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STATUS OF YELLOWFIN TUNA IN THE EASTERN PACIFIC OCEAN IN 2005 AND OUTLOOK FOR 2006

by

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CONTENTS

1. EXECUTIVE SUMMARY

This report presents the most current stock assessment of yellowfin tuna (*Thunnus albacares*) in the eastern Pacific Ocean (EPO). An age-structured, catch-at-length analysis (A-SCALA) was used to assess yellowfin tuna in the eastern Pacific Ocean (EPO). The methods of analysis are described in IATTC Bulletin, Vol. 22, No. 5, and readers are referred to that report for technical details.

The assessment reported here is based on the assumption that there is a single stock of yellowfin tuna in the EPO. Yellowfin are distributed across the Pacific Ocean, but the bulk of the catch is made in the east and west. The purse-seine catches of yellowfin tuna are less in the vicinity of the western boundary of the EPO. The movements of tagged yellowfin tuna are generally over hundreds, rather than thousands, of kilometers, and exchange between the eastern and western Pacific Ocean appears to be limited. This is consistent with the fact that longline catch-per-unit-of-effort (CPUE) trends differ among areas. It is likely that there is a continuous stock throughout the Pacific Ocean, with exchange of individuals at a local level, although there is some genetic evidence for local isolation. Movement rates between the EPO and the western Pacific cannot be estimated with currently available tagging data.

The stock assessment requires substantial amounts of information, including data on retained catches, discards, fishing effort, and the size compositions of the catches of the various fisheries. Assumptions have been made about processes such as growth, recruitment, movement, natural mortality, fishing mortality, and stock structure. The assessment for 2006 differs from that of 2005 in the following ways. The catch and length-frequency data for the surface fisheries have been updated to include new data for 2005 and revised data for 1975-2004. The effort data for these fisheries have been updated to include new data for 2005 and revised data for 1975-2004. The catch data for the Japanese longline fisheries have been updated for 2000-2003, and new data for 2004 have been added. The catch data for the longline fisheries of Chinese Taipei have been updated to include new data for 2002. The catch data for the longline fisheries of the People's Republic of China have been updated to include new data for 2003 and revised data for 2001 and 2002. The longline catch-at-length data for 2001-2002 have been updated, and new data for 2003 have been added. The longline effort data have been standardized by means of a delta-lognormal generalized linear model standardization of the CPUE, using data for 1975-2004, rather than the delta-gamma generalized linear model that was used previously.

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 1984-2005) and that the population has been in the high-recruitment regime for approximately the last 22 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 of the apparent regime shift. The analysis indicates that strong cohorts entered the fishery during 1998-2000, and that these cohorts increased the biomass during 1999-2000. However, these cohorts have now moved through the population, so the biomass decreased during 2002-2006.

The average weights of yellowfin tuna taken from the fishery have been fairly consistent over time (Figure 5.2, lower panel), but vary substantially among the different fisheries (Figure 4.11). In general, the floating-object (Fisheries 1-4), unassociated (Fisheries 5 and 6), and pole-and-line (Fishery 10) fisheries capture younger, smaller yellowfin than do the dolphin-associated (Fisheries 7-9) and longline (Fisheries 11 and 12) fisheries. The longline fisheries and the dolphin-associated fishery in the southern region (Fishery 9) capture older, larger yellowfin than do the northern region (Fishery 7) and coastal (Fishery 8) dolphin-associated fisheries.

Significant levels of fishing mortality have been observed in the yellowfin tuna fishery in the EPO. These levels are highest for middle-aged yellowfin. High mortality seen for the oldest fish is likely to be an artifact of the model. Most of the yellowfin catch is taken in schools associated with dolphins, and, accordingly, this method has the greatest impact on the yellowfin tuna population, although it has almost the least impact per unit of weight captured of all fishing methods.

Historically, the SBR of yellowfin tuna in the EPO was below the level corresponding to the AMSY during the lower productivity regime of 1975-1983 (Section 4.2.1), but above that level for most of the last 21 years. The increase in the SBR is attributed to the regime change. The two different productivity regimes may support two different AMSY levels and associated SBR levels. The SBR at the start of 2006 is estimated to be very close to the level corresponding to AMSY. The effort levels are estimated to be close to those that would support the AMSY (based on the current distribution of effort among the different fisheries), and the catch levels are a little above the corresponding values at AMSY. Because of the flat yield curve (Figure 5.3, upper panel), only substantial changes from the current effort level would reduce average equilibrium yield below the AMSY.

If a stock-recruitment relationship is assumed, the outlook is more pessimistic, and current biomass is estimated to be below the level corresponding to the AMSY for most of the model period, except for a period from the start of 2000 to the end of 2002.

Alternative assumptions about the asymptotic length do not substantially affect the outlook for the fishery. Assuming an asymptotic length of 170 cm gives a slightly more positive impression of the current fishery condition, relative to SBR at AMSY.

The current average weight of yellowfin in the catch is much less than the critical weight, and, therefore, from a yield-per-recruit standpoint, yellowfin in the EPO are probably overfished. The AMSY calculations indicate that, theoretically, at least, 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.

The AMSY has been stable during the assessment period, which suggests that the overall pattern of selectivity has not varied a great deal through time. However, the overall level of fishing effort has varied with respect to the AMSY multiplier.

Under 2005 levels of effort the biomass and SBR are predicted to not decline significantly over the next five years. Biomass and SBR are predicted to rise during 2007-2008, but this prediction is very uncertain. Comparison of biomass and SBR predicted with and without the restrictions from Resolution C-04-09 suggests that without the restrictions biomass and SBR would be at lower levels than seen at present, and would decline a little further in future.

These simulations were carried out using the average recruitment for the 1975-2005 period. If they had been carried out using the average recruitment for the 1984-2005 period, the projected trend in SBR and catches would have been more positive. Both the purse-seine and longline catches are expected to remain close to 2005 levels.

Summary

1. The results are similar to those of the previous six assessments, except that the SBR corresponding to AMSY is less than in the 2005 assessment.
2. The biomass is estimated to have declined in 2005.
3. There is uncertainty about recent and future recruitment and biomass levels.
4. The estimate of the current SBR is very close to that corresponding to the AMSY.
5. The recent fishing mortality rates are very close to those corresponding to the AMSY.
6. Increasing the average weight of the yellowfin caught could substantially increase the AMSY.
7. There have been two different productivity regimes, and the levels of AMSY and the biomasses corresponding to the AMSY may differ between the regimes.
8. The results are more pessimistic if a stock-recruitment relationship is assumed.

2. DATA

Catch, effort, and size-composition data for January 1975-December 2005 were used to conduct the stock assessment of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean (EPO). The data for 2005, which are preliminary, include records that had been entered into the IATTC databases before or on March 15, 2006. 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 schools associated with floating objects, unassociated schools, and dolphin-associated schools), and IATTC length-frequency sampling area or latitude. The yellowfin fisheries are defined in Table 2.1, and their spatial extents are shown in Figure 2.1. The boundaries of the length-frequency sampling areas are also shown in Figure 2.1.

In general, fisheries are defined so that, over time, there is little change in the size composition of the catch. Fishery definitions for purse-seine sets on floating objects are also stratified to provide a rough distinction between sets made mostly on fish-aggregating devices (FADs) (Fisheries 1-2, 4, 13-14, and 16), and sets made on mixtures of flotsam and FADs (Fisheries 3 and 15).

2.2. Catch and effort data

To conduct the stock assessment of yellowfin tuna, the catch and effort data in the IATTC databases are stratified according to the fishery definitions described in Section 2.1 and shown in Table 2.1. The three definitions relating to catch data (landings, discards, and catch) used by Maunder (2002a) and Maunder and Watters (2001 and 2002) are described by Maunder and Watters (2001). The terminology for this report, and those of Maunder and Harley (2004, 2005) and Hoyle and Maunder (2006), is consistent with the terminology used in other IATTC reports. ”Landings” is catch landed in a given year even if the fish were not caught in that year. Previously, landings referred to retained catch taken in a given year. This catch will now be termed retained catch. Throughout the document the term "catch" will be used to reflect both total catch (discards plus retained catch) and retained catch, and the reader is referred to the context to determine the appropriate definition.

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

New and updated catch and effort data for the surface fisheries (Fisheries 1-10 and 13-16) have been incorporated into the current assessment. The effort data for 1975-2004 have been updated, and catch and effort data for 2005 are new.

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

Updates and new catch and effort data for the longline fisheries (Fisheries 11 and 12) have also been incorporated into the current assessment. New catch data are available for Japan (2004), Chinese Taipei (2002), the Peoples Republic of China (2003), and updated data for Japan (1999-2002) and the Peoples Republic of China (2001-2002). Monthly reporting of catch data for the longline fishery provided, at the time of the assessment, full 2004 catch for Japan and the Republic of Korea and partial year catch for the other nations. As in the previous assessments of yellowfin in the EPO (Maunder and Watters 2001, 2002; Maunder 2002a; Maunder and Harley 2004, 2005), the amount of longlining effort was estimated by dividing standardized estimates of the catch per unit of effort (CPUE) from the Japanese longline fleet into the total longline landings. In previous assessments estimates of standardized CPUE were obtained with regression trees (Watters and Deriso 2000, Maunder and Watters 2001, 2002, Maunder 2002a), neural networks (Maunder and Harley 2004, 2005), or a delta-gamma generalized linear model. In this assessment CPUE was standardized using a delta-lognormal generalized linear model (Stefansson 1996) that took into account latitude, longitude, and numbers of hooks between floats.

2.2.1. Catch

No longline catch or effort data for 2005 were available, so effort data was assumed (see section 2.2.2) and the catch was estimated by the stock assessment model. Therefore, the total 2005 longline catch is a function of the assumed 2005 longline effort, the estimated number of yellowfin of catchable size in the EPO in 2004, and the estimated selectivities and catchabilities for the longline fisheries. Catches for the other longline fisheries for the recent years for which the data were not available were estimated, using the ratio, by quarter, of the catch to the Japanese catch for the last year for which data were available for that fishery.

Trends in the catch of yellowfin tuna in the EPO during each quarter from January 1975 to December 2004 are shown in Figure 2.2. It should be noted that there were substantial surface and longline fisheries for yellowfin prior to 1975 (Shimada and Schaefer 1956; Schaefer 1957; Okamoto and Bayliff 2003). The majority of the catch has been taken by purse-seine sets on yellowfin associated with dolphins and in unassociated schools. One main characteristic of the catch trends is the increase in catch taken since about 1993 by purse-seine sets on fish associated with floating objects.

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

2.2.2. Effort

Maunder and Watters (2001, 2002a), Maunder (2002a), and Maunder and Harley (2004, 2005) discuss the historic fishing effort. For the surface fisheries, this assessment includes updated effort data for 1975-2004 and new effort data for 2005.

A complex algorithm, described by Maunder and Watters (2001), was used to estimate the amount of fishing effort, in days fished, exerted by purse-seine vessels. The longline effort data for yellowfin have been estimated from standardized CPUE data, as follows. Detailed data on catch, effort, and hooks between floats by latitude and longitude from the Japanese longline fleet, provided by Mr. Adam Langley of the Secretariat of the Pacific Community, were used in a generalized linear model with a delta lognormal link function to produce an index of standardized CPUE (E.J. Dick, NOAA Santa Cruz, personal communication; see Stefansson (1996) for a description of the method, and Hoyle and Maunder (in prep) longline CPUE working paper for more detailed information. The effect of changing the CPUE standardization method from the delta-gamma link function used in 2005 was investigated as a sensitivity analysis. The Japanese effort data were scaled by the ratio of the Japanese catch to the total catch to compensate for the inclusion of catch data from the other nations into the assessment. This allows inclusion of all the longline catch data into the assessment, while using only the Japanese effort data to provide information on relative abundance.

The IATTC databases do not contain catch and effort information from longlining operations conducted in the EPO during 2005. To conduct the stock assessment of yellowfin tuna, the amount of longlining effort exerted during each quarter of 2005 was assumed to be equal to the estimated effort exerted during the corresponding quarter of 2004. However, the abundance information in the catch and effort data for 2005 was greatly down weighted in the model.

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. The fishing effort in Fisheries 13-16 is equal to that in Fisheries 1-4 (Figure 2.3) because the catches taken by Fisheries 13-16 are derived from those taken by Fisheries 1-4 (see Section 2.2.3). Fishing effort for longliners (Fisheries 11 and 12) is in standardized units.

2.2.3. Discards

For the purposes of stock assessment, it is assumed that yellowfin 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 or national observers, applying methods described by Maunder and Watters (2003a). Regardless of why yellowfin are discarded, it is assumed that all discarded fish die. Maunder and Watters (2001) describe how discards are implemented in the yellowfin assessment. One difference from the method described by Maunder and Watters (2001) is that the discard rates are not smoothed over time, which should allow for a better representation of recruitment in the model. Discard data for 2005 were not available for the analysis, so it was assumed that the discard rate by quarter was the same as for 2004.

Estimates of discards resulting from inefficiencies in the fishing process are added to the catches made by purse-seine vessels (Table 2.1). No observer data are available to estimate discards prior to 1993, and it is assumed that there were no discards before this time. There are periods for which observer data are not sufficient to estimate the discards, in which case it is assumed that the discard rate (discards/landings) is equal to the discard rate for the same quarter in the previous year or, if not available, the year before that.

Discards that result from the process of sorting the catch are treated as separate fisheries (Fisheries 13-16), and the catches taken by these fisheries are assumed to be composed only of fish that are 2-4 quarters old (see Figure 4.5). Maunder and Watters (2001) provide a rationale for treating such discards as separate fisheries. Estimates of the amounts of fish discarded during sorting are made only for fisheries that take yellowfin associated with floating objects (Fisheries 2-5) because sorting is thought to be infrequent in the other purse-seine fisheries.

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

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 shown in Figure 4.2. Maunder and Watters (2001) describe the sizes of yellowfin caught by each fishery. In general, floating-object, unassociated, and pole-and-line fisheries catch smaller yellowfin, while dolphin-associated and longline fisheries catch larger ones. New purse-seine length-frequency data were included for 2005. New longline length-frequency data were available for the Japanese fleet for 2004, and data for 2000 to 2003 were updated. Size composition data for the other longline fleets are not used in the assessment.

The length frequencies of the catches during 2005 from the four floating-object fisheries were similar to those observed over the whole modeling period (compare Figures 4.2 and 4.8a). The cohort responsible for the large modes seen in the dolphin-associated fishery during quarters 1 and 2 of 2004 (Figure 4.8c) appears to have largely left the fishery. Some evidence for a recent strong recruitment event may be seen in quarters 3 and 4 of 2005 in the floating object fisheries. The appearance, disappearance, and subsequent reappearance of strong cohorts in the length-frequency data is a common phenomenon for yellowfin in the EPO. This may indicate spatial movement of cohorts or fishing effort, and the limitations in the length-frequency sampling. Groups of tagged fish have also disappeared and then reappeared (Bayliff 1971), suggesting, among other things, that vulnerability to capture fluctuates.

The length frequencies of the catch for the longline fisheries (Figure 4.8d) were available in adequate sample sizes only for the southern fishery in 2003. Limited data were available for the northern fishery in the last quarter of 2003 and 2004, and for the southern fishery in the first quarter of 2004.

2.4. Auxiliary data

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

3. ASSUMPTIONS AND PARAMETERS

3.1. Biological and demographic information

3.1.1. Growth

The growth model is structured so that individual growth increments (between successive ages) can be estimated as free parameters. These growth increments 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.

In the assessment for yellowfin, a prior distribution is applied to the growth model. The Richards growth equation was changed from $L_t = L_\infty \left(1 - \exp\left(-K\left(t - t_0\right)\right)\right)^m$ to $L_t = L_\infty \left(1 - \frac{\exp\left(-K\left(t - t_0\right)\right)}{b}\right)^b$, which gave a better fit to data from Wild (1986) (Figure 3.1) (L_∞ = 185.7 cm, annual k = 0.761, t_0 = 1.853 years, b = -1.917). The penalties were increased in order to constrain growth to fit the prior at all ages, rather than from the age of 10 quarters as in previous years. Expected asymptotic length (L_∞) cannot be reliably estimated from data, such as Wild's, that do not include many old fish. Two alternative plausible values of L_∞ were investigated in a sensitivity analysis.

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

This assessment used the approach first employed in 2005 (Hoyle and Maunder 2006) to estimate variation in length at age from the data. Both the sampling scheme and the fisheries and time periods in which data were collected were taken into account. The mean lengths of older yellowfin were assumed to be close to those indicated by the growth curve of Wild (1986).

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

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

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

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

3.1.2. Recruitment and reproduction

The A-SCALA method allows a Beverton-Holt (1957) stock-recruitment relationship to be specified. The Beverton-Holt curve is parameterized so that the relationship between spawning biomass and recruitment is determined by estimating the average recruitment produced by an unexploited population (virgin recruitment) and a parameter called steepness. Steepness is defined as the fraction of virgin recruitment that is produced if the spawning stock size is reduced to 20% of its unexploited level, and it controls how quickly recruitment decreases when the size of the spawning stock is reduced. Steepness can vary between 0.2 (in which case recruitment is a linear function of spawning stock size) and 1.0 (in which case recruitment is independent of spawning stock size). In practice, it is often difficult to estimate steepness because of lack of contrast in spawning stock size, high inter-annual (and inter-quarter) variation in recruitment, and confounding with long-term changes in recruitment, due to environmental effects not included in the model, that affect spawning stock size. The base case assessment assumes that there is no relationship between stock size and recruitment. This assumption is the same as that used in the 2000, 2001, 2002, and 2003 assessments (Maunder and Watters 2001, 2002, Maunder 2002a, Maunder and Harley 2004). The influence of a Beverton-Holt stock-recruitment relationship is investigated in a sensitivity analysis.

It is assumed that yellowfin tuna can be recruited to the fishable population during every quarter of the year. Hennemuth (1961) reported that there are two peaks of spawning of yellowfin in the EPO, but it is assumed in this study that recruitment may occur more than twice per year because individual fish can spawn almost every day if the water temperatures are in the appropriate range (Schaefer 1998). 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 33 cm (about 2 quarters old) (Section 3.1.1). At this size (age), the fish are vulnerable to capture by fisheries that catch fish in association with floating objects (*i.e.* they are recruited to Fisheries 13-16).

The spawning potential of the population is estimated from the numbers of fish, proportion of females, percent mature, batch fecundity, and spawning frequency (Schaefer 1998). These quantities (except numbers) are estimated for each age class, based on the mean length at age given by the Richards growth equation fitted to the otolith data of Wild (1986). See Maunder and Watters (2002) for a description of the method, but using the von Bertalanffy growth curve. These quantities were re-estimated when investigating sensitivity to different growth curves. The spawning potential of the population is used in the stock-recruitment relationship and to determine the 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 3.2 and 3.3, 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 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, for which the natural mortality rate was assumed to increase for females after they reached the age of 30 months (*e.g.* Anonymous 1999: 38). Males and females are not treated separately in the current stock assessment, and M is treated as a rate for males and females combined. The values of quarterly M used in the current stock assessment are plotted in Figure 3.4. These values were estimated by making the assumptions described above, fitting to sex ratio at length data (Schaefer 1998), and comparing the values with those estimated for yellowfin in the western and central Pacific Ocean (Hampton 2000; Hampton and Fournier 2001).

Maunder and Watters (2001) describe in detail how the age-specific natural mortality schedule for yellowfin in the EPO is estimated. These quantities were re-estimated when investigating sensitivity to different growth curves.

3.1.5. Stock structure

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

3.2. Environmental influences

Recruitment of yellowfin in the EPO has tended to be greater after El Niño events (Joseph and Miller 1989). Previous stock assessments have included the assumption that oceanographic conditions might influence recruitment of yellowfin tuna in the EPO (Maunder and Watters 2001, 2002; see Maunder and Watters 2003b for a description of the methodology). This assumption is supported by observations that spawning of yellowfin is temperature dependent (Schaefer 1998). To incorporate the possibility of an environmental influence on recruitment of yellowfin in the EPO, a temperature variable was incorporated into previous stock assessment models to determine whether there is a statistically-significant relationship between this temperature variable and estimates of recruitment. 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 (2002a) correlated recruitment with the environmental time series outside the stock assessment model. For candidate variables, Maunder (2002) used the sea-surface temperature (SST) in an area consisting of two rectangles from 20°N-10°S and 100°W-150°W and 10°N-10°S and 85°W-100°W, the total number of 1°x1° areas with average SST ≥24°C, and the Southern Oscillation Index. The data were related to recruitment, adjusted to the period of hatching. However, no relationship with these variables was found. No investigation using environmental variables was carried out in this assessment.

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

4. STOCK ASSESSMENT

A-SCALA, an age-structured statistical catch-at-length analysis model (Maunder and Watters 2003a) and information contained in catch, effort, and size-composition data are used to assess the status of yellowfin tuna 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 (1957) 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 2001 assessment (Maunder 2002a) the main changes were the increase in the modeling period (January 1975 to January 2002), inclusion of otolith data, and removal of environmental indices for recruitment and catchability. The main changes in the 2002 assessment (Maunder and Harley 2004) were the choice of weighting factors for the selectivity smoothness penalties based on cross validation and the iterative reweighting of the length-frequency sample size in a sensitivity analysis. The main change in the 2004 assessment (Maunder and Harley 2005) was the removal of the seasonal effect in recruitment to allow for the new method used for future projections. The main change in the 2005 assessment (Hoyle and Maunder 2006) was revision of the growth model to take into account the sampling strategy used to obtain the length-at-age data.

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 first quarter of 2006;
2. quarterly catchability coefficients for the 16 fisheries that take yellowfin from the EPO;
3. selectivity curves for 12 of the 16 fisheries (Fisheries 13-16 have an assumed selectivity curve);
4. initial population size and age-structure;
5. mean length at age (Figure 3.1);
6. parameters of a linear model relating the standard deviations in length at age to the mean lengths at age.

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

1. fecundity of females at age (Figure 3.2);
2. sex ratio at age (Figure 3.3);
3. natural mortality at age (Figure 3.4);
4. selectivity curves for the discard fisheries (Fisheries 13-16);
5. steepness of the stock-recruitment relationship (steepness = 1 for the base case assessment).

Yield and catchability estimates for estimations of the average maximum sustainable yield (AMSY) or future projections were based on estimates of quarterly fishing mortality or catchability (mean catchability plus effort deviates) for 2003 and 2004, so the most recent estimates were not included in these calculations. It was determined by retrospective analysis (Maunder and Harley 2004) that the most recent estimates were uncertain and should not be considered. Sensitivity of estimates of key management quantities to this assumption was tested.

There is uncertainty in the results of the current stock assessment. This uncertainty arises because the observed data do not perfectly represent the population of yellowfin tuna in the EPO. Also, the stock assessment model may not perfectly represent the dynamics of the yellowfin population nor of the fisheries that operate in the EPO. As in previous assessments (Maunder and Watters 2001, 2002; Maunder 2002a; Maunder and Harley 2004, 2005), uncertainty is expressed as (1) approximate confidence intervals around estimates of recruitment (Section 4.2.2), biomass (Section 4.2.3), and the spawning biomass ratio (Section 5.1), and (2) coefficients of variation (CVs). The confidence intervals and CVs have been estimated under the assumption that the stock assessment model perfectly represents the dynamics of the system. Since it is unlikely that this assumption is satisfied, these values may underestimate the amount of uncertainty in the results of the current assessment.

4.1. Indices of abundance

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

4.2. Assessment results

Below we describe important aspects of the base case assessment (1 below) and changes for the sensitivity analyses (2-4 below):

1. Base case assessment: steepness of the stock-recruitment relationship equals 1 (no relationship between stock and recruitment), species-composition estimates of surface fishery catches scaled back to 1975, delta-lognormal general linear model standardized CPUE, and assumed sample sizes for the length-frequency data.
2. Sensitivity to the steepness of the stock-recruitment relationship. The base case assessment included an assumption that recruitment was independent of stock size, and a Beverton-Holt (1957) stock-recruitment relationship with steepness of 0.75 was used for the sensitivity analysis.
3. Sensitivity to the assumed value for the asymptotic length parameter of the Richards growth curve. A lower value of 170 cm and an upper value of 200 cm were investigated.
4. Sensitivity to changing the longline CPUE standardization method from using a delta-gamma link function to using a delta-lognormal link function.

The results of the base case assessment are described in the text, and the sensitivity analyses are described in the text with figures and tables presented in Appendices A1-A3.

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 reliable estimates of the total amount of fish removed from the stock are not available.

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

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

4.2.1. Fishing mortality

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

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

Selectivity curves estimated for the 16 fisheries defined in the stock assessment of yellowfin tuna are shown in Figure 4.4. Purse-seine sets on floating objects select mostly yellowfin that are about 4 to 14 quarters old (Figure 4.4, Fisheries 1-4). Purse-seine sets on unassociated schools of yellowfin select fish similar in size to those caught by sets on floating objects (about 5 to 15 quarters old, Figure 4.4, Fisheries 5 and 6), but these catches contain greater proportions of fish from the upper portion of this range. Purse-seine sets on yellowfin associated with dolphins in the northern and coastal regions select mainly fish 7 to 15 quarters old (Figure 4.4, Fisheries 7 and 8). The dolphin-associated fishery in the south selects mainly yellowfin 12 or more quarters old (Figure 4.4, Fishery 9). Longline fisheries for yellowfin also select mainly older individuals about 12 or more quarters old (Figure 4.4, Fisheries 11 and 12). Pole-and-line gear selects yellowfin about 4 to 8 quarters old (Figure 4.4, Fishery 10). The southern dolphin-associated fishery and the longline fisheries are highly selective for the oldest individuals. Because few fish survive to this age, these large selectivities are most likely an artifact of the model, and do not influence the results.

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

The ability of purse-seine vessels to capture yellowfin 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 behavior of the 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). The catchability in the southern fishery (Fishery 9) is more variable. All three dolphin-associated fisheries have had higher than average catchability during most of 2001-2005. The average increases in quarterly fishing mortality for the three fisheries associated with dolphins due to greater than average catchabilities, over the period 2001 to 2005 were 22% for northern, 13% for coastal, and 39% for southern. Over the 2003 and 2004 period used in the projections catchabilities were 21%, 6%, and 58% above the long-term average. For 2005 the equivalent increases were 35%, 14%, and 176%.

The ability of pole-and-line gear 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). Catchability in the northern fishery has been very low since the late 1990's.

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

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

4.2.2. Recruitment

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

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

A sensitivity analysis was carried out, fixing the Beverton-Holt (1957) steepness parameter at 0.75 (Appendix A). This means that recruitment is 75% of the recruitment from an unexploited population when the population is reduced to 20% of its unexploited level. (The best estimate of steepness in the current assessment was 0.54). 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 an effect of population size on recruitment. The results when a stock-recruitment relationship is used are described in Section 4.5.

Adjustments to the growth curve estimation process for the 2005 assessment (Hoyle and Maunder 2006) resulted in an unrealistically small growth increment between the ages of 2 to 3 quarters. As a result, recruitment estimates were offset, and appeared one quarter earlier than in previous years. In the current assessment growth has been constrained to match observed age at length data. The resulting recruitment estimate timing is similar to that of assessments prior to 2005.

The estimated time series of yellowfin recruitment is shown in Figure 4.7, and the estimated annual total recruitment 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 of the 1975-2003 period. A sustained period of high recruitment was estimated for mid-1999 until the end of 2000. In the 2004 assessment (Maunder and Harley 2005) a strong recruitment, similar in size to the large 1998 cohort, was estimated for the second quarter of 2003. However, there was substantial uncertainty associated with this estimate, and the current assessment estimates it to have been close to the average recruitment level. The 2005 assessment (Hoyle and Maunder 2005) estimated a moderately large cohort for the first quarter (now second quarter due to the adjusted offset) of 2004, but the current assessment estimates it to have been only slightly above average. A very large recruitment, larger than any other in the time series, has been estimated for the third quarter of 2005, but this estimate is similarly uncertain.

Another characteristic of the recruitment, which was also apparent in previous assessments, is the regime change in the recruitment levels, starting during the second quarter of 1983. The recruitment was, on average, consistently greater after 1983 than before. This change in recruitment levels produces a similar change in biomass (Figure 4.9a). 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 0.61, which is close to the 0.6 assumed in the penalty applied to the recruitment deviates. The average coefficient of variation (CV) of the estimates is 0.16. The estimates of uncertainty are surprisingly small, considering the inability of the model to fit modes in the length-frequency data (Figure 4.8). These modes often appear, disappear, and then reappear.

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

4.2.3. Biomass

Biomass is defined as the total weight of yellowfin tuna that are 1.5 or more years old. The trends in the biomass of yellowfin in the EPO are shown in Figure 4.9a, and estimates of the biomass at the beginning of each year in Table 4.1. Between 1975 and 1983 the biomass of yellowfin declined to about 230,000 metric tons (t); it then increased rapidly during 1983-1986, and reached about 510,000 t in 1986. Since then it has been relatively constant at about 400,000-550,000 t, 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 shown in Figure 4.9b, and estimates of the spawning biomass at the beginning of each year in Table 4.1. The spawning biomass has generally followed a trend similar to that for biomass, described in the previous paragraph. The confidence intervals on the spawning biomass estimates indicate that it is also well estimated. 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 analysis is used to illustrate the influence of fishing and recruitment on the biomass trends (Maunder and Watters, 2001). The simulated biomass trajectories with and without fishing are shown in Figure 4.10a. The large difference in the two trajectories indicates that fishing has a major impact on the biomass of yellowfin in the EPO. The large increase in biomass during 1983-1984 was caused initially by an increase in average size (Anonymous 1999), followed by an increase in average recruitment (Figure 4.7), but increased fishing pressure prevented the biomass from increasing further during the 1986-1990 period.

The impact of each major type of fishery on the yellowfin tuna stock is shown in Figures 4.10b and 4.10c. The estimates of biomass in the absence of fishing were computed as above, and then the biomass trajectory was estimated by setting the effort for each fisheries group, in turn, to zero. The biomass impact for each fishery group at each time step is derived as this biomass trajectory minus the biomass trajectory with all fisheries active. When the impacts of individual fisheries calculated by this method are summed, they are greater than the combined impact calculated when all fisheries are active. Therefore, the impacts are scaled so that the sum of the individual impacts equals the impact estimated when all fisheries are active. These impacts are plotted as a proportion of unfished biomass (Figure 4.10b) and in absolute biomass (Figure 4.10c).

4.2.4. Average weights of fish in the catch

The overall average weights of the yellowfin tuna caught in the EPO predicted by the analysis have been consistently around 12 to 22 kg for most of the 1975-2003 period (Figure 5.2), but have differed considerably among fisheries (Figures 4.11). The average weight was high during the 1985-1992 period (Figure 5.2), when the effort for the floating-object and unassociated fisheries was less (Figure 2.3). The average weight was also greater in 1975-1977 and in 2001-2003. The average weight of yellowfin caught by the different gears varies widely, but remains fairly consistent over time within each fishery (Figure 4.11). The lowest average weights (about 1 kg) are produced by the discard fisheries, followed by the pole-and-line fishery (about 4-5 kg), the floating-object fisheries (about 5-10 kg for Fishery 3, 10 kg for Fisheries 2 and 4, and 10-15 kg for Fishery 1), the unassociated fisheries (about 15 kg), the northern and coastal dolphin-associated fisheries (about 20-30 kg), and the southern dolphin-associated fishery and the longline fisheries (each about 40-50 kg).

4.3. Comparisons to external data sources

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

4.4. Diagnostics

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

4.4.1. Residual plots

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

The estimated annual effort deviations, which are one type of residual in the assessment and represent temporal changes in catchability, are shown plotted against time in Figure 4.5a. These residuals are assumed to be normally distributed (the residual is exponentiated before multiplying by the effort so the distribution is actually lognormal) with a mean of zero and a given standard deviation. A trend in the residuals indicates that the assumption that CPUE is proportional to abundance is violated. The assessment assumes that the southern longline fishery (Fishery 12) provides the most reasonable information about abundance (standard deviation (sd) = 0.2) while the dolphin-associated and unassociated fisheries have less information (sd = 0.3), the floating-object, the pole-and-line fisheries, and the northern longline fishery have the least information (sd = 0.4), and the discard fisheries have no information (sd = 2). Therefore, a trend is less likely in the southern longline fishery (Fishery 12) than in the other fisheries. The trends in effort deviations are estimates of the trends in catchability (see Section 4.2.1). Figure 4.5a shows no overall trend in the southern longline fishery effort deviations, but there are some consecutive residuals that are all above or all below the average. The standard deviation of the residuals is about 140% greater than the 0.2 assumed for this fishery. For the other fisheries, except for the discard fisheries, the standard deviations of the residuals are greater than those assumed. These results indicate that the assessment gives more weight to the CPUE information than it should. The effort residuals for the floating-object fisheries have a declining trend over time, while the effort residuals for the northern and coastal dolphin-associated fisheries have slight increasing trends over time. These trends may be related to true trends in catchability.

The observed proportion of fish caught in a length class is assumed to be normally distributed around the predicted proportion, with the standard deviation equal to the binomial variance, based on the observed proportions, divided by the square of the sample size (Maunder and Watters 2003a). The length-frequency residuals appear to be less than the assumed standard deviation (Figures C.1-C.3) (*i.e.* the assumed sample size is too small; see Section 4.5 for a sensitivity analysis for the length-frequency sample size). They have a negative bias (Figure C.1), and are more variable for some lengths than for others (Figure C.1), but tend to be consistent over time (Figure C.2). The negative bias is due to the large number of zero observations. The zero observation causes a negative residual, and also causes a small standard deviation, which inflates the normalized residual.

4.4.2. Parameter correlation

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

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

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

4.4.3. Retrospective analysis

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

4.5. Sensitivity to assumptions

Sensitivity analyses were carried out to investigate the incorporation of a Beverton-Holt (1957) stock-recruitment relationship (Appendix A1), and the assumed value for the asymptotic length parameter of the Richards growth curve (Appendix C).

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

The assumed value for the asymptotic length parameter of the Richards growth curve was fixed at a lower value of 170, and an upper value of 200, bracketing the base case value of 185 cm estimated from the otolith data (Figure A2.4). The value of 154 cm estimated by stock assessments for the west and central Pacific Ocean (Adam Langley, Secretariat of the Pacific Community, pers. com.) was not consistent with the otolith data. Unlike the EPO bigeye assessment (Hampton and Maunder 2005), the estimated biomass and recruitment are not very sensitive to values of the asymptotic length parameter in the range investigated (Figures A2.1, and A2.2). There are very few individuals in the length-frequency data larger than 160 cm, and the maximum length seen is between 175 and 190 cm in most years (Figure A2.8). There are estimated to be comparatively few large fish in the population throughout the period of the assessment, given the fishing mortality applied by the purse-seine fisheries, and the high natural mortality. The longline fishery selectivities are able to adjust to fit the expected numbers at length (Figure A2.5), such that when asymptotic length is larger, selectivity at older ages is increased to eliminate the older, larger fish (Figures A2.6a, A2.6b, and A2.6c). This flows through into higher fishing mortality at older ages, to an extent that may not be realistic (Figures A2.7a, A2.7b, and A2.7c). The spawning biomass ratio is also insensitive to the asymptotic length parameter (Figure A2.3), which can be explained by the low proportion of females in the population in the older age classes (Figure 3.3). The best fit to the data is from the model with the low value for the asymptotic length parameter, with most of the improvement coming from a better fit to the length frequency data.

A new method was used to standardize the longline catch per of effort (CPUE) data in 2006. A delta-lognormal link function was used instead of a delta-gamma link function. This resulted in slightly different CPUE indices for fisheries 11 and 12: the northern and southern longline fisheries (Figures A3.1a and A3.1b), The biomass was insensitive to this change (Figure A3.2), as were the spawning biomass ratio and spawning biomass ratio associated with AMSY (Figure A3.3).

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

4.6. Comparison to previous assessments

The estimated biomass and SBR trajectories are similar to those from the previous assessments presented by Maunder and Watters (2001, 2002), Maunder (2002a), Maunder and Harley (2004, 2005), and Hoyle and Maunder (2006) (Figure 4.12). These results are also similar to those obtained using cohort analysis (Maunder 2002b). This indicates that estimates of absolute biomass are robust to the assumptions that have been changed as the assessment procedure has been updated. The recent increases and decreases in biomass are similar to those indicated by the most recent previous assessment.

4.7. Summary of the results from the assessment model

In general, the recruitment of yellowfin tuna to the fisheries in the EPO is variable, with a seasonal component. This analysis and previous analyses have indicated that the yellowfin population has experienced two different recruitment regimes (1975-1983 and 1984-2005) and that the population has been in the high-recruitment regime for approximately the last 22 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 of the apparent regime shift. The analysis indicates that strong cohorts entered the fishery during 1998-2000, and that these cohorts increased the biomass during 1999-2000. However, these cohorts have now moved through the population, so the biomass decreased during 2002-2006.

The average weights of yellowfin tuna taken from the fishery have been fairly consistent over time (Figure 5.2, lower panel), but vary substantially among the different fisheries (Figure 4.11). In general, the floating-object (Fisheries 1-4), unassociated (Fisheries 5 and 6), and pole-and-line (Fishery 10) fisheries capture younger, smaller yellowfin than do the dolphin-associated (Fisheries 7-9) and longline (Fisheries 11 and 12) fisheries. The longline fisheries and the dolphin-associated fishery in the southern region (Fishery 9) capture older, larger yellowfin than do the northern region (Fishery 7) and coastal

(Fishery 8) dolphin-associated fisheries.

Significant levels of fishing mortality have been observed in the yellowfin tuna fishery in the EPO. These levels are highest for middle-aged yellowfin. High mortality seen for the oldest fish is likely to be an artifact of the model. Most of the yellowfin catch is taken in schools associated with dolphins, and, accordingly, this method has the greatest impact on the yellowfin tuna population, although it has almost the least impact per unit of weight captured of all fishing methods.

The average increases in quarterly fishing mortality, due to greater than average catchabilities over the period 2001 to 2005, for the three fisheries associated with dolphins were 22% for northern, 13% for coastal, and 39% for southern. For 2005 the equivalent increases were 35%, 14%, and 176%.

5. STATUS OF THE STOCK

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

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

1. S_{AMSY}, the spawning biomass corresponding to the AMSY;
2. F_{AMSY}, the fishing mortality corresponding to the AMSY;
3. S_{min}, the minimum spawning biomass seen in the model period.

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

5.1. Assessment of stock status based on spawning biomass

The spawning biomass ratio, SBR, defined in Section 3.1.2, is useful for assessing the status of a stock. The 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 would be present if there were no fishing for a long period (*i.e.* the equilibrium spawning biomass if $F = 0$). The SBR has a lower bound of 0. If the SBR is 0, or slightly greater than that, the population has been severely depleted and is probably overexploited. If the SBR is 1, or slightly less than that, the fishery has probably not reduced the spawning stock. If the SBR is greater than 1, it is possible that the stock has entered a regime of increased production.

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

Estimates of quarterly SBR_t for yellowfin tuna in the EPO have been computed for every quarter represented in the stock assessment model (the first quarter of 1975 to the first quarter of 2006). Estimates of the spawning biomass during the period of harvest (S_t) are discussed in Section 4.2.3 and presented in Figure 4.9b. The equilibrium spawning biomass after a long period with no harvest ($S_{F=0}$) was estimated by assuming that recruitment occurs at an average level expected from an unexploited population. SBR_{AMSY} is estimated to be about 0.37.

At the beginning of 2006 the spawning biomass of yellowfin tuna in the EPO had increased from mid 2005, which was probably its lowest point since 1989. The estimate of SBR at the beginning of 2006 was about 0.41, with lower and upper 95% confidence limits of 0.33 and 0.50, respectively (Figure 5.1), and similar to the level at start of 2005. The current assessment's estimate of SBR_{AMSY} (0.37) is lower than that of the 2005 assessment (0.44), but similar to those of the 2004 and 2003 assessments (both 0.39) (Figure 4.12b).

The historical trends in SBR are similar to those described by Maunder and Watters (2001, 2002), Maunder (2002a), Maunder and Harley (2004, 2005) and Hoyle and Maunder (2006; Figure 4.12b). However, the SBR has increased and SBR_{AMSY} has reduced compared to the estimates of Maunder and Harley (2004, 2005) and Hoyle and Maunder (2006). The estimates of SBR have increased because of differences in the estimates of growth and changes in fishing mortality, and the SBR_{AMSY} has reduced because of changes in fishing mortality.

In general, the SBR estimates for yellowfin tuna in the EPO are reasonably precise; the average CV of these estimates is about 0.07. The relatively narrow confidence intervals around the SBR estimates suggest that for most quarters during 1985-2001 the spawning biomass of yellowfin in the EPO was above the level currently corresponding to the AMSY (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 kg (Figure 5.2). This value is greater than the value of 32 kg reported by Anonymous (2000). The difference is due to the time step of the calculation (quarterly versus monthly) and differences in weight at age. This value is less than a previous estimate of 49 kg (Maunder 2002a) because of differences in estimates of the weight at age.

The average weight of yellowfin tuna in the combined catches of the fisheries operating in the EPO was only about 14 kg at the end of 2005 (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 for the entire period that was analyzed (Figure 5.2).

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

5.3. Assessment of stock status based on AMSY

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 differ from those of Maunder and Watters (2001) in that the present calculations include the Beverton-Holt (1957) stock-recruitment relationship when applicable.

At the start of 2005, the biomass of yellowfin tuna in the EPO appears to have been very close to the level corresponding to the AMSY, and the recent catches have been slightly above the AMSY level (Table 5.1).

If the fishing mortality is proportional to the fishing effort, and the current patterns of age-specific selectivity (Figure 4.4) are maintained, the current (average of 2003-2004) level of fishing effort is very close to that estimated to produce the AMSY. The effort at AMSY is 98% of the current level of effort. It is important to note that the curve relating the average sustainable yield to the long-term fishing mortality (Figure 5.3, upper panel) is very flat around the AMSY level. Therefore, changes in the long-term levels of effort will only marginally change the long-term catches, while considerably changing the biomass. The spawning stock biomass changes substantially with changes in the long-term fishing mortality (Figure 5.3, lower panel). Decreasing the effort would increase CPUE and thus might also reduce the cost of fishing. Reducing fishing mortality below the level at AMSY would provide only a marginal decrease in the long-term average yield, with the benefit of a relatively large increase in the spawning biomass.

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

The estimation of the AMSY, and its associated quantities, is sensitive to the age-specific pattern of selectivity that is used in the calculations. To illustrate how AMSY might change if the effort is reallocated among the various fisheries (other than the discard fisheries) that catch yellowfin tuna in the EPO, the previously-described calculations were repeated, using the age-specific selectivity pattern estimated for groups of fisheries. If the management objective is to maximize the AMSY, the age-specific selectivity of the longline fisheries will perform the best, followed by that of the dolphin-associated fisheries, and then the unassociated fisheries. The selectivity of the fisheries that catch yellowfin by making purse-seine sets on floating objects would perform the worst (Table 5.2a). If an additional management objective is to maximize the S_{AMSY}, the order is the same. The age-specific selectivity of the purse-seine fisheries alone gives slightly less than the current AMSY (Table 5.2c). It is not plausible, however, that the longline fisheries, which would produce the greatest AMSYs, would be efficient enough to catch the full AMSYs predicted. On its own, the effort for purse-seine fishery for dolphin-associated yellowfin would have to doubled to achieve the AMSY.

If it is assumed that all fisheries but one are operating, and that each fishery maintains its current pattern of age-specific selectivity, the AMSY is increased by removing the floating object or unassociated fisheries, and reduced by removing the dolphin-associated or longline fisheries (Table 5.2b). If it is assumed that all fisheries are operating, but either the purse-seine or the longline fisheries are adjusted to obtain AMSY, the purse-seine fisheries must be reduced 9%, or the longline fisheries must be increased 19-fold. If it is also assumed that there is a stock-recruitment relationship, the AMSY is achieved if purse-seine fisheries are reduced by 42%, or the longline fisheries increased by 133% (Table 5.2c).

AMSY and S_{AMSY} have been very stable during the modeled period (Figure 4.12c). This suggests that the overall pattern of selectivity has not varied a great deal through time. The overall level of fishing effort, however, has varied with respect to the AMSY multiplier (Fscale).

5.4. Lifetime reproductive potential

One common management objective is the conservation of spawning biomass. Conservation of spawning biomass allows an adequate supply of eggs, so that future recruitment is not adversely affected. If reduction in catch is required to protect the spawning biomass, it is advantageous to know at which ages to avoid catching fish to maximize the benefit to the spawning biomass. This can be achieved by estimating 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 would produce over its remaining lifetime). This value is a function of the fecundity of the fish at the different stages of its remaining life and the natural and fishing mortality. The higher the mortality, the less likely the individual is to survive and continue reproducing.

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

The lifetime reproductive potential for each quarterly age class was estimated, using the average fishing mortality at age for 2003 and 2004. 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). Examination of the figure suggests that restricting the catch from fisheries that capture intermediate-aged yellowfin (ages 10-17 quarters) would provide the greatest benefit to the spawning biomass. However, the costs of forgoing catch are better compared in terms of weight rather than numbers, and an individual of age 11 quarters is much heavier than a recent recruit aged 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 aged 2 quarters (Figure 5.4, lower panel). This suggests 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 1 ton of young yellowfin would protect approximately the same amount of spawning biomass as reducing the catch of middle-aged yellowfin by about 2.6 tons.

5.5. MSY_{ref} and SBR_{ref}

Section 5.3 discusses how AMSY and the SBR at AMSY are dependent on the selectivity of the different fisheries and the effort distribution among these fisheries. AMSY can be increased or decreased by applying more or less effort to the various fisheries. If the selectivity of the fisheries could be modified at will, there is an optimum yield that can be obtained (Global MSY, Beddington and Taylor 1973; Getz 1980; Reed 1980). Maunder (2002b) showed that the optimal yield can be approximated (usually exactly) by applying a full or partial harvest at a single age. He termed this harvest MSY_{ref}, and suggested that two-thirds of MSY_{ref} might be an appropriate limit reference point (*i.e.* effort allocation and selectivity patterns should produce AMSY that is at or above $^{2}/_{3}MSY_{ref}$). The two-thirds suggestion was based on analyses in the literature indicating that 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} does not depend on the selectivity of the gear or the effort allocation among gears. Therefore, SBR_{ref} may be more appropriate than SBR_{AMSY} for stocks with multiple fisheries, and should be more precautionary because SBR_{ref} is usually greater than SBR_{AMSY}. However, when recruitment is assumed to be constant (*i.e.* no stock-recruitment relationship), SBR_{ref} may still be dangerous to the spawning stock because it is possible that MSY_{ref} occurs before the individuals become fully mature. SBR_{ref} may be a more appropriate reference point than the generally-suggested $SBR_{x\%}$ (*e.g.* $SBR_{30\%}$ to $SBR_{50\%}$ see section 5.1) because SBR_{ref} is estimated using information on 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 413,210 t (Figure 5.5, upper panel) and SBR_{ref} is estimated to be 0.44 (Figure 5.5, lower panel). 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 very similar to AMSY 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, AMSY at the current effort allocation is only 70% of MSY_{ref}. More research is needed to determine if reference points based on MSY_{ref} and SBR_{ref} are useful.

5.6. Sensitivity analyses

When the Beverton-Holt (1957) stock-recruitment relationship is included in the analysis with a steepness of 0.75, the SBR is reduced and the SBR level corresponding to the AMSY is increased (Figure A1.3). The SBR is estimated to be less than that at AMSY for most of the model period, except for the period 2000-2002. The current effort level is estimated to be above the AMSY level (Figure A1.4, Table 5.1), and current catch very close to the AMSY (Table 5.1). In contrast to the analysis without a stock-recruitment relationship, the addition of this relationship implies that catch may be moderately reduced if effort is increased beyond the level required for AMSY. The analysis without a stock-recruitment relationship has a relative yield curve equal to the relative yield-per-recruit curve because recruitment is constant. The yield curve bends over slightly more rapidly when the stock-recruitment relationship is included (Figure A1.4) than when it is not included (Figure 5.3). The equilibrium catch under the current effort levels is estimated to be 96% of AMSY, indicating that reducing effort would not greatly increase the catch.

When the asymptotic length is adjusted to either 170 cm or 200 cm, the SBR does not change significantly; the SBR level corresponding to the AMSY is reduced slightly for asymptotic length of 170 cm (Figure A2.3). The current effort level is estimated to be either slightly below (L_∞ = 170 cm) or very close to (L_∞ = 200 cm) the AMSY level (Figure A1.4, Table 5.1), and current catch very close to the AMSY (Table 5.1). The implications of increasing effort are very similar to the base case. The equilibrium catch under the current effort levels for asymptotic length of 170 cm is estimated to be 100% of AMSY, indicating that increasing effort would not increase the equilibrium catch.

5.7. Summary of stock status

Historically, the SBR of yellowfin tuna in the EPO was below the level corresponding to the AMSY during the lower productivity regime of 1975-1983 (Section 4.2.1), but above that level for most of the last 21 years. The increase in the SBR is attributed to the regime change. The two different productivity regimes may support two different AMSY levels and associated SBR levels. The SBR at the start of 2006 is estimated to be very close to the level corresponding to AMSY. The effort levels are estimated to be close to those that would support the AMSY (based on the current distribution of effort among the different fisheries), and the catch levels are a little above the corresponding values at AMSY. Because of the flat yield curve (Figure 5.3, upper panel), only substantial changes from the current effort level would reduce average equilibrium yield below the AMSY.

If a stock-recruitment relationship is assumed, the outlook is more pessimistic, and current biomass is estimated to be below the level corresponding to the AMSY for most of the model period, except for a period from the start of 2000 to the end of 2002.

Alternative assumptions about the asymptotic length do not substantially affect the outlook for the fishery. Assuming an asymptotic length of 170 cm gives a slightly more positive impression of the current fishery condition, relative to SBR at AMSY.

The current average weight of yellowfin in the catch is much less than the critical weight, and, therefore, from a yield-per-recruit standpoint, yellowfin in the EPO are probably overfished. The AMSY calculations indicate that, theoretically, at least, 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.

The AMSY has been stable during the assessment period, which suggests that the overall pattern of selectivity has not varied a great deal through time. However, the overall level of fishing effort has varied with respect to the AMSY multiplier.

6. Simulated effects of future fishing operations

A simulation study was conducted to gain further understanding as to how, in the future, hypothetical changes in the amount of fishing effort exerted by the surface fleet might simultaneously affect the stock of yellowfin tuna in the EPO and the catches of yellowfin by the various fisheries. Several scenarios were constructed to define how the various fisheries that take yellowfin in the EPO would operate in the future, and also to define the future dynamics of the yellowfin stock. The assumptions that underlie these scenarios are outlined in Sections 6.1 and 6.2.

A method based on the normal approximation to the likelihood profile has been applied, which considers both parameter uncertainty and 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, so this should be considered in any forward projections. Unfortunately, the appropriate methods are often not applicable to models as large and computationally-intense as the yellowfin stock assessment model. Therefore, we have used a normal approximation to the likelihood profile that allows for the inclusion of both parameter uncertainty and uncertainty about future recruitment. This method is implemented by extending the assessment model an additional 5 years with effort data equal to that for 2005, by quarter, scaled by the average catchability for 2003 and 2004. No catch or length-frequency data are included for these years. The recruitments for the five years are estimated as in the assessment model with a lognormal penalty with a standard deviation of 0.6. Normal approximations to the likelihood profile are generated for SBR, surface catch, and longline catch.

6.1. Assumptions about fishing operations

6.1.1. Fishing effort

Several future projection studies were carried out to investigate the influence of different levels of fishing effort on the stock biomass and catch. The quarterly catchability was assumed to be equal to the average catchability in 2003 and 2004, except for the northern longline fishery. The average was weighted by the effort to ensure that extreme values of catchability for years in which effort was restricted due to management did not overly influence the catchability used in the future projections.

The scenarios investigated were:

1. Quarterly effort for each year in the future equal to the quarterly effort in 2005 for the surface fisheries, and 2004 for the longline fisheries, which reflects the reduced effort due to the conservation measures of Resolution C-04-09;
2. Quarterly effort for each year in the future and for 2005 was set equal to the effort in scenario 1 adjusted for the effect of the conservation measures, and for 2004 was set equal to the effort in

2004 adjusted for the effect of the conservation measures. For the adjustment, the effort for the purse-seine fishery in the fourth quarter was increased by 85%, and the southern longline fishery effort was increased by 39%.

6.2. Simulation results

The simulations were used to predict future levels of the SBR, total biomass, 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). There is probably more uncertainty in the future levels of these outcome variables than suggested by the results presented in Figures 6.1-6.5. The amount of uncertainty is probably underestimated because the simulations were conducted under the assumption that the stock assessment model accurately describe the dynamics of the system, and because no account is taken for variation in catchability.

These simulations were carried out using the average recruitment for the 1975-2005 period. If they had been carried out using the average recruitment for the 1984-2005 period, the projected trend in SBR and catches would have been more positive.

6.2.1. Current effort levels

Under 2005 levels of effort the biomass is predicted to not decline significantly over the next five years (Figure 6.1). SBR is predicted to rise during 2007-2008 due to a large but uncertain recruitment about to enter the fishery. After this time the SBR is predicted to return to the level corresponding to the AMSY (Figure 6.2). However, the confidence intervals are wide, and there is a moderate probability that the SBR will be substantially above or below this level. Both surface and longline catches are predicted to be follow similar trajectories, with surface catches lifting in 2007-2008 and then returning to 2005 levels, followed by longline catches (Figure 6.3).

If catchability of all fisheries is set to average levels rather than those of 2003 and 2004, purse-seine catches in the first quarter of 2006 decline nearly 20% (Figure 6.3a) below those otherwise predicted, and approximately 35% below the high purse-seine catches observed in quarter 1 of 2005. This lower prediction is similar to the observed catch for that period.

6.2.2. No management restrictions

The 2004 Resolution on a Multi-Annual Program on the Conservation of Tuna in the Eastern Pacific Ocean for 2004, 2005, and 2006 (Resolution C-04-09) called for restrictions on purse-seine effort and longline catches for 2004: a 6-week closure during the third or fourth quarter of the year for purse-seine fisheries, and longline catches not to exceed 2001 levels. To assess the utility of these management actions, we projected the population forward five years, assuming that these conservation measures had not been implemented.

Comparison of the biomass and SBR predicted with and without the restrictions from the resolution show some difference (Figures 6.4 and 6.5). Without the restrictions, the simulations suggest that biomass and SBR would have declined to slightly lower levels than seen at present, and would decline in future to slightly lower levels (SBR of 0.32).

6.3. Summary of the simulation results

Under 2005 levels of effort the biomass and SBR are predicted to not decline significantly over the next five years. Biomass and SBR are predicted to rise during 2007-2008, but this prediction is very uncertain. Comparison of biomass and SBR predicted with and without the restrictions from Resolution C-04-09 suggests that without the restrictions biomass and SBR would be at lower levels than seen at present, and would decline a little further in future.

These simulations were carried out using the average recruitment for the 1975-2005 period. If they had been carried out using the average recruitment for the 1984-2005 period, the projected trend in SBR and catches would have been more positive. Both the purse-seine and longline catches are predicted to average close to 2005 levels.

7. FUTURE DIRECTIONS

7.1. Collection of new and updated information

The IATTC staff intends to continue its collection of catch, effort, and size-composition data for the fisheries that catch yellowfin tuna in the EPO. New data collected during 2006 and updated data for previous years will be incorporated into the next stock assessment.

7.2. Refinements to the assessment model and methods

The IATTC staff is considering moving the assessment to the stock synthesis II general model, based on the outcome of the midyear workshop on stock assessment methods.

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

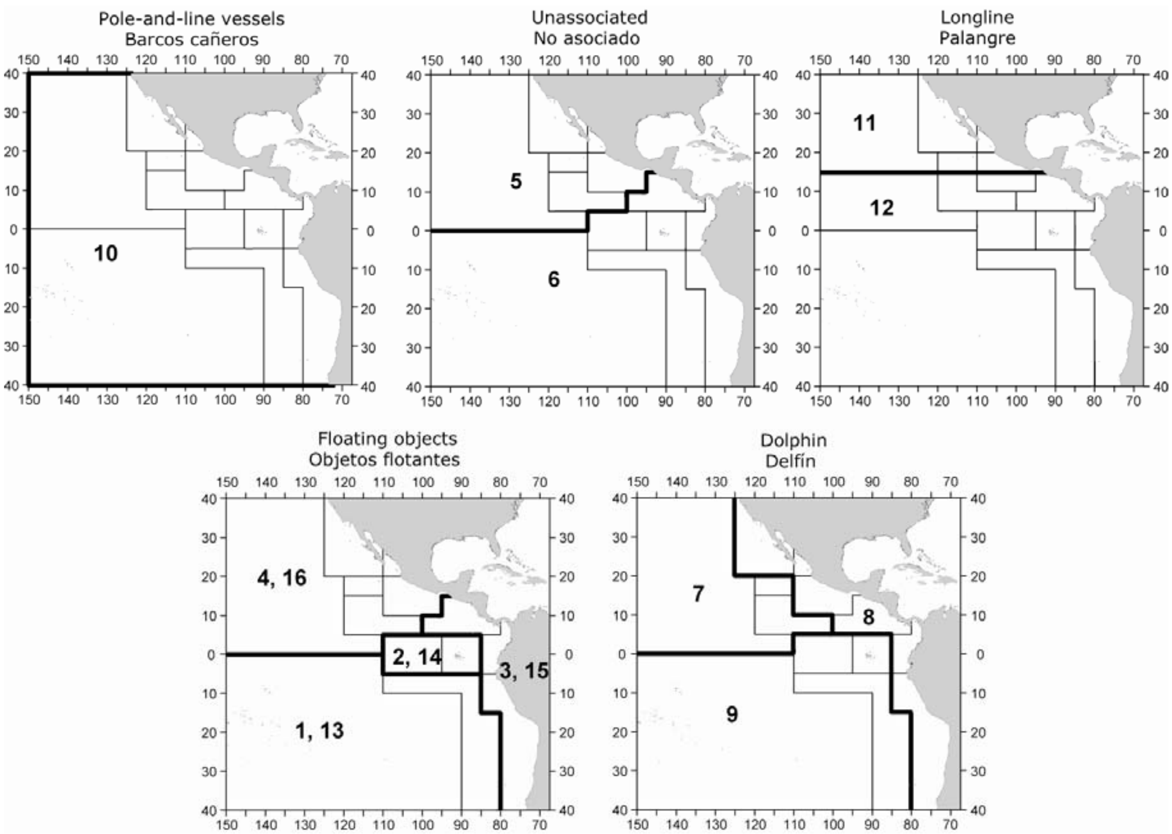


FIGURE 2.1. Spatial extents of the fisheries defined by the IATTC staff for the stock assessment of yellowfin tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the bold numbers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

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

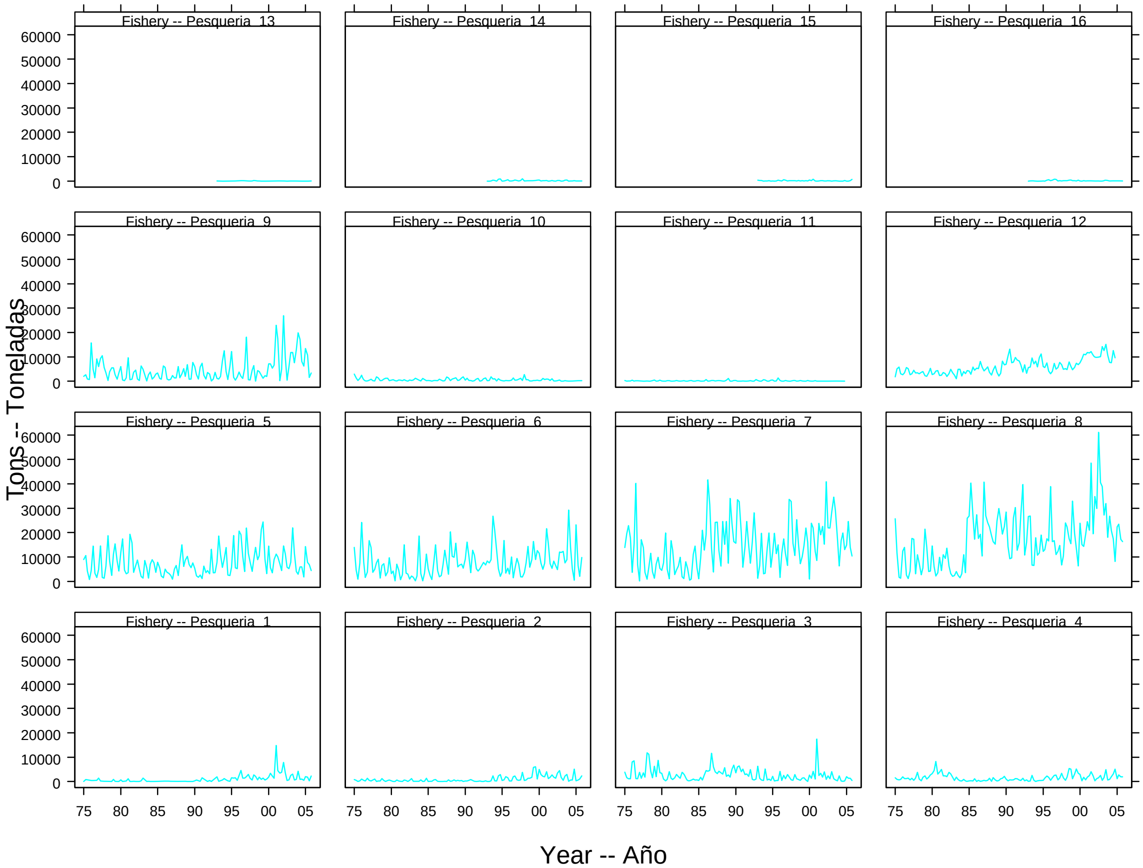


FIGURE 2.2. Catches by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were analyzed on a quarterly basis, there are four observations of catch for each year. Although all the catches are displayed as weights, the stock assessment model uses catches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

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

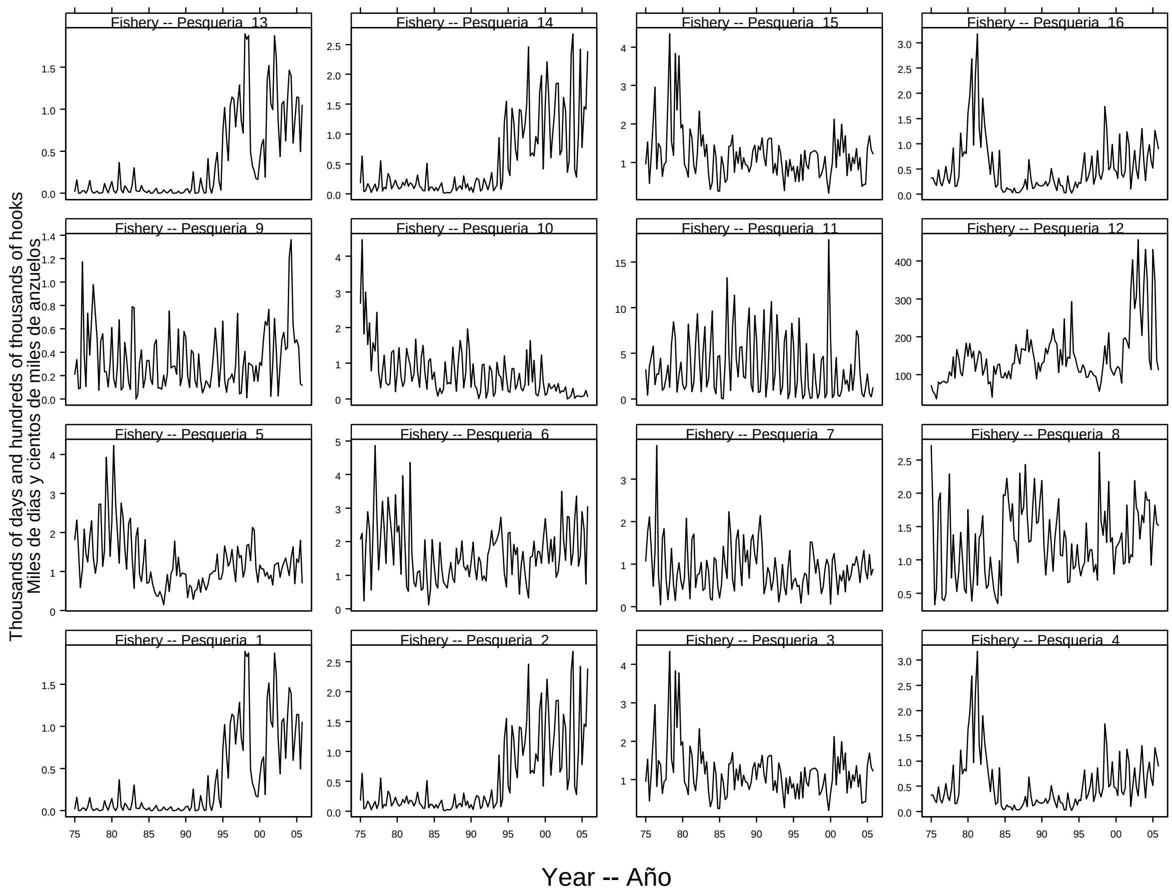


FIGURE 2.3. Fishing effort exerted by the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of effort for each year. The effort for Fisheries 1-10 and 13-16 is in days fished, and that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

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

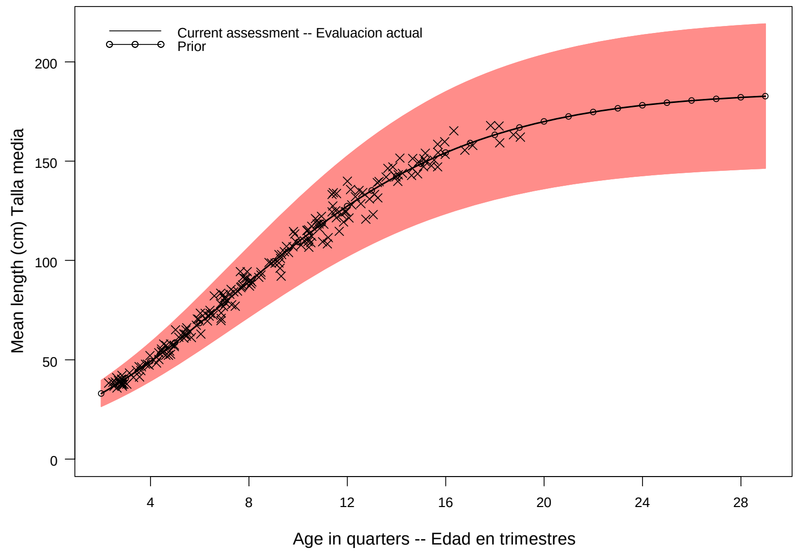


FIGURE 3.1. Growth curve estimated for the assessment of yellowfin tuna in the EPO (solid line). The connected points represent the mean length-at-age prior used in the assessment. The crosses represent length-at-age data from otoliths (Wild 1986). The shaded region represents the variation in length at age (± 2 standard deviations).
FIGURA 3.1. Curva de crecimiento usada para la evaluación del atún aleta amarilla en el OPO (línea sólida). Los puntos conectados representan la distribución previa (*prior*) de la talla a edad usada en la evaluación. Las cruces representan datos de otolitos de talla a edad (Wild 1986). La región sombreada representa la variación de la talla a edad (± 2 desviaciones estándar).

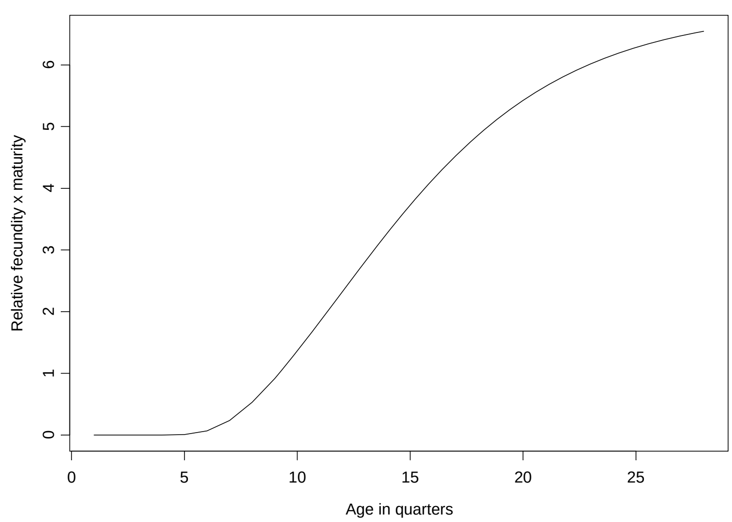


FIGURE 3.2. Relative fecundity-at-age curve (from Schaefer 1998) used to estimate the spawning biomass of yellowfin tuna in the EPO.
FIGURA 3.2. Curva de madurez relativa a edad (de Schaefer 1998) usada para estimar la biomasa reproductora de atún aleta amarilla en el OPO.

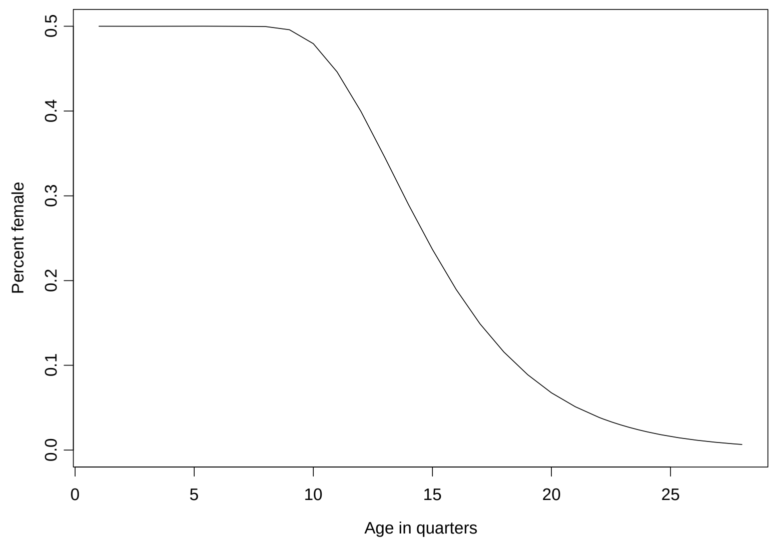


FIGURE 3.3. Sex ratio curve (from Schaefer 1998) used to estimate the spawning biomass of yellowfin tuna in the EPO.
FIGURA 3.3. Curva de proporciones de sexos (de Schaefer 1998) usada para estimar la biomasa reproductora de atún aleta amarilla en el OPO.

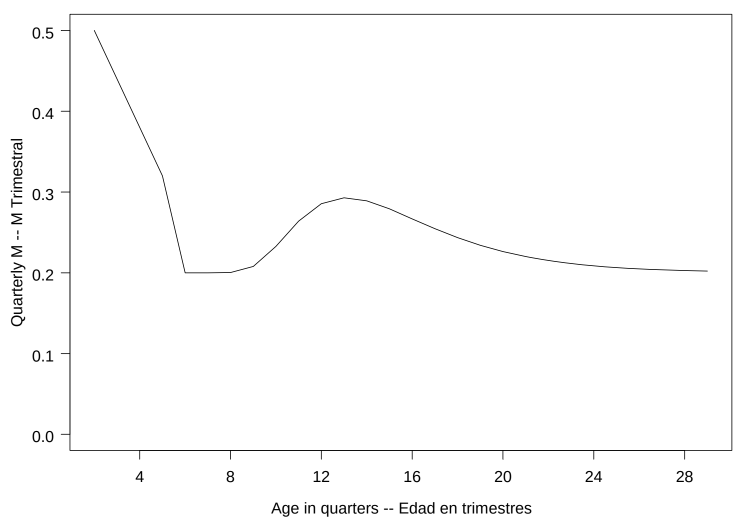


FIGURE 3.4. Natural mortality (*M*) rates, at quarterly intervals, used for the assessment of yellowfin tuna in the EPO. Descriptions of the three phases of the mortality curve are provided in Section 3.1.4.
FIGURA 3.4. Tasas de mortalidad natural (*M*), a intervalos trimestrales, usadas para la evaluación del atún aleta amarilla en el OPO. En la Sección 3.1.4 se describen las tres fases de la curva de mortalidad.

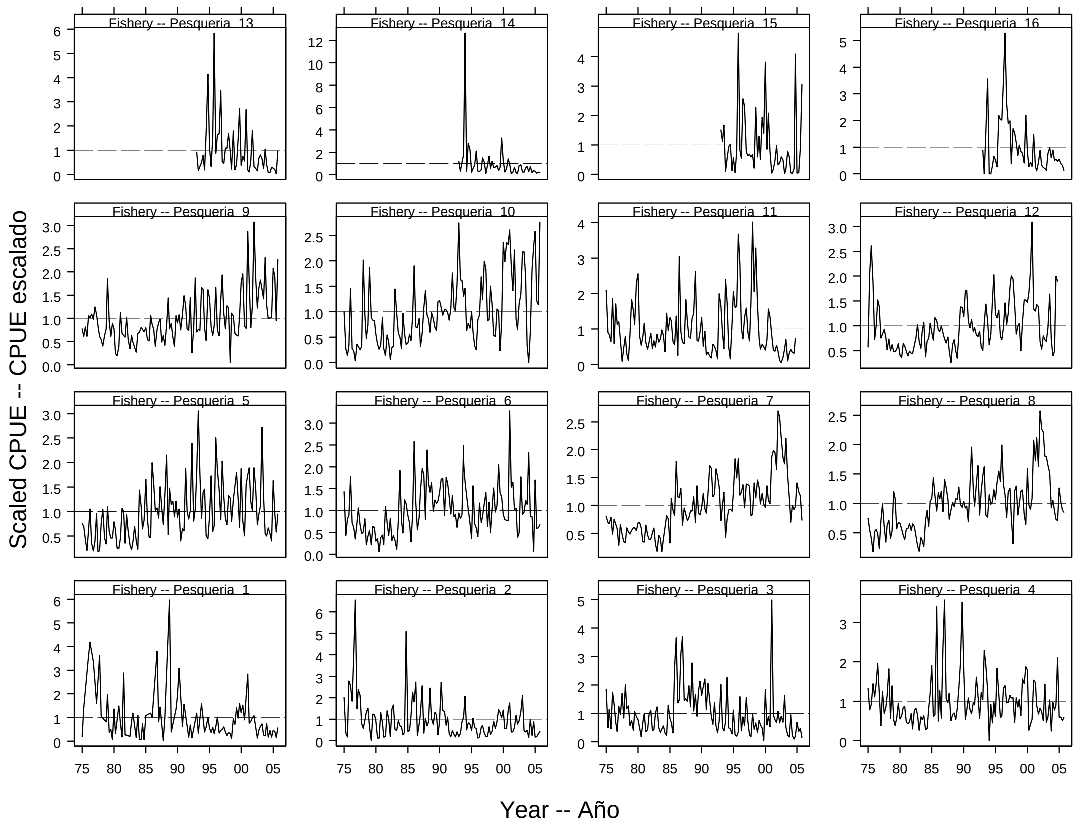


FIGURE 4.1. CPUEs for the fisheries defined for the stock assessment of yellowfin tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of CPUE for each year. The CPUEs for Fisheries 1-10 and 13-16 are in kilograms per day fished, and those for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

FIGURA 4.1. CPUE de las pesquerías definidas para la evaluación del stock de atún aleta amarilla en el OPO (Tabla 2.1). Ya que se resumieron los datos por trimestre, hay cuatro observaciones de CPUE para cada año. Se expresan las CPUE de las Pesquerías 1-10 y 13-16 en kilogramos por día de pesca, y las de las Pesquerías 11 y 12 en unidades estandarizadas basadas en número de anzuelos. Se ajustaron los datos para que el promedio de cada serie de tiempo equivalga a 1,0. Nótese que las escalas verticales de los recuadros son diferentes.

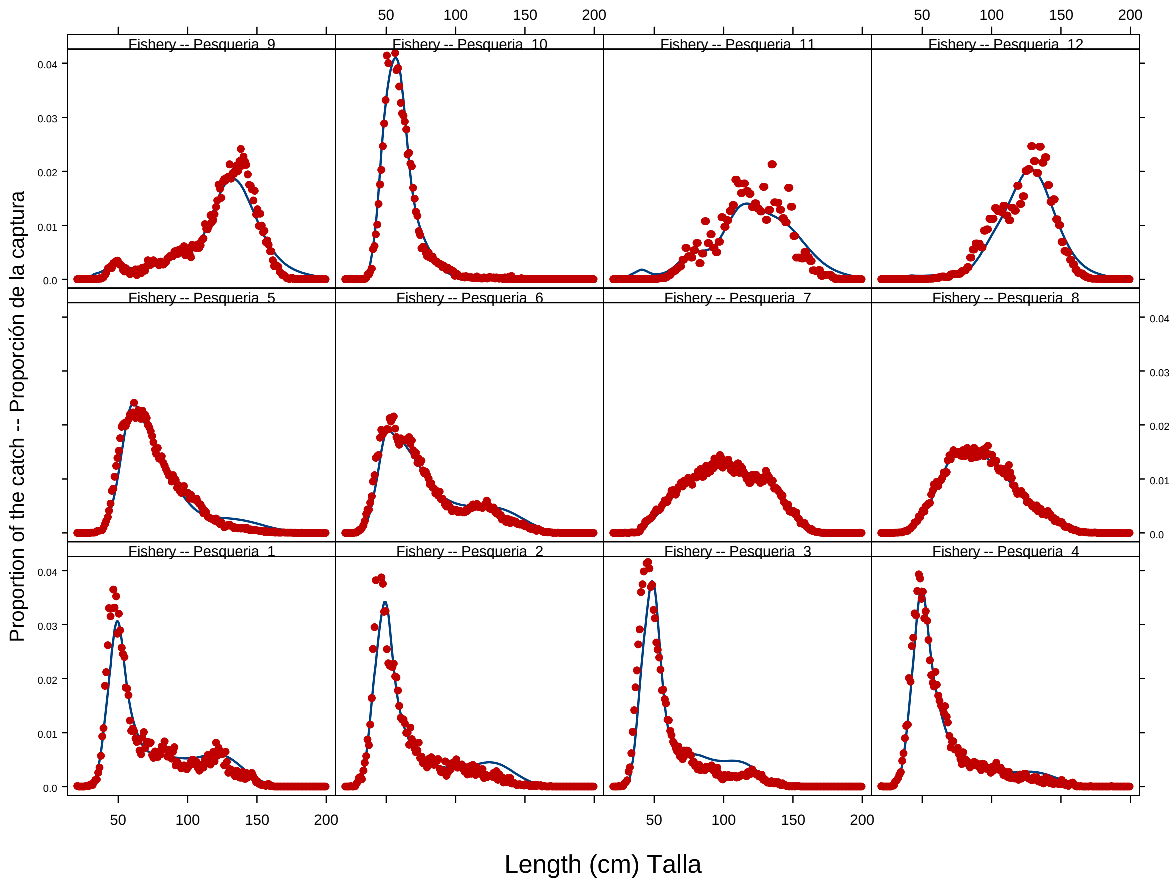


FIGURE 4.2. Average observed (dots) and predicted (curves) size compositions of the catches taken by the fisheries defined for the stock assessment of yellowfin tuna in the EPO.
FIGURA 4.2. Composición media por tamaño observada (puntos) y predicha (curvas) de las capturas realizadas por las pesquerías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

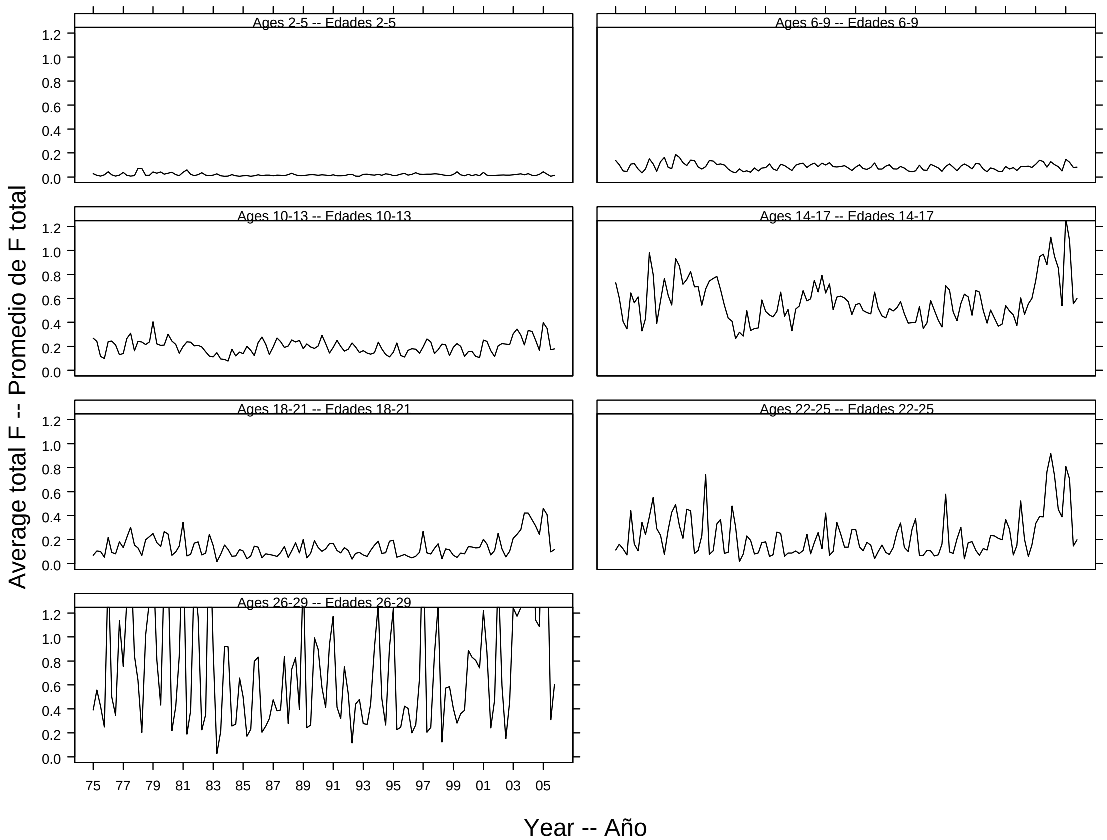


FIGURE 4.3a. Average quarterly fishing mortality at age, by all gears, on yellowfin tuna recruited to the fisheries of the EPO. Each panel illustrates an average of four quarterly fishing mortality vectors that affected the fish within the range of ages indicated in the title of each panel. For example,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

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

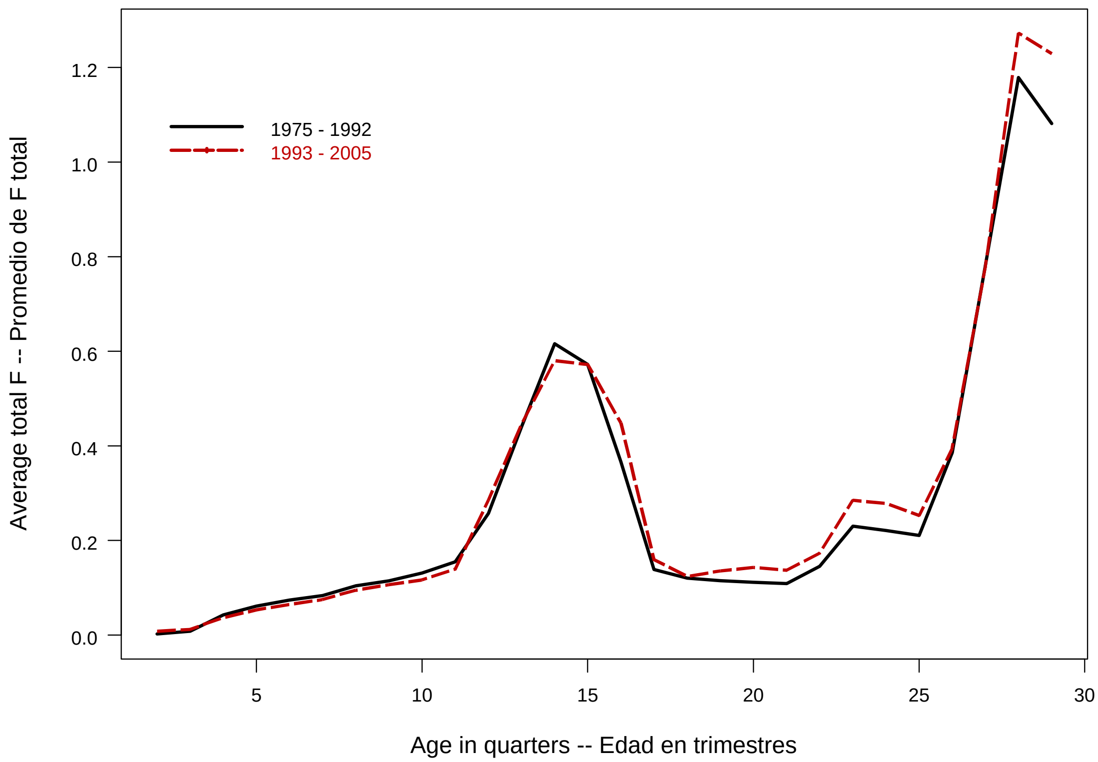


FIGURE 4.3b. Average quarterly fishing mortality by age of yellowfin tuna, by all gears, in the EPO. The estimates are presented for two periods, the latter period relating to the increase in effort associated with floating objects.

FIGURA 4.3b. Mortalidad por pesca trimestral media por edad de atún aleta amarilla, por todos los artes, en el OPO. Se presentan estimaciones para dos períodos, el segundo relacionado con aumento en el esfuerzo asociado con objetos flotantes.

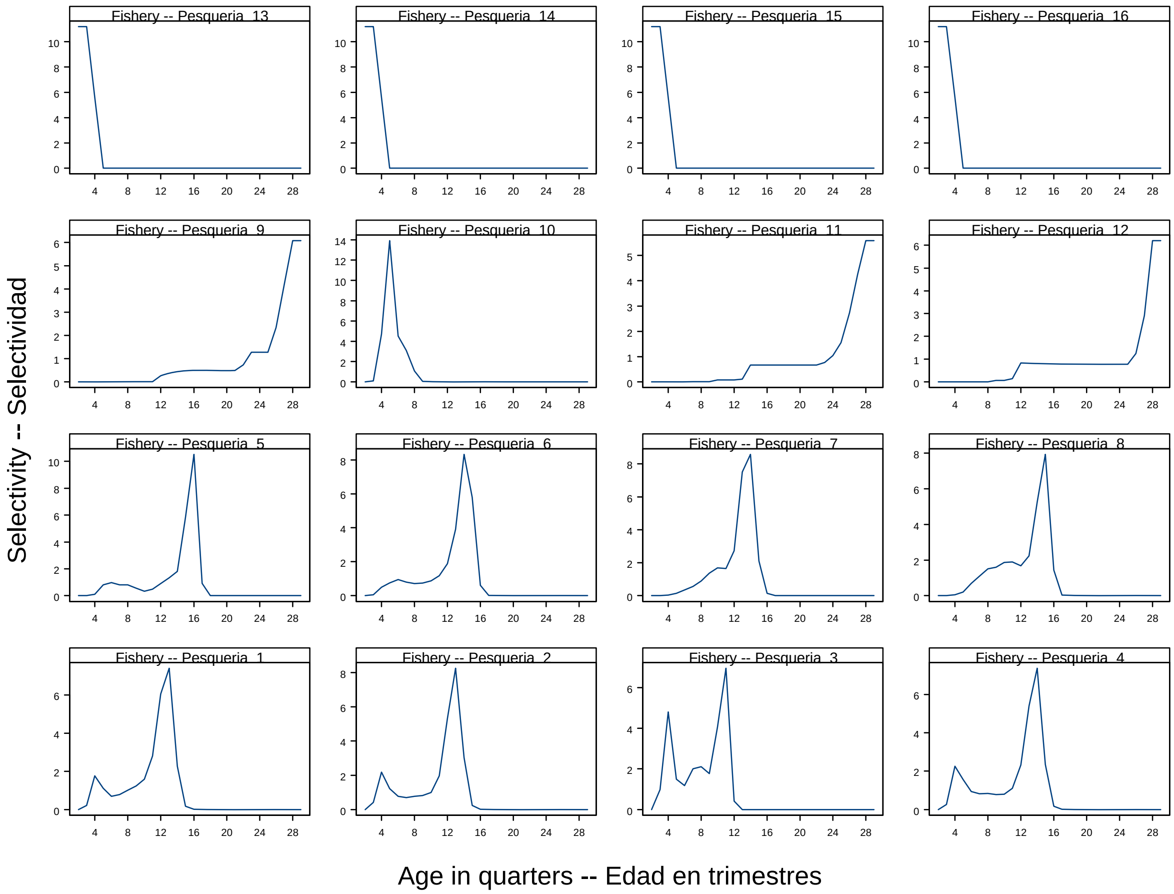


FIGURE 4.4. Selectivity curves for the 16 fisheries that take yellowfin tuna in the EPO. The curves for Fisheries 1-12 were estimated with the A-SCALA method, and those for Fisheries 13-16 are based on assumptions. Note that the vertical scales of the panels are different.

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

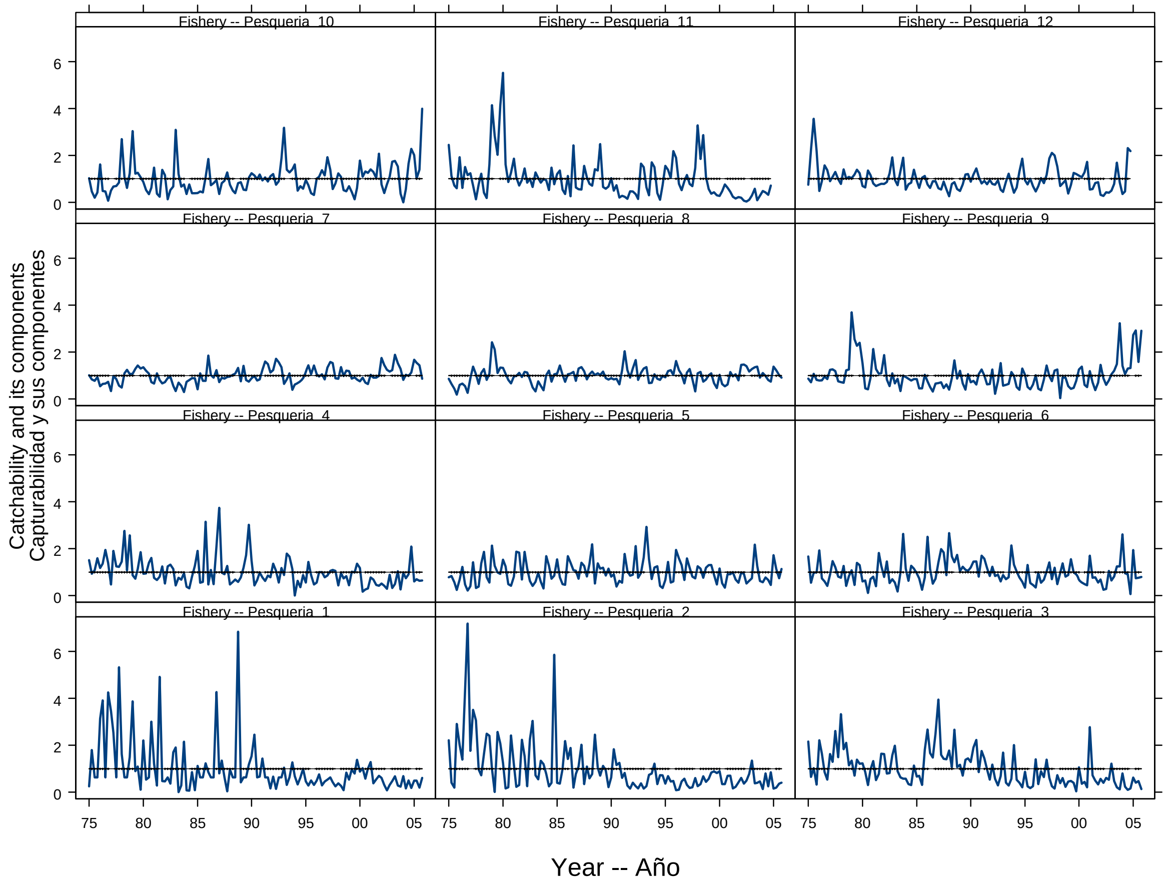


FIGURE 4.5a. Trends in catchability (*q*) for the 12 retention fisheries that take yellowfin tuna in the EPO. The estimates are scaled to average 1.

FIGURA 4.5a. Tendencias en capturabilidad (*q*) para las 12 pesquerías de retención que capturan atún aleta amarilla en el OPO. Se escalan las estimaciones a un promedio de 1.

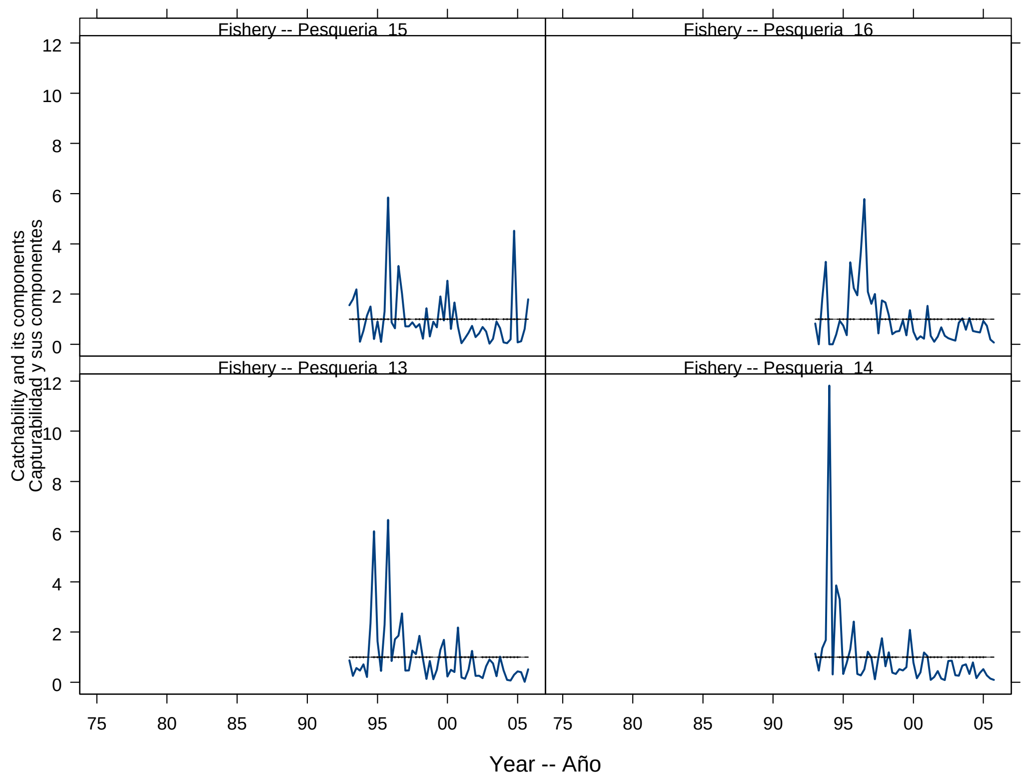


FIGURE 4.5b. Trends in catchability (q) for the four discard fisheries that take yellowfin tuna in the EPO. The estimates are scaled to average 1.

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

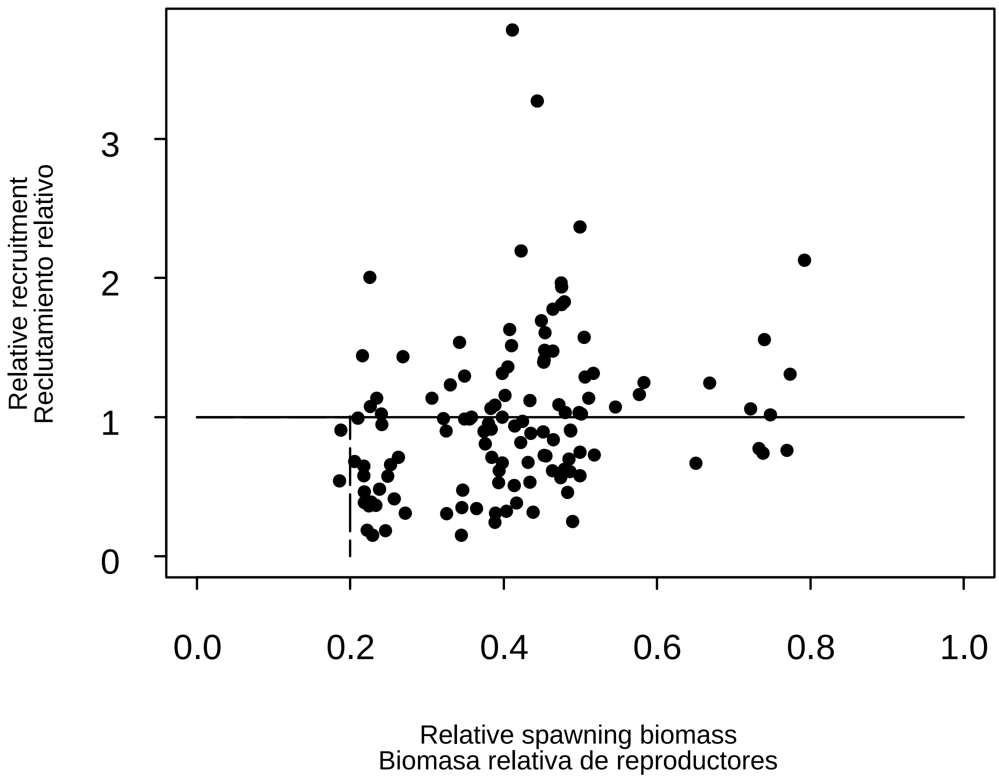


FIGURE 4.6. Estimated relationship between recruitment of yellowfin tuna and spawning biomass. The recruitment is scaled so that the average recruitment is equal to 1.0. The spawning biomass is scaled so that the average unexploited spawning biomass is equal to 1.0.
FIGURA 4.6. Relación estimada entre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

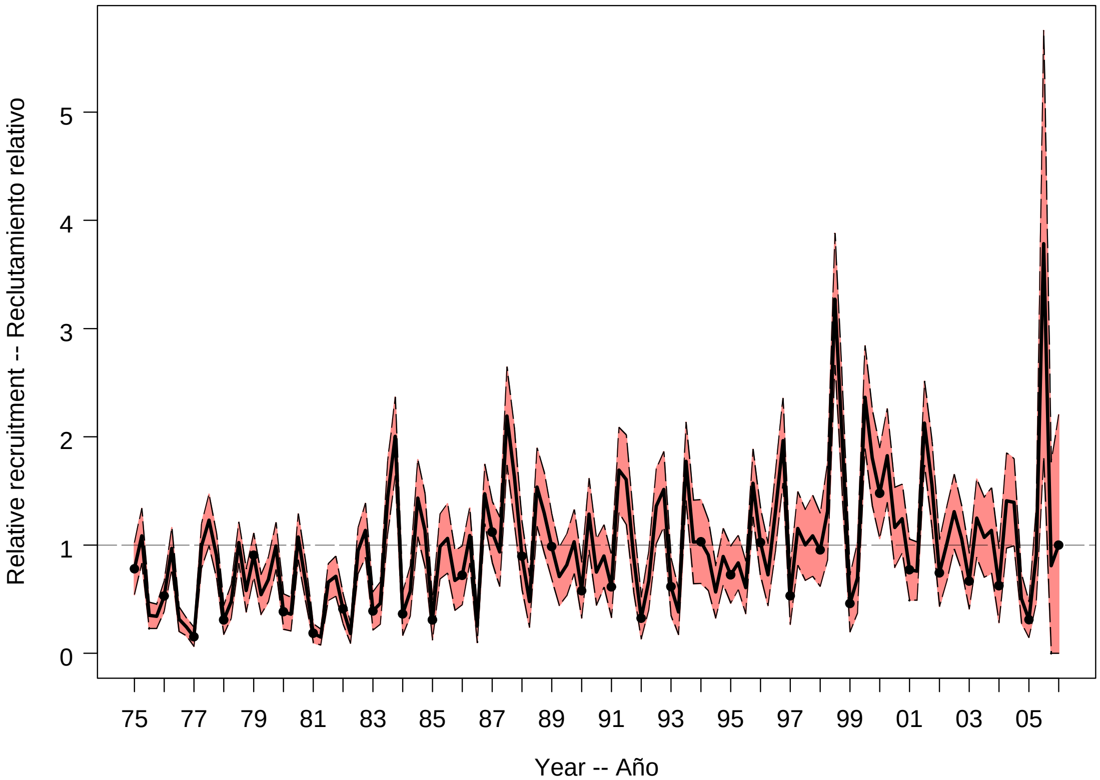


FIGURE 4.7. Estimated recruitment of yellowfin tuna to the fisheries of the EPO. The estimates are scaled so that the average recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the shaded area indicates the approximate 95% confidence intervals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

FIGURA 4.7. Reclutamiento estimado de atún aleta amarilla a las pesquerías del OPO. Se escalan las estimaciones para que el reclutamiento medio equivalga a 1,0. La línea gruesa ilustra las estimaciones de probabilidad máxima del reclutamiento, y el área sombreada los intervalos de confianza de 95% aproximados de esas estimaciones. Se dibujan las leyendas en el eje de tiempo al principio de cada año, pero, ya que el modelo de evaluación representa el tiempo por trimestres, hay cuatro estimaciones de reclutamiento para cada año.

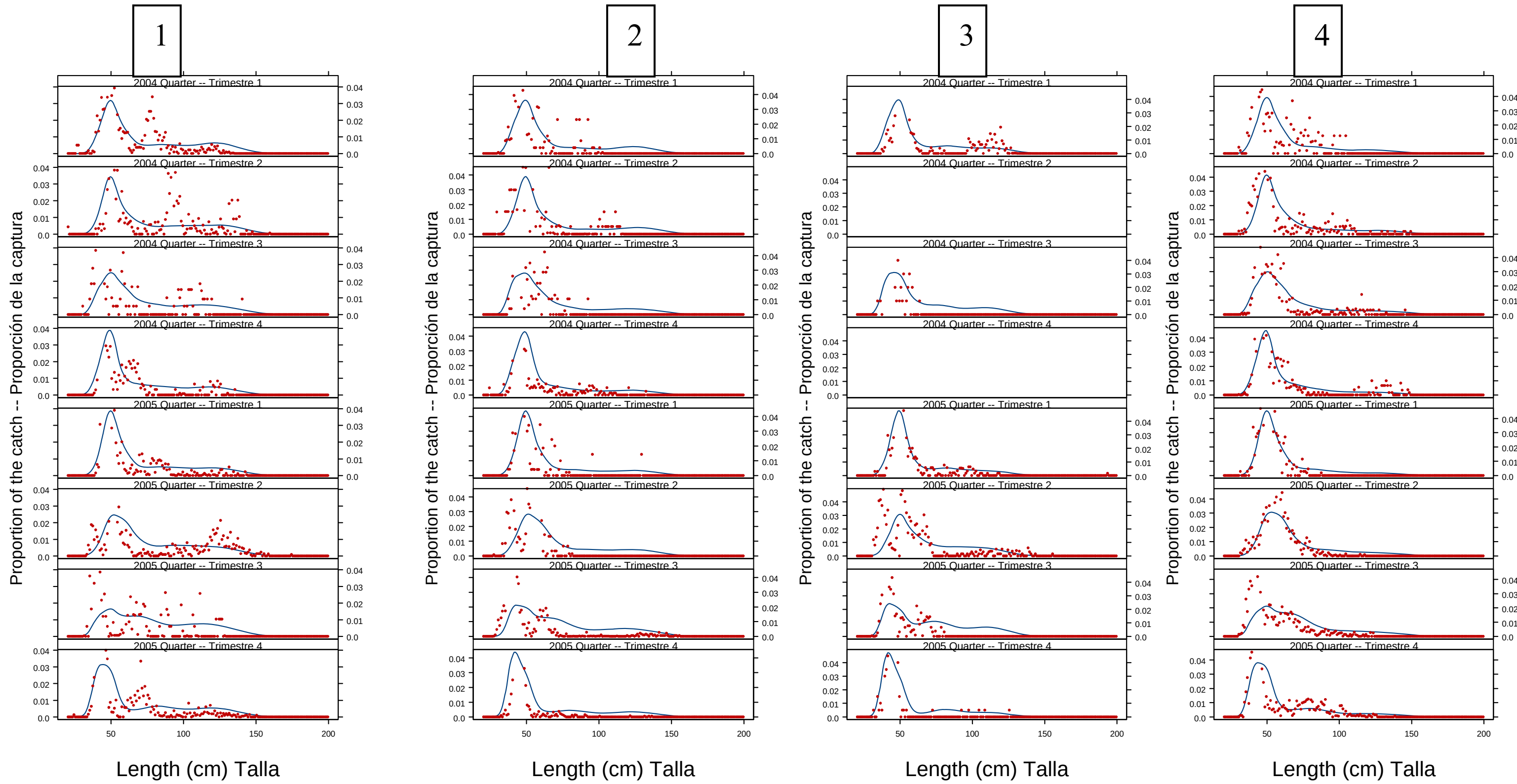


FIGURE 4.8a. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin by the fisheries that take tunas in association with floating objects (Fisheries 1-4).

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

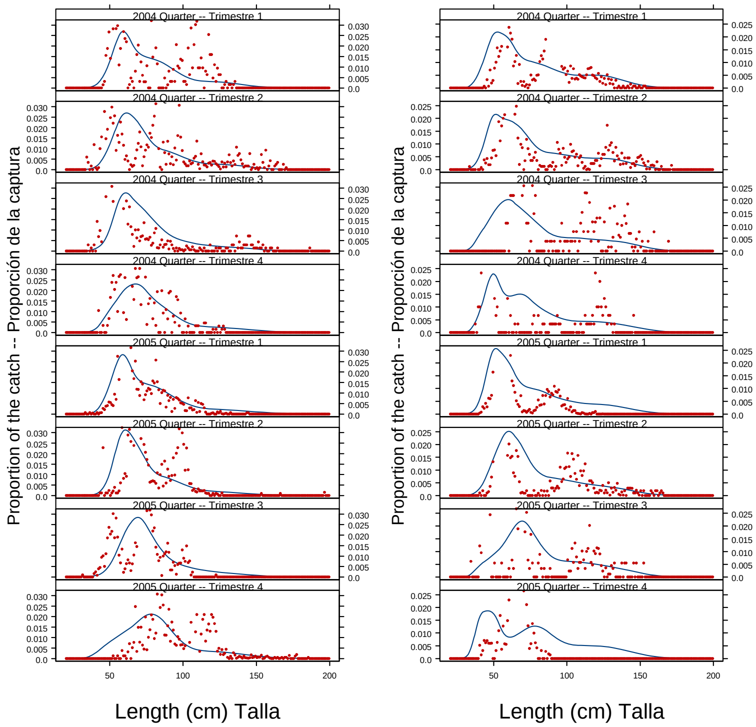


FIGURE 4.8b. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin tuna by the fisheries that take tunas in unassociated schools (Fisheries 5 and 6).

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

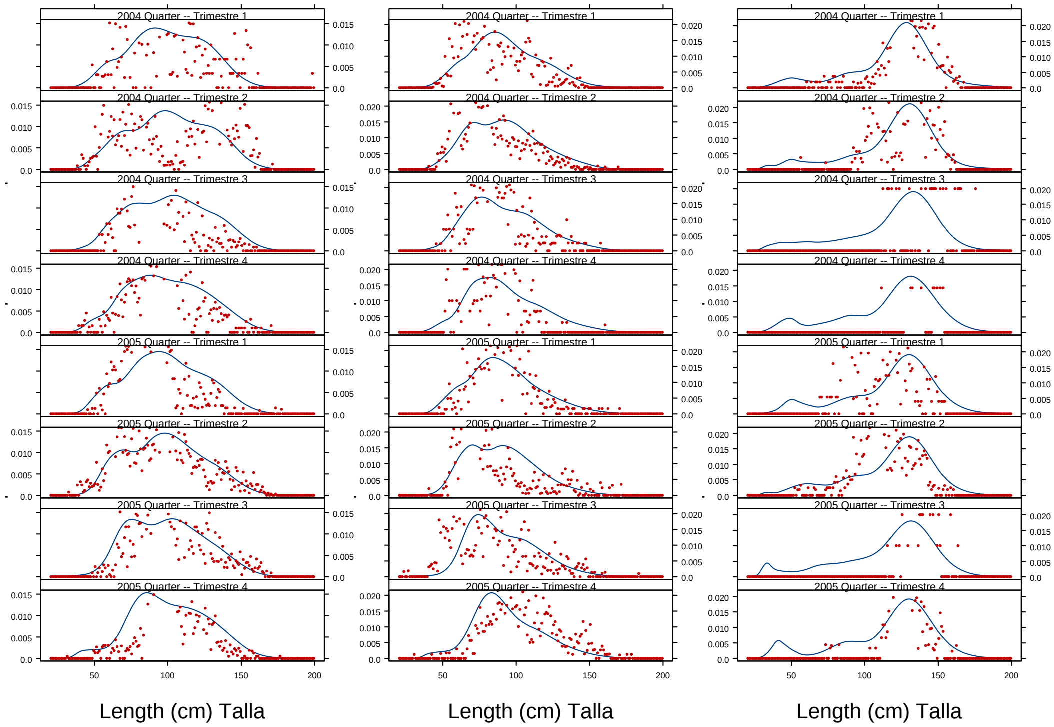


FIGURE 4.8c. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin tuna by the fisheries that take tunas in association with dolphins (Fisheries 7-9).

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

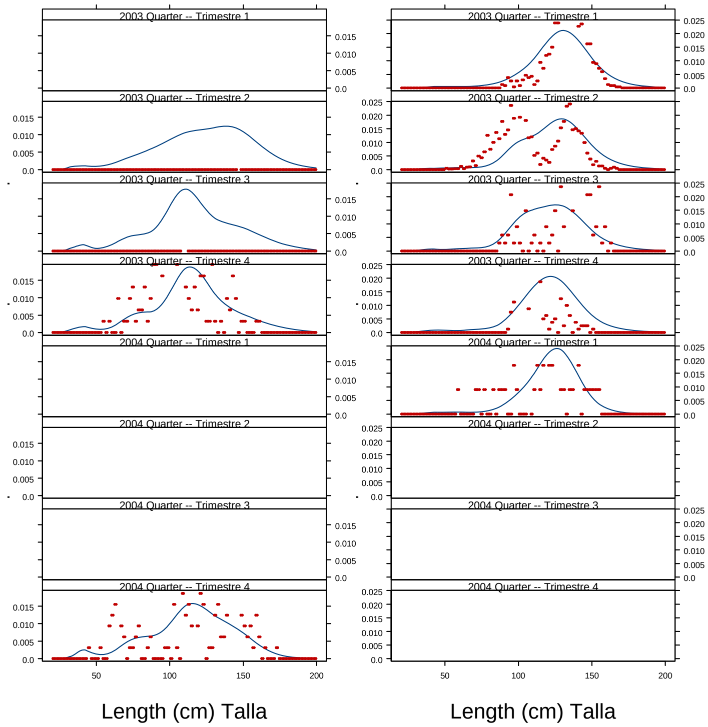


FIGURE 4.8d. Observed (dots) and predicted (curves) size compositions of the recent catches of yellowfin tuna by the longline fisheries (Fisheries 11-12).

FIGURA 4.8d. Composiciones por tamaño observadas (puntos) y predichas (curvas) de las capturas recientes de atún aleta amarilla por las pesquería cañera (Pesquería 11).

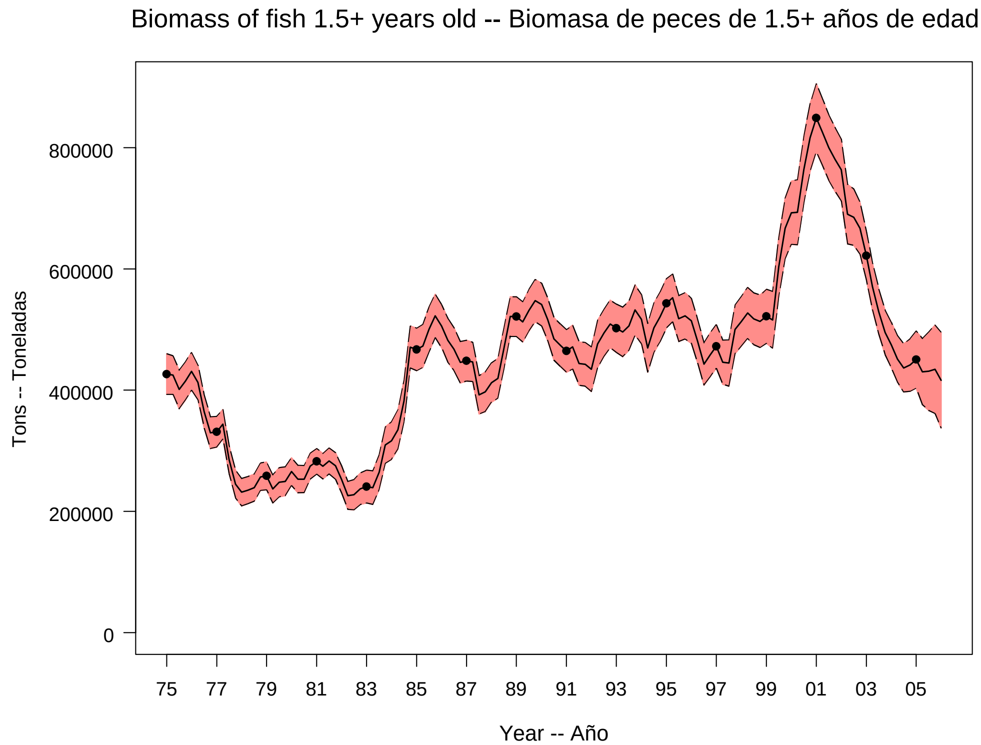


FIGURE 4.9a. Estimated biomass of yellowfin tuna in the EPO. The bold line illustrates the maximum likelihood estimates of the biomass, and the thin dashed lines the approximate 95% confidence intervals around those estimates. Since the assessment model represents time on a quarterly basis, there are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

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

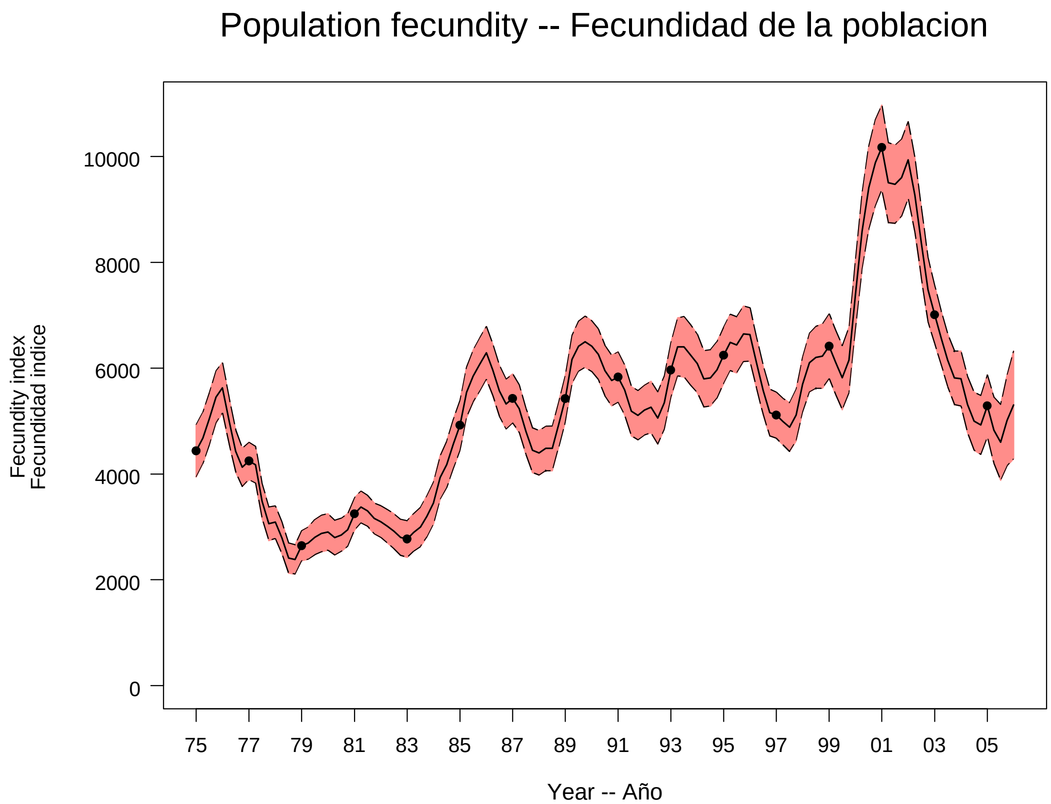


FIGURE 4.9b. Estimated relative spawning biomass of yellowfin tuna in the EPO. The bold line illustrates the maximum likelihood estimates of the biomass, and the thin dashed lines the approximate 95% confidence intervals around those estimates. Since the assessment model represents time on a quarterly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

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

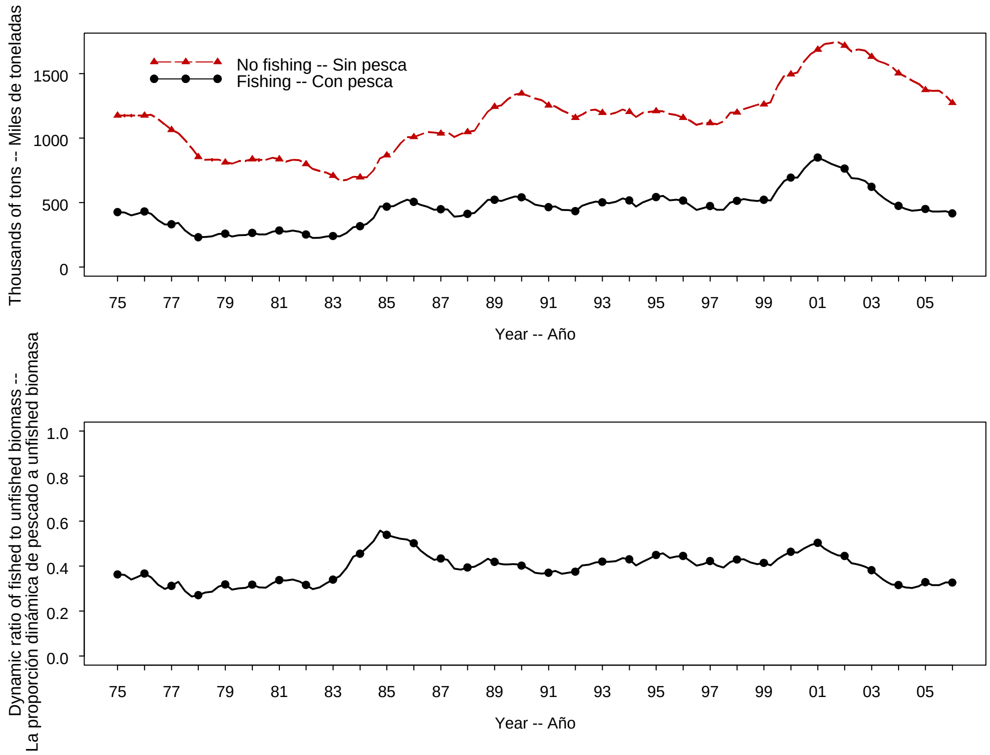


FIGURE 4.10a. Biomass trajectory of a simulated population of yellowfin tuna that was not exploited during 1975-2004 ("no fishing") and that predicted by the stock assessment model ("fishing"). t = metric tons.

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

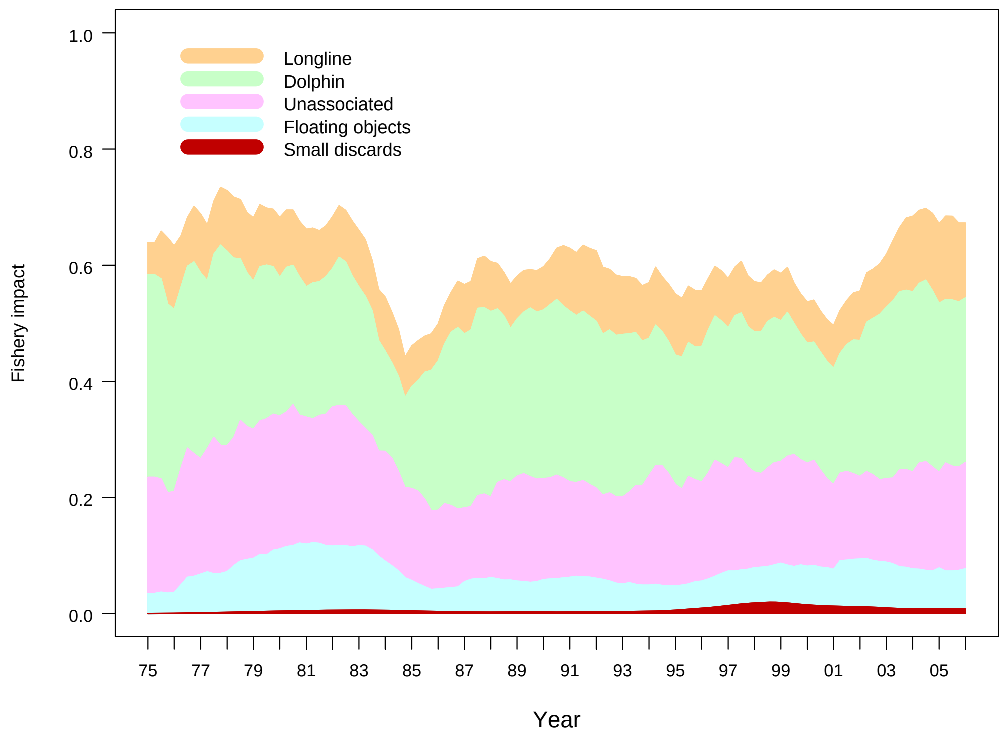


FIGURE 4.10b. Comparison of the relative impacts of the major fisheries on the biomass of yellowfin tuna in the EPO.

FIGURA 4.10b. Comparación de los impactos relativos de las pesquerías mayores sobre la biomasa de atún aleta amarilla en el OPO.

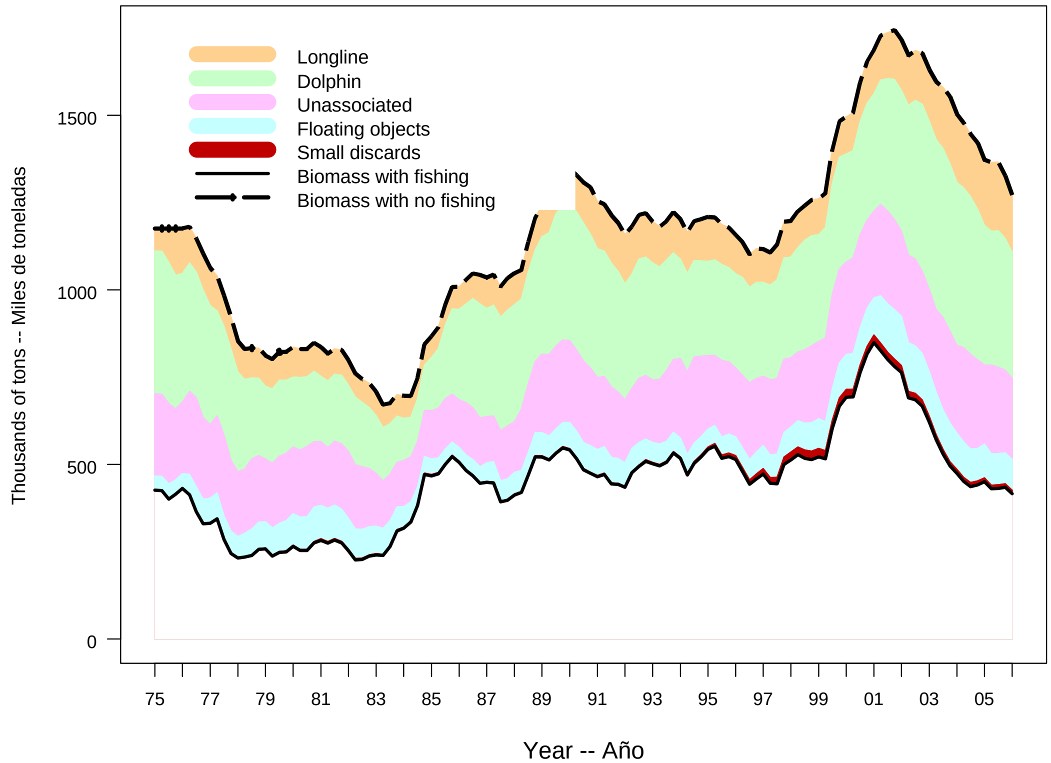


FIGURE 4.10c. Biomass trajectory of a simulated population of yellowfin tuna that was not exploited during 1975-2006 (dashed line) and that predicted by the stock assessment model (solid line). The shaded areas between the two lines show the portions of the fishery impact attributed to each fishing method. t = metric tons.

FIGURA 4.10c. Trayectoria de la biomasa de una población simulada de atún aleta amarilla no explotada durante 1975-2006 (línea de trazos) y la que predice el modelo de evaluación (línea sólida). Las áreas sombreadas entre las dos líneas represantan la porción del impacto de la pesca atribuida a cada método de pesca. t = toneladas métricas.

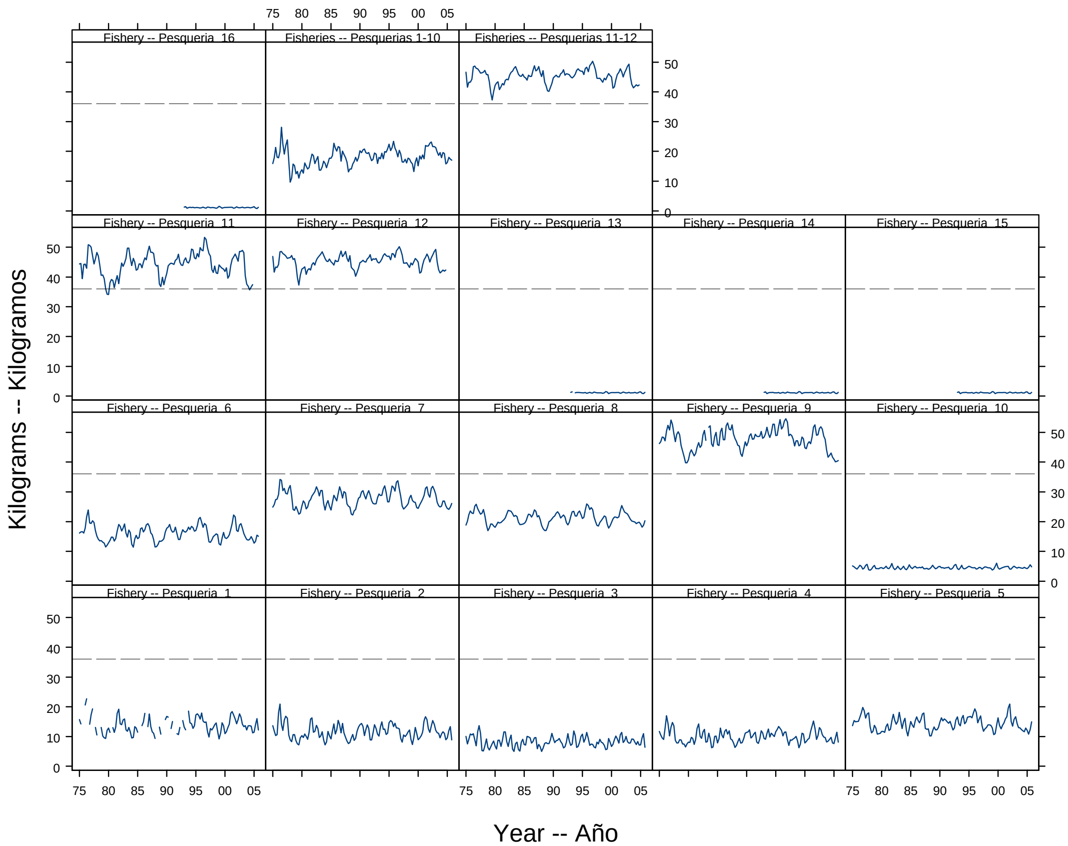


FIGURE 4.11. Estimated average weights of yellowfin tuna caught by the fisheries of the EPO. The time series for "Fisheries 1-10" is an average of Fisheries 1 through 10, and that for "Fisheries 11-12" is an average of Fisheries 11 and 12. The dashed line identifies the critical weight (35.2 kg).

FIGURA 4.11. Peso medio estimado de atún aleta amarilla capturado en las pesquerías del OPO. La serie de tiempo de "Pesquerías 1-10" es un promedio de las Pesquerías 1 a 10, y la de "Pesquerías 11-12" un promedio de las Pesquerías 11 y 12. La línea de trazos identifica el peso crítico (35,2 kg).

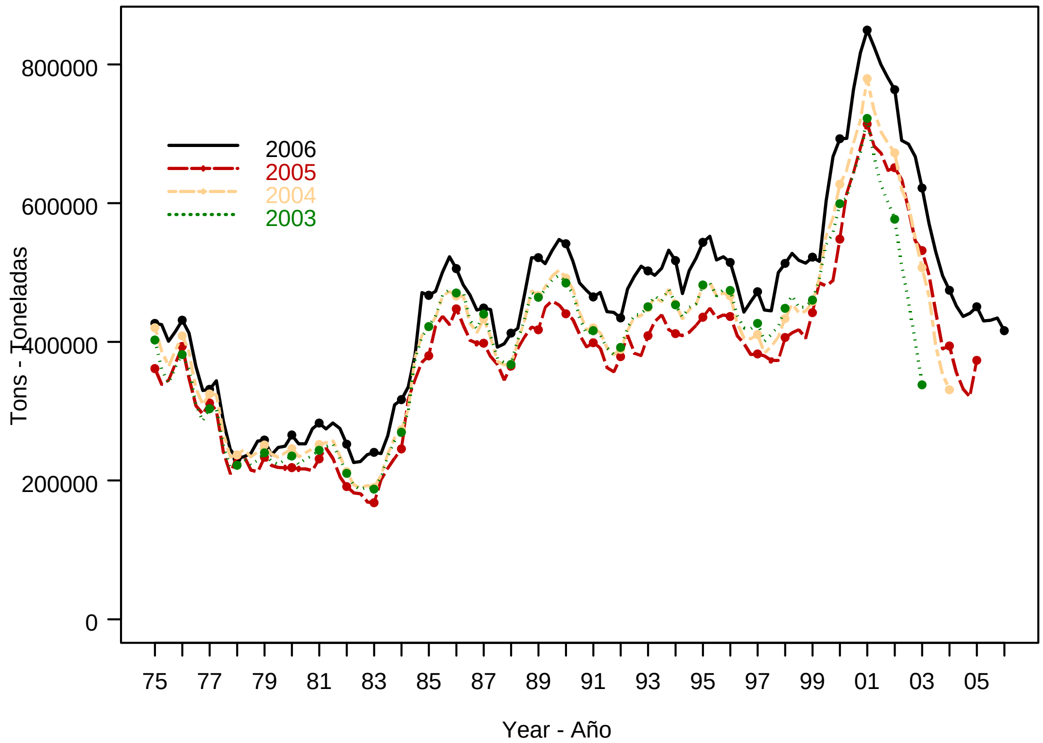


FIGURE 4.12a. Comparison of estimated biomasses of yellowfin tuna in the EPO from the most recent previous assessment and the current assessment. t = metric tons.
FIGURA 4.12a. Comparación de la biomasa estimada de atún aleta amarilla en el OPO de la evaluación previa más reciente y de la evaluación actual. t = toneladas métricas.

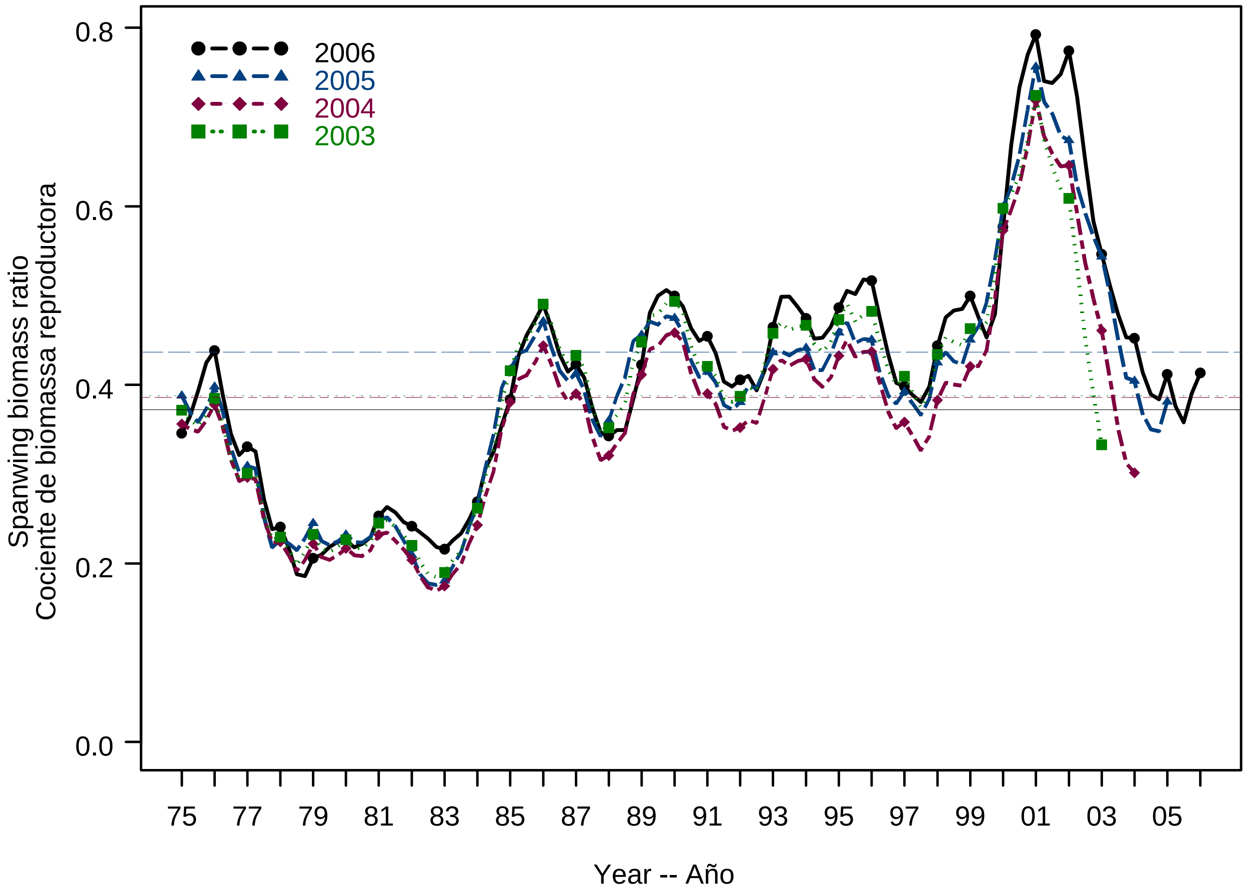


FIGURE 4.12b. Comparison of estimated spawning biomass ratios (SBRs) of yellowfin tuna from the current assessment with the most three recent previous assessments. The horizontal lines identify the SBRs at AMSY.

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

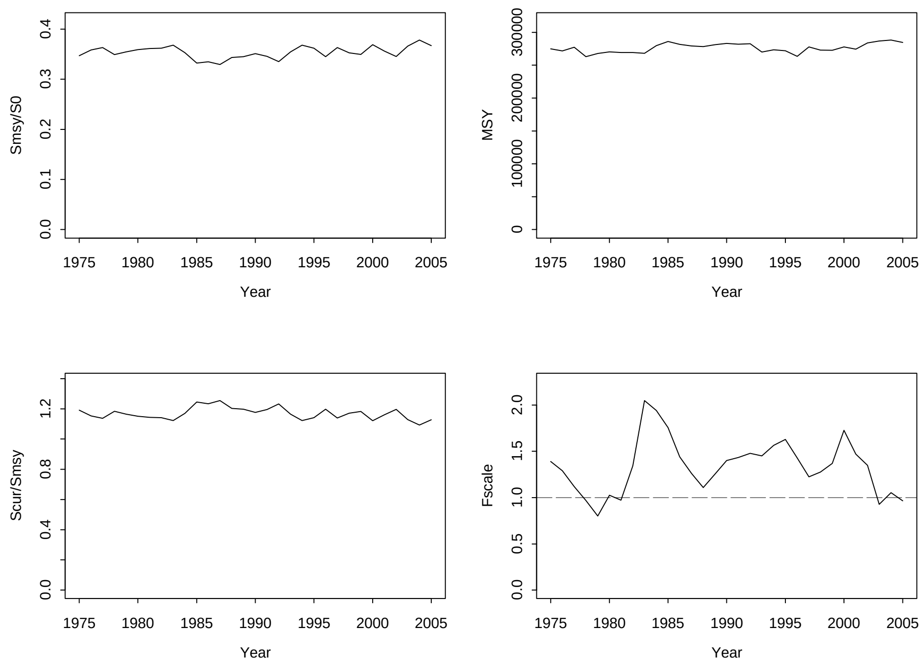


FIGURE 4.12c. Estimates of AMSY-related quantities calculated using the average age-specific fishing mortality for each year. (S_{cur} is the spawning biomass at the start of 2006). See the text for definitions.
FIGURA 4.12c. Estimaciones de cantidades relacionadas con el RMSP calculadas a partir de la mortalidad media por pesca por edad para cada año. (S_{cur} es la biomasa reproductora al principio de 2006). Ver definiciones en el texto.

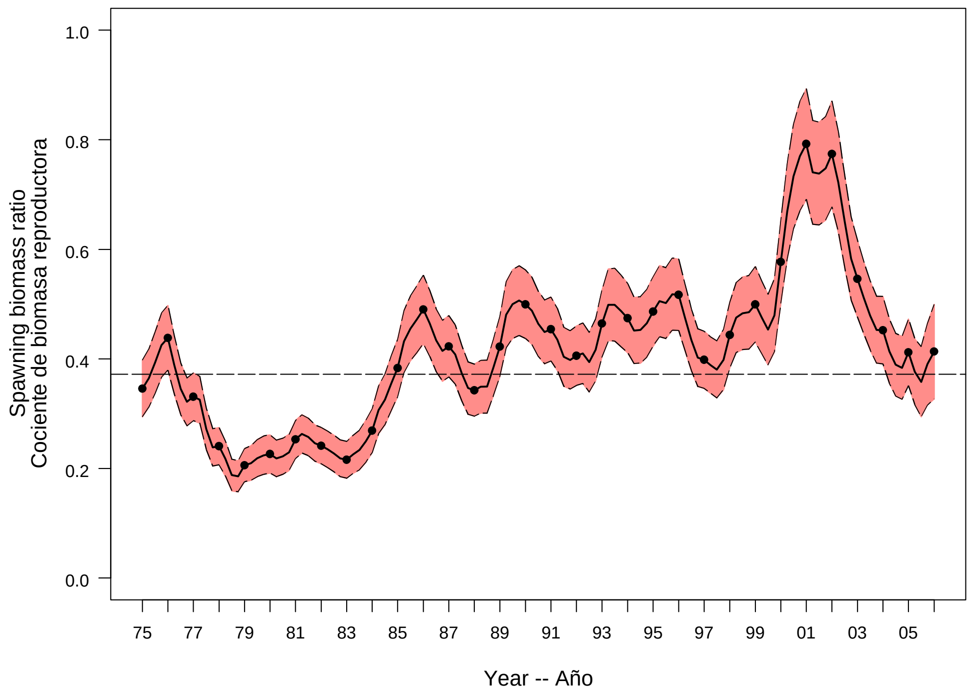


FIGURE 5.1. Estimated spawning biomass ratios (SBRs) for yellowfin tuna in the EPO. The thin dashed lines represent approximate 95% confidence intervals. The dashed horizontal line (at about 0.44) identifies the SBR at AMSY.

FIGURA 5.1. Cocientes de biomasa reproductora (SBR) estimadas para atún aleta amarilla en el OPO. Las líneas delgadas de trazos representan los intervalos de confianza de 95% aproximados. La línea de trazos horizontal (en aproximadamente 0,38) identifican el SBR en RMSP.

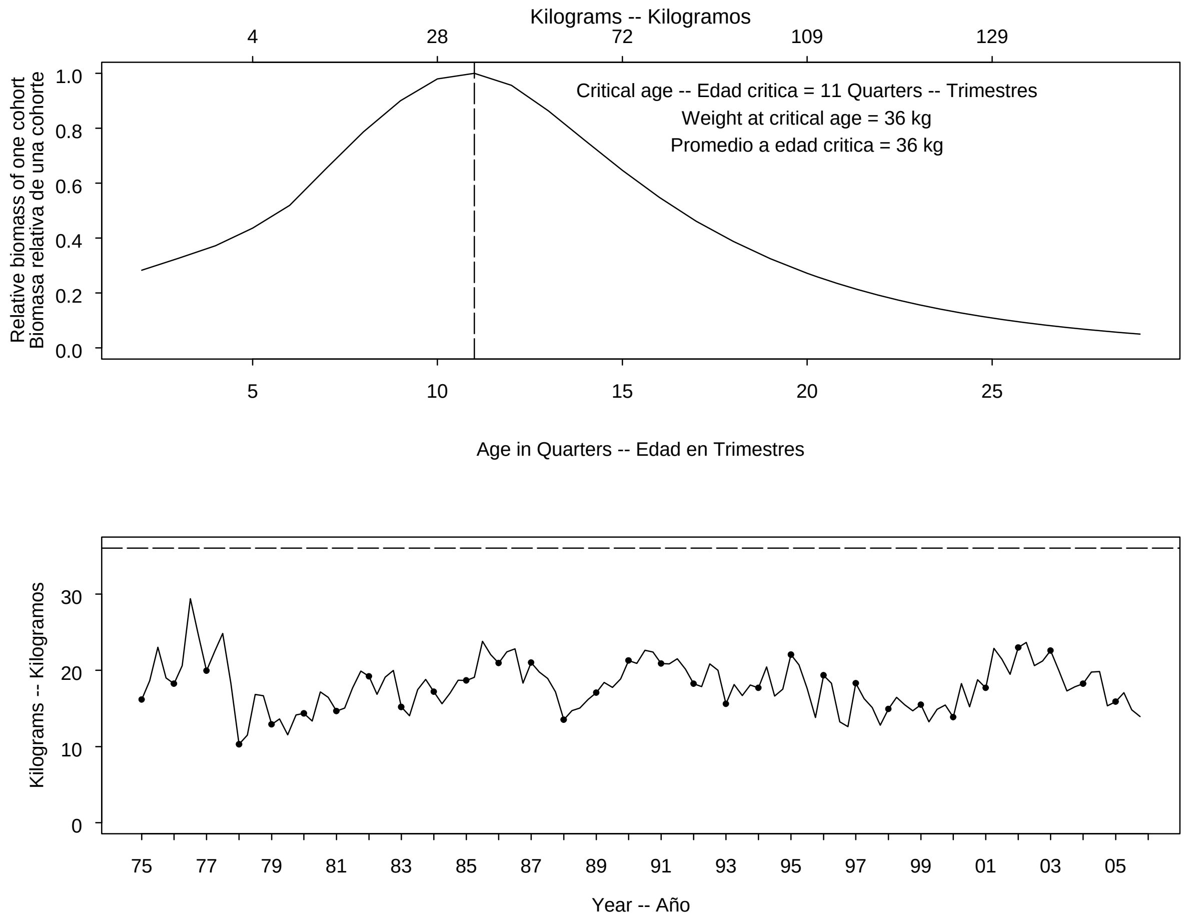


FIGURE 5.2. Combined performance of all fisheries that take yellowfin tuna in the EPO at achieving the maximum yield per recruit. The upper panel illustrates the growth (in weight) of a single cohort of yellowfin, and identifies the critical age and critical weight (Section 5). The lower panel illustrates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

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

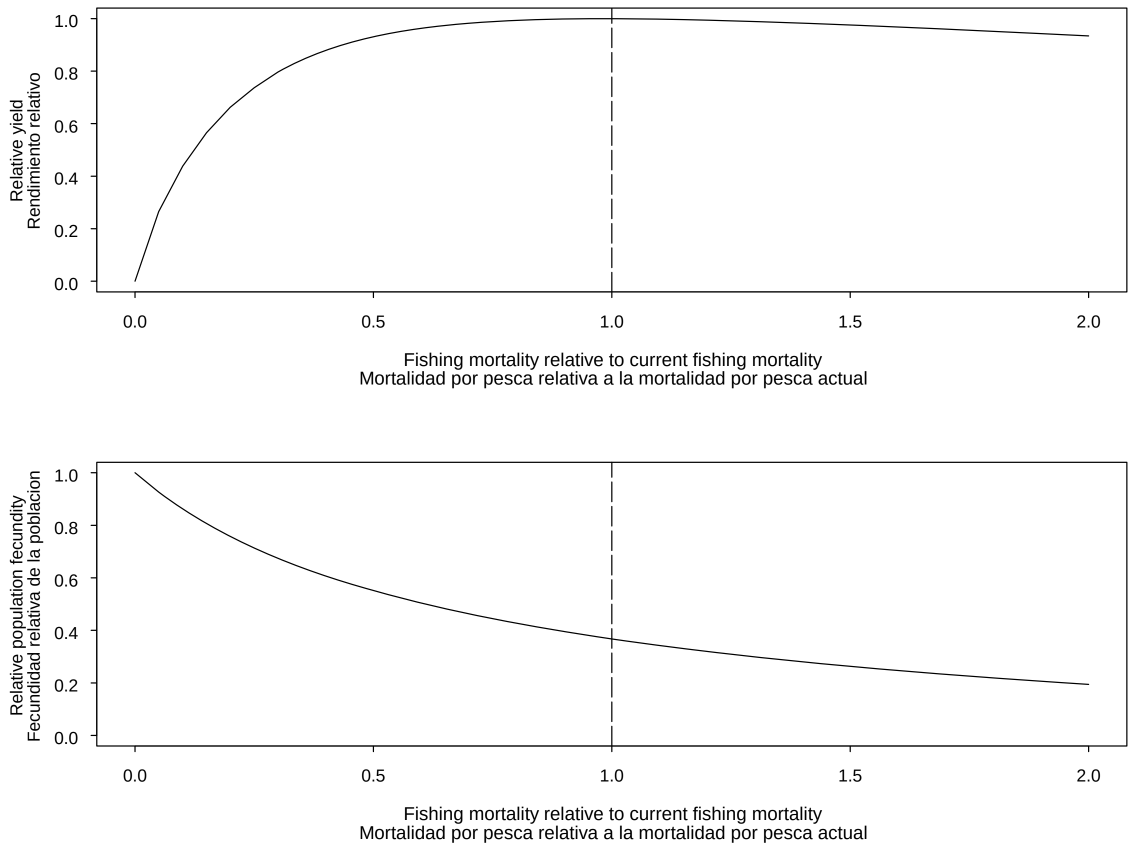


FIGURE 5.3. Predicted effects of long-term changes in fishing effort on the yield (upper panel) and spawning biomass (lower panel) of yellowfin tuna under average environmental conditions, constant recruitment, and the current age-specific selectivity pattern of all fisheries combined. The yield estimates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

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

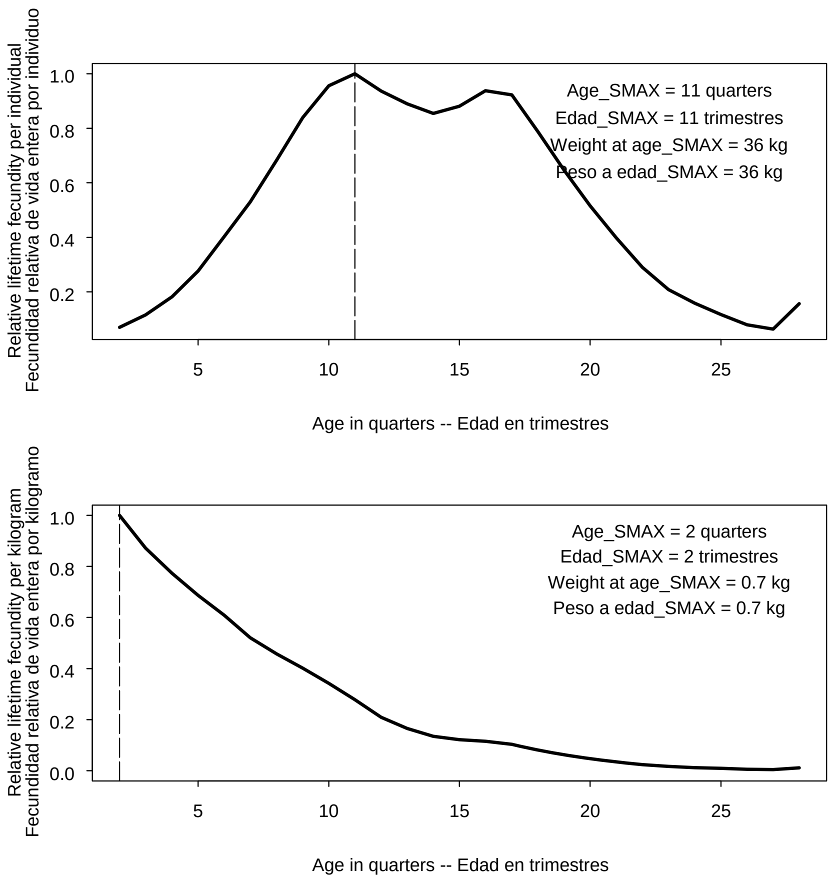


FIGURE 5.4. Marginal relative lifetime reproductive potential of yellowfin tuna at age based on individuals (upper panel) and weight (lower panel). Age_{SMAX} is the age at which the maximum marginal relative lifetime reproductive potential is realized. The vertical lines indicate the locations of Age_{SMAX}**.**

FIGURA 5.4. Potencial de reproducción relativo marginal de atún aleta amarilla 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 $Edad_{SMAX}$.

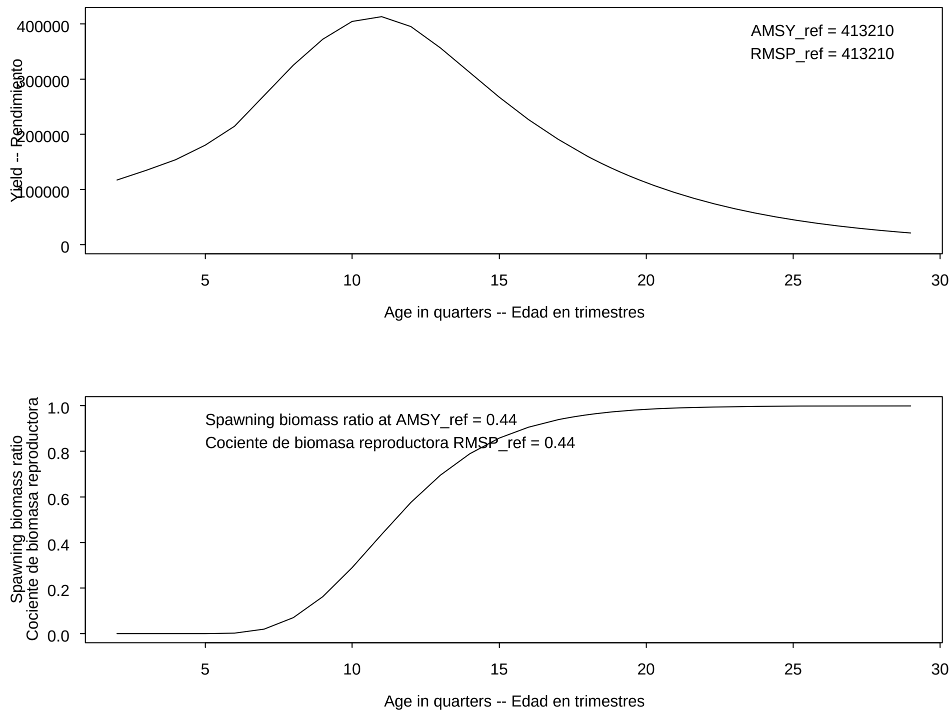


FIGURE 5.5. Yield calculated when catching only individual yellowfin tuna at a single age (upper panel) and the associated spawning biomass ratio (lower panel). t = metric tons.

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

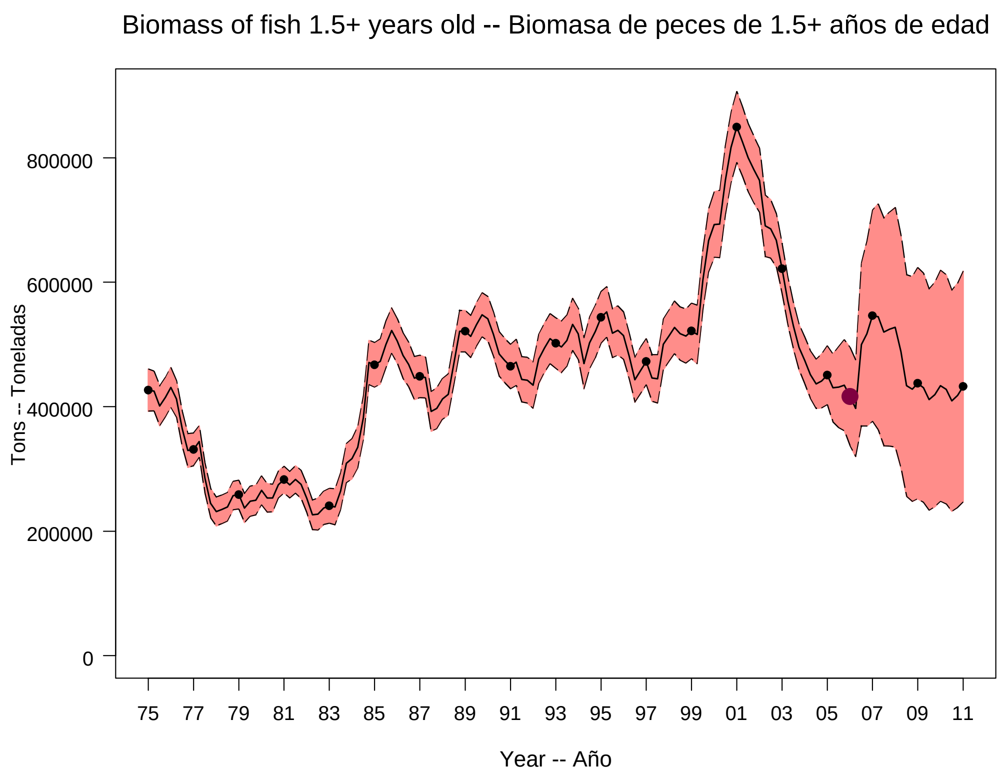


FIGURE 6.1. Biomasses projected during 2006-2010 for yellowfin tuna in the EPO under current effort. The thin dashed lines represent the 95% confidence intervals. The estimates after 2006 indicate the biomasses predicted to occur if the effort continues at the average of that observed in 2005 for surface fisheries, or 2004 for longline fisheries, catchability (with effort deviates) continues at the average of that observed in 2003 and 2004 for surface fisheries, or 2002 and 2003 for longline fisheries, and average environmental conditions occur during the next 5 years. t = metric tons.

FIGURA 6.1. Biomasa predicha durante 2004-2008 de atún aleta amarilla con esfuerza corriente. Las líneas delgadas de trazos representan los intervales de confianza de 95%. Las estimaciones a partir de 2004 (el punto grande) señalan la biomasa predicho si el esfuerzo continúa en el nivel promedio de 2003, la capturabilidad (con desvíos de esfuerzo) continúa en el promedio de 2001 y 2002, y con condiciones ambientales promedio en los 10 próximos años. t = toneladas métricas.

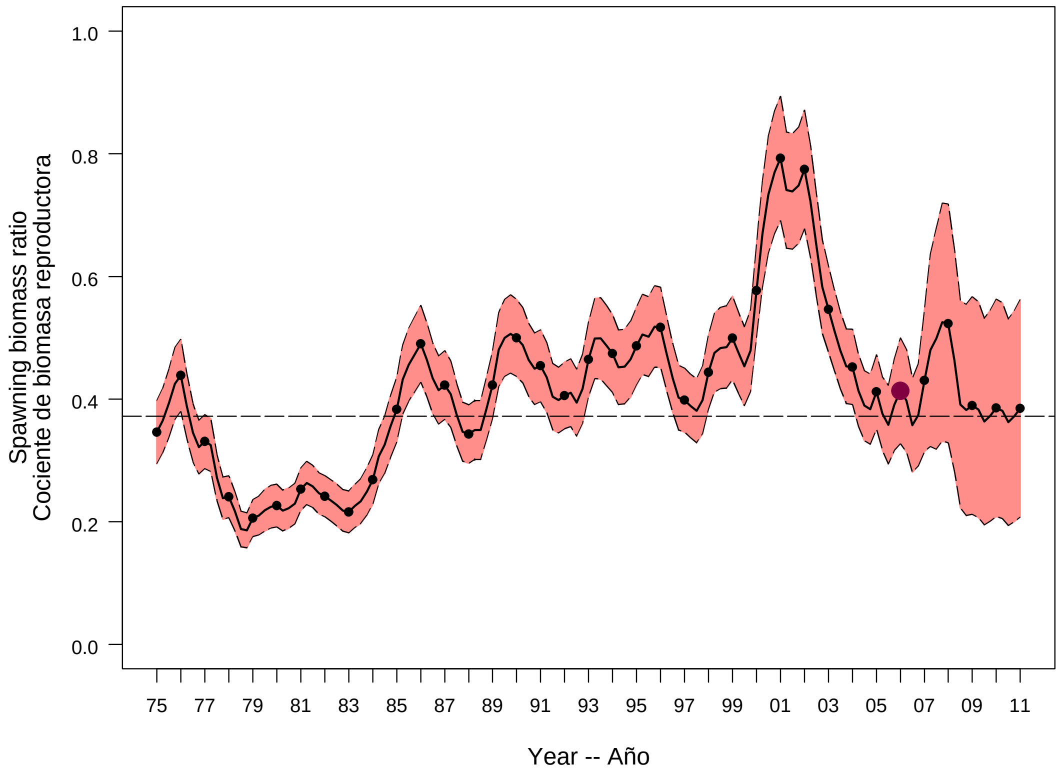


FIGURE 6.2. Spawning biomass ratios (SBRs) for 1975-2004 and SBRs projected during 2006-2010 for yellowfin tuna in the EPO. The dashed horizontal line (at 0.44) identifies SBR_{AMSY} (Section 5.3), and the thin dashed lines represent the 95% confidence intervals of the estimates. The estimates after 2006 indicate the SBR predicted to occur if the effort continues at the average of that observed in 2005 for surface fisheries, or 2004 for longline fisheries, catchability (with effort deviates) continues at the average of that observed in 2003 and 2004 for surface fisheries, or 2002 and 2003 for longline fisheries, and average environmental conditions occur during the next 5 years.

FIGURA 6.2. Cocientes be biomasa reproductora **(**SBR) para 1975-2003 y SBRs proyectados durante 2004-2009 para el atún aleta amarilla en el OPO por el método de aproximación de perfil de verosimilitud. La línea de trazos horizontal (en 0.38) identifica SBR_{RMSP} (Sección 5.3), y las líneas delgadas de trazos representan los intervalos de confianza de 95% de las estimaciones. Las estimaciones a partir de 2004 (el punto grande) señalan el SBR predicho si el esfuerzo continúa en el nivel promedio de 2003, la capturabilidad (con desvíos de esfuerzo) continúa en el promedio de 2001 y 2002, y con condiciones ambientales promedio en los 10 próximos años.

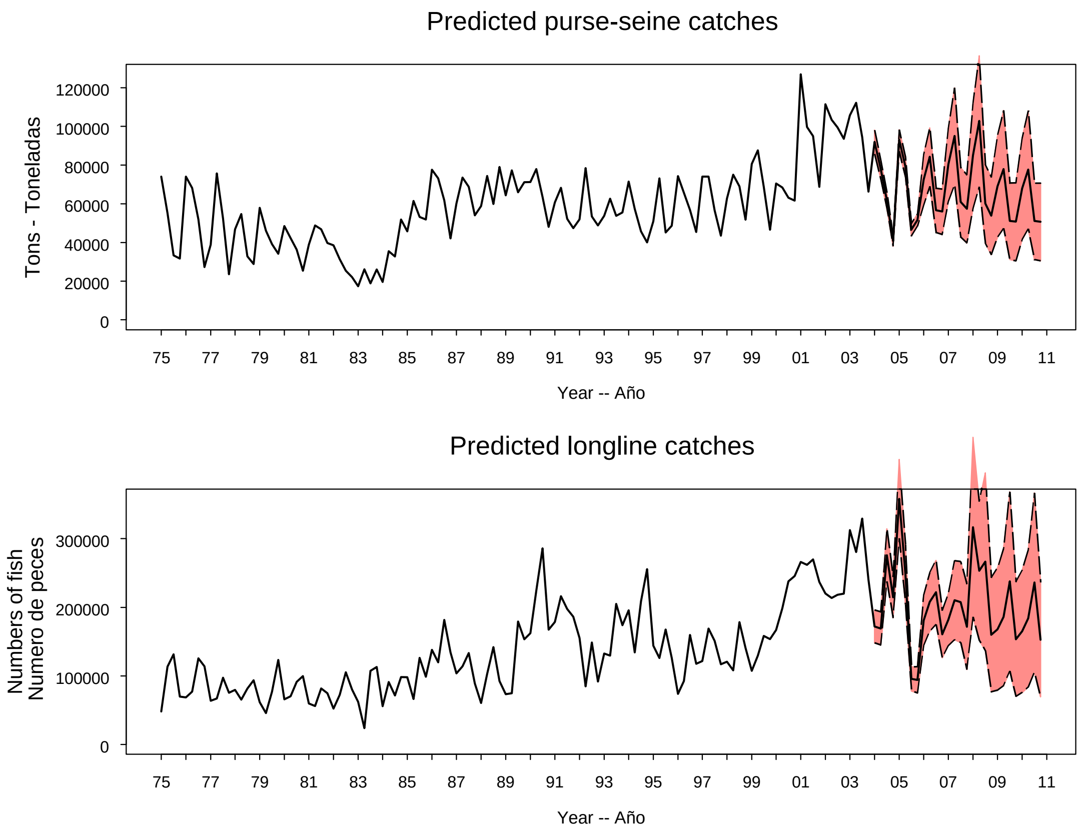


FIGURE 6.3. Catches of yellowfin tuna during 1975-2005 and simulated catches of yellowfin tuna during 2006-2010 by the purse-seine and pole-and-line fleets (upper panel) and the longline fleet (lower panel). The thin dashed lines represent the estimated 95% confidence limits of the estimates. The estimates after 2006 indicate the catches predicted to occur if the effort continues at the average of that observed in 2005 for surface fisheries, or 2004 for longline fisheries, catchability (with effort deviates) continues at the average of that observed in 2003 and 2004 for surface fisheries, or 2002 and 2003 for longline fisheries, and average environmental conditions occur during the next 5 years. t = metric tons.

FIGURA 6.3. Capturas de atún aleta amarilla durante 1975-2003 y capturas simuladas de atún aleta amarilla durante 2004-2008 por las flotas de cerco y caña (recuadro superior) y la flota palangrera (recuadro inferior), usando el método de aproximación de perfil de verosimilitud. Las líneas delgadas de trazos representan los intervalos de confianza de 95% de las estimaciones. Las estimaciones a partir de 2004 señalan las capturas predichas si el esfuerzo continúa en el nivel promedio de 2003, la capturabilidad (con desvíos de esfuerzo) continúa en el promedio de 2001 y 2002, y con condiciones ambientales promedio en los 10 próximos años. t = toneladas métricas.

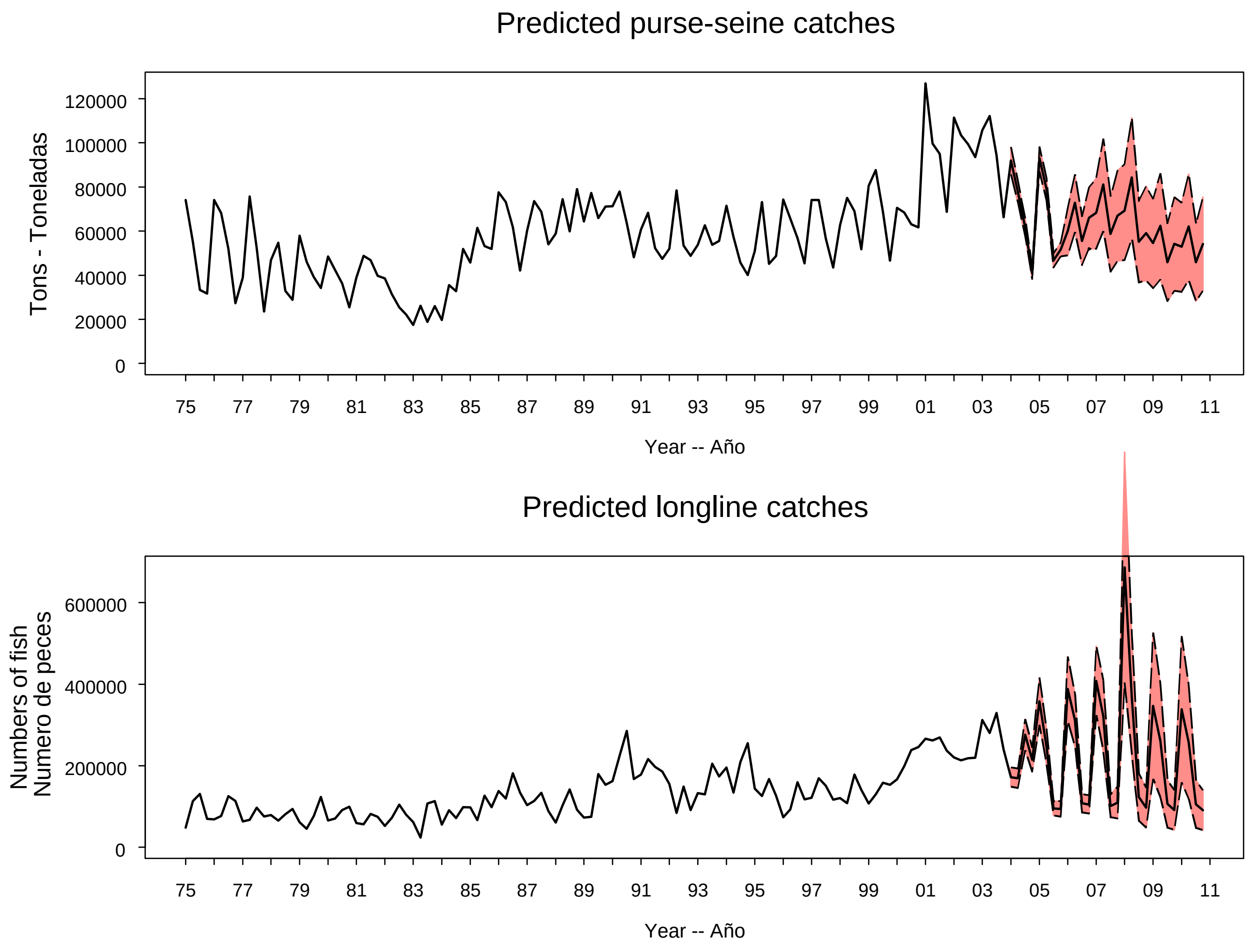


FIGURE 6.3a. Catches of yellowfin tuna during 1975-2005 and simulated catches of yellowfin tuna during 2006-2010 by the purse-seine and pole-and-line fleets (upper panel) and the longline fleet (lower panel). The figure differs from Figure 6.3 in that catchability (with effort deviates) after 2006 continues at the long term median. The thin dashed lines represent the estimated 95% confidence limits of the estimates. t = metric tons.

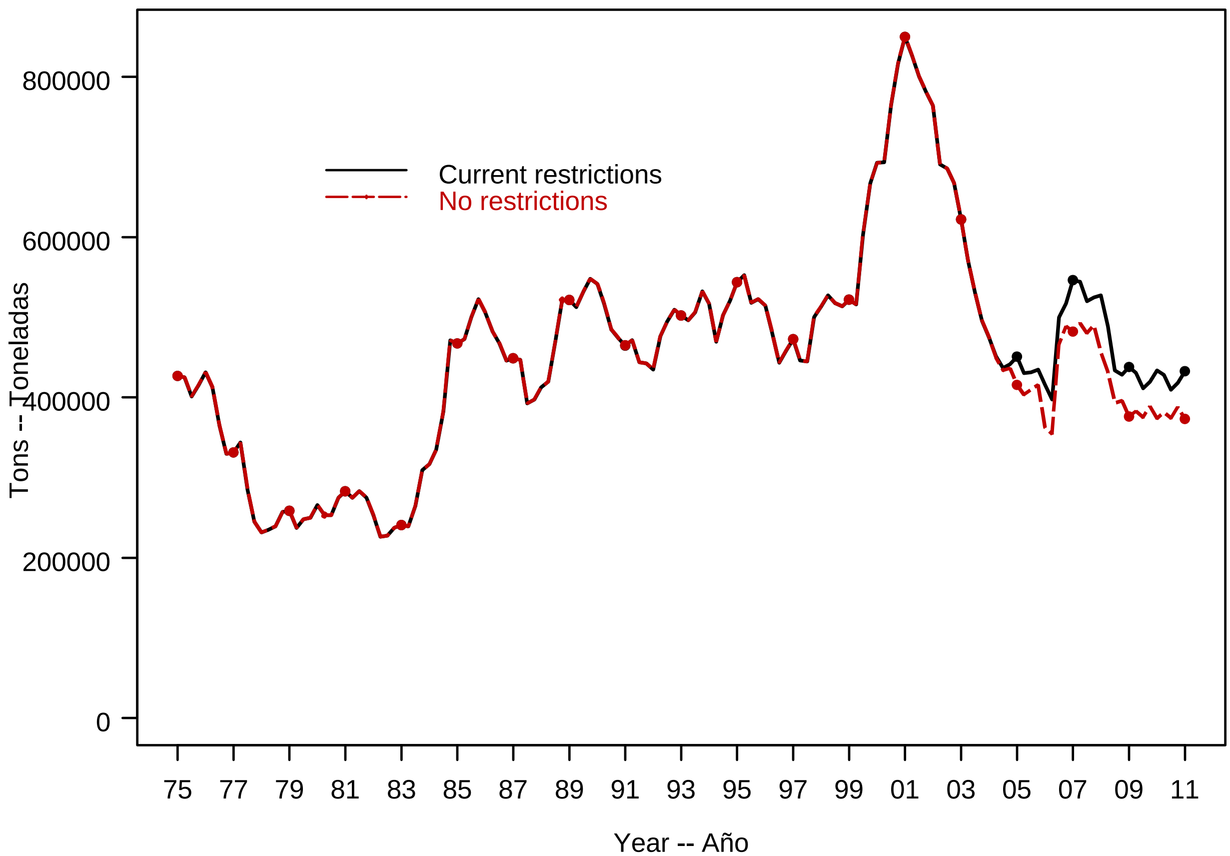


FIGURE 6.4. Biomass projected during 2005-2011 for yellowfin tuna in the EPO under the current resolution and under effort projected without the current resolution. t = metric tons.

FIGURA 6.4. Proyección de la biomasa de atún aleta amarilla en el OPO durante 2004-2008, con el esfuerzo actual y una veda de seis semanas de la pesquería de superficie en el tercer trimestre. t = toneladas métricas.

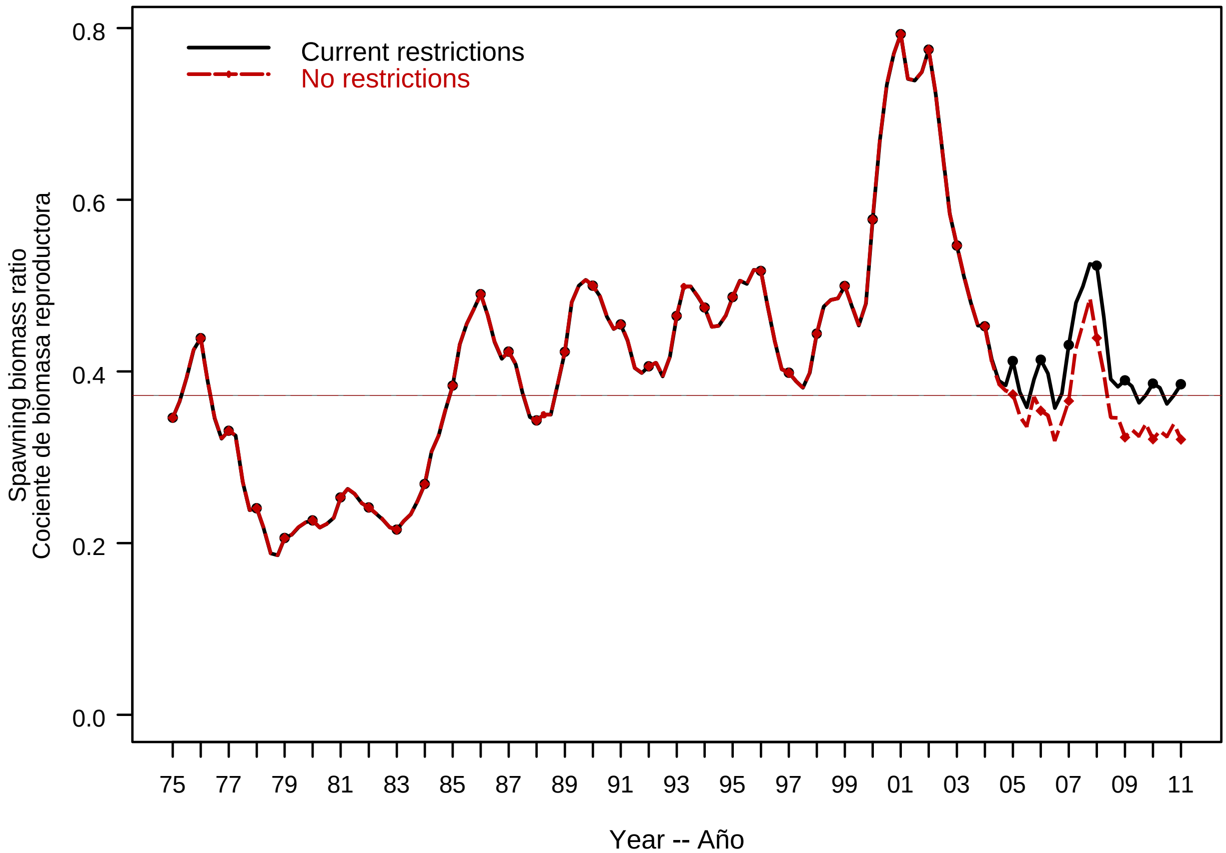


FIGURE 6.5. Spawning biomass ratios (SBRs) projected during 2005-2011 for yellowfin tuna in the EPO under the current resolution and under effort projected without the current resolution. The horizontal line (at 0.37) identifies SBR_{AMSY} (Section 5.3).

FIGURA 6.5. Cocientes de biomasa reproductora (SBR) de atún aleta amarilla en el OPO proyectados durante 2004-2008, con el esfuerzo actual y una veda de seis semanas de la pesquería de superficie en el tercer trimestre. La línea horizontal (en 0.38) identifica SBR_{RMSP} (Sección 5.3).

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

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

Fishery	Gear type	Set type	Years	Sampling areas	Catch data
Pesquería	**Tipo de arte**	**Tipo de lance**	**Año**	**Zonas de muestreo**	**Datos de captura**
1	PS	OBJ	1975-2005	11-12	retained catch + discards from inefficiencies in fishing process–captura retenida + descartes de ineficacias en el proceso de pesca
2	PS	OBJ	1975-2005	7, 9	
3	PS	OBJ	1975-2005	5-6, 13	
4	PS	OBJ	1975-2005	1-4, 8, 10	
5	PS	NOA	1975-2005	1-4, 8, 10	retained catch + discards–captura retenida + descartes
6	PS	NOA	1975-2005	5-7, 9, 11-13	
7	PS	DEL	1975-2005	2-3, 10	
8	PS	DEL	1975-2005	1, 4-6, 8, 13	
9	PS	DEL	1975-2005	7, 9, 11-12	
10	LP		1975-2005	1-13	retained catch only— captura retenida solamente
11	LL		1975-2005	N of-de 15°N	
12	LL		1975-2005	S of-de 15°N	
13	PS	OBJ	1993-2005	11-12	discards of small fish from size-sorting the catch by Fishery 1–descartes de peces pequeños de clasificación por tamaño en la Pesquería 1
14	PS	OBJ	1993-2005	7, 9	discards of small fish from size-sorting the catch by Fishery 2–descartes de peces pequeños de clasificación por tamaño en la Pesquería 2
15	PS	OBJ	1993-2005	5-6, 13	discards of small fish from size-sorting the catch by Fishery 3–descartes de peces pequeños de clasificación por tamaño en la Pesquería 3
16	PS	OBJ	1993-2005	1-4, 8, 10	discards of small fish from size-sorting the catch by Fishery 4–descartes de peces pequeños de clasificación por tamaño en la Pesquería 4

TABLE 4.1. Estimated total annual recruitment to the fishery at the age of two quarters (thousands of fish), initial biomass (metric tons present at the beginning of the year), and spawning biomass (relative to maximum spawning biomass) of yellowfin tuna in the EPO. Biomass is defined as the total weight of yellowfin one and half years of age and older; spawning biomass is estimated with the maturity schedule and sex ratio data of Schaefer (1998) and scaled to have a maximum of 1.
TABLA 4.1. Reclutamiento anual total estimado a la pesquería a la edad de dos trimestres (en miles de peces), biomasa inicial (toneladas métricas presentes al principio de año), y biomasa reproductora relativa del atún aleta amarilla en el OPO. Se define la biomasa como el peso total de aleta amarilla de año y medio o más de edad; se estima la biomasa reproductora con el calendario de madurez y datos de proporciones de sexos de Schaefer (1998) y la escala tiene un máximo de 1.

Year	Total recruitment	Biomass of age-1.5+ fish	Relative spawning biomass
Año	Reclutamiento total	Biomasa de peces de edad 1.5+	Biomasa reproductora relativa
1975	107,145	426,529	0.44
1976	86,142	431,149	0.55
1977	136,982	331,325	0.42
1978	100,104	231,528	0.30
1979	130,710	258,521	0.26
1980	103,383	265,574	0.29
1981	71,397	282,666	0.32
1982	112,015	252,612	0.30
1983	179,842	240,695	0.27
1984	146,806	316,723	0.34
1985	126,731	467,199	0.48
1986	147,930	505,730	0.62
1987	246,042	448,544	0.53
1988	175,992	412,491	0.43
1989	148,305	521,366	0.53
1990	146,973	541,380	0.63
1991	200,722	464,648	0.57
1992	161,934	434,594	0.51
1993	159,036	502,146	0.59
1994	142,245	516,974	0.60
1995	156,629	543,379	0.61
1996	210,540	514,339	0.65
1997	157,813	472,231	0.50
1998	312,826	513,260	0.56
1999	223,036	521,922	0.63
2000	239,119	692,843	0.73
2001	218,297	849,415	1.00
2002	172,654	763,585	0.98
2003	172,478	621,776	0.69
2004	164,714	474,425	0.57
2005	243,300	450,601	0.52
2006		416,171	0.52

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	33.06	0.7	16	154.22	80.96
3	40.73	1.33	17	159.06	89.07
4	49.01	2.35	18	163.25	96.51
5	58.34	4.03	19	166.84	103.2
6	68.48	6.61	20	169.89	109.14
7	78.74	10.17	21	172.48	114.36
8	89.2	14.95	22	174.67	118.9
9	99.43	20.89	23	176.51	122.81
10	109.28	27.96	24	178.06	126.16
11	118.63	36.03	25	179.35	129
12	127.36	44.86	26	180.43	131.41
13	135.17	53.9	27	181.33	133.45
14	142.28	63.15	28	182.08	135.16
15	148.64	72.26	29	182.7	136.59

TABLE 5.1. AMSY and related quantities for the base case and the stock-recruitment relationship sensitivity analysis. All analyses are based on average fishing mortality for 2003 and 2004. B_{recent} and B_{AMSY} are defined as the biomass of fish 2+ quarters old at the start of 2006 and at AMSY, respectively, and S_{recent} and S_{AMSY} are defined as indices of spawning biomass (therefore, they are not in metric tons). C_{recent} is the estimated total catch in 2005.
TABLA 5.1. RMSP y cantidades relacionadas para el caso base y los análisis de sensibilidad a la relación población-reclutamiento.

	Base case	h = 0.75	Linf.170	Linf.200
	Caso base	**h = 0.75**		
AMSY–RMSP	287,377	301,706	296,085	292,675
B_{AMSY} –B_{rm2}	420,343	551,532	421,933	432,480
S_{AMSY} —S_{rm2}	4,775	6,555	4,708	4,958
C_{RECENT}/AMSY—$C_{????}$/RMSP	1.06	1.01	1.03	1.04
B_{RECENT}/B_{AMSY} –$B_{????}/B_{RMSP}$	0.99	0.76	1.01	0.99
S_{RECENT}/S_{AMSY} –$S_{????}/S_{RMSP}$	1.11	0.82	1.14	1.10
$S_{AMSY}/S_{F=0}$ –$S_{RMSP}/S_{F=0}$	0.37	0.43	0.36	0.38
F multiplier—Multiplicador de *F*	0.98	0.67	1.05	1.00

TABLE 5.2a. Estimates of the AMSY and its associated quantities, obtained by assuming that each fishery is the only fishery operating in the EPO and that each fishery maintains its current pattern of age-specific selectivity (Figure 4.4). The estimates of the AMSY and B_{AMSY} are expressed in metric tons. OBJ = sets on floating objects; NOA = sets on unassociated fish; DEL = sets on dolphin-associated fish; LL = longline.

TABLA 5.2a. Estimaciones del RMSP y sus cantidades asociadas, obtenidas suponiendo que cada pesquería mantiene su patrón actual de selectividad por edad (Figure 4.4) y que cada pesquería es la única operando en el OPO. Se expresan las estimaciones de RMSP y B_{RMSP} en toneladas métricas. OBJ = lance sobre objeto flotante; NOA = lance sobre atunes no asociados; DEL = lances sobre delfines; LL = palangre.

Fishery	AMSY	B_{AMSY}	S_{AMSY}	$B_{\text{AMSY}}/B_{F=0}$	$S_{\text{AMSY}}/S_{F=0}$	*F* multiplier
Pesquería	**RMSP**	B_{RMSP}	S_{RMSP}	$B_{\text{RMSP}}/B_{F=0}$	$S_{\text{RMSP}}/S_{F=0}$	**Multiplicador de *F***
All—Todos	287,377	420,343	4,775	0.36	0.37	0.98
OBJ	209,807	320,228	3,591	0.27	0.28	10.63
NOA	258,003	389,755	4,492	0.33	0.35	4.06
DEL	305,963	408,646	4,408	0.35	0.34	2.07
LL	353,004	461,909	5,016	0.39	0.39	24.89

TABLE 5.2b. Estimates of the AMSY and its associated quantities, obtained by assuming that one fishery is not operating in the EPO and that each fishery maintains its current pattern of age-specific selectivity (Figure 4.4) . The estimates of the AMSY and B_{AMSY} are expressed in metric tons. OBJ = sets on floating objects; NOA = sets on unassociated fish; DEL = sets on dolphin-associated fish; LL = longline.

TABLA 5.2b. Estimaciones del RMSP y sus cantidades asociadas, obtenidas suponiendo que cada pesquería mantiene su patrón actual de selectividad por edad (Figure 4.4) y que cada pesquería es la única operando en el OPO. Se expresan las estimaciones de RMSP y B_{RMSP} en toneladas métricas. OBJ = lance sobre objeto flotante; NOA = lance sobre atunes no asociados; DEL = lances sobre delfines; LL = palangre.

Fishery	AMSY	B_{AMSY}	S_{AMSY}	$B_{\text{AMSY}}/B_{F=0}$	$S_{\text{AMSY}}/S_{F=0}$	*F* multiplier
Pesquería	**RMSP**	B_{RMSP}	S_{RMSP}	$B_{\text{RMSP}}/B_{F=0}$	$S_{\text{RMSP}}/S_{F=0}$	**Multiplicador de *F***
All—Todos	287,377	420,343	4,775	0.36	0.37	0.98
No OBJ	295,639	419,459	4,697	0.36	0.37	1.16
No NOA	296,778	424,910	4,775	0.36	0.37	1.35
No DEL	267,189	423,448	4,993	0.36	0.39	2.01
No LL	281,810	410,509	4,643	0.35	0.36	1.09

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

Steepness = 1

	All gears	**Purse-seine only**	**Longline only**	**Purse-seine adjusted**	**Longline adjusted**
	Base				
AMSY—RMSP	287,377	281,810	373,759	287,664	305,795
B_{AMSY}—B_{RMSP}	420,343	410,509	577,040	438,100	325,337
S_{AMSY}—S_{RMSP}	4,775	4,643	6,755	5,030	3,213
B_{AMSY}/B_0—B_{RMSP}/B_0	0.36	0.35	0.41	0.37	0.28
S_{AMSY}/S_0—S_{RMSP}/S_0	0.37	0.36	0.44	0.39	0.25
F multiplier—Multiplicador de *F*	0.98	1.09	12.41	0.91	19.26

Steepness = 0.75

	All gears	**Purse-seine only**	**Longline only**	**Purse-seine scaled**	**Longline scaled**
	h75				
AMSY—RMSP	301,706	294,402	373,759	305,618	290,117
B_{AMSY}—B_{RMSP}	551,532	543,385	577,040	581,968	398,508
S_{AMSY}—S_{RMSP}	6,555	6,431	6,755	6,974	4,454
B_{AMSY}/B_0—B_{RMSP}/B_0	0.39	0.39	0.41	0.41	0.28
S_{AMSY}/S_0—S_{RMSP}/S_0	0.43	0.42	0.44	0.46	0.29
F multiplier—Multiplicador de *F*	0.67	0.74	12.41	0.58	2.33

APPENDIX A1: SENSITIVITY ANALYSIS FOR THE STOCK-RECRUITMENT RELATIONSHIP

ANEXO A1: ANÁLISIS DE SENSIBILIDAD A LA RELACIÓN POBLACIÓN-RECLUTAMIENTO

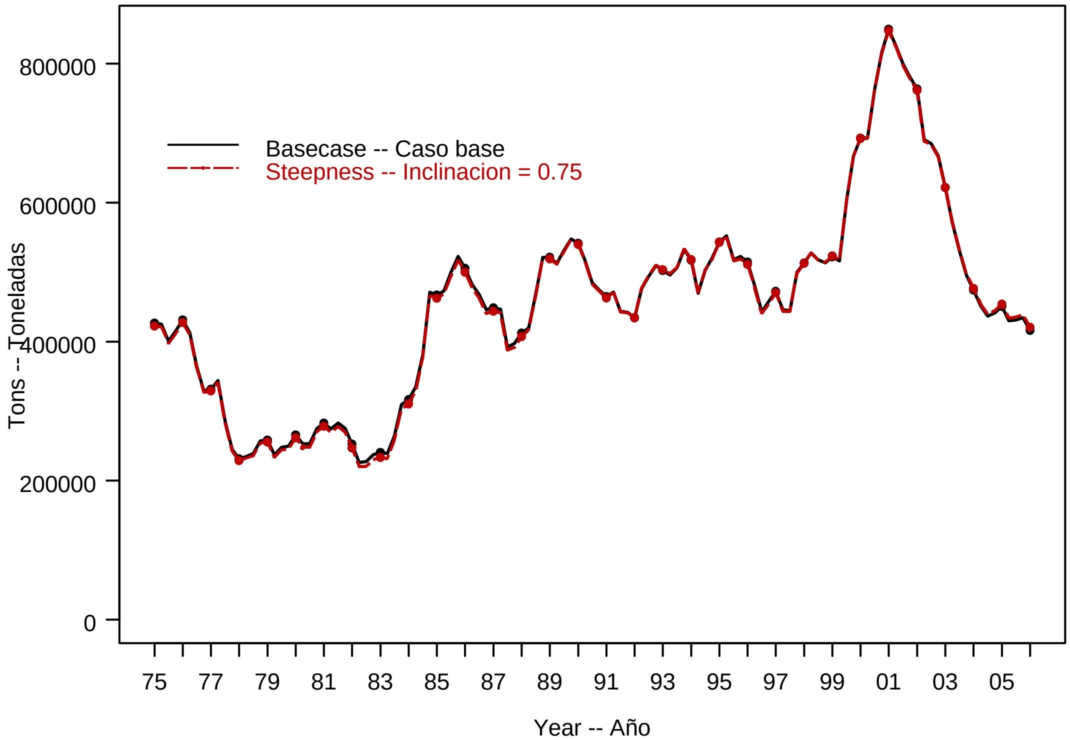


FIGURE A1.1. Comparison of the estimates of biomass of yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).
FIGURA A1.1. Comparación de las estimaciones de la biomasa de atún aleta amarilla del análisis sin relación población-reclutamiento (caso base) y con relación población-reclutamiento (inclinación = 0,75).

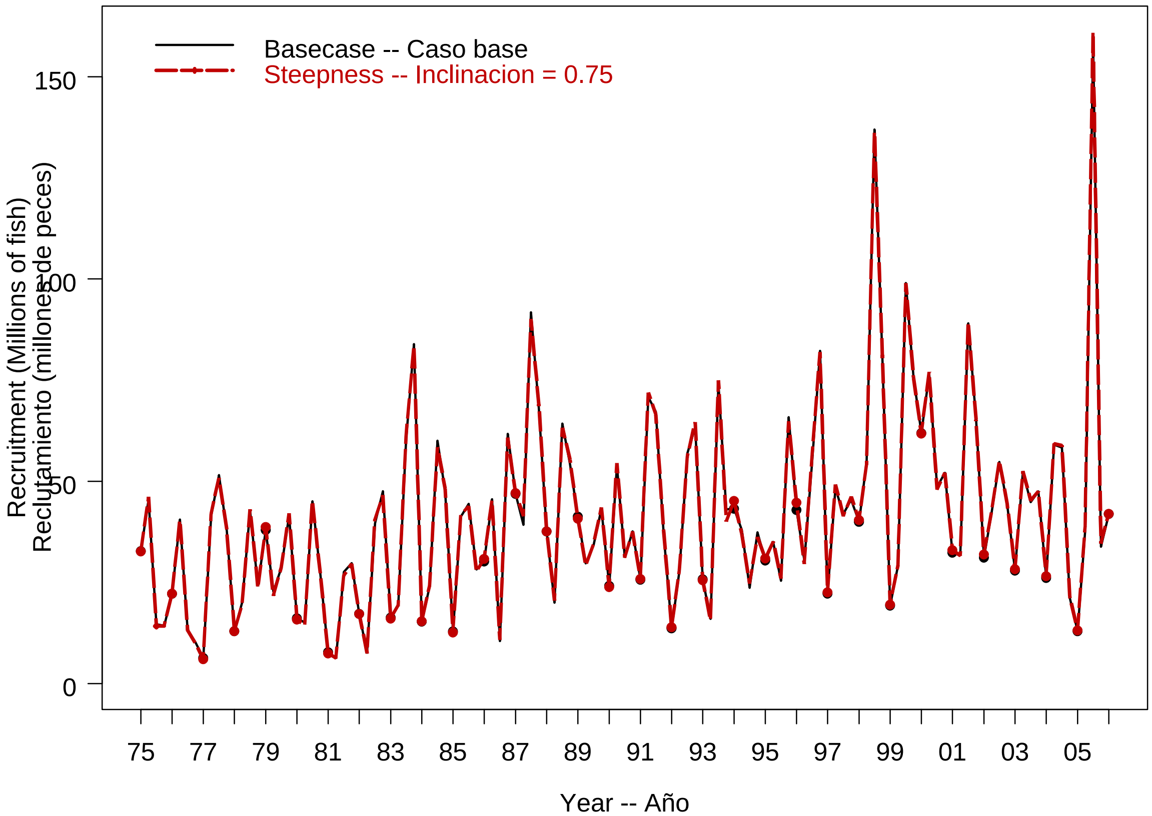


FIGURE A1.2. Comparison of estimates of recruitment of yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).
FIGURA A1.2. Comparación de las estimaciones de reclutamiento de atún aleta amarilla del análisis sin relación población-reclutamiento (caso base) y con relación población-reclutamiento (inclinación = 0,75)

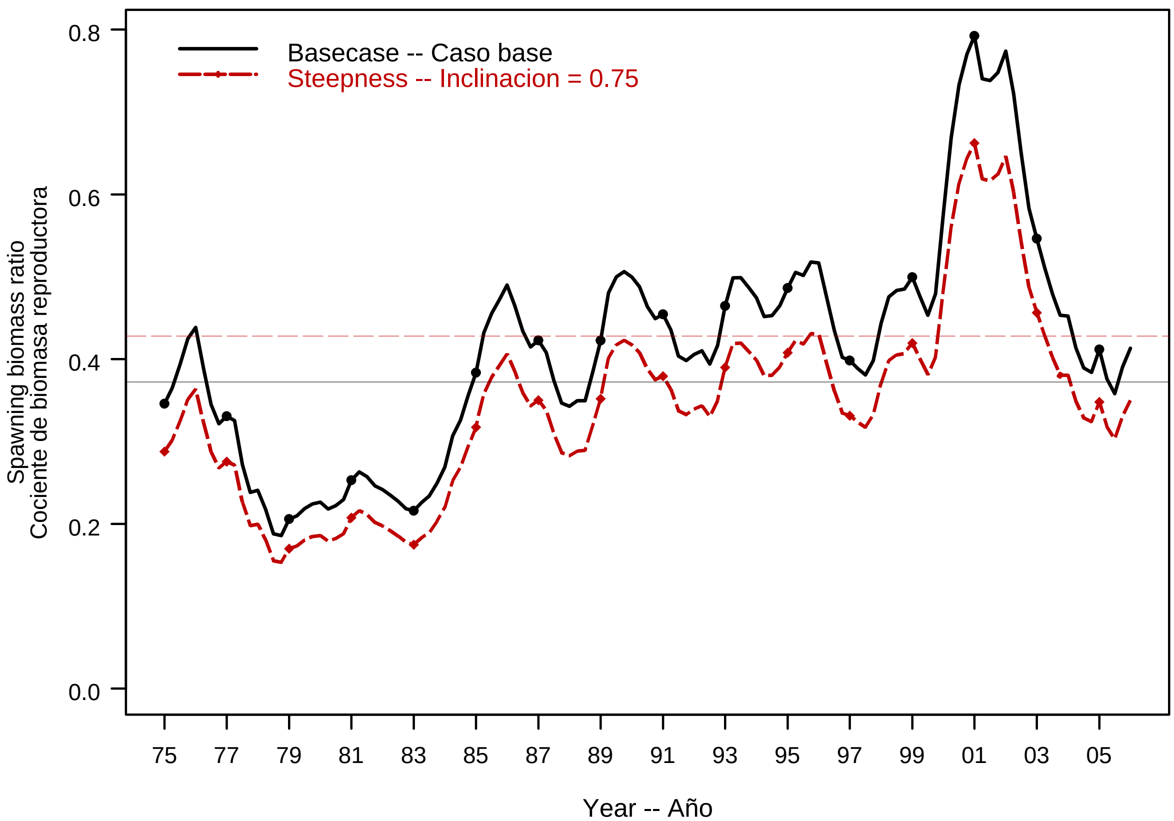


FIGURE A1.3a. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). The horizontal lines represent the SBRs associated with AMSY for the two scenarios.
FIGURA A1.3a. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún aleta amarilla del análisis sin (caso base) y con relación población-reclutamiento (inclinación = 0,75). Las líneas horizontales representan el SBR asociado con el RMSP para los dos escenarios.

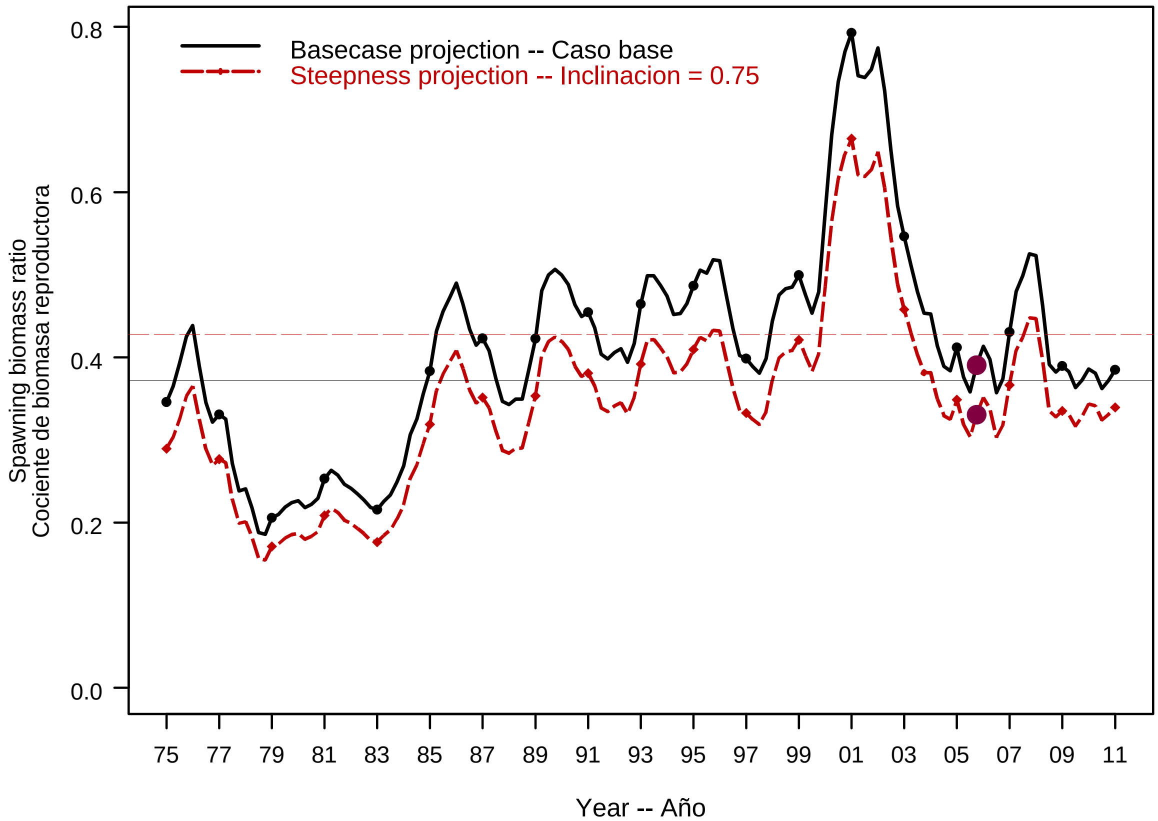


FIGURE A1.3b. Comparison of estimates of the spawning biomass ratios (SBRs) projectied during 2005-2011 for yellowfin tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). The horizontal lines represent the SBRs associated with AMSY for the two scenarios.

FIGURA A1.3b. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún aleta amarilla del análisis sin (caso base) y con relación población-reclutamiento (inclinación = 0,75). Las líneas horizontales representan el SBR asociado con el RMSP para los dos escenarios.

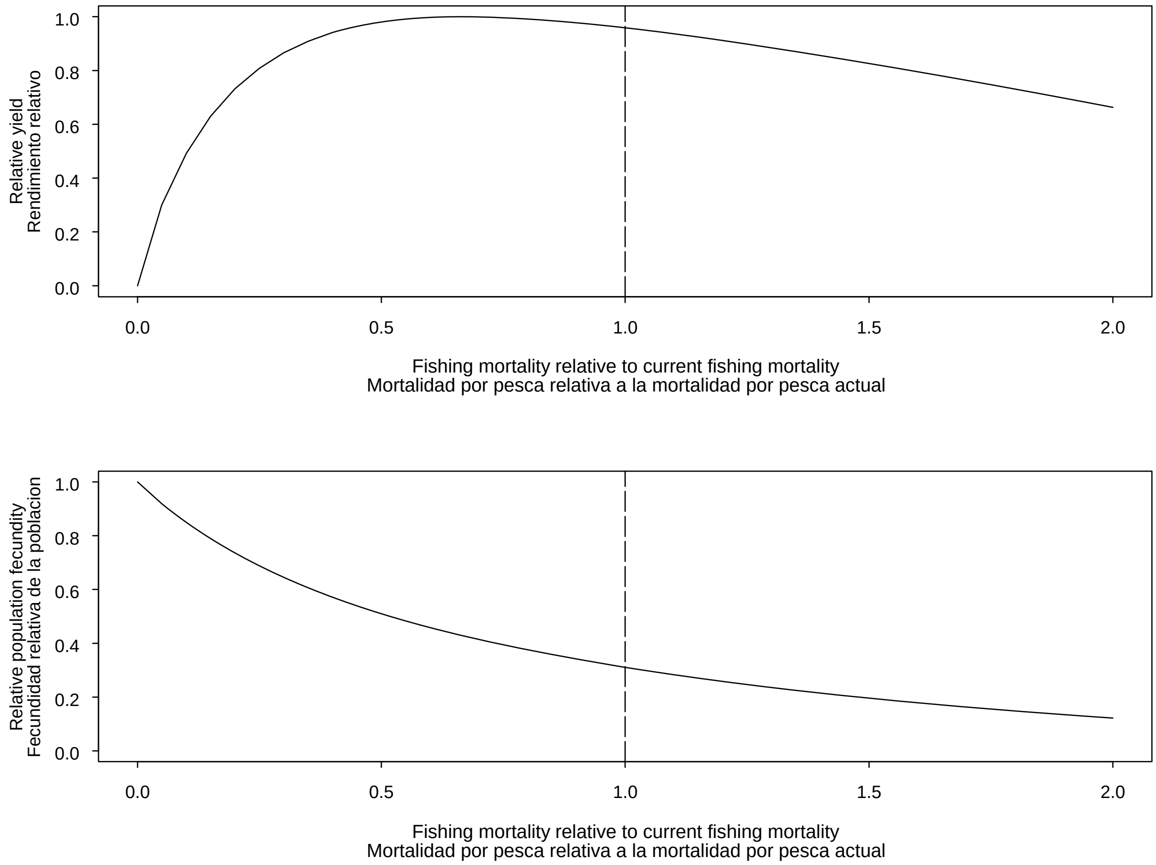


FIGURE A1.4. Relative yield (upper panel) and the associated spawning biomass ratio (lower panel) of yellowfin tuna when the stock assessment model has a stock-recruitment relationship (steepness = 0.75).
FIGURA A1.4. Rendimiento relativo (recuadro superior) y el cociente de biomasa reproductora asociado (recuadro inferior) de atún aleta amarilla cuando el modelo de evaluación de la población incluye una relación población-reclutamiento (inclinación = 0.75).

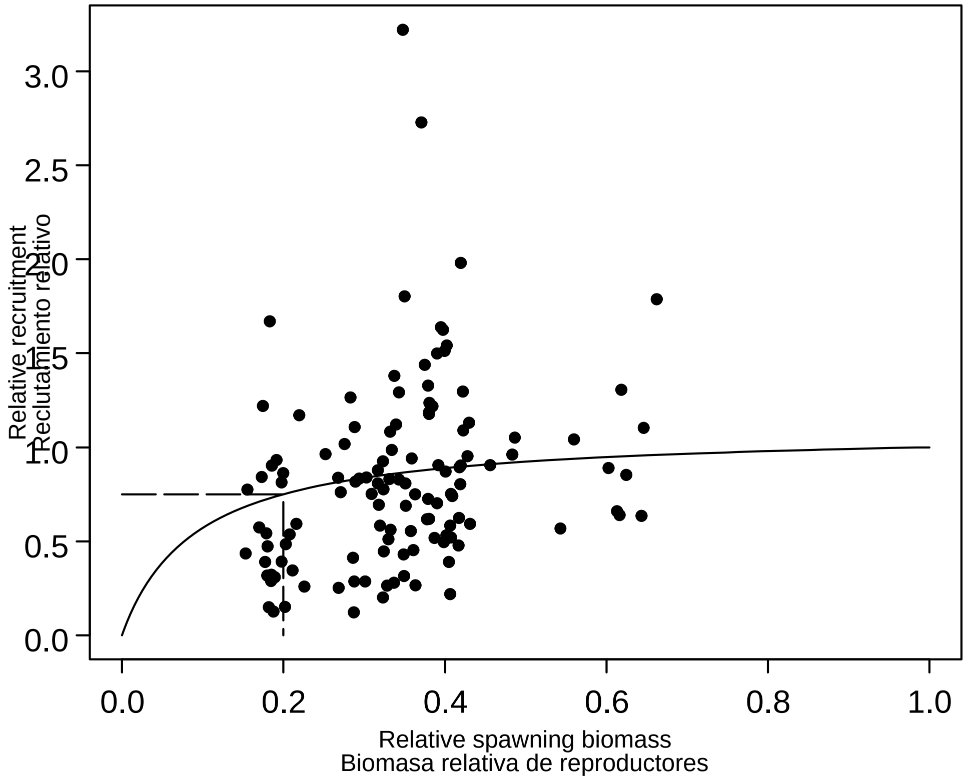


FIGURE A1.5. Recruitment plotted against spawning biomass of yellowfin tuna when the analysis has a stock-recruitment relationship (steepness = 0.75).

FIGURA A1.5. Reclutamiento graficado contra biomasa reproductora de atún aleta amarilla cuando el análisis incluye una relación población-reclutamiento (inclinación = 0,75).

APPENDIX A2: SENSITIVITY ANALYSIS FOR THE ASYMPTOTIC LENGTH RELATIONSHIP

ANEXO A2: ANÁLISIS DE SENSIBILIDAD A LA RELACIÓN DE TALLA ASINTÓTICA

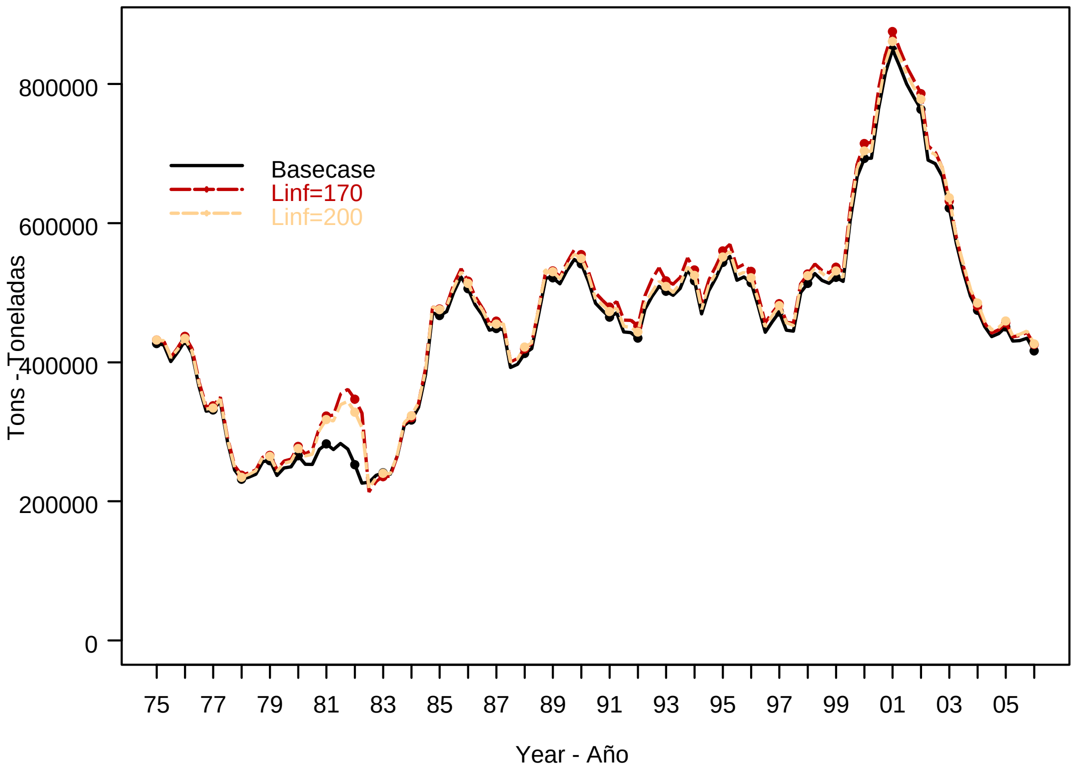


FIGURE A2.1. Comparison of the estimates of biomass of yellowfin tuna from the analysis with Linfinity of 185 cm (base case), 170 cm, and 200 cm.
FIGURA A2.1. Comparación de las estimaciones de la biomasa de atún aleta amarilla del análisis sin relación población-reclutamiento (caso base) y con relación población-reclutamiento (inclinación = 0,75).

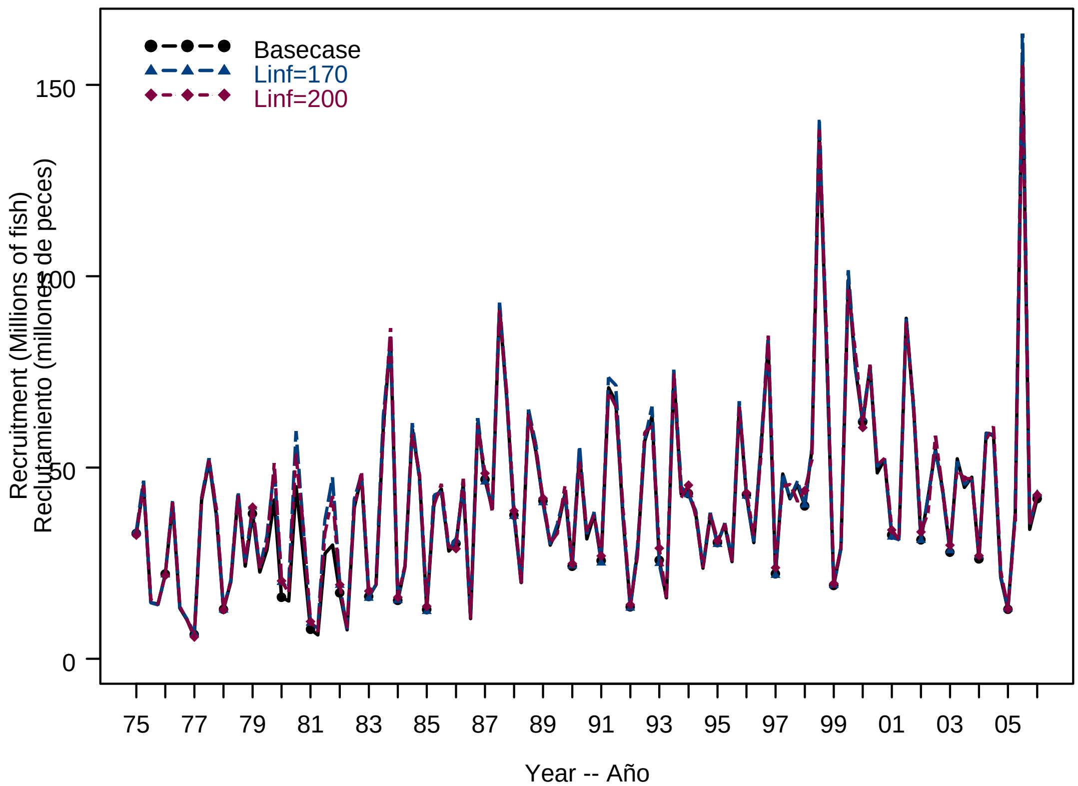


FIGURE A2.2. Comparison of estimates of recruitment of yellowfin tuna from the analysis with Linfinity of 185 cm (base case), 170 cm, and 200 cm.
FIGURA A2.2. Comparación de las estimaciones de reclutamiento de atún aleta amarilla del análisis sin relación población-reclutamiento (caso base) y con relación población-reclutamiento (inclinación = 0,75)

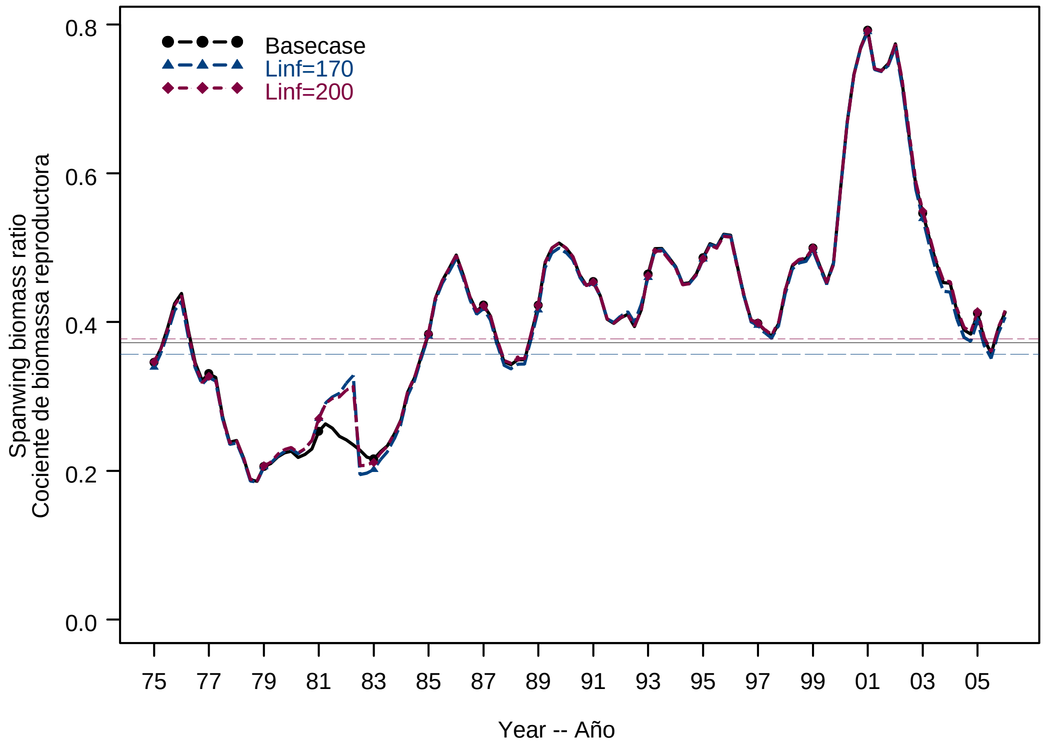


FIGURE A2.3. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from the analysis with Linfinity of 185 cm (base case), 170 cm, and 200 cm.. The horizontal lines represent the SBRs associated with AMSY for the two scenarios.

FIGURA A2.3. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún aleta amarilla del análisis sin (caso base) y con relación población-reclutamiento (inclinación = 0,75). Las líneas horizontales representan el SBR asociado con el RMSP para los dos escenario

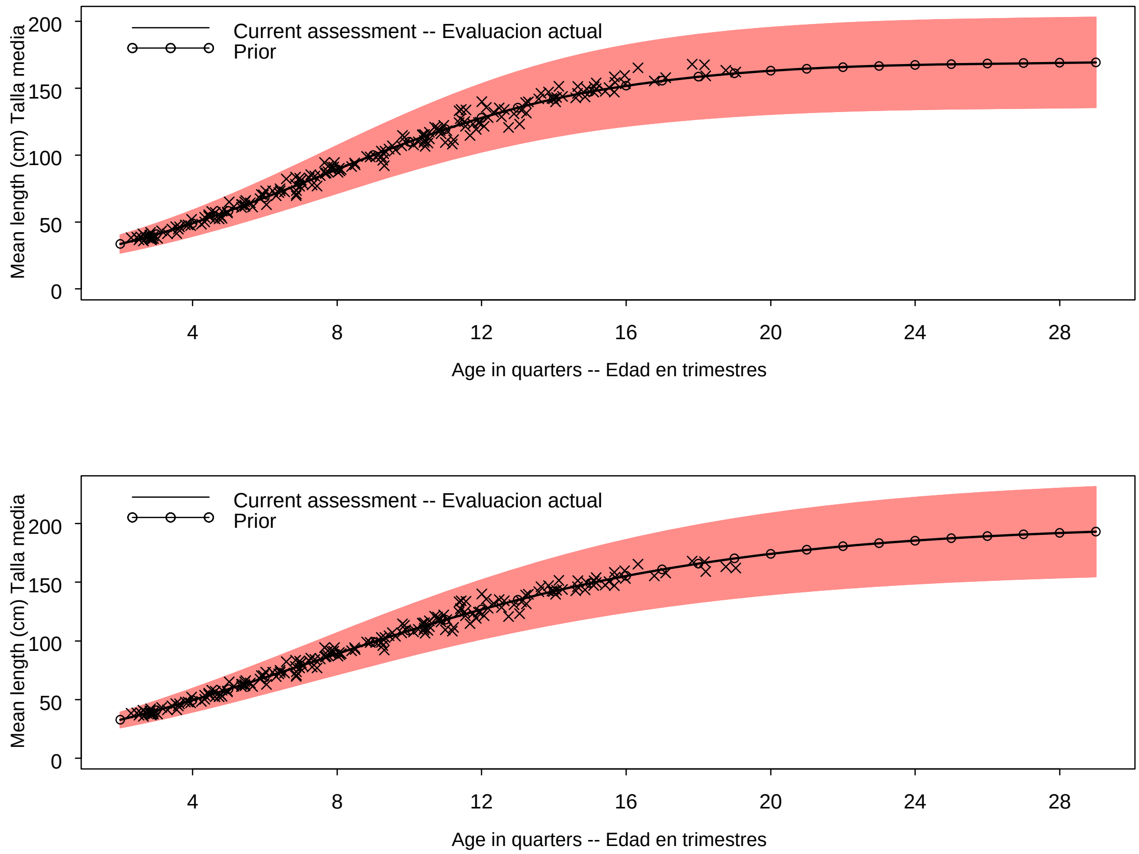
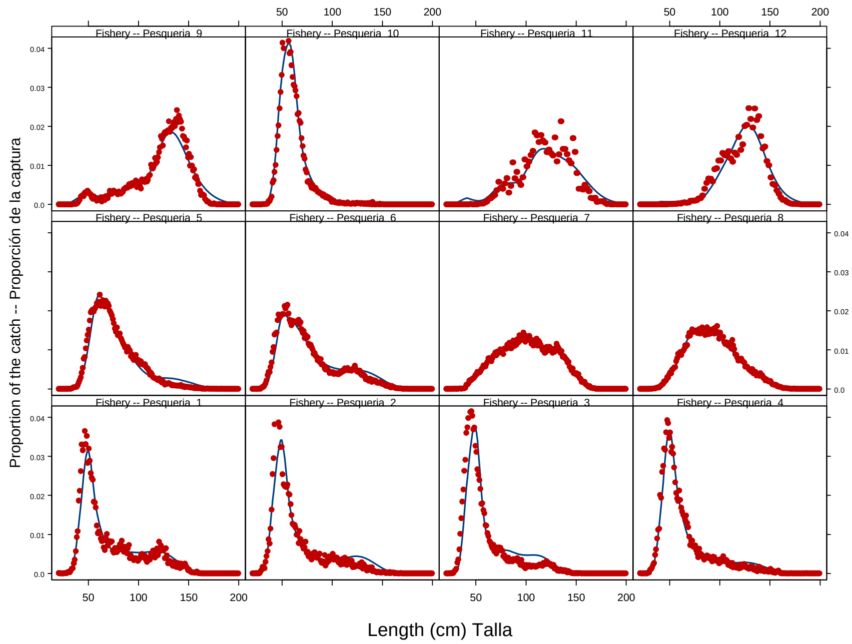


FIGURE A2.4. Comparison of growth curves estimated for yellowfin tuna in the EPO (solid line), assuming Linfinity of 170 cm and 200 cm. The connected points represent the mean length-at-age prior used in the assessment. The crosses represent length-at-age data from otoliths (Wild 1986). The shaded region represents the variation in length at age (± 2 standard deviations).

(a)



(b)

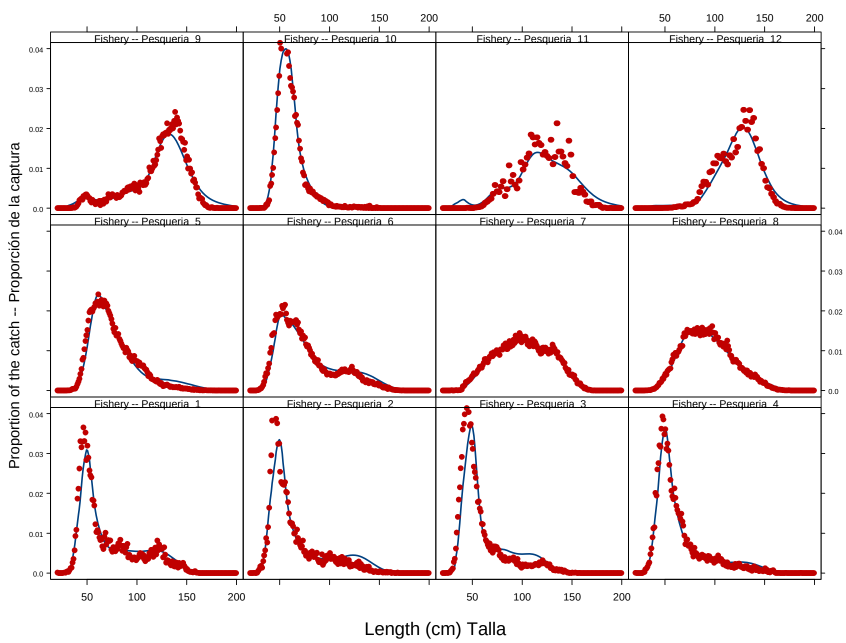
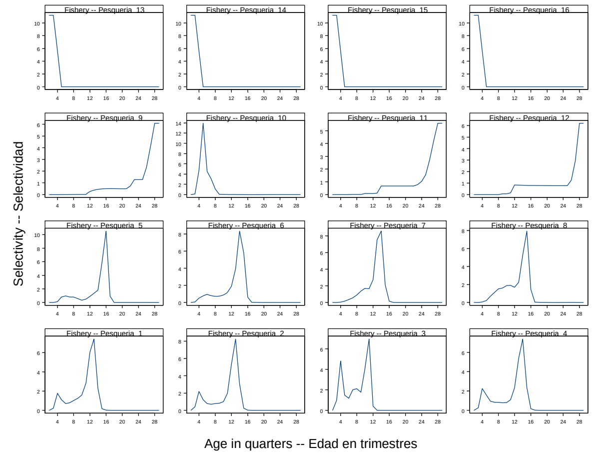
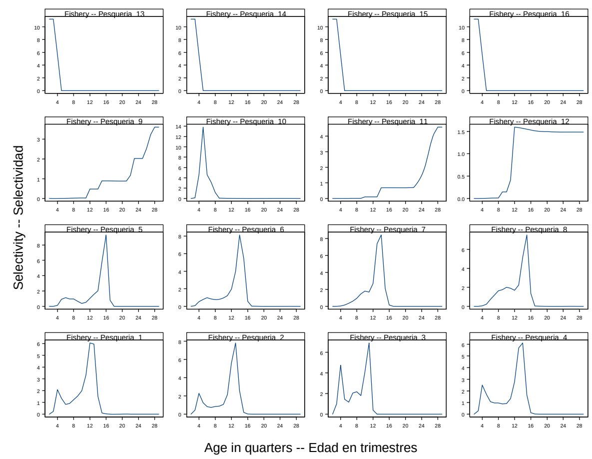


FIGURE A2.5 Comparison of average observed (dots) and predicted (curves) size compositions of the catches taken by the fisheries defined for the stock assessment of yellowfin tuna in the EPO, assuming Linfinity of (a) 170 cm and (b) 200 cm.

(a)



(b)



(c)

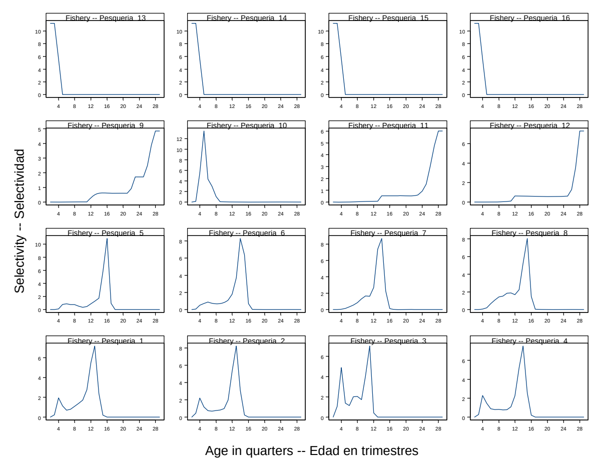


FIGURE A2.6. Comparison of selectivity curves for the 16 fisheries that take yellowfin tuna in the EPO, from a) the base case, b) L_∞ of 170 cm, and c) L_∞ of 200 cm. The curves for Fisheries 1-12 were estimated with the A-SCALA method, and those for Fisheries 13-16 are based on assumptions. Note that the vertical scales of the panels are different.

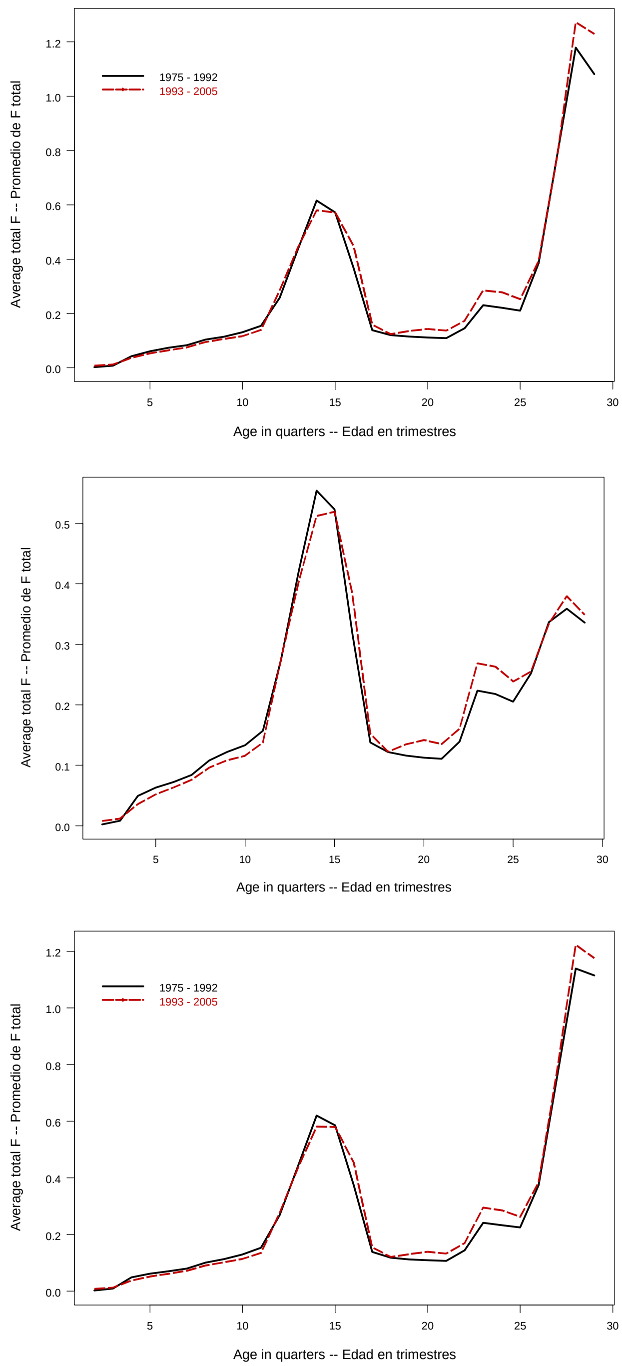
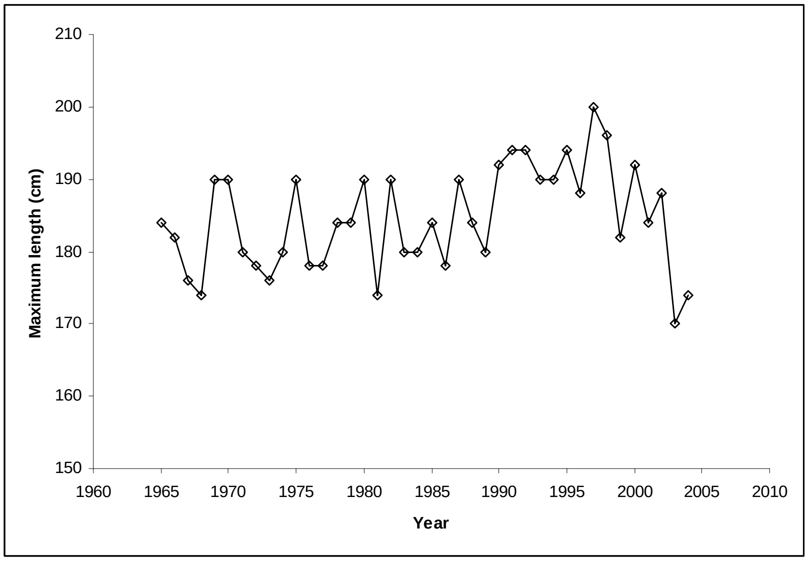


FIGURE A2.7. Comparison of average quarterly fishing mortalities by age of yellowfin tuna, by all gears, in the EPO, from a) the base case, b) L_∞ of 170 cm, and c) L_∞ of 200 cm. The estimates are presented for two periods, the latter period relating to the increase in effort associated with floating objects.

(a)



(b)

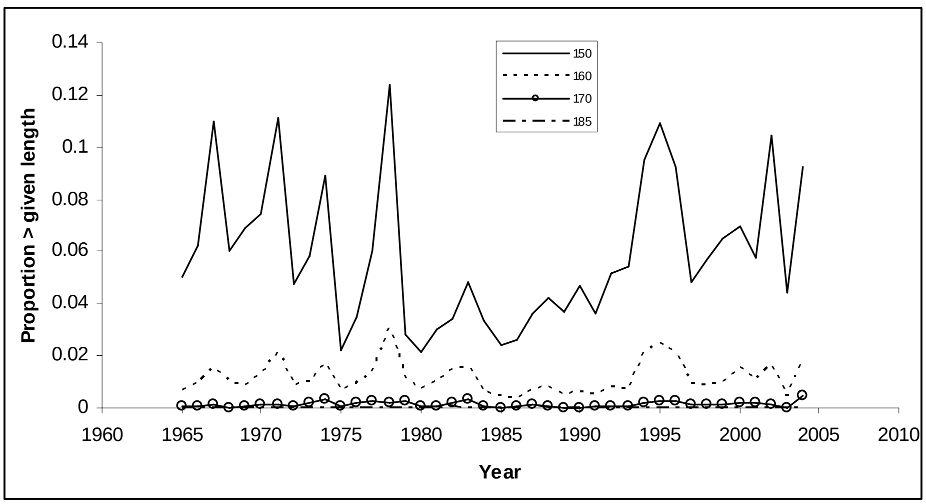


FIGURE A2.8. Maximum length and proportion above a given size by year for the Japanese longline length-frequency data.

APPENDIX A3: SENSITIVITY ANALYSIS FOR CPUE STANDARDIZATION METHOD

ANEXO A3: ANÁLISIS DE SENSIBILIDAD PARA EL MÉTODO DE ESTANDARIZACIÓN DE LA CPUE

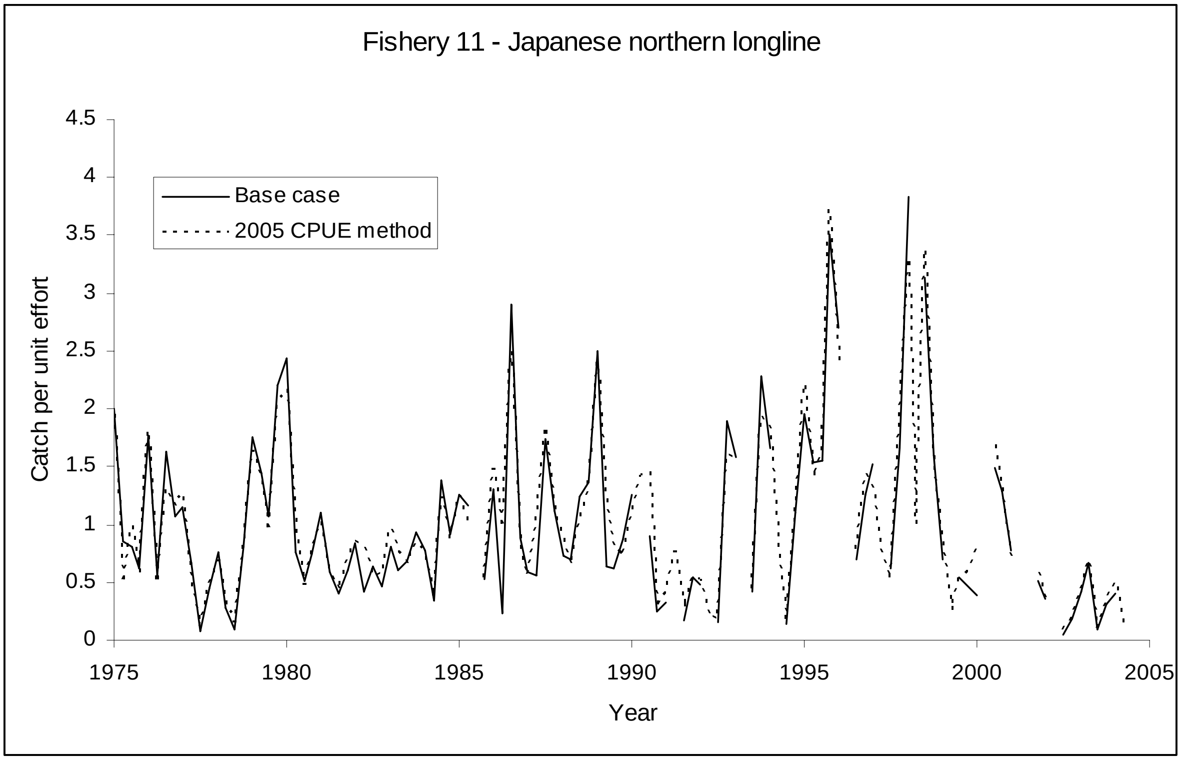


FIGURE A3.1a. Comparison of the Japanese yellowfin longline catch per unit of effort in the northern longline fishery, standardized with generalized linear models based on either the delta-lognormal method (base case) or the delta-gamma method used in the 2005 analysis (2005 CPUE method).

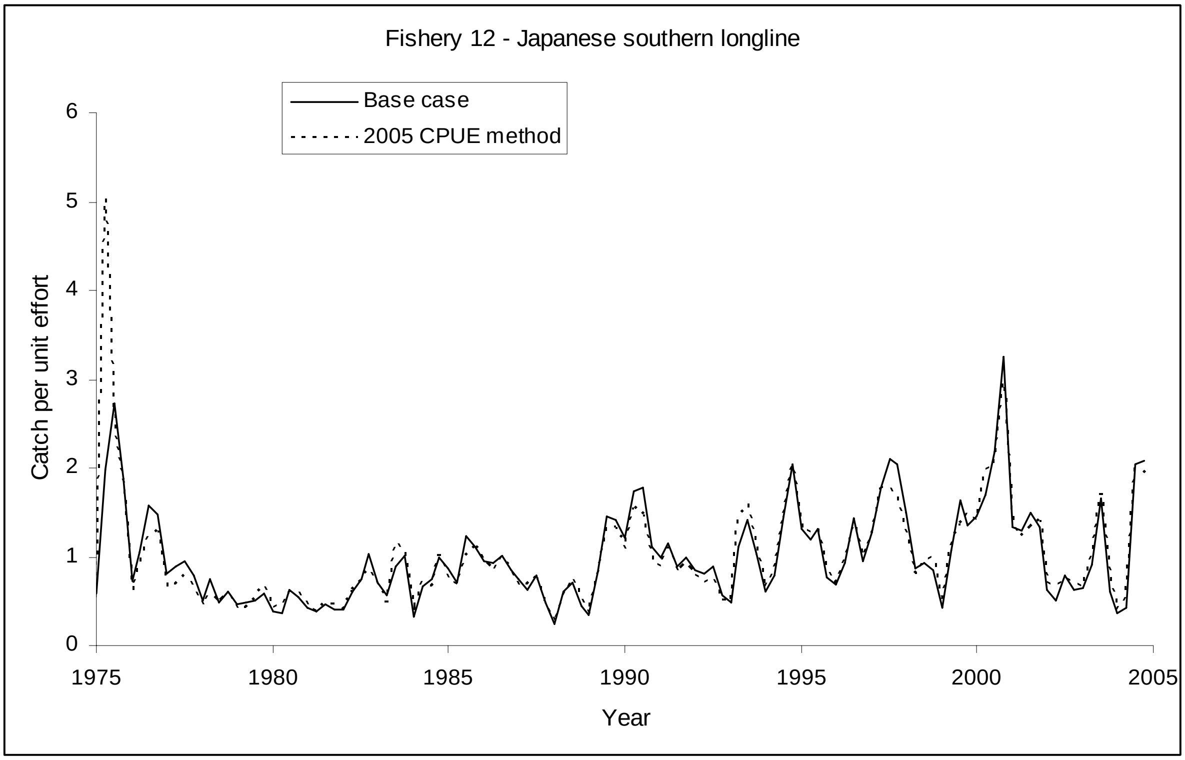


FIGURE A3.1b. Comparison of the Japanese yellowfin longline catch per unit of effort in the southern longline fishery, standardized with generalized linear models based on either the delta-lognormal method (base case) or the delta-gamma method used in the 2005 analysis (2005 CPUE method).

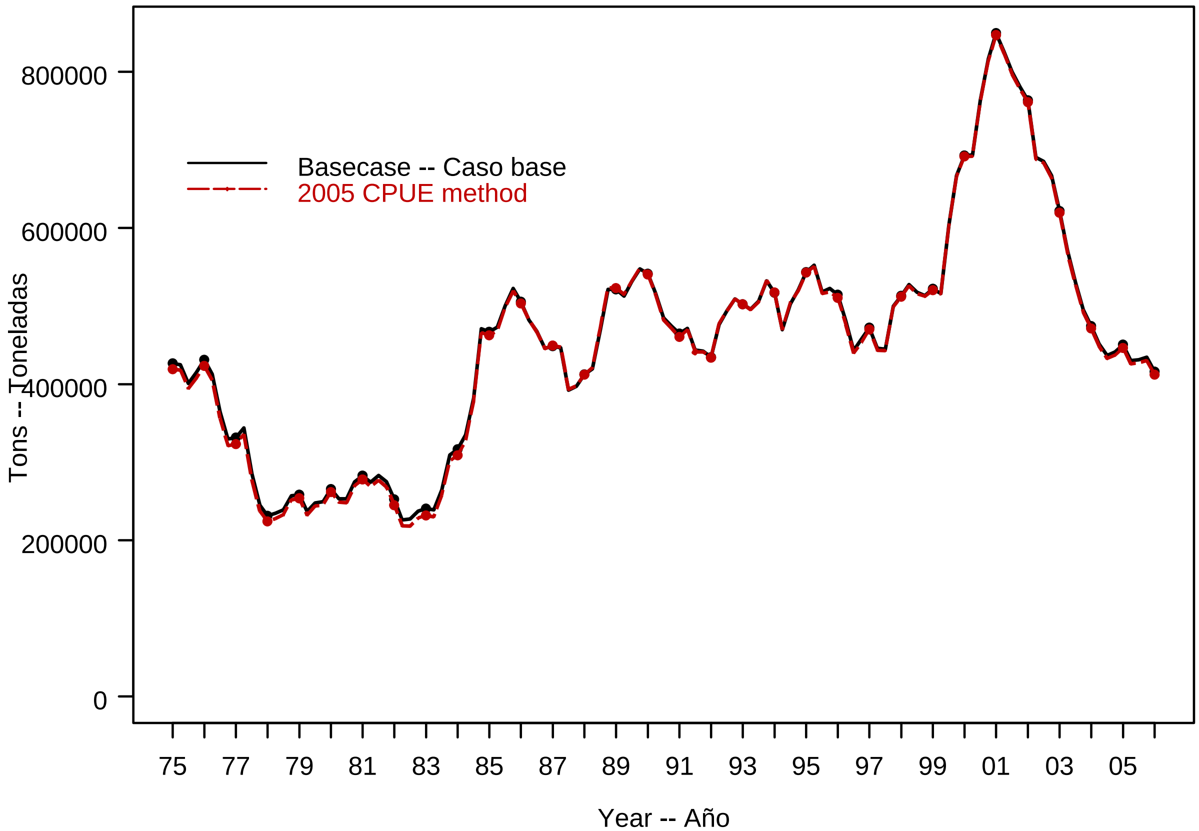


FIGURE A3.2. Comparison of the estimates of biomass of yellowfin tuna from analyses that used longline CPUE standardized with generalized linear models based on either the delta-lognormal method (base case) or the delta-gamma method used in the 2005 analysis (2005 CPUE method).

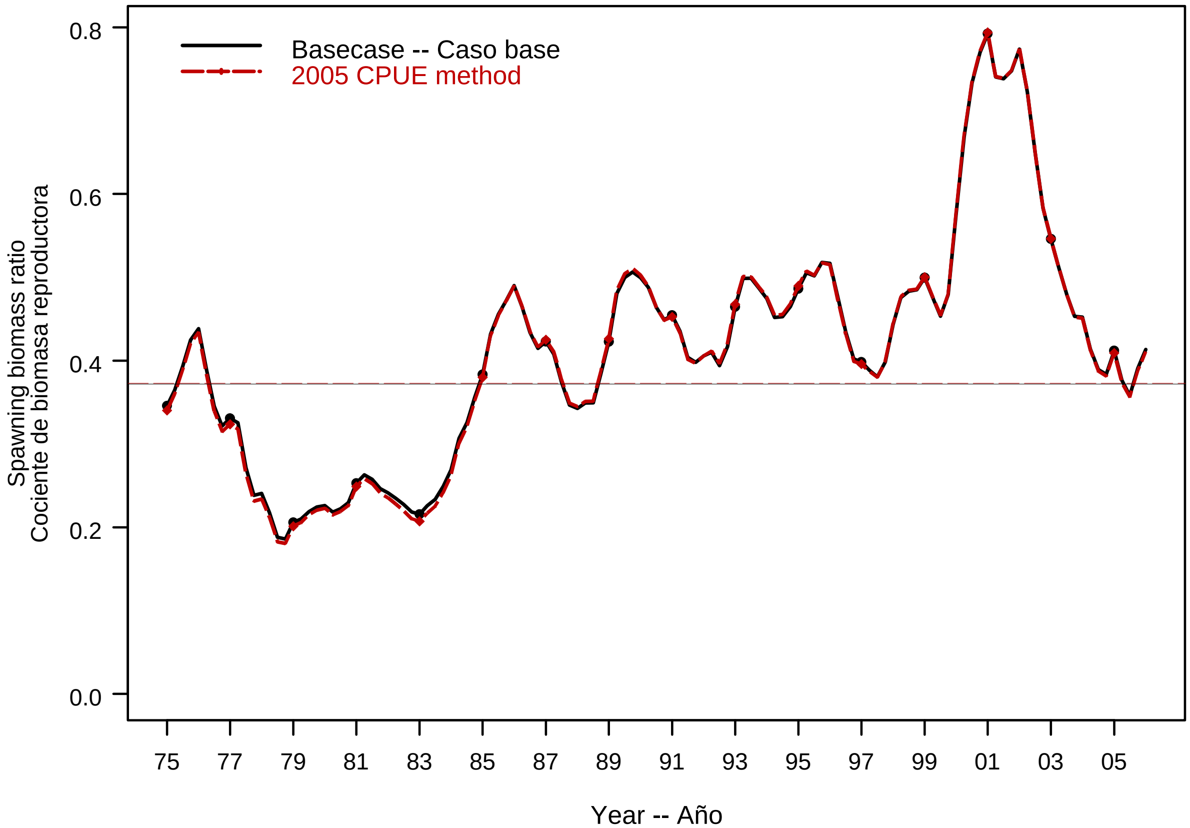


FIGURE A3.3. Comparison of estimates of the spawning biomass ratio (SBR) of yellowfin tuna from analyses that used longline CPUE standardized with generalized linear models based on either the delta-lognormal method (base case) or the delta-gamma method used in the 2005 analysis (2005 CPUE method). The horizontal lines represent the SBRs associated with AMSY for the two scenarios.

APPENDIX B: ADDITIONAL RESULTS FROM THE BASE CASE ASSESSMENT

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

ANEXO B: RESULTADOS ADICIONALES DE LA EVALUACION DEL CASO BASE

Este anexo contiene resultados adicionales de la evaluación de caso base del atún aleta amarilla en el OPO: resúmenes anuales de las estimaciones por edad de la abundancia y las tasas de mortalidad por pesca total. Fue preparado en respuesta a solicitudes expresadas durante la segunda reunión del Grupo de Trabajo Científico.

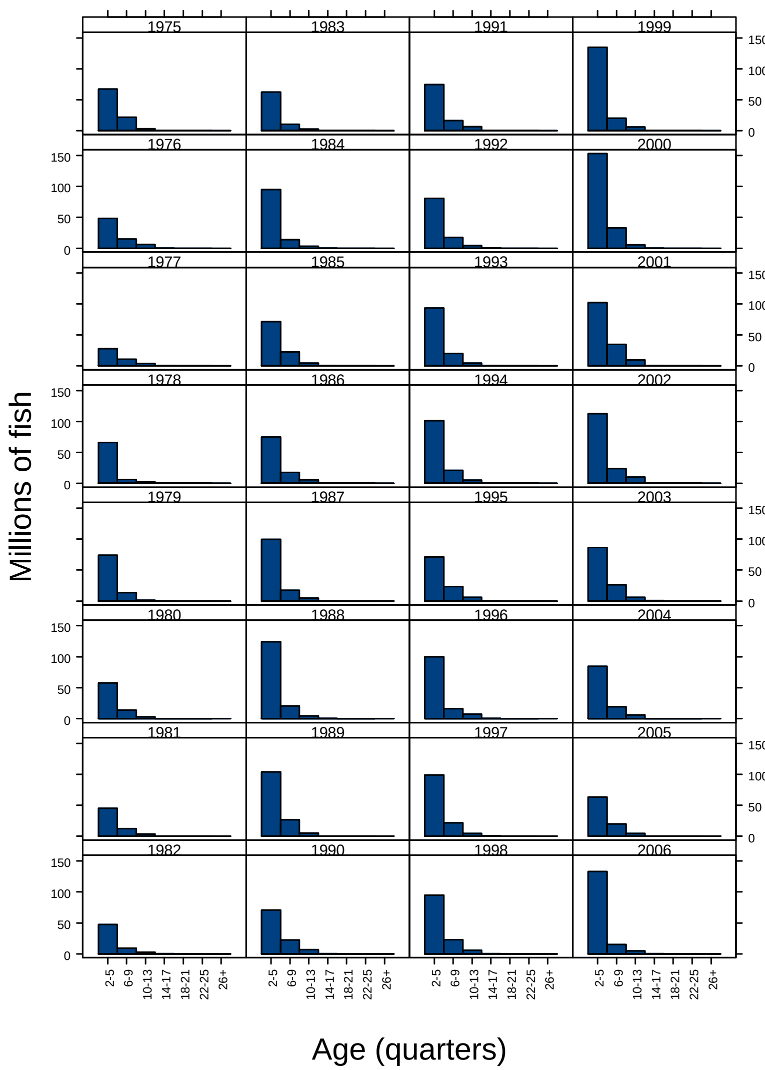


FIGURE B.1. Estimated numbers of yellowfin tuna present in the EPO on January 1 of each year.
FIGURA B.1. Número estimado de atunes aleta amarilla presentes en el OPO el 1 de enero de cada año.

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

Year	Age in quarters—Edad en trimestres						
Año	2-5	6-9	10-13	14-17	18-21	22-25	26+
1975	0.1244	0.4404	1.2505	2.2439	0.3461	0.6358	2.2978
1976	0.1763	0.4303	1.2204	1.9783	0.6853	1.5042	5.6184
1977	0.2391	0.4919	1.2469	1.9572	0.9256	1.8552	4.6438
1978	0.3283	0.6039	1.3355	2.5294	0.6818	1.4187	3.2484
1979	0.2426	0.7110	1.8551	3.3463	0.9250	2.0208	6.4981
1980	0.1998	0.5168	1.4772	2.6660	0.6805	1.2551	5.4120
1981	0.2738	0.4952	1.2037	2.4348	0.8989	2.3024	6.7770
1982	0.1433	0.4036	1.0314	2.3053	0.6986	1.7591	4.1824
1983	0.1207	0.2135	0.7687	0.9918	0.4212	1.0937	2.8923
1984	0.1040	0.2816	0.7675	1.0628	0.3972	0.7135	3.1959
1985	0.0917	0.4047	0.9259	1.5623	0.4066	0.8053	2.1147
1986	0.1194	0.4679	1.1909	1.7239	0.3742	0.7368	2.7480
1987	0.1254	0.5140	1.3157	1.5025	0.3794	0.7461	2.3160
1988	0.1784	0.5068	1.3370	1.9405	0.4257	0.8535	2.6452
1989	0.1242	0.4807	1.0932	2.0150	0.6249	1.3955	5.1892
1990	0.1241	0.4007	1.2279	1.8859	0.5565	1.1454	3.6570
1991	0.1323	0.4171	1.0902	1.7312	0.5454	1.0423	4.2957
1992	0.1547	0.4478	1.1180	1.6987	0.3603	0.5821	2.0409
1993	0.1453	0.3983	1.0057	1.6677	0.3981	0.8130	1.9830
1994	0.1057	0.3353	1.1162	1.7318	0.6094	1.1908	4.5482
1995	0.1043	0.3011	0.9141	1.2181	0.4765	0.9884	3.9100
1996	0.1244	0.3995	0.9005	1.8682	0.2956	0.6535	1.8373
1997	0.1417	0.4253	1.2273	2.2134	0.7051	1.7091	6.5766
1998	0.1588	0.4202	1.0477	1.8953	0.5020	1.0305	4.3302
1999	0.1625	0.4295	1.1084	2.2905	0.3021	0.5488	1.9255
2000	0.1044	0.3134	0.9081	1.4752	0.5823	1.1981	3.9247
2001	0.1553	0.3552	1.1938	1.6750	0.6406	1.2776	4.8094
2002	0.1283	0.4621	1.1384	1.6908	0.6741	1.5011	5.3646
2003	0.1726	0.5768	1.8062	2.8641	1.1835	2.0495	5.7879
2004	0.1449	0.5058	1.6675	3.8400	1.5820	3.6105	9.0536
2005	0.2159	0.5781	1.7680	4.3572	1.5234	3.0245	11.2227

APPENDIX C: DIAGNOSTICS

ANEXO C: DIAGNÓSTICOS

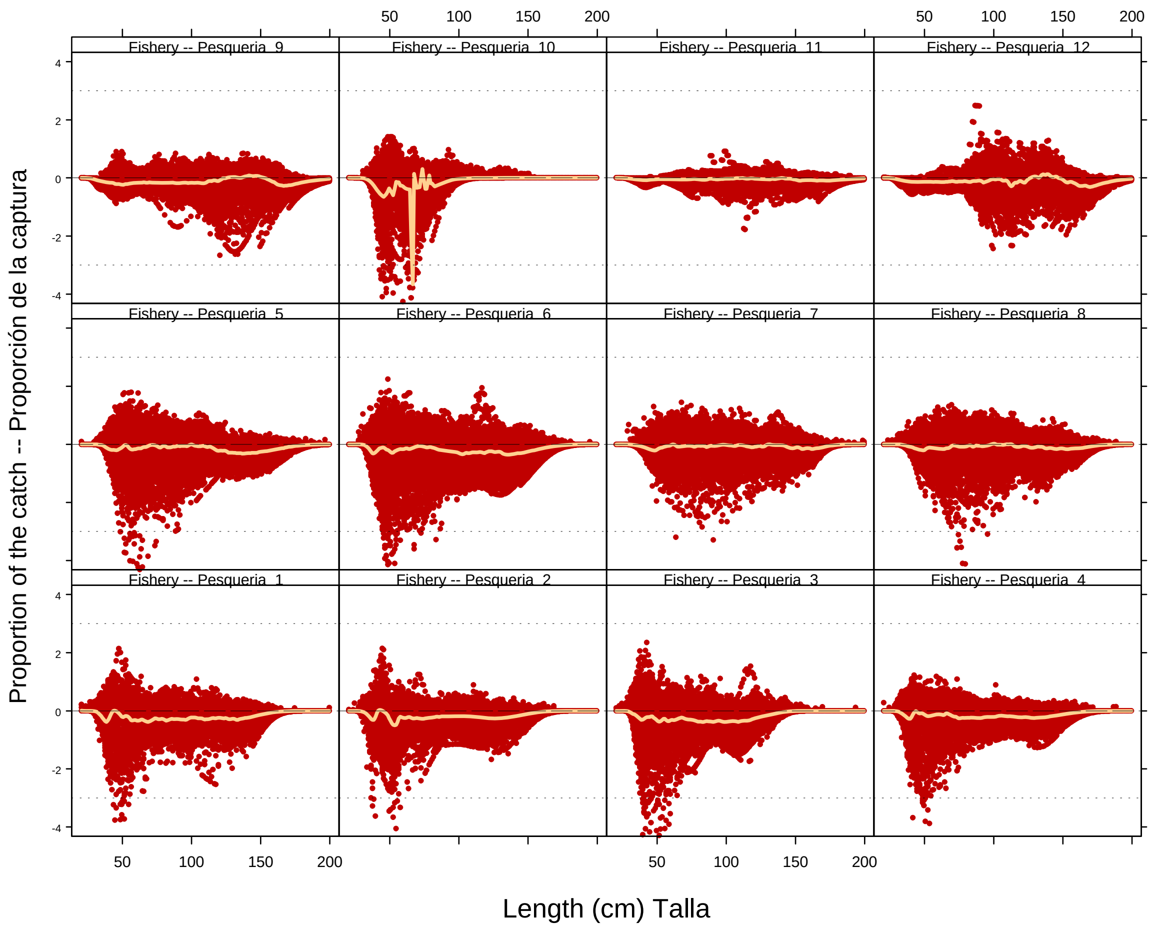


FIGURE C.1. Standardized residuals for the length-frequency data of yellowfin tuna by length. The dotted horizontal lines represent three standard deviations on either side of the mean.
FIGURA C.1. Residuales estandarizados para los datos de frecuencia de talla de atún aleta amarilla, por talla. Las líneas horizontales con puntos representan tres desviaciones estándar en cualquier lado del medio.

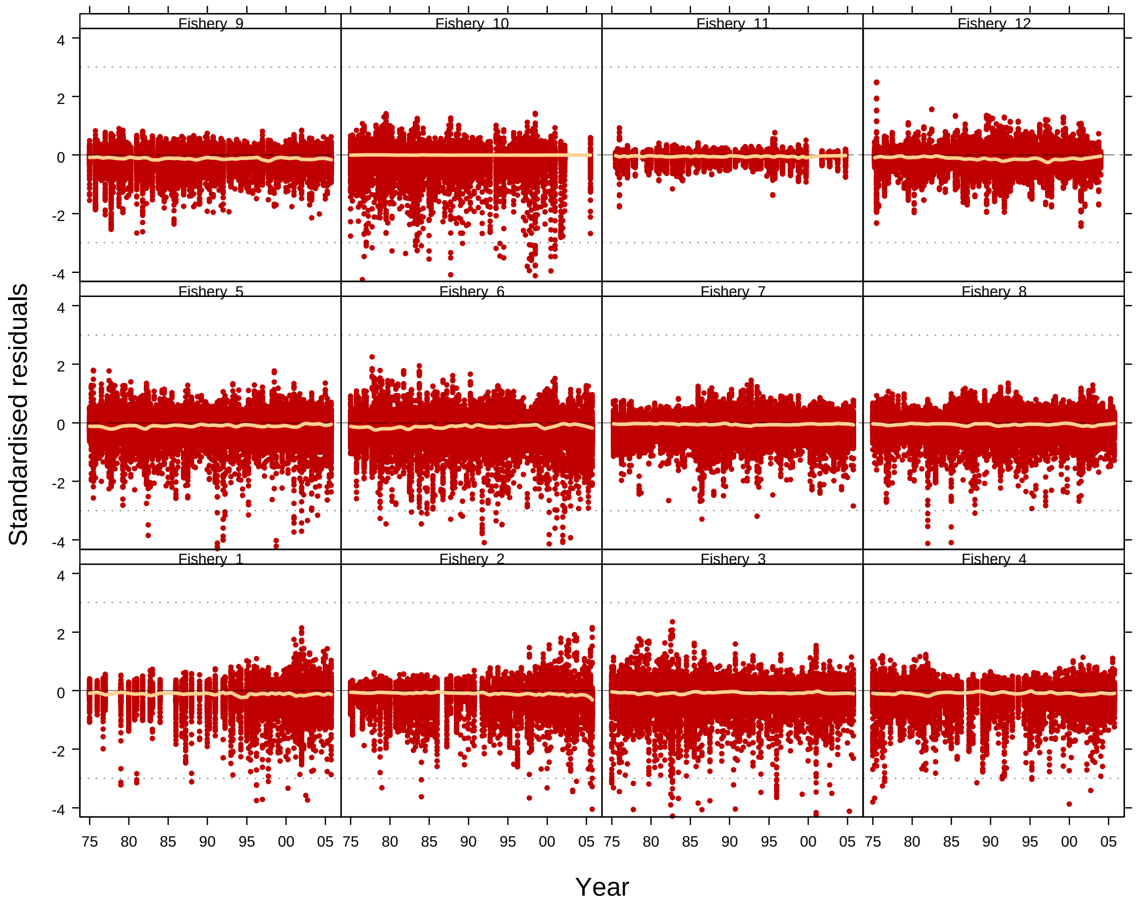


FIGURE C.2. Standardized residuals for the length-frequency data of yellowfin tuna by quarter. The dotted horizontal lines represent three standard deviations on either side of the mean.

FIGURA C.2. Residuales estandarizados para los datos de frecuencia de talla de atún aleta amarilla, por trimestre. Las líneas horizontales con puntos representan tres desviaciones estándar en cualquier lado del medio.

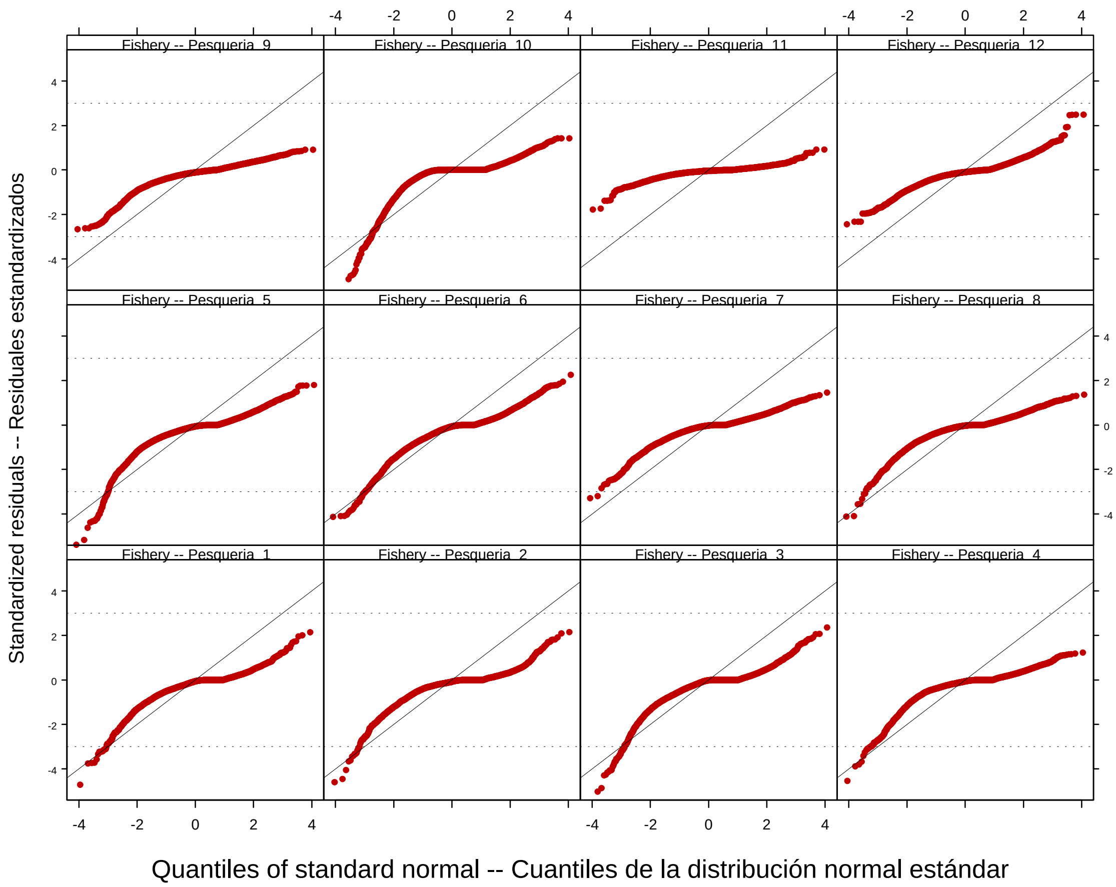


FIGURE C.3. Q-Qnorm plots for the length-frequency data for yellowfin tuna. The diagonal lines indicate the expectations for the residuals following normal distributions. The dotted horizontal lines represent three standard deviations on either side of the mean.

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

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