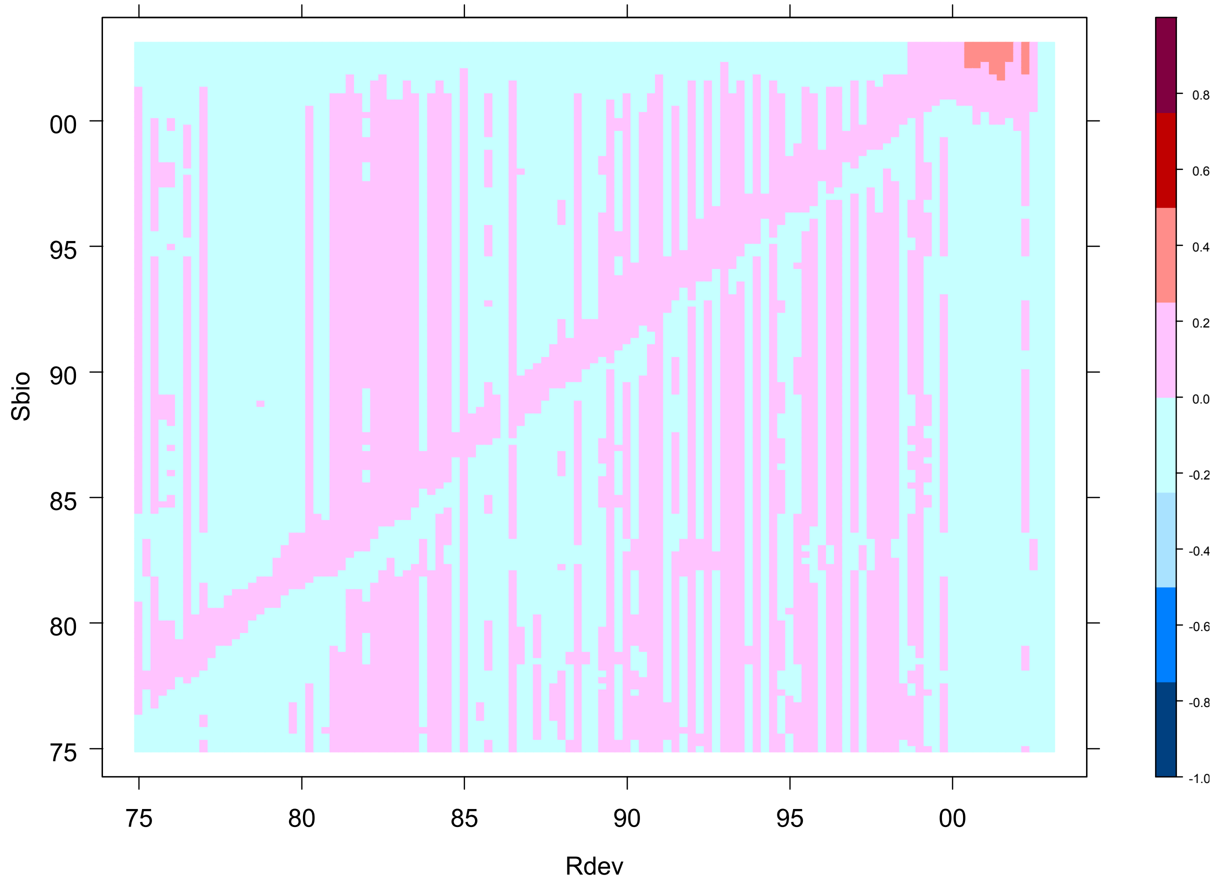

FIGURE D8. Correlation between the estimated spawning biomass and recruitment deviates.
FIGURA D8. .

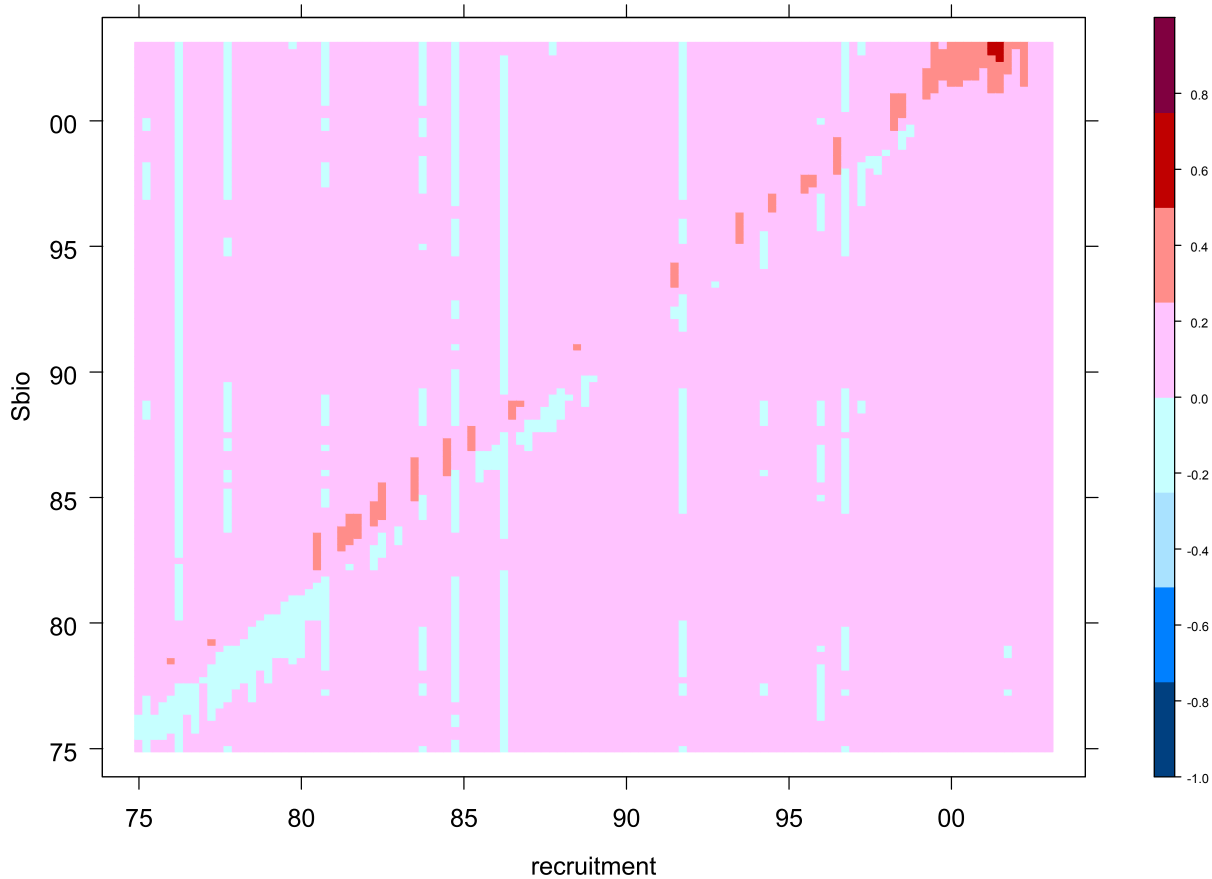

FIGURE D9. Correlation between the estimated spawning biomass and recruitment.
FIGURA D9. .

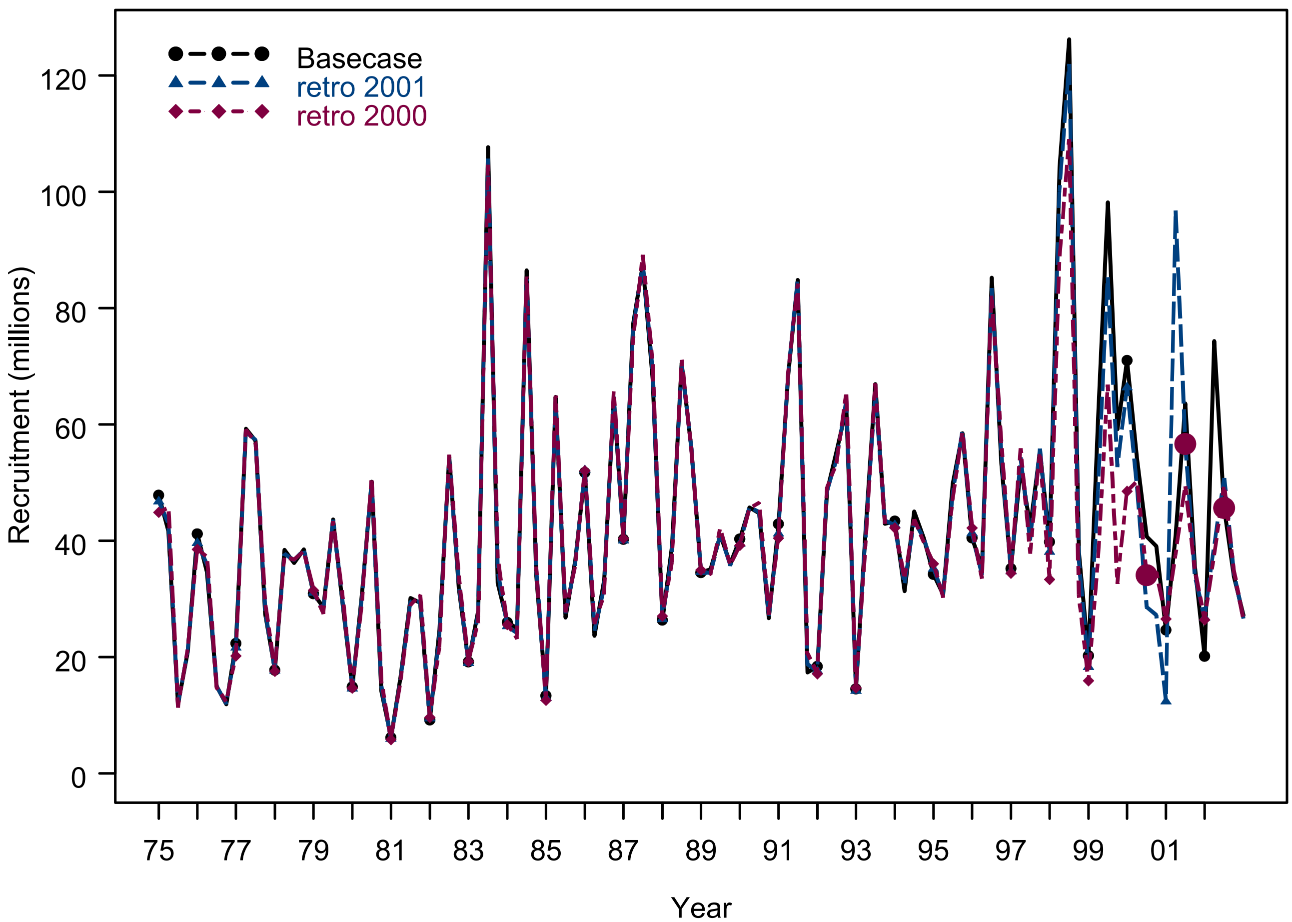

FIGURE D10. Recruitment estimated by the retrospective analyses compared to the basecase. Retro 2001 uses data only up to 2001 and retro 2000 uses data only up to 2000. The large solid circles indicate the first recruitment estimated by the model with information from the length-frequency data.
FIGURA D10. .

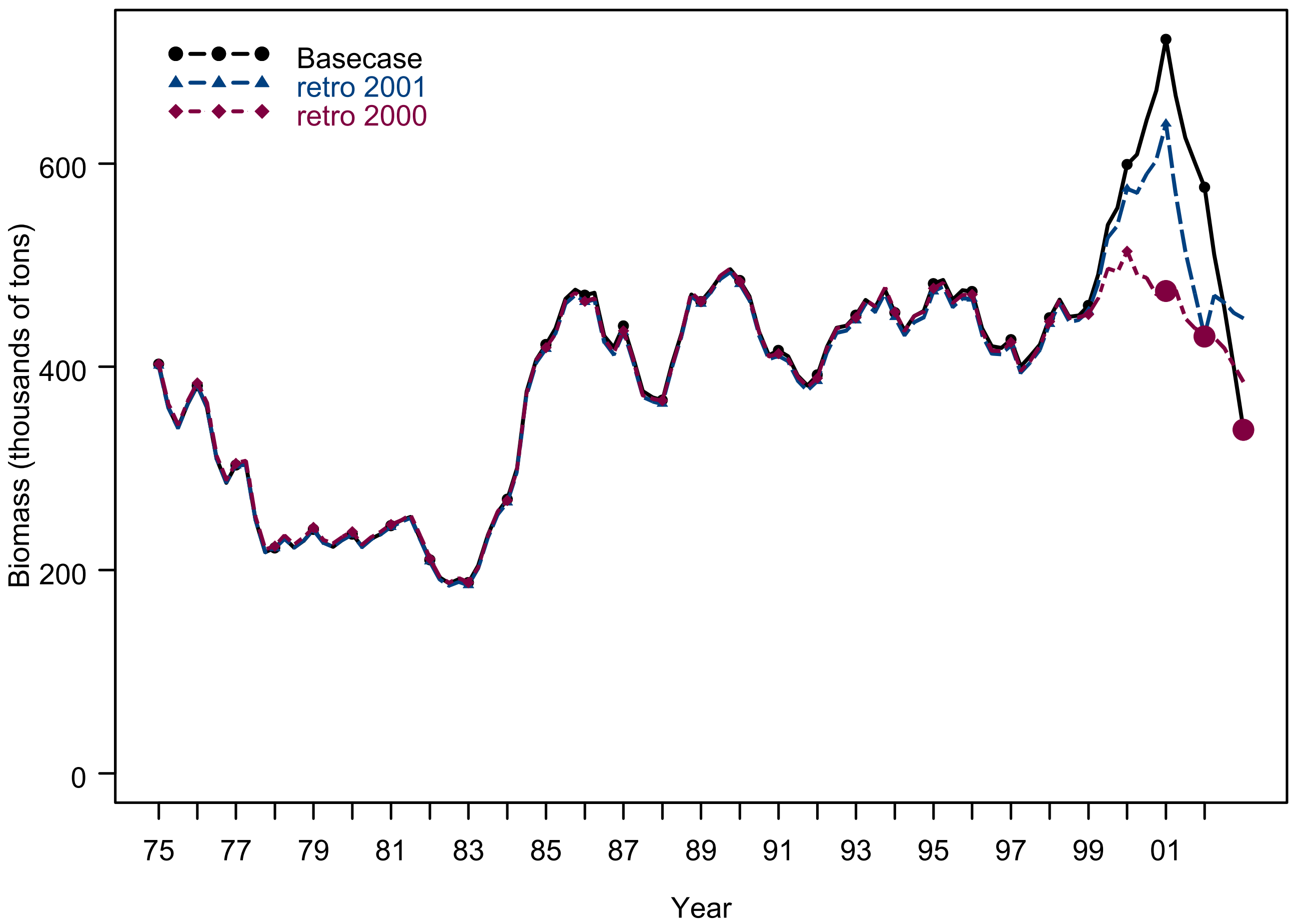

FIGURE D11. Biomass estimated by the retrospective analyses compared to the basecase. Retro 2001 uses data only up to 2001 and retro 2000 uses data only up to 2000. The large solid circles indicate the last time period estimated by the model without projecting the biomass.
FIGURA D11. .

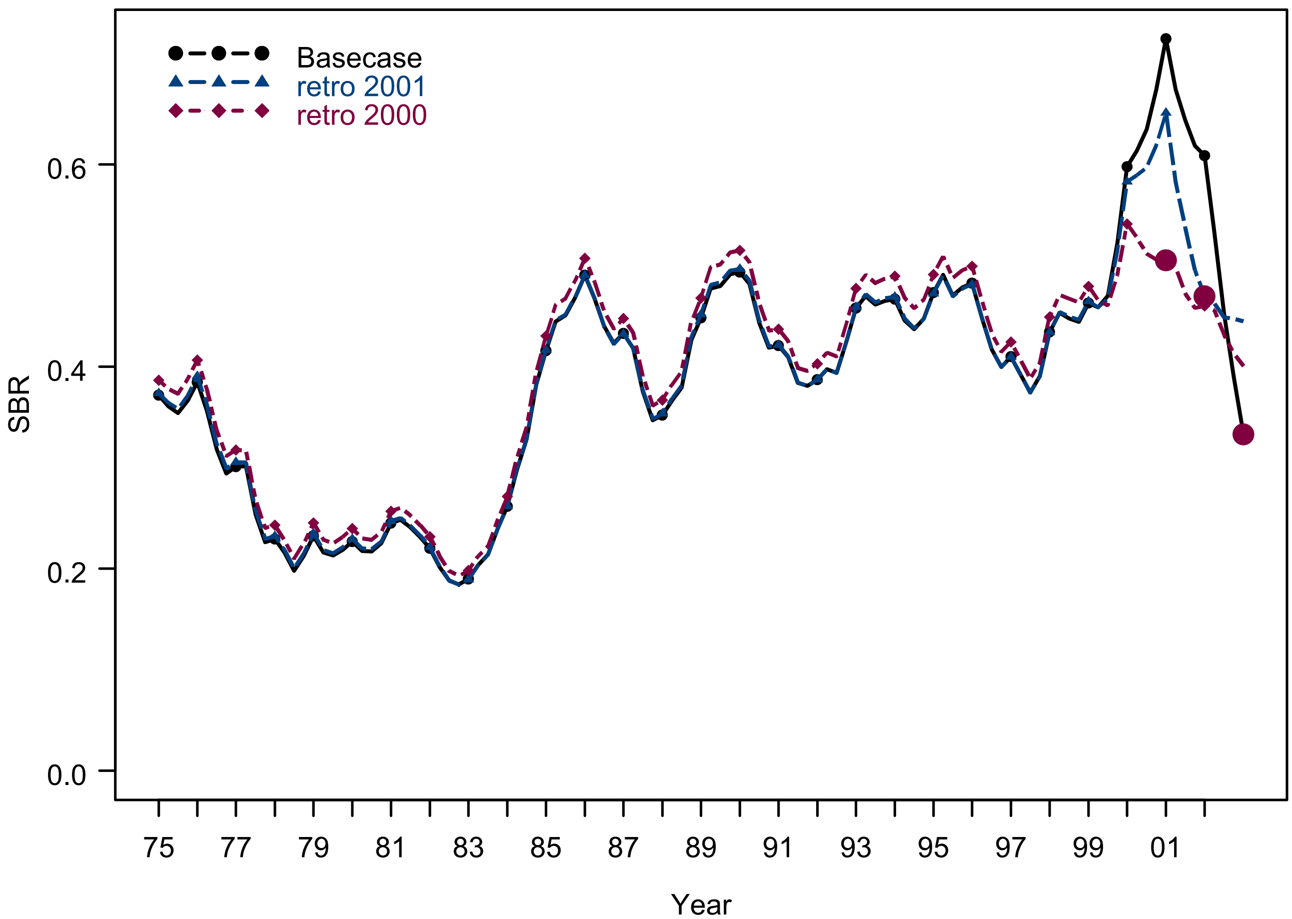

FIGURE D12. SBR estimated by the retrospective analyses compared to the basecase. Retro 2001 uses data only up to 2001 and retro 2000 uses data only up to 2000. The large solid circles indicate the last time period estimated by the model without projecting the biomass.

FIGURA D12.