INTER-AMERICAN TROPICAL TUNA COMMISSION

SCIENTIFIC ADVISORY COMMITTEE

1ST MEETING

La Jolla, California (USA)
31 August -3 September 2010

DOCUMENT SAC-01-08a

STATUS OF BIGEYE TUNA IN THE EASTERN PACIFIC OCEAN IN 2009 AND OUTLOOK FOR THE FUTURE

Alexandre Aires-da-Silva and Mark N. Maunder

CONTENTS

1. SUMMARY

This report presents the current stock assessment of bigeye tuna (*Thunnus obesus*) in the eastern Pacific Ocean (EPO). This assessment was conducted using Stock Synthesis (Version 3). The assessment reported here is based on the assumption that there is a single stock of bigeye in the EPO, and that there is limited exchange of fish between the EPO and the western and central Pacific Ocean (WCPO).

The assessment assumptions have been modified from the previous assessment based on extensive investigatory analysis and a series of recommendations of the external review of the IATTC staff's assessment of bigeye tuna, held in May 2010. The spatial definitions of the longline fisheries have been re-evaluated and four, rather than two, longline fisheries are assumed in this assessment. With respect to data weighting, the observation error coefficient of variation for the southern longline fishery was pre-specified at a fixed value, rather than being treated as an estimated parameter. Changes to the growth modeling consisted of assuming a Richards model instead of the less flexible von Bertalanffy curve. In addition, the parameters which determine the variance of the length-at-age were estimated rather than fixed, while the average size of the oldest fish (L_2 parameter) was pre-specified at a fixed value, as in previous assessments. Changes in the modeling of catchability and selectivity have also been made. In order to reduce the residual patterns of the model fit to the catch length-frequency data of the longline fishery, the assumption of logistic selectivity for the southern longline fishery throughout the entire time period of the assessment was relaxed. In particular, all longline fisheries were split into two periods at 1990, each with its independent catch rate time series, and estimated catchability and selectivity parameters. The size selectivity curves of the pre-1990 longline fisheries were assumed to be dome-

shaped, rather than asymptotic as in previous assessments. Dome-shaped size selectivity curves have also been assumed for two of the four longline fisheries during the late period (post-1990).

The stock assessment requires a substantial amount of information. Data on retained catch, discards, catch per unit of effort (CPUE), and age-at-length data and size compositions of the catches from several different fisheries have been analyzed. Several assumptions regarding processes such as growth, recruitment, movement, natural mortality, and fishing mortality, have also been made. Catch and CPUE for the surface fisheries have been updated to include new data for 2009. New or updated longline catch data are available for China (2008), Chinese Taipei (2006-2009), French Polynesia (2008), Japan (2006-2009), Korea (2008) and the United States (2007-2008). New purse-seine length-frequency data are available for 2009. New or updated length-frequency data are available for the Japanese longline fleet (2006-2008). Analyses were carried out to assess the sensitivity of results to: 1) a stock-recruitment relationship with various different assumed values for the steepness parameter; 2) assuming different values for the average size of the oldest fish in the Richards growth curve; 3) assuming lower and higher rates of natural mortality (M) for adult bigeye; and 4) using data only from the late period of the fishery (1995-2009), which best reflects the current mix of tuna fisheries operating in the EPO.

There have been important changes in the amount of fishing mortality caused by the fisheries that catch bigeye tuna in the EPO. On average, since 1993 the fishing mortality of bigeye less than about 15 quarters old has increased substantially, and that of fish more than about 15 quarters old has increased to a much lesser extent. The increase in the fishing mortality of the younger fish was caused by the expansion of the fisheries that catch tuna in association with floating objects. Fishing mortality of fish more than 20 quarters old has also increased significantly since the early 1990s, as larger bigeye became vulnerable to the longline fisheries.

Over the range of spawning biomasses estimated by the base case assessment, the abundance of bigeye recruits appears to be unrelated to the spawning potential of adult females at the time of hatching.

There are several important features in the estimated time series of bigeye recruitment. First, estimates of recruitment before 1993 are very uncertain, as the floating-object fisheries were not catching significant amounts of small bigeye. There was a period of above-average annual recruitment in 1994-1998, followed by a period of below-average recruitment in 1999-2000. The recruitments were above average from 2001 to 2006, and were particularly high in 2005 and 2006. The 2007 recruitment was below average, but the recruitment in 2008 appears to have been particularly high. The most recent annual recruitment estimate (2009) is slightly below average levels. However, this recent estimate is very uncertain and should be regarded with caution, due to the fact that recently-recruited bigeye are represented in only a few length-frequency samples.

The biomass of 3+-quarter-old bigeye increased during 1983-1985, and reached its peak level of about 845 thousand metric tons (t) in 1986, after which it decreased to a historic low of about 347 thousand t at the beginning of 2004. Since then, the biomass of 3+-quarter-old bigeye has shown an increasing trend in the EPO. Spawning biomass has generally followed a trend similar to that for the biomass of 3+-quarter-olds, but with a lag of 1-2 years. There is uncertainty in the estimated biomasses of both 3+-quarter-old bigeye and spawners. Nevertheless, it is apparent that fishing has reduced the total biomass of bigeye in the EPO. The biomasses of both 3+quarter-old fish and spawners are estimated to have been increasing over the last five years. This increasing trend may be partly attributed to the effect of IATTC tuna conservation resolutions during 2004-2009, above-average recruitments, and reduced longline fishing effort in the EPO in recent years.

The estimates of summary biomass are moderately sensitive to the steepness of the stock-recruitment relationship. Specifically, the estimates of biomass are greater than those estimated in the base case assessment, but the trends are similar. The trends in recruitment are similar to those of the base case. The estimated biomass and recruitment time series are very sensitive to the assumed value of the average size of the oldest fish – the L_2 parameter – in the growth function. Biomass and recruitment estimates are greater for a lesser value of that parameter. The estimated biomass and recruitment time series are very sensitive to the assumed rate of adult natural mortality for bigeye. Biomass and recruitment estimates increase with higher levels of adult natural mortality.

When data from only the late period of the fishery (1995-2009) are used in the bigeye assessment, and no stock-recruitment relationship is assumed (steepness = 1), the summary biomass estimates are lower than the base case estimates. When a stock-recruitment relationship is assumed (steepness = 0.75), the summary biomass estimates are slightly higher than the base case estimates. These results are partially explained by differences in absolute recruitment, but the relative recruitment trends are very similar.

At the beginning of January 2010, the spawning biomass ratio (the ratio of the spawning biomass at that time to that of the unfished stock; SBR) of bigeye tuna in the EPO had recovered from its historic low level of 0.17 at the start of 2005 to 0.26. This most recent SBR estimate is about 37% higher than the the maximum sustainable yield (MSY) level.

Recent catches are estimated to have been 17% greater than those corresponding to the MSY levels. If fishing mortality (F) is proportional to fishing effort, and the current patterns of age-specific selectivity are maintained, the level of fishing effort corresponding to the MSY is about 13% higher than the current (2007-2009) level of effort. The MSY of bigeye in the EPO could be maximized if the age-specific selectivity pattern were similar to that of the longline fisheries, because they catch larger individuals that are close to the critical weight. Before the expansion of the floating-object fishery that began in 1993, the MSY was greater than the current MSY and the fishing mortality was less than F_{MSY}.

All sensitivity analyses indicate that, at the beginning of 2005, the bigeye spawning biomass (S) had initiated a recovery trend. Although the results from the base case model show that, at the beginning of 2010, the spawning biomass was higher than S_{MSY} (stock not overfished), and the fishing mortality rate was below that corresponding to F_{MSY} (overfishing not occurring), this interpretation is subject to uncertainty and mainly dependent upon the assumptions made on three key biological parameters: the steepness of the stock recruitment relationship, the average size of the older fish in the population, and the levels of adult natural mortality. It also depends on the historic period of the bigeye exploitation used in the assessment.

Recent spikes in recruitment are predicted to sustain, in the short term, the recent increasing trend observed for SBR since 2004. However, high levels of fishing mortality are expected to subsequently reduce and then stabilize SBR under average recruitment conditions. Under current effort levels, the base case assessment estimates that the population is likely to remain above the level corresponding to MSY .These simulations are based on the assumption that selectivity and catchability patterns will not change in the future. Changes in targeting practices or increasing catchability of bigeye as abundance declines (*e.g*. density-dependent catchability) could result in differences from the outcomes predicted here.

Key results

1. The results of this assessment indicate a recent recovery trend for bigeye tuna in the EPO (2005-2009), subsequent to IATTC tuna conservation resolutions initiated in 2004;
2. There is uncertainty about recent and future recruitment and biomass levels;
3. The recent fishing mortality rates are estimated to be below the level corresponding to MSY, and the recent levels of spawning biomass are estimated to be above that level. However, these interpretations are uncertain and highly sensitive to the assumptions made about the steepness parameter of the stock-recruitment relationship, the average size of the older fish, the assumed levels of natural mortality for adult bigeye, and the historic period of the bigeye exploitation used in the assessment. The results are more pessimistic if a stock-recruitment relationship is assumed, if a higher value is assumed for the average size of the older fish, if lower rates of natural mortality are assumed for adult bigeye, and if only the late period of the fishery (1995-2009) is

included in the assessment;

4. The results are more optimistic if a lower value is assumed for the average size of the older fish, and if higher levels of natural mortality are assumed for adult bigeye;

2. DATA

Catch, effort, and size-composition data for January 1975 through December 2009 were used to conduct the stock assessment of bigeye tuna, *Thunnus obesus*, in the eastern Pacific Ocean (EPO). The data for 2009, which are preliminary, include records that had been entered into the IATTC databases as of mid-June 2010. All data are summarized and analyzed on a quarterly basis.

2.1. Definitions of the fisheries

Twenty three fisheries are defined for the stock assessment of bigeye tuna. They are defined on the basis of gear type (purse seine, pole and line, and longline), purse-seine set type (on floating objects, unassociated schools, and dolphins), time period, IATTC length-frequency sampling area or latitude, and unit of longline catch (in numbers or weight). The longline fishery definitions have been improved for this bigeye stock assessment. Rather than assuming two longline fisheries (northern and southern) separated at latitude 15°N as in previous assessments, this assessment considers four longline fisheries (Northern, Central, Southern and Inshore). The new spatial definitions are based on the results of a regression tree analysis using longline catch-per-unit-effort data and length-frequency data to investigate the stock structure of bigeye in the EPO (Lennert-Cody, Maunder and Aires-da-Silva 2010).

A major shift in residual patterns that occurred in the late 1980s has been previously identified in the bigeye longline length-composition distributions (Aires-da-Silva and Maunder 2010; Aires-da-Silva, Maunder and Lennert-Cody 2010). This may be due to important temporal changes of longline catchability and/or selectivity. A spatial analysis of trends in the numbers of hooks per basket, which determine the fishing depth of the longline gear, indicates a transition, around the late 1980s, from an early period of increasing and more variable numbers of hooks per basket, to a late period of stabilized and less variable numbers of hooks per basket (Aires-da-Silva, Maunder and Lennert-Cody 2010). On the basis of these major changes in fishing technology that occurred around 1990, all four longline fisheries were subdivided into two temporal blocks with different catchability/selectivity (1975-1989 and 1990-2009).The bigeye fisheries are defined in Table 2.1, and the spatial extent of each fishery and the boundaries of the length-frequency sampling areas are shown in Figure 2.1.

In general, the fisheries are defined so that, over time, there is little change in the average size composition of the catch. The fishery definitions for purse-seine sets on floating objects are also stratified to provide a rough distinction between sets made mostly on flotsam (Fishery 1), sets made mostly on fish-aggregating devices (FADs) (Fisheries 2-3, 5, 10-11, and 13), and sets made on a mixture of flotsam and FADs (Fisheries 4 and 12). It is assumed that it is appropriate to pool data relating to catches by pole-and-line gear and by purse-seine vessels setting on dolphins and unassociated schools (Fisheries 6 and 7). Relatively few bigeye are captured by the first two methods, and the data from Fisheries 6 and 7 are dominated by information on catches from unassociated schools of bigeye. Given this latter fact, Fisheries 6 and 7 will be referred to as fisheries that catch bigeye in unassociated schools in the remainder of this report.

The catch data reported by the longline fisheries are a mixture of catch in numbers and weight records. Since the Stock Synthesis model (see description in section 4) has the flexibility of including catch data in either numbers or weight, twelve longline fisheries are defined: eight fisheries with catch reported in numbers caught (Fisheries 12-19), and four additional longline fisheries that report catch in weight for the late period (Fisheries 20-23).

2.2. Catch

To conduct the stock assessment of bigeye tuna, the catch and effort data in the IATTC databases are stratified in accordance with the fishery definitions described in Section 2.1 and listed in Table 2.1. The three definitions relating to catch data used in previous reports (landings, discards, and catch) are described by Maunder and Watters (2001). The terminology in this report is consistent with the standard terminology used in other IATTC reports. Catches taken in a given year are assigned to that year even if they were not landed until the following year. Catches are assigned to two categories, retained catches and discards. Throughout this document, the term "catch" is used to reflect either total catch (retained catch plus discards) or retained catch; the appropriate definition is determined by the context.

Three types of catch data are used to assess the stock of bigeye tuna (Table 2.1). Removals by Fisheries 1, 6, and 12-23 are simply retained catch. Removals by Fisheries 2-5 and 7 are retained catch, plus some discards resulting from inefficiencies in the fishing process (Section 2.2.1). Removals by Fisheries 8-11 are discards resulting only from sorting the catch taken by Fisheries 2-5 (Section 2.2.1).

Updated and new catch data for the surface fisheries (Fisheries 1-12) have been incorporated into the current assessment. The species-composition method (Tomlinson 2002) was used to estimate catches of the surface fisheries. We calculated average scaling factors for 2000-2008 by dividing the total catch for all years and quarters for the species composition estimates by the total catch for all years and quarters for the standard estimates, and applied these to the cannery and unloading estimates for 1975-1999. For Fisheries 1, 6, and 7 we used the average over Fisheries 2-5, for Fisheries 2 and 3 we used the average over Fisheries 2 and 3, and for Fisheries 4 and 5 we used the average over Fisheries 4 and 5. Harley and Maunder (2005) provide a sensitivity analysis that compares the results from the stock assessment using the species composition estimates of purse-seine fishery landings with the results from the stock assessment using cannery unloading estimates.

Updated or new catch data for the longline fisheries (Fisheries 12-23) are available for China (2008), Chinese Taipei (2006-2009), French Polynesia (2008), Japan (2006-2009), Korea (2008) and the United States (2007-2008). Catch data for 2009 are available for China, French Polynesia, the Republic of Korea, the United States, and Vanuatu from the monthly reporting statistics. Trends in the catches of bigeye tuna taken by each fishery from the EPO during each year of the 1975-2009 period are shown in the upper panel of Figure 2.2. The annual catch trends for the combined surface fleet (Fisheries 1-11) and longline fleet (Fisheries 12-23) are also shown (lower panel of Figure 2.2). There has been substantial annual variation in the catches of bigeye by all fisheries operating in the EPO (Figure 2.2, upper panel). Prior to 1996, the longline fleet (Fisheries 12-23) removed more bigeye (in weight) from the EPO than did the surface fleet (Fisheries 1-11) (Figure 2.2, lower panel). Since 1996, however, the catches by the surface fleet have mostly been greater than those by the longline fleet. It should be noted that the assessment presented in this report uses data starting from 1 January 1975, and substantial amounts of bigeye were already being removed from the EPO by that time.

2.2.1. Discards

For the purposes of the stock assessment, it is assumed that bigeye tuna are discarded from the catches made by purse-seine vessels for one of two reasons: 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 discarded bigeye is estimated with information collected by observers from the IATTC or national programs, applying methods described by Maunder and Watters (2003). Regardless of why bigeye are discarded, it is assumed that all discarded fish die.

Estimates of discards resulting from inefficiencies in the fishing process are added to the retained catches made by purse-seine vessels (Table 2.1). No observer data are available to estimate discards for surface fisheries that operated prior to 1993 (Fisheries 1 and 6), and it is assumed that there were no discards from these fisheries. For surface fisheries that have operated since 1993 (Fisheries 2-5 and 7), there are periods for which observer data are not sufficient to estimate the discards. For these periods, it is assumed that the discard rate (discards/retained catches) is equal to the average discard rate for the same quarter from adjacent years or, if not available, the following year.

Discards that result from the process of sorting the catch are treated as separate fisheries (Fisheries 8-11), and the catches taken by these fisheries are assumed to be composed only of fish that are 2-4 quarters old (Maunder and Hoyle 2007). Watters and Maunder (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 bigeye associated with floating objects (Fisheries 2-5), because sorting is thought to be infrequent in the other purse-seine fisheries.

Time series of annual discards as proportions of the total (retained plus discarded) catches for the surface fisheries that catch bigeye tuna in association with floating objects are shown in Figure 2.3. For the four main floating-object fisheries (Fisheries 2-5) with corresponding discard fisheries (Fisheries 8-11), the proportions of the catches discarded have been low since the late 1990s relative to those observed during fishing on the strong cohorts produced in 1997. There is strong evidence that some of this is due to year classes that were weaker than the 1997 year class. However, recruitments since 1997 have been greater than the long-term average (Figure 4.5). It is possible that regulations prohibiting discarding of tuna (2001-2007; Resolution C-00-08 and subsequent renewals of that resolution) have caused the proportion of discarded fish to decrease. However, the recent high proportions of discards observed in Fishery 10 (inshore) are an exception.

It is assumed that bigeye tuna are not discarded from longline fisheries (Fisheries 12-23).

2.3. Indices of abundance

Indices of abundance were derived from purse-seine and longline catch and effort data. Fishing effort data for the surface fisheries (Fisheries 1-7) have been updated and new data included for 2009. New or updated catch and effort data are available for the Japanese longline fisheries (2006-2009). Trends in the amount of fishing effort exerted by the fisheries defined for the stock assessment of bigeye tuna in the EPO are shown in Figure 2.4. While purse-seine fishing effort (in days fished) has shown an increasing trend during the present decade (Fisheries 2, 3 and 5), longline fishing effort has gradually decreased (late longline Fisheries 13, 15, 17, and 19).

The catch per unit of effort (CPUE) of purse-seine vessels with a fish-carrying capacity greater than 363 t was calculated as catch divided by number of days fished. The number of days fished by set type was estimated from the number of sets, using a multiple regression of total days fished against number of sets by set type (Maunder and Watters 2001).

Estimates of standardized CPUE (1975-2009) were obtained for the eight (early and late) longline fisheries (Fisheries 12-19). A delta-lognormal general linear model, in which the explanatory variables were latitude, longitude, and hooks per basket, was used (Hoyle and Maunder 2006).

The CPUE time series for the different fisheries are presented in Figure 2.5. The indices of abundance that were considered appropriate for use in the assessment were the CPUE series from Fisheries 2, 3 and 5 (purse-seine sets on floating objects) and 12-19 (longline fisheries). The fisheries excluded were considered inappropriate because the catch rates were extremely low (Fishery 1) or because they combined gears (purse seine and pole and line; Fisheries 6 and 7). In addition, the first two years of the purse-seine fisheries were excluded because these fisheries were still expanding. There is a noticeable increasing trend in the standardized CPUE of the longline fisheries (Fisheries 13, 15, 17, and 19) during the 3 to 4 most recent years.

2.4. Size composition data

New length-frequency data for 2009 are available for the surface fisheries. New or updated length-frequency data are available for the Japanese longline fleet (2006-2008). Size composition data for the other longline fleets are not used in the assessment.

The length-frequency data for the Chinese Taipei fleet include more smaller fish than those for the

Japanese fleet. However, there is concern about the representativeness of the length-frequency samples from the Chinese Taipei fleet (Stocker 2005, Anonymous 2006), and therefore these data are not used in the base case assessment. Maunder and Hoyle (2007) conducted a sensitivity analysis in which the Chinese Taipei fleet was treated as a separate fishery. Also, Wang *et al.* (2009) carried out an investigation that treated the Chinese Taipei fishery as a separate entity, rather than combining data for that fishery with those for other longline fisheries, as in this assessment. The results from these studies revealed few differences with respect to the base case results.

The fisheries of the EPO catch bigeye tuna of various sizes. The average size compositions of the catches from each fishery defined in Table 2.1 have been described in previous assessments. The fisheries that catch bigeye associated with floating objects typically catch small (<75 cm) and medium-sized (75 to 125 cm) bigeye (Figures 2.6a-b, Fisheries 1-5). Prior to 1993, the catch of small bigeye was roughly equal to that of medium-sized bigeye (Figure 2.6a, Fishery 1). Since 1993, however, small bigeye from fisheries that catch bigeye in association with floating objects have dominated the catches (Figures 2.6a-b, Fisheries 2-5). An exception is the 1999-2002 period, when a strong cohort moved through the fishery and medium-sized fish dominated the catch of the floating-object fisheries.

Prior to 1990, mostly medium-sized bigeye were captured in unassociated schools (Figure 2.6b, Fishery 6). Since 1990, more small and large (>125 cm) bigeye have been captured in unassociated schools (Figure 2.6c, Fishery 7). The catches taken by the longline fisheries (Fisheries 12-19) have distinctly different size compositions. In the area north of 10°N (Northern longline Fisheries 12 and 13), longliners catch mostly medium-sized fish, and the average size composition has two distinct peaks (these appear as bands at 80 cm and 120 cm in Figure 2.6c). In the Central and Southern longline areas (Fisheries 14-15 and 16-17, respectively), longliners catch substantial numbers of both medium-sized and large bigeye (Figures 2.6d and 2.6e). However, there appears to have been a transition from medium-sized fish to fish over 150 cm during the late 1980s. There also seems to be a shift to larger fish caught by longliners in the inshore area (Fisheries 18 and 19) around the late 1980s, but these fish are not as large as those caught in the central and southern areas in the late period (Fisheries 15 and 17). In order to better model these observed shifts in the size-composition data of bigeye caught by longliners, and deal with the associated residual pattern (see Section 4.3.1), the present assessment considers two time blocks with different catchabilities and/or selectivities for all longline fisheries (see Section 2.1).

2.5. Age-at-length data

Age-at-length data derived from otolith readings (Schaefer and Fuller 2006) were integrated into the stock assessment model to provide information on mean length at age and variation in length at age. These data consist of age estimates from counts of daily increments on otoliths, and the lengths of 254 fish caught in 2002 by the floating-object fisheries (Schaefer and Fuller 2006).

3. ASSUMPTIONS AND PARAMETERS

3.1. Biological and demographic information

3.1.1. Growth

As with many tuna species, specifying growth in the bigeye stock assessment for the EPO presents some challenges. Age-at-length data derived from otolith readings are available for fish up to four years of age only (Schaefer and Fuller 2006). This is a narrow spectrum of ages of a longevity of at least 15-16 years estimated from tagging studies (Langley *et al*. 2008). Otolith daily increments for large (older) fish are very difficult to interpret. Bigeye growth estimates from tagging studies are available but again these are mostly limited to juvenile ages (Schaefer and Fuller 2006). Acquiring tag-recapture information for the older fish is problematic since it is difficult to capture large bigeye for tagging and few samples of tag recaptures from larger fish are available from the longline fisheries.

The most recent study of the age and growth of bigeye in EPO was made by Schaefer and Fuller (2006), who used tag-recapture data and otolith daily increments to estimate growth. The two data sources provided very similar estimates, but the asymptotic length of the von Bertalanffy growth curve is much greater than any length recorded. This is reasonable as long as no biological meaning is given to the asymptotic parameter and the growth model is used only as a representation of the ages of fish that were sampled. The maximum age in their data set is around 4 years (16 quarters), and hence the resulting von Bertalanffy growth curve cannot be used to predict growth beyond this age.

An attempt has been made to estimate growth internally in recent EPO bigeye stock assessment models. The growth model is fitted to the age-at-length data from otolith readings (Schaefer and Fuller 2006) and the bigeye length-composition data sampled from different fisheries. Using the A-SCALA stock assessment model (Maunder and Watters 2003), a Richards growth curve was fitted while setting the asymptotic length parameter at about the size of the largest bigeye in the data (186.5 cm; Maunder and Hoyle 2006). This resulting curve has also been taken as a prior for all ages in the bigeye stock assessment (Maunder and Hoyle 2007).

Previous growth studies and stock assessments of tuna species (*e.g.* Harley and Maunder 2005; Maunder 2002a) indicate that rapid and almost linear growth of juvenile tuna is best fitted by a Richards growth model. In two early stock assessments of bigeye (Aires-da-Silva and Maunder 2007, 2009), a von Bertalanffy growth curve was used to predict the mean length-at-age. This was due mainly to a Richards function not being available yet in Stock Synthesis (version 2; Methot 2005). In the latest bigeye assessment (Aires-da-Silva and Maunder 2010a), a sensitivity analysis was performed using the Richards growth model. There were substantial improvements in the model fit to the data, particularly to the bigeye age-at-length (otolith readings) and length-composition data.

Following the recommendations of the external review of the IATTC staff's assessment of bigeye tuna, held in May 2010, a transition is made in the present assessment from the traditional von Bertalanffy model to a more flexible Richards growth model. Previous sensitivity analyses have shown that the bigeye stock assessment results are highly sensitive to the assumed value for the average size of the older fish, the L_2 parameter in the growth model (Hampton and Maunder 2005; Aires-da-Silva and Maunder 2007; Aires da Silva and Maunder 2010c). The choice of L_2 for bigeye is somewhat arbitrary, and the parameter has generally been fixed at about the size of the largest fish in the data. As in previous assessments, and following the recommendation of the external review, L_2 is pre-specified rather than estimated in the present bigeye stock assessment; it is fixed at 185.5 cm, a value which is about the average size of the largest fish in the data. A sensitivity analysis was performed to investigate the effect on the assessment results of assuming different values of $L_{2,}$ and a likelihood profile of this parameter was also computed (Appendix B).

Another important component of growth used in age-structured statistical catch-at-length models is the variation in length at age, which can be just as influential as the mean length-at-age. Information on the variability of length-at-age can be obtained from age-at-length data, which is available for bigeye tuna (Schaefer and Fuller 2006). Unfortunately, the bigeye otolith samples were not collected randomly, but rather to cover a range of sizes to provide information on mean length-at-age. Therefore, these data do not provide a good measure of variation of length-at-age. In a previous assessment using A-SCALA (Maunder and Hoyle 2007), conditional probability was used to apply an appropriate likelihood to the data and estimate variation of length-at-age. These variability estimates have been used (fixed) in the latest assessments of bigeye that use Stock Synthesis. Following a recommendation of the external review, the parameters which determine the variance of the length-at-age are estimated, rather than set to the values estimated from A-SCALA. Age-at-length data derived from otolith readings (Schaefer and Fuller 2006) were integrated into the stock assessment model to provide information on variation in length at age.

The following weight-length relationship, from Nakamura and Uchiyama (1966), was used to convert lengths to weights in the current stock assessment:

$$w = 3.661 \times 10^{-5} \cdot l^{2.90182}$$

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

3.1.2. Natural mortality

Age-specific vectors of natural mortality (M) are assumed for bigeye. This assessment uses a sex-specific model, and therefore natural mortality schedules are provided for each sex (Figure 3.2). A higher level of natural mortality (M = 0.25) is assumed for fish of both sexes 0 quarters old, decreasing to 0.1 at 5 quarters of age. As in previous assessments, it is assumed that the natural mortality of females increases after they mature. These age-specific vectors of natural mortality are based on fitting to the estimates of age-specific proportions of females, maturity at age, and natural mortality of Hampton (2000).

The previous observation that different levels of natural mortality had a large influence on the absolute population size and the population size relative to that corresponding to the maximum sustainable yield (MSY; see definition in Section 5) (Watters and Maunder 2001) is retained. Harley and Maunder (2005) performed a sensitivity analysis to assess the effect of increasing natural mortality for bigeye younger than 10 quarters. In addition, the effect on the bigeye stock assessment of assuming alternative scenarios of juvenile natural mortality rates has been evaluated (Document SARM-9-INF-B[1]). The management quantities showed little sensitivity when higher levels of M were assumed for fish 0-5 quarters of age. In contrast, the management quantities showed a greater sensitivity to the assumption made about the oldest of the early ages (5-12 quarters old) included in the early high levels of M. However, the high levels of M assumed for bigeye 5-12 quarters (60-120 cm) old seem unrealistic. This report presents a sensitivity analysis to assuming lower and higher rates of adult natural mortality for bigeye (Appendix C).

An ongoing investigation of natural mortality rates for bigeye, based on an integrated analysis which includes tagging and sex ratio data, indicates levels of M for adult bigeye higher than previously assumed (Maunder *et al.* 2010). However, these estimates are highly uncertain, and strongly dependent on the assumptions made about the tag-reporting rates by longliners.

3.1.3. Recruitment and reproduction

It is assumed that bigeye tuna can be recruited to the fishable population during every quarter of the year. Recruitment may occur continuously throughout the year, because individual fish can spawn almost every day if the water temperatures are in the appropriate range (Kume 1967; Schaefer *et al*. 2005).

The Stock Synthesis 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 (biomass of mature females) and recruitment is determined by estimating the average recruitment produced by an unexploited population (virgin recruitment), a parameter called steepness. Steepness controls how quickly recruitment decreases when the spawning biomass is reduced. It is defined as the fraction of virgin recruitment that is produced if the spawning biomass is reduced to 20% of its unexploited level. Steepness can vary between 0.2 (in which case recruitment is a linear function of spawning biomass) and 1.0 (in which case recruitment is independent of spawning biomass). In practice, it is often difficult to estimate steepness because of a lack of contrast in spawning biomass and because there are other factors (*e.g.* environmental influences) that can cause recruitment to be extremely variable. For the current assessment, recruitment is assumed to be independent of stock size (steepness = 1). There is no evidence that recruitment is related to spawning stock size for bigeye in the EPO and, if steepness is estimated as a free parameter, it is estimated to be close to 1. However, simulation analyses have shown that estimation of steepness is problematic, with large uncertainty and frequent estimates equal to one even if the true steepness is moderately less than one (Conn *et al*. 2010). A sensitivity analysis with steepness = 0.75, and a likelihood profile on this parameter are presented in this report (Appendix A). In addition to the assumptions required for the stock-recruitment relationship, a constraint on quarterly recruitment deviates

[1] http://www.iattc.org/PDFFiles2/SARM-9-INF-B-Comments-on-Document-SARM-9-11d.pdf

with a standard deviation of 0.6 is applied. Recruitment is modeled at age-0 in Stock Synthesis.

Reproductive inputs are based on the results of Schaefer *et al*. (2005) and data provided by Dr. N. Miyabe of the National Research Institute of Far Seas Fisheries (NRIFSF) of Japan. Information on age at length (Schaefer and Fuller 2006) was used to convert proportion mature at length into an age-at-maturity schedule (Figure 3.3, Table 3.1).

3.1.4. Movement

The current assessment does not consider movement explicitly. Rather, it is assumed that the population is randomly mixed at the beginning of each quarter of the year. The IATTC staff is studying the movement of bigeye within the EPO, using data recently collected from conventional and archival tags, and these studies indicate substantial levels of regional fidelity of bigeye within the EPO. The results of these studies may eventually provide information useful for stock assessment. This implies that localized depletion patterns of bigeye may exist in the EPO. A preliminary evaluation of spatial structure in the bigeye stock assessment has been initiated (Aires-da-Silva and Maunder 2010b). A spatially-structured framework will be considered in future stock assessments. The spatial definition of the fisheries accommodates some forms of movement by means of different selectivity and catchability.

3.1.5. Stock structure

Schaefer and Fuller (2009) provide an overview of current knowledge about the stock structure of bigeye in the EPO. The results of tagging studies indicate regional fidelity of the species in the region, and suggest a very low level of mixing between the eastern and the western Pacific (Schaefer and Fuller 2002; Schaefer and Fuller 2009). Accordingly, and for the purposes of the current stock assessment, it is assumed that there are two stocks, one in the EPO and the other in the western and central Pacific Ocean (WCPO), and that there is no net exchange of fish between these regions. The IATTC staff periodically conducts a Pacific-wide assessment of bigeye in collaboration with scientists of the Oceanic Fisheries Programme of the Secretariat of the Pacific Community and of the NRIFSF. This work may help indicate how the assumption of a single stock in the EPO is likely to affect interpretation of the results obtained from the Stock Synthesis method. Recent analyses (Hampton *et al*. 2003) that estimate movement rates within the Pacific Ocean provided biomass trends very similar to those estimated by Harley and Maunder (2004), and differences in absolute levels of biomass were mainly due to differences in growth rates between the two sides of the Pacific Ocean.

In order to investigate the sensitivity of the assessment results to the assumptions made about stock structure, a sensitivity analysis to extending the western limit of the bigeye stock distribution was conducted (Aires-da-Silva and Maunder 2010a). When the assumed western limit of the bigeye stock distribution was extended from 150°W to 170°E, and the additional catch taken from the WCPO was included in the model, the recruitments and biomasses were greater than those estimated by the base case model, but the relative trends are very similar. When the model was also fitted to the additional CPUE and length-composition data from the WCPO, the biomass estimates for most years became lower than the base case, but the relative trends are also similar. The stock status evaluation for these sensitivity analyses was similar to that for the base case.

3.2. Environmental influences

Oceanographic conditions might influence the recruitment of bigeye tuna to fisheries in the EPO. In previous assessments (*e.g.* Watters and Maunder 2001, 2002), zonal-velocity anomalies (velocity anomalies in the east-west direction) at 240 m depth were used as the candidate environmental variable for affecting recruitment. The mechanism that is responsible for this relationship has not been identified, and correlations between recruitment and environmental indices are often spurious, so the relationship between zonal velocity and bigeye recruitment should be viewed with skepticism. Nevertheless, this relationship tends to indicate that bigeye recruitment is increased by strong El Niño events and decreased by strong La Niña events. In fact, two of the periods of greatest recruitment (1982-1983 and 1997-1998) coincide with the two strongest El Niño events of the 20th century. Maunder and Hoyle (2007) conducted a sensitivity analysis to investigate the relationship between recruitment and the El Niño index; this showed that there was a significant negative relationship, but it explained only a small proportion of the total variability in the recruitment.

Other sensitivity analyses in which environmental indices were incorporated into the stock assessment model have been conducted in previous assessments. It was assumed that oceanographic conditions might influence the efficiency of the fisheries that catch bigeye associated with floating objects (Fisheries 1-5) (Watters and Maunder 2001, 2002; Maunder and Harley 2002). In the assessment of Maunder and Harley (2002), an environmental influence on catchability was assumed for the central floating-object Fishery 3 only. It was found that including this effect did not greatly affect the results.

In general, analyses in which no environmental indices were included produced estimates of recruitment similar to those that used zonal velocity (Harley and Maunder 2004). This suggests that there is sufficient information in the length-frequency data to estimate most historical year-class strengths, but the index may be useful for reducing uncertainty in estimates of the strengths of the most recent cohorts, for which few size-composition samples are available. A previous sensitivity analysis of the effect of including the environmental index showed that the index was not statistically significant (Maunder and Hoyle 2006), or explained only a small proportion of the total variation in recruitment (Maunder and Hoyle 2007). However, the "two-stanza" recruitment pattern for bigeye in the EPO (Section 4.1.2), which consists of a period of lower recruitments (1975-1993) followed by a period of relatively large recruitments (1994-2009), may be preventing a significant correlation. Investigating environmental correlations for the late period only may be preferable. In Appendix B, the time series of estimated bigeye quarterly recruitments for only the late period of the fishery (1995-2009) are compared with the Southern Oscillation Index (SOI; Philander 1990) (see Appendix D). An evaluation of spatial structure in the bigeye assessment indicates that similar recruitment trends in different regions of the EPO may be driven by a similar large-scale environmental effect (*e.g*., El Niño/La Niña events) (Aires-da-Silva and Maunder 2010b)

In view of the results from previous sensitivity analyses described above, no environmental index was incorporated into this assessment.

4. STOCK ASSESSMENT

The Stock Synthesis method (SS - Version 3.10b; Methot 2005, 2009) was used to assess the status of bigeye tuna in the EPO. It consists of a size-based, age-structured, integrated (fitted to many different types of data) statistical stock assessment model.

The model is fitted to the observed data (indices of relative abundance and size compositions) by finding a set of population dynamics and fishing parameters that maximize a penalized likelihood, given the amount of catch taken by each fishery. Many aspects of the underlying assumptions of the model are described in Section 3. It also includes the following important assumptions:

1. Bigeye tuna are recruited to the discard fisheries (Fisheries 8-11) one quarter after hatching, and these discard fisheries catch only fish of the first few age classes (fully selected between 1 and 3 quarters of age).
2. The size-based selectivity curves for the late longline fisheries in the Central and Southern areas (Fisheries 15 and 17) are assumed to be asymptotic.
3. The data for fisheries that catch bigeye tuna in unassociated schools (Fisheries 6 and 7), the pre-1993 and coastal floating-object fisheries (Fisheries 1 and 4), and fisheries whose catch is composed of the discards from sorting (Fisheries 8-11), provide relatively little information about biomass levels, because these fisheries do not direct their effort at bigeye. For this reason, the CPUE time series for these fisheries were not used as indices of abundance.

The following parameters have been estimated in the current stock assessment of bigeye tuna from the

EPO:

1. Mean length at age and variability of the length at age. As proposed in the previous bigeye assessment as a future modification (Aires-da-Silva and Maunder 2010a), and following a recommendation by the external review, a more flexible Richards growth curve was adopted as an alternative to the von Bertalanffy growth function used in previous assessments. In addition, the parameters of a linear model relating the standard deviations in length at age to the mean lengths at age were estimated, rather than fixed.
2. Recruitment in every quarter from the first quarter of 1975 through the fourth quarter of 2009 (includes estimation of virgin -or average - recruitment and temporal recruitment penalized anomalies);
3. Catchability coefficients for the eleven CPUE time series that are used as indices of abundance (floating-object Fisheries 2, 3, and 5, longline Fisheries 12-19). Following a recommendation by the external review, two time blocks (early and late fisheries, split at 1990) with different catchability parameters are assumed for the newly-defined longline fisheries (Northern, Central, Southern and Inshore; Fisheries 12-19).
4. Coefficients of variation (CVs) for the three CPUE indices that are used as indices of abundance for the floating-object fisheries (Fisheries 2, 3, and 5), and CPUE indices of early and late Northern (12 and 13), Central (14 and 15), and Inshore (18 and 19) longline fisheries. Following a recommendation by the external review, the CVs of the CPUE for the early and late Southern longline Fisheries (16 and 17) were fixed at 0.15, rather than estimated, as these are the most reliable longline indices of abundance.
5. Selectivity curves for fifteen of the 23 fisheries (Fisheries 8-11 have an assumed selectivity curve, and the selectivities of Fisheries 20, to 23 are the same as those of Fisheries 13, 15, 17 and 19, respectively). Except for the late Central and Southern longline fisheries (15 and 17), which catch larger bigeye, the selectivity curves of all fisheries that retain their catches are assumed to be dome-shaped (double normal).
6. Initial population size and age structure. Two initial fishing mortality parameters (for surface and combined longline fisheries, respectively) are estimated. In addition, the average recruitment used to estimate the initial conditions and deviates for the youngest 15 age classes are estimated.

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

1. Sex- and age-specific natural mortality rates (Figure 3.2);
2. Age-specific maturity curve (Table 3.1 and Figure 3.3);
3. Selectivity curves for the discard fisheries (Fisheries 8-11);
4. The steepness of the stock-recruitment relationship.

The estimates of management quantities and future projections were computed based on 3-year average fishing mortality rates, by gear, for 2007-2009. The sensitivity of estimates of key management quantities to including the last year (2009) in the 3-year average fishing mortality rate estimate was tested. For this purpose, a 2-year (2007-2008) average fishing mortality rate was used in the calculations.

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 bigeye tuna in the EPO. Also, the stock assessment model may not perfectly represent the dynamics of the bigeye population or of the fisheries that operate in the EPO. Uncertainty is expressed as approximate confidence intervals and 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. The model structure uncertainty is investigated in several sensitivity analyses.

The following summarizes the important aspects of the base case assessment (1) and the four sensitivity analyses (2-4):

1. **Base case assessment**: steepness of the stock-recruitment relationship = 1 (no relationship between stock and recruitment); average size of the older fish (L_2) is fixed at 185.5 cm, and the parameters that define the variability of the length-at-age are estimated; fitted to CPUE time series for floating-object Fisheries 2-5 and longline Fisheries 12-19; two time blocks of catchability and selectivity for longline Fisheries 12-19; asymptotic size-based selectivities for the late longline Fisheries 15 and 17, which catch larger bigeye.
2. **Sensitivity to the steepness of the stock-recruitment relationship**. The base case assessment includes an assumption that recruitment is independent of stock size, and a Beverton-Holt (1957) stock-recruitment relationship with a steepness of 0.75 was used for the sensitivity analysis. In addition, a likelihood profile for steepness was computed (steepness ranging from 0.5 to 1, with 0.1 increments).
3. **Sensitivity to the average size of the older fish** (L_2 parameter of the Richards growth function). L_2 is fixed at 185.5 cm in the base case model. Two alternative fixed values of L_2 were considered for the sensitivity analysis, a lower and a higher value of 170 cm and 200 cm, respectively. In addition, a likelihood profile for L_2 was computed (L_2 ranging from 160 to 200 cm, with 5-cm increments).
4. **Sensitivity to assuming lower and higher values of adult natural mortality (*M*) for both females and males.** While defining the alternative *M* schedules for bigeye, and in order to maintain the age-specific absolute differences of natural mortality estimated from sex-ratio data (Figure 3.2), the *M* values for adult (12+ quarters old) females and males assumed in the base case were decreased/increased by the same multiplicative factor (Figure C.1).
5. **Sensitivity to using data for only the late period of the fishery (1995-2009).** This period best reflects the current mix of tuna fisheries (surface and longline) and selectivities operating in the EPO. This sensitivity analysis is motivated by heightened concerns about potential biases in the bigeye stock productivity estimates (virgin recruitment) and derived management quantities, which may be caused by a shift from lower to higher recruitment estimates coinciding with the expansion of the floating-object fisheries since 1993 (Document SARM-9-INF-B[2]; Aires-da-Silva, Maunder and Tomlinson 2010). It is also done to address potential causes for the observed residual pattern in the model fit to the longline length compositions, other than changes of catchability and selectivity which are already addressed by means of two time-blocks for longline fisheries.

4.1. Assessment results

The results presented in the following sections 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 absolute estimates of biomass, recruitment, and fishing mortality.

4.1.1. Fishing mortality

There have been important changes in the amount of fishing mortality of bigeye in the EPO. On average, the fishing mortality of fish less than about 15 quarters old has increased greatly since 1993, and that of fish more than about 15 quarters old has increased to a much lesser extent since then (Figure 4.1). The

[2] http://www.iattc.org/PDFFiles2/SARM-9-INF-B-Comments-on-Document-SARM-9-11d.pdf

increase in average fishing mortality of younger fish can be attributed to the expansion of the fisheries that catch bigeye in association with floating objects (Fisheries 2-5). These fisheries catch substantial amounts of bigeye (Figure 2.2), select fish that are generally less than about 100 cm in length (Figure 4.2), and have expended a relatively large amount of fishing effort since 1993 (Figure 2.4).

Temporal trends in the age-specific amounts of annual fishing mortality of bigeye are shown in Figure 4.3. These trends reflect the distribution of fishing effort among the various fisheries that catch bigeye (Figure 2.4) and changes in catchability. The trend in annual fishing mortality rate by time shows that fishing mortality has increased greatly for young fish (ages 9-12 quarters) since the early 1990s, and has remained nearly stable during the most recent decade. This was due to the expansion of the purse-seine fisheries that catch juvenile bigeye on floating objects since 1993. Fishing mortality for older fish (13+ quarters) has also increased over the historic period of the assessment (1975-2009). However, the average levels of adult fishing mortality have remained nearly half of those for juvenile bigeye since the mid-1990s. In fact, a sharp decline of the fishing mortality of older fish has been observed during the present decade as a result of decreased longline fishing effort in the EPO (Figure 2.4). Fishing mortality rates for older fish (20+ quarters) increased greatly in the early 1990s as higher proportions of larger (>150 cm) fish became vulnerable to the longline fisheries, particularly in the Central and Southern areas (Fisheries 15 and 17, respectively; Figures 2.6d,e). An annual summary of the estimates of total fishing mortality is presented in Appendix E (Table E.1).

4.1.2. Recruitment

Over the range of estimated spawning biomasses shown in Figure 4.7, the abundance of bigeye recruits appears to be unrelated to the spawning biomass of adult females at the time of hatching (Figure 4.4). Previous assessments of bigeye in the EPO (*e.g.* Watters and Maunder 2001, 2002) also failed to show a relationship between adult biomass and recruitment over the estimated range of spawning biomasses. The base case estimate of steepness is fixed at 1, which corresponds to a model with an assumption that recruitment is independent of stock size. The consequences of overestimating steepness, in terms of lost yield and potential for recruitment overfishing, are far worse than those of underestimating it (Harley *et al*. unpublished analysis). A sensitivity analysis is presented in Appendix A that assumes that recruitment is related to stock size in varying degrees (steepness ranging from 0.5 to 1).

The time series of estimated quarterly recruitment (age-0 quarters fish) of bigeye is shown in Figure 4.5a, and the total recruitment estimated to occur during each year is shown in Figure 4.5b and Table 4.1. There are several important features in the time series of estimated recruitment of bigeye. First, estimates of recruitment before 1993 are very uncertain, as the techniques for catching small bigeye associated with floating-objects were not in use. In addition, a "two-stanza" pattern can be identified in the time series of bigeye recruitments for the EPO (Figure 4.5a). This pattern is characterized by an early period of low recruitments (1975-1993) followed by a period of relatively large recruitments (1994-2009). This shift coincided with the expansion of the fisheries that catch bigeye in association with floating objects. A series of potential alternative hypothesis to explain this pattern has been advanced elsewhere (Document SARM-9-INF-B[3]; Aires-da-Silva, Maunder and Tomlinson 2010). The impact on the bigeye assessment results of potentially biased low recruitments prior to 1994 has been investigated. Adjustment of the spawning biomass ratios (SBRs, see definition in Section 5.1) and management quantities would result in a more pessimistic stock evaluation (see Appendix A of SARM-9-INF-B). A sensitivity analysis was performed using fishery data covering the most recent period of the fishery only (1995-2009), which best reflects the current mix of tuna fisheries (surface and longline) and selectivities operating in the EPO (see Appendix D). In Appendix D, the time series of estimated bigeye quarterly recruitments (1995-2009) are compared with the Southern Oscillation Index (SOI; Philander 1990). The relationship tends to indicate that the bigeye recruitment is increased by strong El Niño events and decreased by strong La Niña events (Figure D.5). There was a period of above-average annual recruitment during 1994-1998, followed by a

[3] http://www.iattc.org/PDFFiles2/SARM-9-INF-B-Comments-on-Document-SARM-9-11d.pdf

period of below-average recruitment in 1999-2000. The recruitments were above average from 2001 to 2006, and were particularly large in 2005 and 2006. The recruitment in 2007 was below average, but the recruitment in 2008 appears to have been particularly high. The most recent annual recruitment estimate (2009) is slightly below average levels. However, this estimate is highly uncertain, and should be regarded with caution, due to the fact that recently-recruited bigeye are represented in only a few length-frequency data sets.

4.1.3. Biomass

Trends in the biomass of 3+-quarter-old bigeye tuna in the EPO are shown in Figure 4.6, and estimates of the biomass at the beginning of each year are presented in Table 4.1. The biomass of 3+-quarter-old bigeye increased during 1983-1985, and reached a peak of about 845 thousand t in 1986, after which it decreased to a historic low of about 347 thousand t at the beginning of 2004. Since then, the biomass of 3+-quarter-old bigeye tuna has shown a gradual increasing trend.

The trend in spawning biomass is also shown in Figure 4.7, and estimates of the spawning biomass at the beginning of each year are presented in Table 4.1. The spawning biomass has generally followed a trend similar to that of the biomass of 3+-quarter-old bigeye, but with a 1- to 2-year time lag. The biomasses of both 3+-quarter-old fish and spawners are estimated to have been increasing over the last five years. A simulation study indicates that this population increase may be attributed to the effect of IATTC tuna conservation resolutions during 2004-2009 (Section 6.2.3). Additional factors likely contributing to this increase are above-average recruitments and reduced longline effort in the EPO in recent years.

There is uncertainty in the estimated biomasses of spawners. The average CV of the spawning biomass estimates is 0.19.

Given the amount of uncertainty in the estimates of both recruitment and biomass (Sections 4.1.2 and 4.1.3), it is difficult to determine whether trends in the biomass of bigeye have been influenced more by variation in recruitment or fishing mortality. Nevertheless, the assessment suggests two conclusions. First, the biomass of bigeye can be substantially increased by strong recruitment events. Both peaks in the biomass of 3+-quarter-old bigeye (1986 and 2000; Figure 4.6) were preceded by peak levels of recruitment (1982-1983 and 1997-1998, respectively; Figure 4.5).

Second, it is apparent that fishing has reduced the total biomass of bigeye present in the EPO. This conclusion is drawn from the results of a simulation in which the biomass of bigeye tuna estimated to be present in the EPO if fishing had not occurred was projected over the historic period of the assessment (1975-2009), using the time series of estimated recruitment anomalies in the absence of fishing. To estimate the impact that different fisheries have had on the depletion of the stock, we ran simulations in which each gear was excluded and the model was run forward as in the no-fishing simulation (see Wang *et al*. 2009 for details of the simulation methodology). The results of this analysis are shown in Figure 4.8. It is clear that the longline fishery had the greatest impact on the stock prior to 1995, but with the decrease in effort by the longline fisheries, and the expansion of the floating-object fishery, at present the impact of the purse-seine fishery on the population is far greater than that of the longline fishery. The discarding of small bigeye has a small, but detectable, impact on the depletion of the stock. Overall, the current spawning biomass is estimated to be about 26% of that expected had no fishing occurred.

4.1.4. Average weights of fish in the catch

Trends in the average weights of bigeye caught by the fisheries that operate in the EPO are shown in Figure 4.9. The fisheries that catch bigeye in association with floating objects (Fisheries 1-5) have taken mostly small fish that, on average, weigh less than the critical weight, which indicates that these fisheries do not maximize the yield per recruit (Maunder and Hoyle 2007). The average weight of bigeye taken by the longline fisheries (Fisheries 12 and 19) has been around the critical weight, which indicates that these fisheries tend to maximize the yield per recruit. The average weight for all fisheries combined declined substantially after 1993 as the catch of bigeye in purse-seine sets on floating objects increased and that of bigeye by longline decreased.

The average weight in both the surface and longline fisheries declined around 1997-1998 as a strong cohort entered the fishery. The average weights then increased as the fish in that cohort increased in size. The average weight then declined again as that cohort was removed from the population.

The average weights for the surface fishery predicted by the model differ from the observed mean weights, particularly before 1984 (Figure 4.9, middle panel). The observed average weights are estimated by scaling up the length-frequency samples to the total catch, which differs from the method used in the stock assessment model, which uses the selectivity curves and estimated fishing mortality rates for each fishery to estimate the average weight. There was an apparent shift around 1985 from higher proportions of smaller (<75 cm) bigeye caught to higher proportions of medium-sized (75-125 cm) bigeye caught by the early floating-object fishery (Fishery 1; Figure 2.6a). Therefore, assuming two time blocks of selectivity (pre- and post-1985) in future assessments may help to minimize the differences between observed and predicted average weights for this early fishery.

An improvement was made with regard to the differences identified in previous assessments between the observed weights of bigeye caught by Japanese longliners and the estimates predicted by the stock assessment model (Figure 4.9, bottom panel). This better correspondence between the observed and predicted average weights of bigeye results from the new assumption of two blocks of catchability and selectivity for the longline fisheries, split at 1990. There are some exceptions, particularly in the late 1990s and early 2000s, which coincide with the expansion of the Chinese Taipei fishery in the EPO.

4.2. Comparisons to external data sources

No comparisons to external data were made in this assessment.

4.3. Diagnostics

Diagnostics are discussed in the next two sections, residual analysis and retrospective analysis.

4.3.1. Residual analysis

The model fits to the CPUE data from different fisheries are shown in Figure 4.10a-c. The model fits the longline CPUE observations closely. The exception is the northern longline fishery, which is seasonal and shows higher variability of CPUE. The model fits particularly well to the CPUE data of the southern longline fishery (both early and late Fisheries 16 and 17, respectively). When compared to model fits from previous assessments (Figure 4.10 of Aires-da-Silva and Maunder 2010a), the new assumption of two time blocks (early and late) for longline catchability and selectivity greatly improved the model fit to the CPUE increases observed around the mid-1980s (Fishery 16) and early 2000s (Fishery 17). The fits to the surface fisheries CPUE data series are less satisfactory.

Pearson residual plots are presented for the model fits to the length-composition data (Figures 4.11a-f). The gray and black circles represent observations that are less than and greater than the model predictions, respectively. The areas of the circles are proportional to the absolute values of the residuals. There are several notable characteristics of the residuals. The model underestimates (black circles) the proportions of medium and small fish for the post-1993 floating-object fisheries. In particular, it underestimates the proportions of large fish during 1999-2002, when a strong cohort moved through the fishery.

No prominent residual pattern is identifiable in the model fit to length-composition data collected for both periods of the Northern (Fisheries 12 and 13), Central (Fisheries 14 and 15), and Inshore (Fisheries 18 and 19) longline fisheries. Also, the model fit to the Southern longline length-composition data has been improved. The major shift in residual pattern around the late 1980s identified in early assessments has been minimized (Aires-da-Silva and Maunder 2010a; Aires-da-Silva, Maunder and Lennert-Cody 2010). This could be due to the new longline fishery definitions and also to the two time blocks of longline catchability/selectivity assumed in the present assessment. Nonetheless, the residual pattern is still strong in the model fit to the length data from the late period of the Southern longline fishery (Fishery 17; Figure 4.11e). Specifically, the proportions of medium-sized fish are systematically underestimated around two distinct length modes, centered at about 100 and 150 cm. Possible reasons for the remaining pattern are further spatial misspecification issues, time-varying selectivity, and not enough flexibility in the assumed double normal size-selectivity curve. The average fits to the observed length-compositions of the catches taken by the surface and longline fisheries defined in the stock assessment model are shown in Figure 4.11g and 4.11h, respectively. The model fits to the length-compositions of the recent catches of bigeye are also shown for different fisheries (Figures 4.11e-h).

The fit to the data, as measured by root mean square error, suggests that the model fits the CPUE index for the early and late Southern longline fisheries (Fisheries 16 and 17) better (CV = 0.12 and 0.15, respectively) than those for other fisheries. The worst fits to the CPUE data are those for floating-object Fisheries 3 (CV = 0.54) and 5 (CV = 0.55), followed by the late Northern longline fishery (Fishery 13; CV = 0.43). With respect to the length-frequency data, the model fits the data better (as indicated by the estimated effective sample size) than is reflected by the assumed sample sizes in the likelihood functions. In an earlier assessment (Aires-da-Silva and Maunder 2007), a sensitivity analysis, using iterative reweighting, was conducted to investigate the weighting of the data sets. Specifically, the appropriate standard deviations and sample sizes for the likelihood functions were determined iteratively, based on the fit to the data. When iterative reweighting was applied, more weight was given to the length-frequency data, and the biomasses were estimated to be lower in the earlier and later segments of the historical period.

4.3.2. Retrospective analysis

Retrospective analysis is useful for determining how consistent a stock assessment method is from one year to the next. Inconsistencies can often highlight inadequacies in the stock assessment method. This approach is different from the comparison of recent assessments (Section 4.5), in which the model assumptions differ among these assessments, and differences would be expected. Retrospective analyses are usually carried out by repeatedly eliminating one year of data from the analysis while using the same 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 analyses were conducted by removing one year (2009), two years (2009 and 2008), three years (2009, 2008, 2007) and four years (2009, 2008, 2007, 2006) of data (Figures 4.12-4.14). Although the retrospective analyses show the same relative increasing trend in the summary biomass since 2005 as the base case model, the biomass estimates from the base case model are lower than those estimated when the last years of data are not incorporated into the model (Figure 4.12). The retrospective pattern seems to be weaker for the recent levels of the SBR (Figure 4.13). As noted in previous assessments, the recent recruitment levels are highly subject to recent retrospective bias (Figure 4.14). Retrospective bias does not necessarily indicate the magnitude and direction of the bias in the current assessment, only that the model may be misspecified.

4.4. Sensitivity analyses

The results of the four sensitivity analyses are presented in the appendices: sensitivity to (a) the stock–recruitment relationship (Appendix A); (b) an assumed fixed value of the average size of the older fish (L_2 parameter) in the Richards growth function (Appendix B); (c) assuming higher rates of adult natural mortality (M) for bigeye (Appendix C); and (d) using data only for the late period of the fishery (1995-2009) (Appendix D). Here we describe differences in model fit and model prediction, and defer our discussion of differences in stock status until Section 5. A comparison of the likelihoods for the base case and sensitivity analyses is provided in Table 4.3.

The steepness of the Beverton-Holt (1957) stock-recruitment relationship was set at 0.75. The estimates of the summary biomass (Figure A.1) are greater than those estimated in the base case assessment, but the trends are similar. Absolute recruitment estimates are slightly greater than those estimated in the base case (Figure A.2a), but the recruitment time series is similar to that of the base case (Figure A.2b). The trends in the SBR are very similar between the base case and the model that assumes a stock-recruitment relationship, but the initial SBR levels are slightly higher for the base case (Figure A.3). The estimated stock-recruitment relationship is shown in Figure A.4. A likelihood profile on the steepness parameter indicates that the model fits the data better for higher values of steepness, and that the base case (steepness = 1) produced the best fit. In addition, different data components all support a steepness of 1.

The base case model assumes a Richards (1959) growth function. The choice of the average size of the older fish – the L_2 parameter – is somewhat arbitrary, since otolith readings are not available for larger (older) fish. In the base case model, L_2 is fixed at 185.5 cm (Section 3.1.1). A sensitivity analysis was conducted to study the effect of fixing L_2 at different values (Figure B.1). The estimated biomass and recruitment time series are very sensitive to the assumed value of L_2 (Figures B.2 and B.3); they are greater for a lesser value of that parameter. This has been reported previously (Maunder and Hoyle 2007; Aires-da-Silva and Maunder 2007; Aires-da-Silva and Maunder 2010c). It can be explained by the need to fit the length-composition data with an asymptotic selectivity for some longline fisheries (Maunder and Hoyle 2007). A likelihood profile on L_2 indicates that the model fits better with a fixed L_2 value around 170 cm (Figure B.5).

A sensitivity analysis was conducted to assuming several scenarios of adult natural mortality (*M*) for both sexes of bigeye tuna (Figure C.1). To be consistent with the absolute differences in *M* between females and males estimated from sex-ratio data, the absolute difference in *M* between sexes was kept the same in all sensitivity analyses. The biomass and recruitment estimates are very sensitive to adult *M* (Figures C.2 and C.3); they are greater for higher levels of adult *M*. As expected, absolute recruitment estimates increase in order to explain observed catches with higher natural mortality rates (Figure C.3a). As described in Aires-da-Silva, Maunder and Tomlinson (2010), assuming higher rates of adult *M* contributes to minimizing the “two-stanza” bigeye recruitment pattern (Section 4.1.2). A likelihood profile on adult *M* indicates that the model fits better for higher values of *M* than those assumed in the base case (Figure C.5). However, these rates seem unreasonably high for bigeye.

Concerns have been raised about the potential biases in the bigeye stock productivity estimates (virgin recruitment), and its derived management quantities, which may be caused by a shift from lower to higher estimated recruitments coinciding with the expansion of the floating-object fisheries since 1993 (Document SARM-9-INF-B; Aires-da-Silva, Maunder and Tomlinson 2010). A sensitivity analysis using data for only the late period of the fishery (1995-2009) was conducted. Two values of steepness were considered in this sensitivity analysis: 1 (as in the base case), and 0.75.

When data for only the late period of the fishery (1995-2009) are used in the bigeye assessment, and no stock-recruitment relationship is assumed (steepness = 1), the summary biomass estimates are lower than the base case estimates (Figure D.1). When a stock-recruitment relationship is assumed (steepness = 0.75), the summary biomass estimates are slightly higher than the base case estimates (Figure D.1). These results are partially explained by differences in absolute recruitment (Figure D.2a), but the relative recruitment trends are very similar (Figure D.2b).

Other sensitivity analyses, including investigation of growth estimation, environmental effects on recruitment and catchability, natural mortality, use of iterative reweighting, and use of two time blocks for selectivity and catchability for the southern longline fishery, were conducted by Watters and Maunder (2002), Harley and Maunder (2004, 2005), Maunder and Hoyle (2007), and Aires-da-Silva and Maunder (2007, 2009, 2010a, b, c).

4.5. Comparison to previous assessment

There are substantial differences between the summary and the spawning biomasses (Figures 4.15 and 4.16, respectively) estimated by the current and the previous stock assessment model (Aires-da-Silva and

Maunder 2010). These differences are mainly due to revised important assumptions (mainly fishery definitions, growth modeling, data weighting, and modeling of catchability and/or selectivity) following the recommendation of the external review. The absolute and relative differences in the biomasses in recent years are more likely due to the new data available for those years. The recruitments estimated by the current assessment are slightly higher than the estimates from the previous assessment, but the recruitment in 2007 is estimated to be much smaller than the base case estimates (Figure 4.18a). The differences in relative recruitment are minor (Figure 4.18b). The trends in the SBRs are also very similar, with very minor absolute differences during the post-2000 period (Figure 4.17).

The transition from the previous to the current base case model, following the recommendations of the external review, is illustrated in detail by a series of additional model runs and sensitivity analyses (see Document SAC-01-08b).

4.6. Summary of results from the assessment model

There have been important changes in the amount of fishing mortality caused by the fisheries that catch bigeye tuna in the EPO. On average, the fishing mortality on bigeye less than about 15 quarters old has increased substantially since 1993, and that on fish more than about 15 quarters old has increased to a much lesser extent. The increase in fishing mortality on the younger fish was caused by the expansion of the fisheries that catch bigeye in association with floating objects.

Over the range of spawning biomasses estimated by the base case assessment, the abundance of bigeye recruits appears to be unrelated to the spawning potential of adult females at the time of hatching.

There are several important features in the estimated time series of bigeye recruitment. First, estimates of recruitment before 1993 are very uncertain, as the floating-object fisheries were not catching significant amounts of small bigeye. There was a period of above-average annual recruitment in 1994-1998, followed by a period of below-average recruitment in 1999-2000. The recruitments were above average from 2001 to 2006, and were particularly large in 2005 and 2006. The 2007 recruitment was below average, but the recruitment in 2008 appears to have been particularly high. The most recent annual recruitment estimate (2009) is slightly below average levels. However, this estimate is very uncertain, due to the fact that recently-recruited bigeye are represented in only a few length-frequency samples.

The biomass of 3+-quarter-old bigeye increased during 1983-1985, and reached its peak level of about 845 thousand t in 1986, after which it decreased to a historic low of about 347 thousand t at the beginning of 2004. Since then, the biomass of 3+-quarter-old bigeye has shown an increasing trend in the EPO. Spawning biomass has generally followed a trend similar to that for the biomass of 3+-quarter-olds, but with a lag of 1 to 2 years. There is uncertainty in the estimated biomasses of both 3+-quarter-old bigeye and spawners. Nevertheless, it is apparent that fishing has reduced the total biomass of bigeye in the EPO. The biomasses of both 3+-quarter-old fish and spawners are estimated to have been increasing over the last five years. Results from a simulation study (Section 6.2.2) indicate that this increasing trend may be attributed to the effect of IATTC tuna conservation resolutions during 2004-2009. Additional factors likely contributing to this increase are above-average recruitments and reduced longline effort in the EPO in recent years.

The estimates of summary biomass are moderately sensitive to the steepness of the stock-recruitment relationship. Specifically, the estimates of biomass are greater than those estimated in the base case assessment, but the trends are similar. The relative trend in recruitment is similar to the base case.

The estimated biomass and recruitment time series are very sensitive to the assumed value of the average size of the older fish - L_2 parameter – in the growth function. Biomass and recruitment estimates are greater for a lesser value of that parameter. A likelihood profile on L_2 indicates that the model fits better with a fixed L_2 value around 170 cm.

The estimated biomass and recruitment time series are very sensitive to the assumed rate of adult natural mortality for bigeye. Biomass and recruitment estimates increase with higher levels of adult *M*. A likelihood profile on adult *M* indicates that the model fits better to all data components for higher values of adult *M*, which indicates higher productivity for the bigeye stock than estimated by the base case model. However, the higher rates of natural mortality seem unreasonably high for bigeye.

When data from only the late period of the fishery (1995-2009) are used in the bigeye assessment, and no stock-recruitment relationship is assumed (steepness = 1), the summary biomass estimates are lower than the base case estimates. When a stock-recruitment relationship is assumed (steepness = 0.75), the summary biomass estimates are slightly higher than the base case estimates. These results are partially explained by differences in absolute recruitment, but the relative recruitment trends are very similar.

5. STOCK STATUS

The status of the stock of bigeye tuna in the EPO is assessed by considering calculations based on the spawning biomass and the maximum sustainable yield (MSY). MSY is defined as the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions.

Maintaining tuna stocks at levels that produce the MSY is the management objective specified by the IATTC Convention. The IATTC has not adopted any target or limit reference points for the stocks that it manages, but some possible reference points are described in the following subsections.

5.1. Assessment of stock status based on spawning biomass

The spawning biomass ratio (the ratio of the current spawning biomass to that of the unfished stock; SBR), described by Watters and Maunder (2001), has been used to define reference points in many fisheries. It has a lower bound of zero. If it is near zero, the population has been severely depleted, and is probably overexploited. If the SBR is one, or slightly less than that, the fishery has probably not reduced the spawning stock. If the SBR is greater than one, it is possible that the stock has entered a regime of increased production.

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

Estimates of SBR for bigeye tuna in the EPO have been computed from the base case assessment. Estimates of the spawning biomass during the study period (1975-2009) are presented in Section 4.1.3. The SBR corresponding to the MSY (SBR_{MSY}) is estimated to be about 0.19.

At the beginning of January 2010, the spawning biomass of bigeye tuna in the EPO was at about 98 thousand tons (Figure 4.7). At that time the SBR was about 0.26, 37% higher than the level corresponding to the MSY (Figure 5.1).

At the beginning of 1975, the SBR was about 0.55 (Figure 5.1), which is consistent with the fact that bigeye had been fished by longliners in the EPO for a long period prior to 1975 and that the spawning biomass is made up of older individuals that are vulnerable to longline gear. The SBR decreased to about 0.43 at the beginning of 1983, followed by an increase during 1984-1986, reaching 0.57 at the beginning of 1987. This increase can be attributed to the above-average recruitment during 1982 and 1983 (Figure 4.5) and to the relatively small catches that were taken by the surface fisheries during that period (Figure 2.2, Fisheries 1 and 6). This peak in spawning biomass was soon followed by a peak in the longline catch

(Figure 2.2, Fishery 9). After 1987 the SBR decreased to a level of about 0.20 by mid-1999. This depletion can be attributed mostly to a long period (1984-1993) during which recruitment was low. Also, it should be noted that the southern longline fishery took relatively large catches during 1985-1994 (Figure 2.2, Fisheries 16 and 17). In 1999 the SBR began to increase, and reached about 0.32 in 2002. This increase can be attributed to the relatively high levels of recruitment that are estimated to have occurred during 1994-1998 (Figure 4.5). During the latter part of 2002 through 2003, the SBR decreased rapidly, due to the weak year classes in 1999 and 2000, large catches from surface fisheries, and increased longline catches. Beginning in 2005, the SBR has gradually increased to a level of 0.26 at the start of 2010. This may be attributed to a combined effect of a series of above-average recruitments since 2001 (Figure 4.5), the IATTC tuna conservation resolutions during 2004-2009 (Section 6.2.3), and decreased longline fishing effort in the EPO.

5.2. Assessment of stock status based on MSY

Maintaining tuna stocks at levels that permit the MSY to be taken is the management objective specified by the IATTC Convention. Watters and Maunder (2001) describe how the MSY and its related quantities are calculated. These calculations have, however, been modified to include, where applicable, the Beverton-Holt (1957) stock-recruitment relationship (see Maunder and Watters (2003) for details). It is important to note that estimates of the MSY and its associated quantities are sensitive to the steepness of the stock-recruitment relationship (Section 5.4), and, for the base case assessment, steepness was fixed at 1 (an assumption that recruitment is independent of stock size); however, a sensitivity analysis (steepness = 0.75) is provided to investigate the effect of a stock-recruitment relationship.

The MSY-based estimates were computed with the parameter estimates from the base case assessment and estimated fishing mortality patterns averaged over 2007 and 2009. Therefore, while these MSY-based results are currently presented as point estimates, there are uncertainties in the results.

At the beginning of January 2010, the spawning biomass of bigeye tuna in the EPO appears to have been about 33% higher than S_{MSY}, and the recent catches are estimated to have been about 17% greater than the MSY (Table 5.1).

If fishing mortality is proportional to fishing effort, and the current patterns of age-specific selectivity (Figure 4.2) are maintained, F_{MSY} is about 13% higher than the current level of effort.

The MSY-based quantities are estimated by assuming that the stock is at equilibrium with fishing, but during 1995-1998 that was not the case. This has potentially important implications for the surface fisheries, as it suggests that the catch of bigeye by the surface fleet may be determined largely by the strength of cohorts recruited to the fishery. For example, the catches of bigeye taken by the surface fleet declined when the large cohorts recruited during 1995-1998 were no longer vulnerable to those fisheries.

Estimates of the MSY, and its associated quantities, are sensitive to the age-specific pattern of selectivity that is used in the calculations. The MSY-based quantities described previously were based on an average selectivity pattern for all fisheries combined (estimated from the current allocation of effort among fisheries). Different allocations of fishing effort among fisheries would change this combined selectivity pattern. To illustrate how the MSY might change if the effort is reallocated among the various fisheries that catch bigeye in the EPO, the previously-described calculations were repeated, using the age-specific selectivity pattern estimated for each group of fisheries (Table 5.2). If only the purse-seine fishery were operating, the MSY would be about 25% less. If bigeye were caught only by the longline fishery, the MSY would about 131% greater than that estimated for all gears combined. To achieve this MSY level, longline effort would need to be increased by 856%.

The MSY-related quantities vary with the size composition of the catch. The evolution of four of these quantities during 1975-2009 is shown in Figure 5.2. Before the expansion of the floating-object fishery that began in 1993, MSY was greater than the current MSY, and the fishing mortality was less than that corresponding to MSY (Figure 5.2).

When MSY is estimated using the average fishing mortality rates for 2006-2007, it is about 2,870 t (0.3%) higher than that of the base case.

The historical time series of exploitation rates, spawning biomass, and summary biomasses relative to the MSY reference points are shown in Figure 5.3a. Overall, the reference points were not exceeded until recent years. According to the base case results, the two most recent estimates indicate that the bigeye stock in the EPO is probably not overfished ($S>S_{MSY}$) and that overfishing is not taking place ($F<F_{MSY}$). However, this interpretation is strongly dependent on the assumptions made about the steepness parameter of the stock-recruitment relationship, the average size of the older fish, the assumed levels of adult natural mortality, and the historic period of the fishery considered (Figure 5.3b).

5.3. Sensitivity to alternative parameterizations and data

Yields and reference points are highly sensitive to alternative model assumptions, input data, and the periods assumed for fishing mortality (Tables 5.1 and 5.2).

The sensitivity analysis that included a stock-recruitment relationship with a steepness of 0.75 estimated the SBR required to support the MSY to be at 0.30, compared to 0.19 for the base case assessment (Table 5.1). The sensitivity analysis for steepness = 0.75 estimated an *F* multiplier of 0.83, considerably lower than that for the base case assessment (1.13). Assuming lower values of steepness results in much lower *F* multipliers (Table A.1, Figure A.6). Although the base case model results indicate that the recent spawning biomass level is above that corresponding to MSY (S_{recent}/S_{MSY} = 1.33), this ratio is estimated to be less than 1 for assumed steepness values lower than 1.

The *F* multiplier is highly sensitive to the assumed fixed value of the average size of the oldest fish in the Richards growth curve ($L_{2;}$ Table B.1). Specifically, the estimated *F* multiplier is higher (less pessimistic) for lower values of L_2, and lower (more pessimistic) for higher values of L_2 than that assumed in the base case (185.5 cm) (Figure B.6). This relationship degenerates at extreme low values of L_2 (around 160 cm). Likewise, the ratio S_{recent}/S_{MSY} is highly sensitive to the assumed value of $L_{2.}$ In particular, S_{recent}/S_{MSY} increases and decreases towards lower and higher assumed values of L_2, respectively.

When lower rates of adult natural mortality are assumed for both sexes of bigeye, the stock status is more pessimistic than the base case results (lower *F* multiplier). Assuming higher adult natural mortality rates produces the opposite effect (higher *F* multiplier). However, the higher rates considered in this sensitivity analysis seem biologically unrealistic for bigeye. Likewise, the ratio S_{recent}/S_{MSY} is highly sensitive to the assumed rates of adult natural mortality. Specifically, the ratio decreases and increases towards lower and higher assumed values of *M*, respectively.

Finally, if no stock-recruitment relationship is assumed (steepness = 1), and only data for the late period of the fishery (1995-2009) are used, the *F* multiplier is 1 (F_{MSY}). Assuming a stock-recruitment relationship (steepness = 0.75) produces an *F* multiplier of 0.73. Regardless of steepness assumption (1 or 0.75), S_{recent}/S_{MSY} is estimated to be less than 1 when only data for the late period of the fishery is used.

The management quantities showed little sensitivity to the recent periods for fishing mortality used in the calculations (Table 5.2).

5.4. Summary of stock status

At the beginning of January 2010, the SBR of bigeye tuna in the EPO was at about 0.26, about 37% higher than the level corresponding to the MSY.

Recent catches are estimated to have been 17% higher than the MSY level (Table 5.1). If fishing mortality is proportional to fishing effort, and the current patterns of age-specific selectivity are maintained, the level of fishing effort corresponding to the MSY is about 13% higher than the current (2007-2009) level of effort. The MSY of bigeye in the EPO could be maximized if the age-specific selectivity pattern were similar to that for the longline fishery that operates south of 10°N, because it catches larger individuals that are close to the critical weight. Before the expansion of the floating-object fishery that began in 1993, the MSY was greater than the current MSY, and the fishing mortality was less than F_{MSY} (Figure 5.2).

The management quantities are sensitive to how the assessment model is parameterized and the data that are included in the assessment. In particular, the F multiplier and S_{recent}/S_{MSY} are highly sensitive to the assumptions made about the steepness parameter of the stock-recruitment relationship, the average size of the oldest fish in the population, the rates of adult natural mortality assumed for both sexes of bigeye, and the historic period of the fishery used in the assessment.

6. SIMULATED EFFECTS OF TUNA CONSERVATION RESOLUTIONS AND FUTURE FISHING OPERATIONS

A simulation study was conducted to gain further understanding on the effects of the IATTC tuna conservation resolutions implemented during 2004-2009 (C-04-09, C-06-02 and C-09-01), and of how changes in the amount of fishing effort exerted by the tuna fisheries in the EPO in the future might simultaneously affect the stock of bigeye tuna in the EPO and the catches of bigeye by the various fisheries.

In order to evaluate the effects of the resolutions, a model was constructed in which the fishing effort (fishing mortality) of different fisheries was increased to simulate a scenario in which no resolutions were in force during 2004-2009. Beginning in 2004, this model was then projected into the future, using the time series of historic recruitment anomalies estimated by the base case model.

With respect to future fishing operations, different scenarios were constructed to define how the various fisheries that catch bigeye in the EPO would operate in the future, and also to define the future dynamics of the bigeye stock. The assumptions that underlie these scenarios are outlined in Sections 6.1 and 6.2. The method is implemented by extending the assessment model an additional 10 years (40 quarters), with exploitation rates equal to the average for 2007-2009. No catch or length-frequency data are included for these years. The recruitments for the 10 years are estimated as in the assessment model, with a lognormal penalty with a standard deviation of 0.6. The uncertainty in the projected recruitment is implemented following Maunder *et al*. (2006).

6.1. Assumptions about fishing operations

6.1.1. Fishing effort

Projection studies were carried out to investigate the influence of different levels of fishing effort (fishing mortality rates) on the stock biomass and catch.

The analyses carried out were:

1. Quarterly fishing effort (fishing mortality rates) during 2004-2009 was increased to simulate a scenario in which IATTC tuna conservation resolutions C-04-09, C-06-02, and C-09-01 had not been in force.
    a. Resolutions C-04-09 and C-06-02 call for restrictions on purse-seine effort and longline catches during 2004-2007: a six-week closure during the third or fourth quarter of the year for purse-seine fisheries, and longline catches not to exceed 2001 levels. For 2004-2007, fishing mortality rates were increased by 86% for the purse-seine fisheries in the third quarter and by 13% for the longline fisheries in all quarters.
    b. Resolution C-09-01, adopted in 2009, calls for more restrictive measures than previous resolutions. For purse-seine vessels, fishing effort must stop for a period of 59 days in 2009, 62 days in 2010, and 73 days (12 weeks) in 2011. In addition, the resolution calls for a closure for purse-seiners in the area from 96° to 110°W between 4°N and 3°S from 29 September to 29 October. The “no resolution” scenario corresponds to an 80%

increase in fishing mortality by purse-seine fisheries in the third and fourth quarters of 2009, and to a 19% increase of fishing mortality by longliners in all quarters.

2. Quarterly fishing mortality rates for each year in the future were set equal to the average rates during 2007-2009, to simulate that fishing mortality rates are maintained at current levels (F_{cur}) – a *status quo* exploitation strategy. Assuming increased closure periods in 2010 and 2011, as called for in Resolution C-09-01, yields more optimistic results than assuming a *status quo* exploitation strategy.
3. An additional analysis was carried out that estimates the population status if fishing effort is approximated to the levels corresponding to MSY (F_{MSY}).

6.2. Simulation results

The simulations were used to predict future levels of the spawning biomass, SBR, the total annual catch taken by the primary surface fisheries that would presumably continue to operate in the EPO (Fisheries 2-5 and 7), and the total annual catch taken by the longline fleet (Fisheries 12-23). There is probably more uncertainty in the future levels of these outcome variables than is suggested by the results presented in Figures 6.1-6.5. The amount of uncertainty is probably underestimated, because the simulations were conducted under the assumption that the stock assessment model accurately describes the dynamics of the system, with no account taken of variation in catchability.

6.2.1. Current fishing mortality rates (F_{cur}) – *status quo*

Projections were undertaken, assuming that fishing mortality rates would remain at the average 2007-2009 levels.

SBR is estimated to have gradually increased since 2005 and attained a level of 0.26 at the start of 2010 (Figure 5.1). This increase may be attributed to the combined effect of two spikes in recent recruitment (Figure 4.5b), IATTC tuna conservation resolutions during 2004-2009, and decreased longline fishing effort in the EPO (Section 6.2.3). If recent levels of effort and catchability continue and average recruitment levels persist, the SBR is predicted to further increase during 2010 and reach a peak of 0.28 by 2011 (Figure 6.1a). After that, the SBR is predicted to gradually decline and stabilize at about 0.23 around 2020. Under the *status quo* scenario and the assumption of no stock-recruitment relationship, purse-seine catches are predicted to decline from 2010-2012 and then stabilize at around 61,000 t in 2012 (Figure 6.3a, upper panel). Under current effort, longline catches are predicted to increase moderately to around 34,000 t during 2010-2011, but then decline to around 29,000 t in 2018 (Figure 6.3a, lower panel). The catches of the surface fisheries would not stabilize during the projection period, and would continuously decline if a stock-recruitment relationship is included, due to reductions in the levels of recruitment that contribute to purse-seine catches (Figure 6.3a, upper panel).

Predicted catches for both gears are based on the assumption that the selectivity of each fleet will remain the same and that catchability will not increase as abundance declines. If the catchability of bigeye increases at low abundance, catches will, in the short term, be greater than those predicted here.

6.2.2. Fishing mortality rates at MSY (F_{MSY})

Maintaining tuna stocks at levels that permit MSY to be taken is the management objective specified by the IATTC Convention. To assess the impact on the bigeye stock of an exploitation strategy targeting MSY, we projected the population forward 10 years, assuming the fishing mortality rates (fishing effort) corresponding to MSY (F_{MSY}). While projected catches for the surface fisheries at F_{MSY} are about 4,000 tons higher than the levels obtained at F_{cur} (Figure 6.3b, upper panel), the projected longline catches at F_{cur} and F_{MSY} stabilize at about the same level of 28,000 tons. (Figure 6.3b, lower panel) . However, the long-term SBR levels which would be attained if the current fishing mortalities persist in the future (0.23) are higher than those corresponding to the MSY (0.19) (Figure 6.4).

6.2.3. Effect of IATTC tuna conservation resolutions

A comparison of the spawning biomass predicted with and without the restrictions of the resolutions shows substantial differences (Figure 6.4). Without the effect of the resolutions from 2004 to 2009, the SBR would have varied around the level corresponding to MSY (0.19), apparently sustained by the above-average recruitments observed during 2001-2006. However, future projections assuming the "no resolution" scenario and average recruitment conditions indicate that the SBR would decline and stabilize at around 0.17, a level that would not support MSY.

6.2.4. Sensitivity analysis

The analysis that includes a stock-recruitment relationship indicates that the population is substantially below SBR_{MSY} and will remain at this level under current effort levels (Figure 6.1b).

6.3. Summary of the simulation results

Recent spikes in recruitment are predicted to sustain the recent increasing trend observed for SBR since 2004. However, high levels of fishing mortality are expected to subsequently reduce and then stabilize SBR under average recruitment conditions. Under current effort levels, the population is likely to remain above the level corresponding to MSY.

These simulations are based on the assumption that selectivity and catchability patterns will not change in the future. Changes in targeting practices or increasing catchability of bigeye as abundance declines (*e.g.* density-dependent catchability) could result in differences from the outcomes predicted here.

7. FUTURE DIRECTIONS

7.1. Collection of new and updated information

The IATTC staff intends to continue its collection of catch, effort, and size-composition data from the fisheries that catch bigeye tuna in the EPO. Updated and new data will be incorporated into the next stock assessment.

The IATTC staff will continue to compile catch, effort and size-composition data for the longline fisheries operating in the EPO. In particular, it will attempt to obtain data for recently-developed and growing fisheries.

7.2. Refinements to the assessment model and methods

The IATTC staff will continue developing the Stock Synthesis (Version 3) assessment for bigeye tuna in EPO. Much of the progress will depend on how the Stock Synthesis software is modified in the future. The following changes would be desirable for future assessments:

1. Determine appropriate weighting of the different data sets;
2. Include available tagging data in the assessment;
3. Explore alternative assumptions on stock structure (spatial analysis).

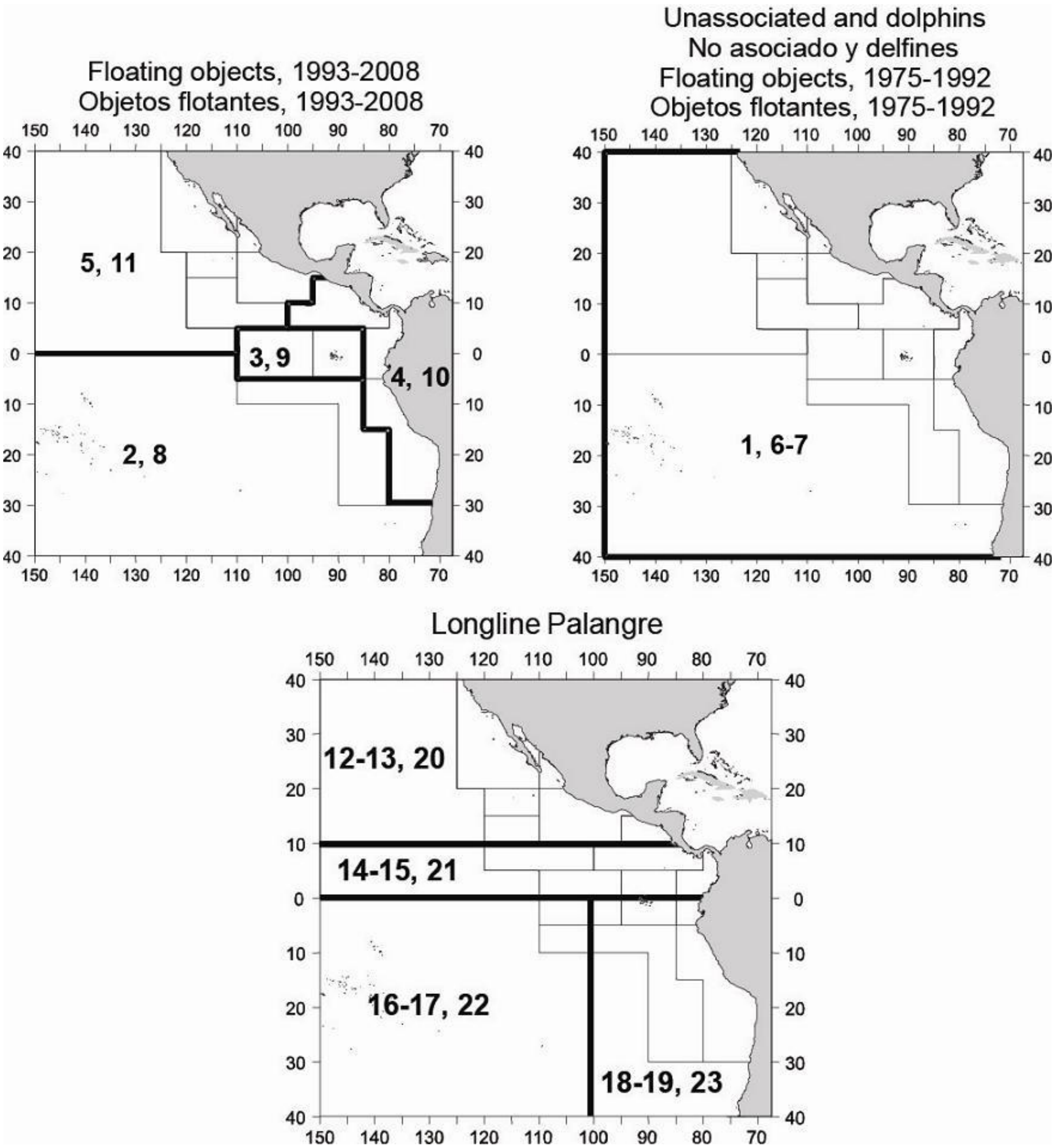

FIGURE 2.1. Spatial extents of the fisheries defined for the stock assessment of bigeye tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the bold numbers the fisheries to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

FIGURA 2.1. Extensión espacial de las pesquerías definidas para la evaluación de la población de atún patudo 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 de la población, y los números en negritas las pesquerías correspondientes a estos últimos límites. En la Tabla 2.1 se describen las pesquerías.

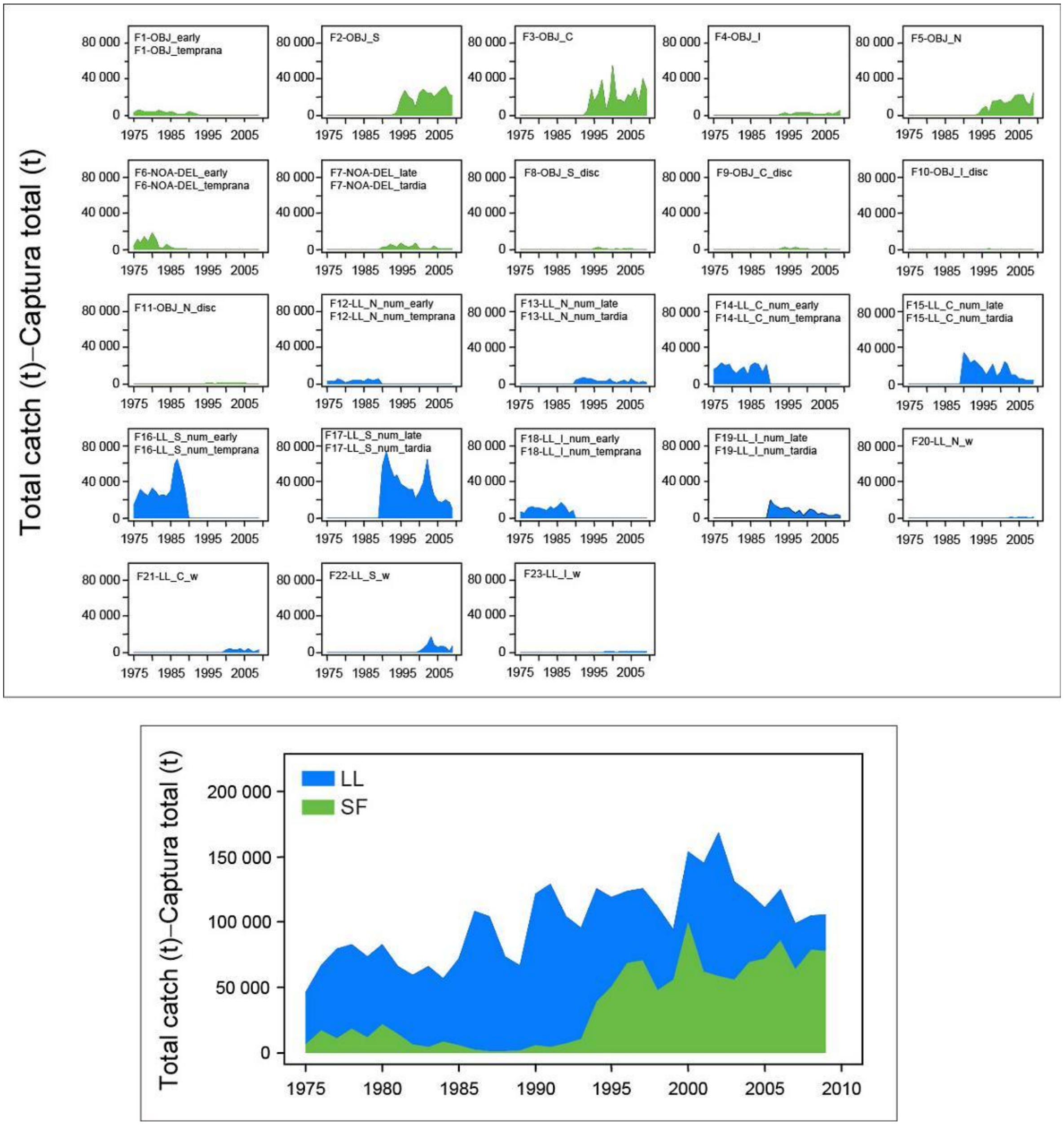

FIGURE 2.2. Upper panel: Annual catches of bigeye tuna taken by the fisheries defined for the stock assessment of that species in the EPO (Table 2.1). The stock assessment model uses catches in numbers of fish for longline Fisheries 12-19, but the figure shows catches in weight estimated by the model for those fisheries. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1. Lower panel: Annual catches of bigeye tuna pooled by longline and surface fisheries in the EPO. LL = longline; SF = surface fisheries; t = metric tons.

FIGURA 2.2. Panel superior: Capturas anuales de atún patudo por las pesquerías definidas para la evaluación de la población de esa especie en el OPO (Tabla 2.1). El modelo de evaluación usa capturas en número de peces para las Pesquerías 12 a 19, pero en la figura se presentan capturas en peso estimadas por el modelo para esas pesquerías. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1. Panel inferior: Capturas anuales de atún patudo en el OPO de las pesquerías de palangre y de superficie combinadas. LL = palangre; SF = pesquerías de superficie; t = toneladas métricas.

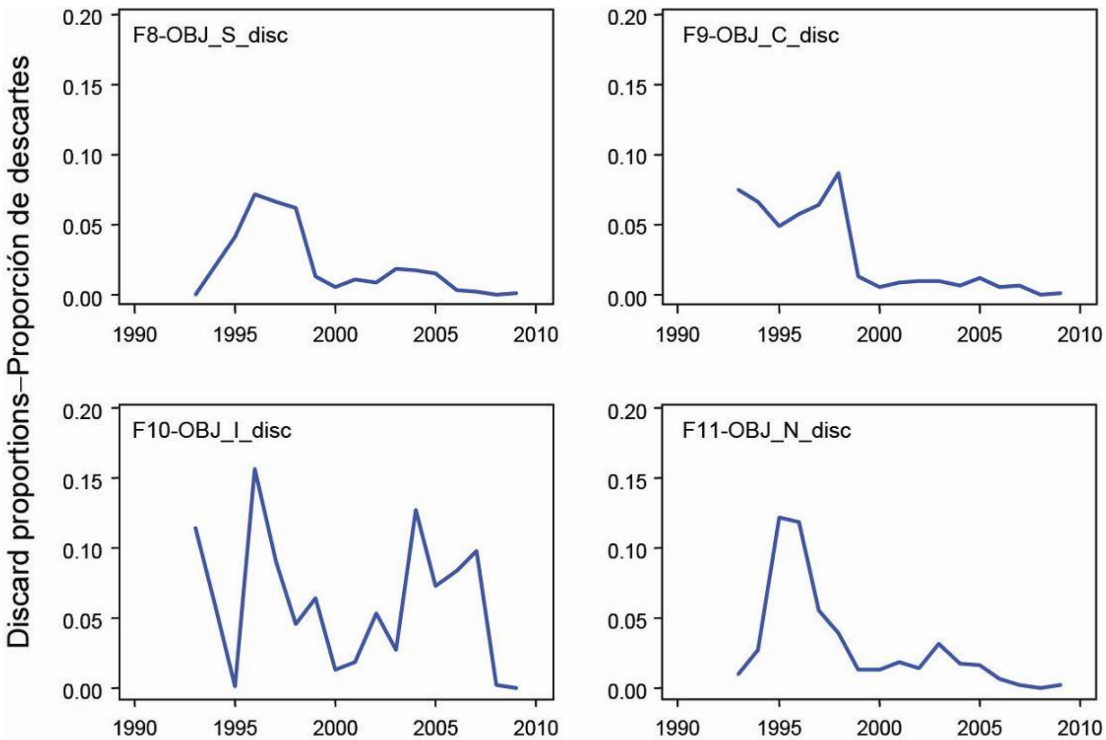

FIGURE 2.3. Weights of discarded bigeye tuna as proportions of the total (retained plus discarded) annual catches for the four floating-object fisheries. Fisheries 2-5 are the "real" fisheries, and Fisheries 8-11 are the corresponding discard fisheries. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 2.3. Pesos de atún patudo descartado como proporción de las capturas anuales totales (retenidas más descartadas) de las cuatro pesquerías sobre objetos flotantes. Las Pesquerías 2-5 son las pesquerías "reales", y las Pesquerías 8-11 las pesquerías de descarte correspondientes. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

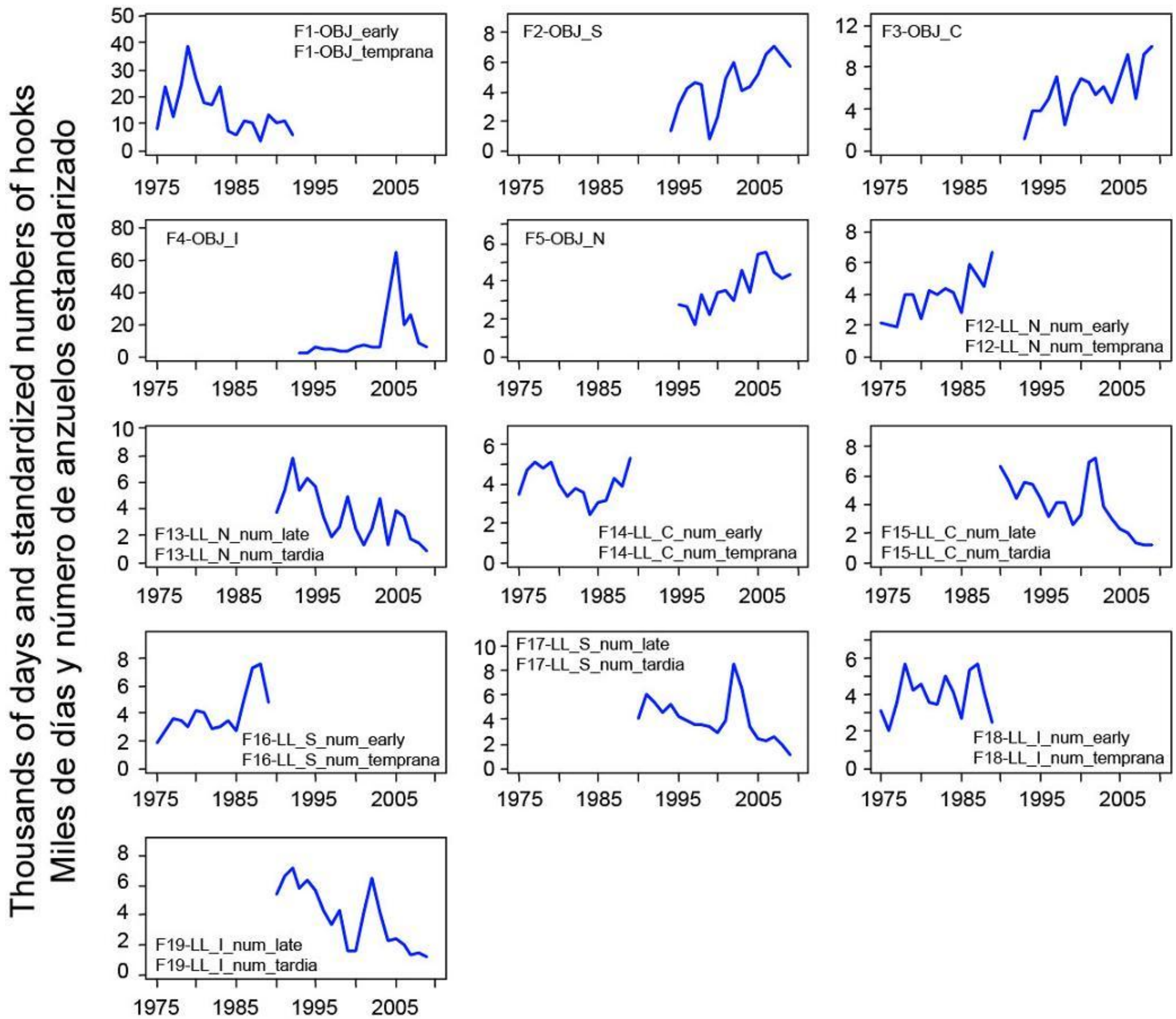

FIGURE 2.4. Annual fishing effort by purse-seine vessels of more than 363 metric tons of capacity and longline vessels in the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). The effort for Fisheries 1-5 is in days fished, and that for Fisheries 12-19 in standardized numbers of hooks. Fishing effort is not shown for Fisheries 6 and 7, since two gears (purse seine and pole-and-line) were combined for these fisheries. Fishing effort for the discard fisheries (8-11) is that of their corresponding 'real' fisheries (2-5). Note that the vertical scales of the panels are different. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 2.4. Esfuerzo de pesca anual por buques de cerco de más de 363 toneladas métricas de capacidad y buques de palangre en las pesquerías definidas para la evaluación de la población de atún patudo en el OPO (Tabla 2.1). Se expresa el esfuerzo de las Pesquerías 1-5 en días de pesca, el de las Pesquerías 12-19 en número estandarizado de anzuelos. No se ilustra el esfuerzo de pesca de las Pesquerías 6 y 7, ya que se combinaron dos artes (red de cerco y caña) en las mismas. El esfuerzo de pesca de las pesquerías de descarte (8-11) es aquél de sus pesquerías 'reales' correspondientes (2-5). Nótese que las escalas verticales de los recuadros son diferentes. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

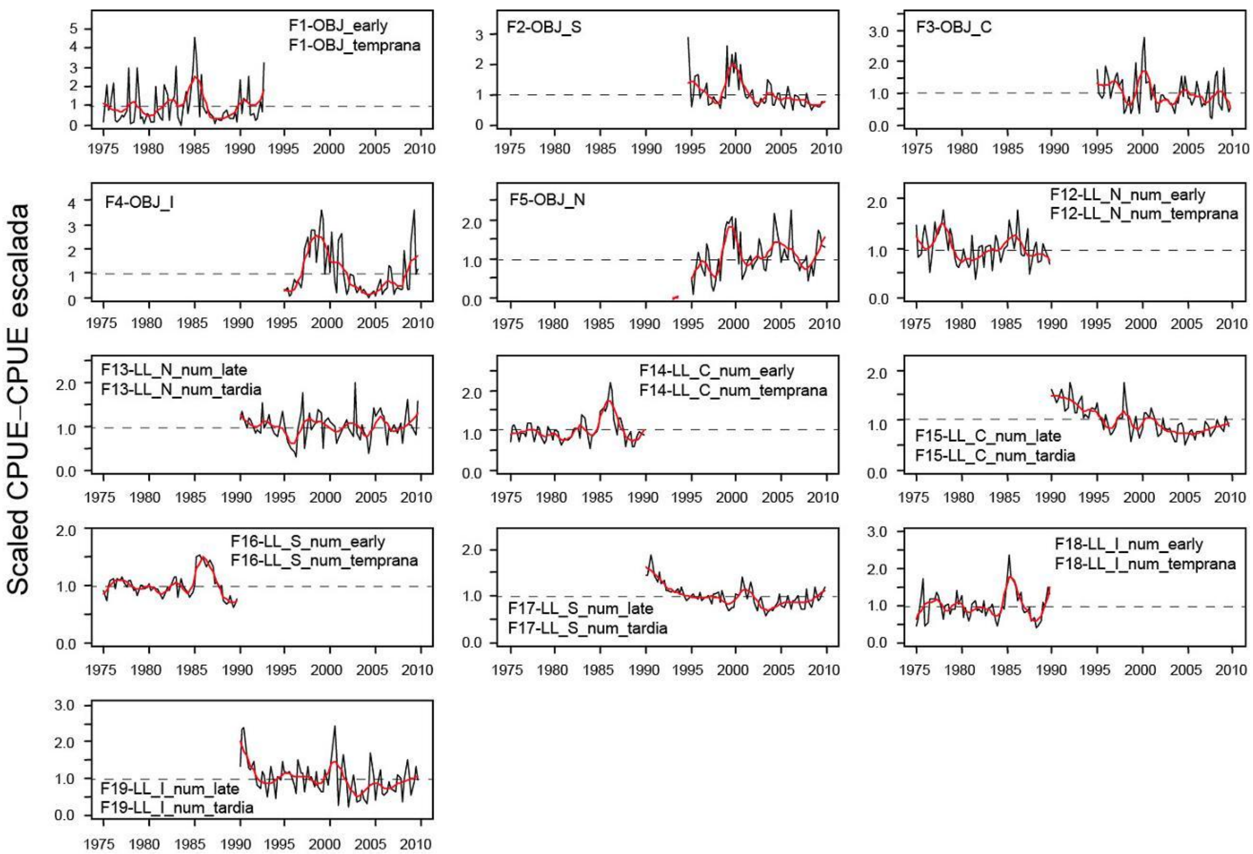

FIGURE 2.5. Quarterly CPUE and four-quarterly running average CPUEs of the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). The CPUEs for the floating-object fisheries (1-5) are in kilograms per day fished, and those for the longline fisheries (12-19) are standardized CPUE. 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. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 2.5. CPUE trimestral y promedio móvil de cuatro trimestres de CPUE de las pesquerías definidas para la evaluación de la población de atún patudo en el OPO (Tabla 2.1). Se expresan las CPUE de las pesquerías de superficie (1-5) en kilogramos por día de pesca, y las de las pesquerías de palangre (12-19) en CPUE estandarizada. 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. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

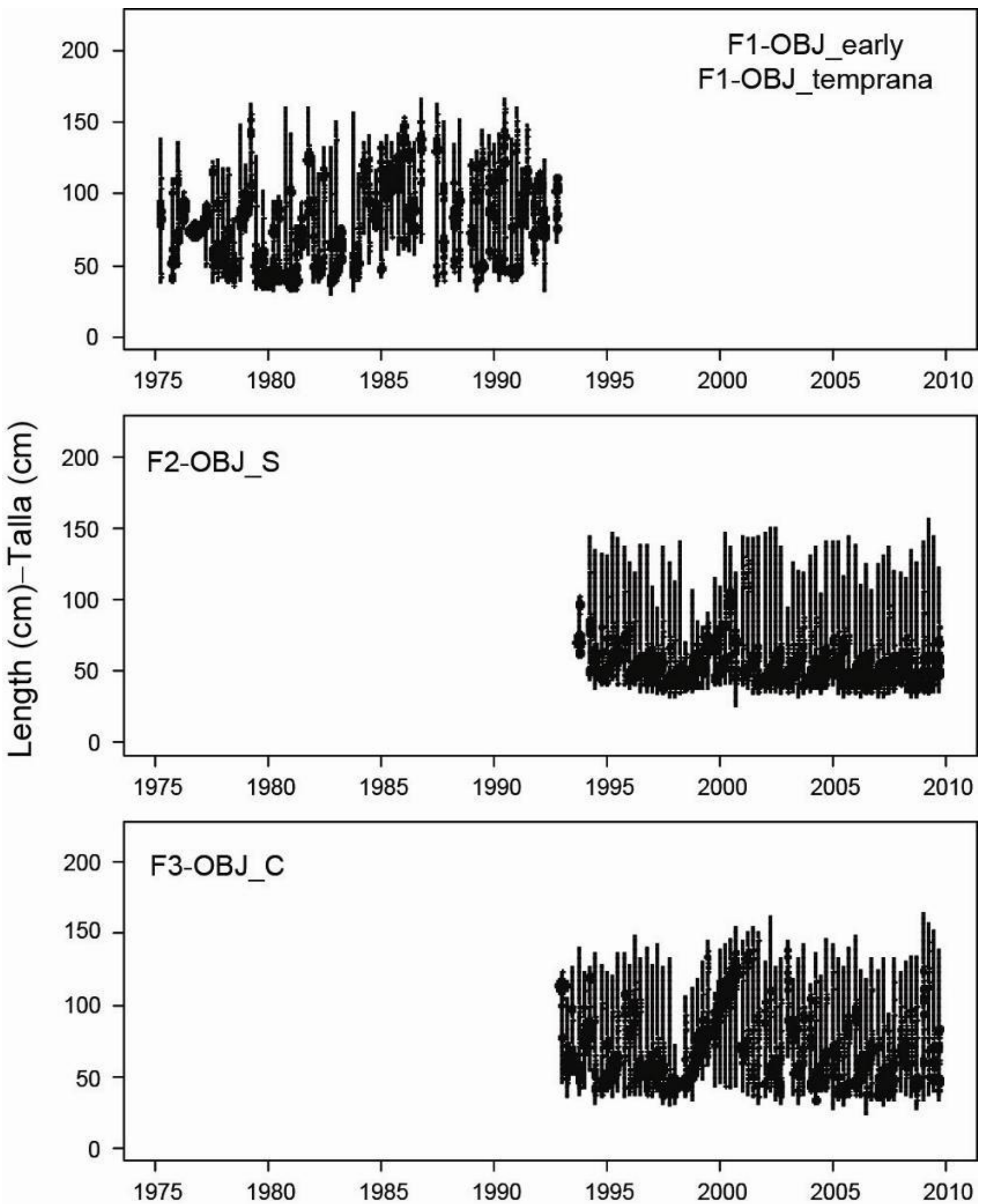

FIGURE 2.6a. Size compositions of the catches of bigeye tuna taken by Fisheries 1, 2 and 3, by quarter. The areas of the circles are proportional to the catches. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 2.6a. Composición por talla de las capturas de patudo de las Pesquerías 1, 2 y 3, por trimestre. El área de los círculos es proporcional a la captura. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

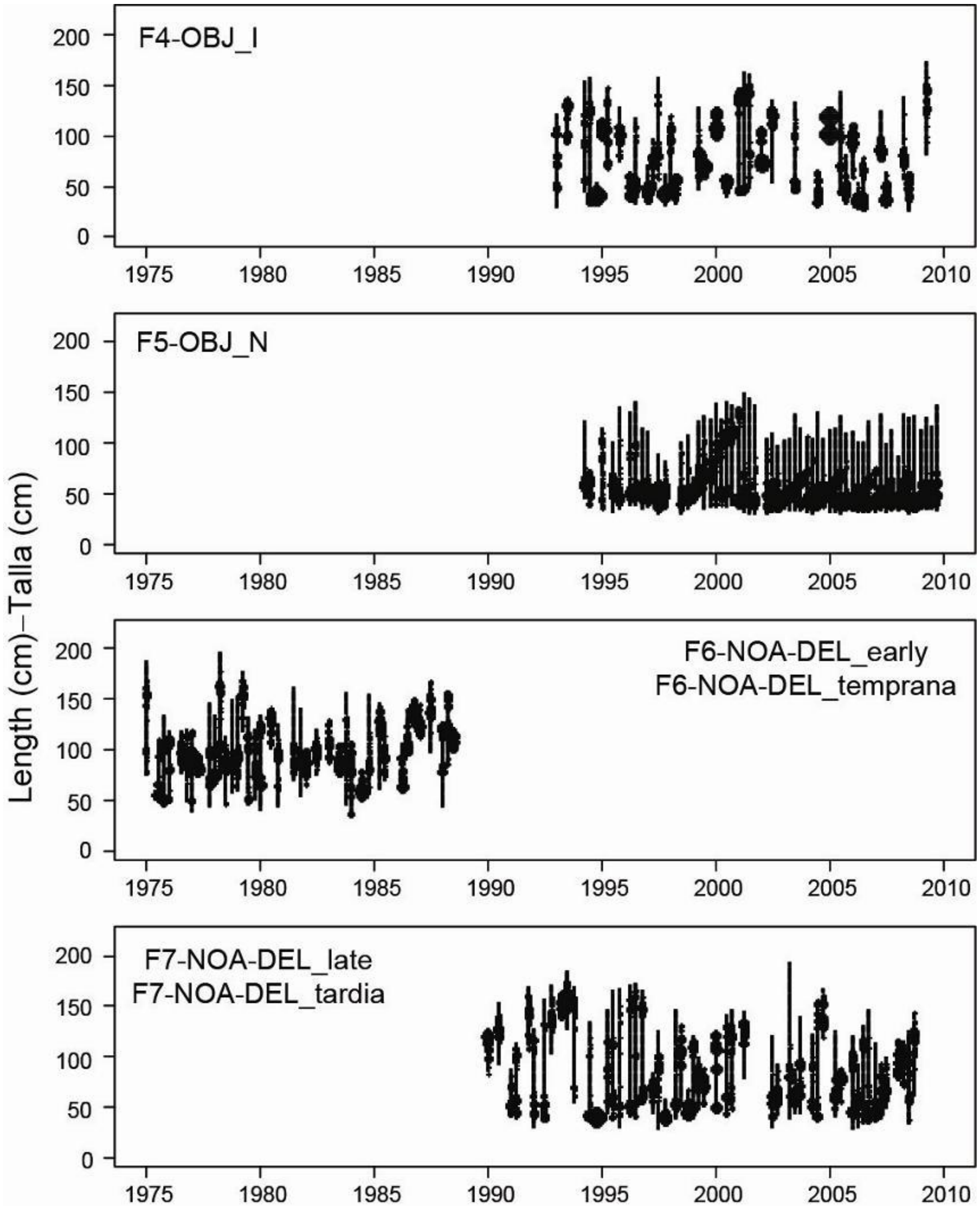

FIGURE 2.6b. Size compositions of the catches of bigeye tuna taken by Fisheries 4, 5, 6, and 7, by quarter. The areas of the circles are proportional to the catches. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 2.6b. Composición por talla de las capturas de patudo de las Pesquerías 4, 5, 6, y 7, por trimestre. El área de los círculos es proporcional a la captura. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

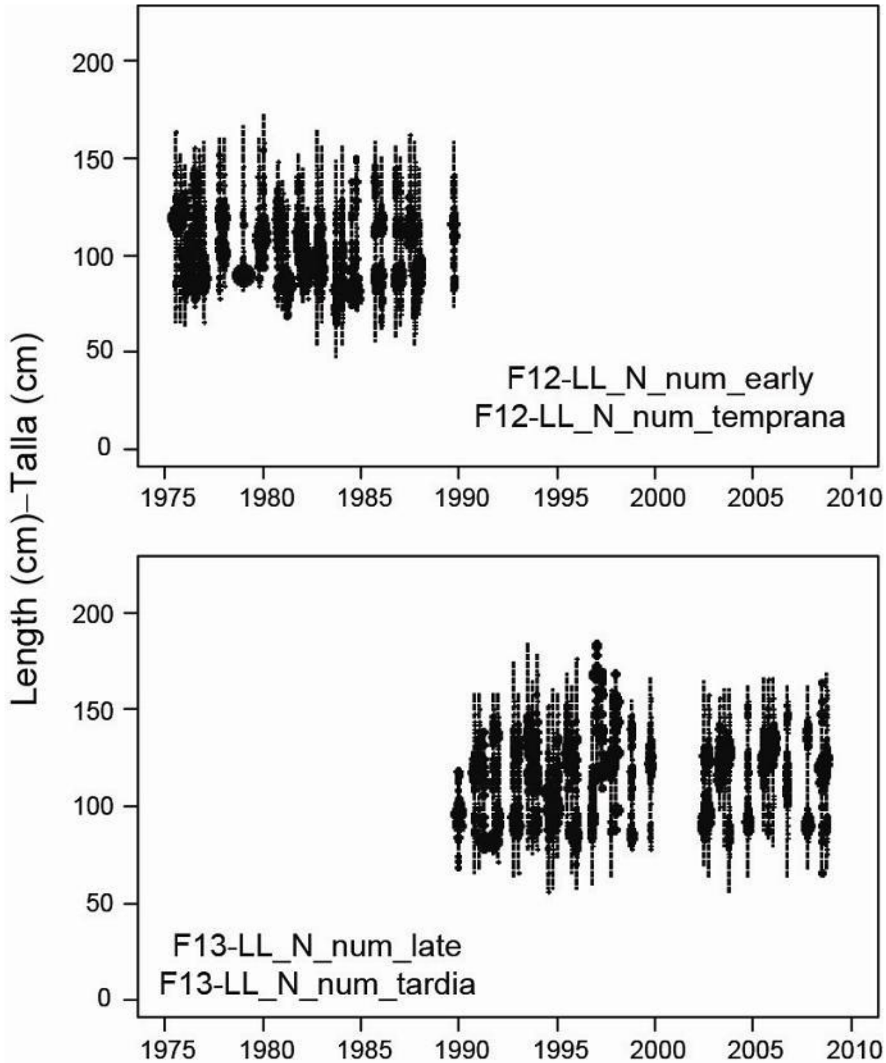

FIGURE 2.6c. Size compositions of the catches of bigeye tuna taken by the northern longline fishery (Fisheries 12 and 13), by quarter. The areas of the circles are proportional to the catches. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.
FIGURA 2.6c. Composición por talla de las capturas de patudo de la pesquería de palangre del norte (Pesquerías 12 y 13), por trimestre. El área de los círculos es proporcional a la captura. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

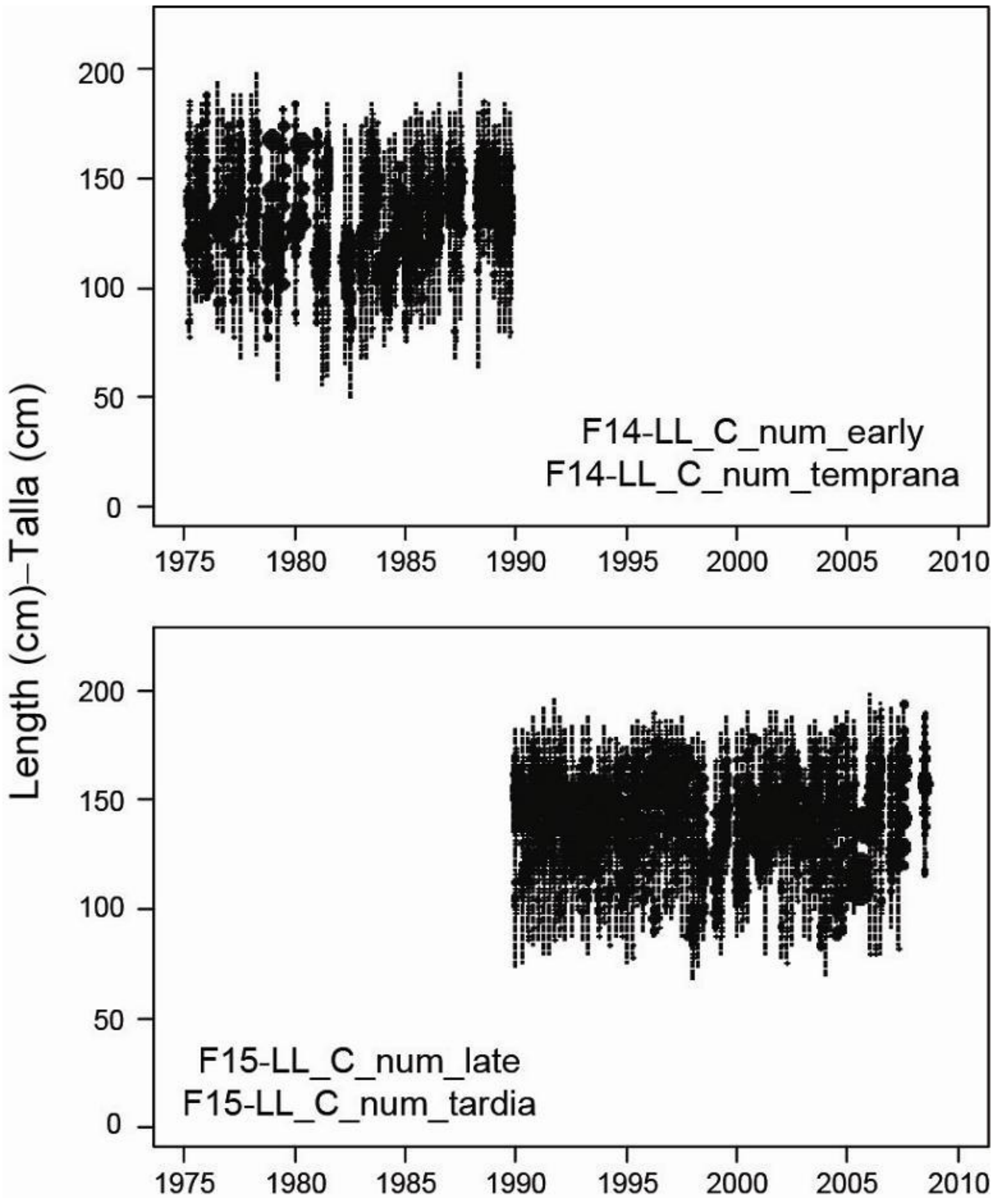

FIGURE 2.6d. Size compositions of the catches of bigeye tuna taken by the central longline fisheries (Fisheries 14 and 15), by quarter. The areas of the circles are proportional to the catches. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 2.6d. Composición por talla de las capturas de patudo de las pesquerías de palangre centrales (Pesquerías 14 y 15), por trimestre. El área de los círculos es proporcional a la captura. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

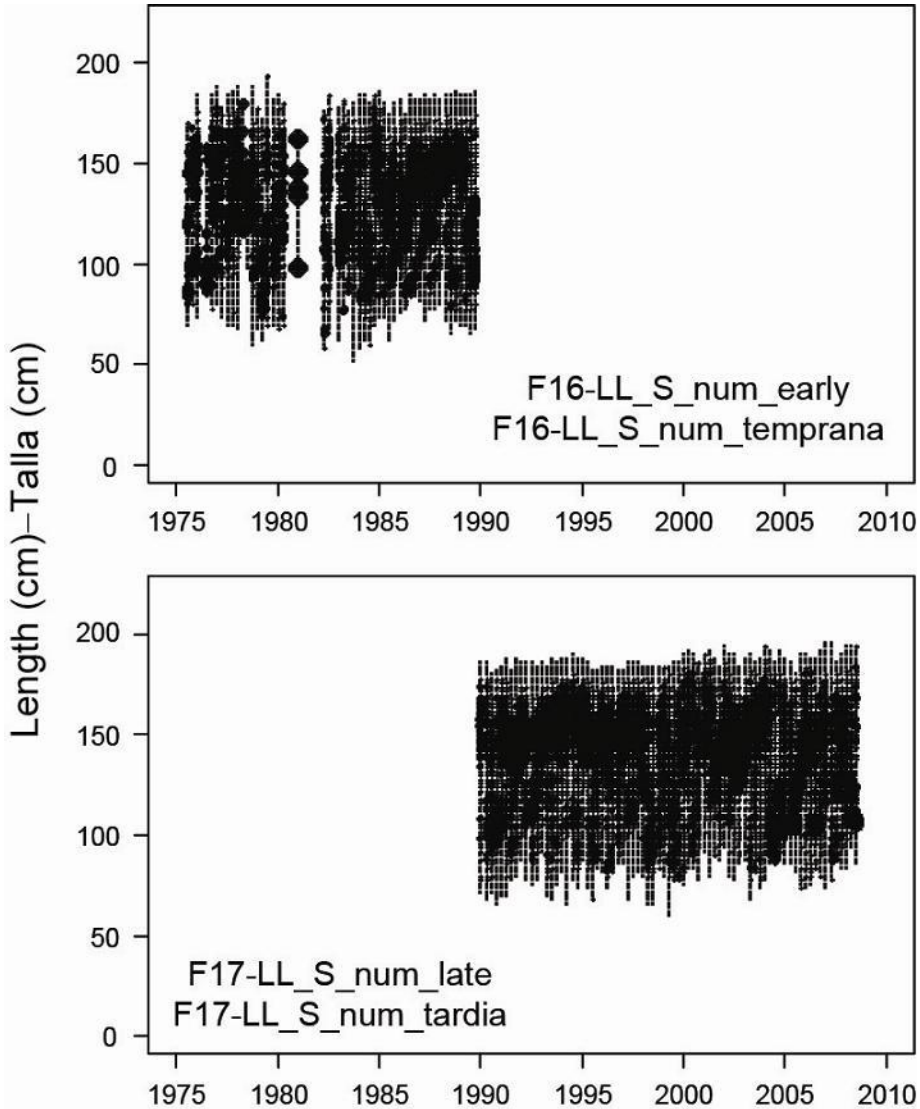

FIGURE 2.6e. Size compositions of the catches of bigeye tuna taken by the southern longline fisheries (Fisheries 16 and 17), by quarter. The areas of the circles are proportional to the catches. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 2.6e. Composición por talla de las capturas de patudo de las pesquerías de palangre del sur (Pesquerías 16 y 17), por trimestre. El área de los círculos es proporcional a la captura. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

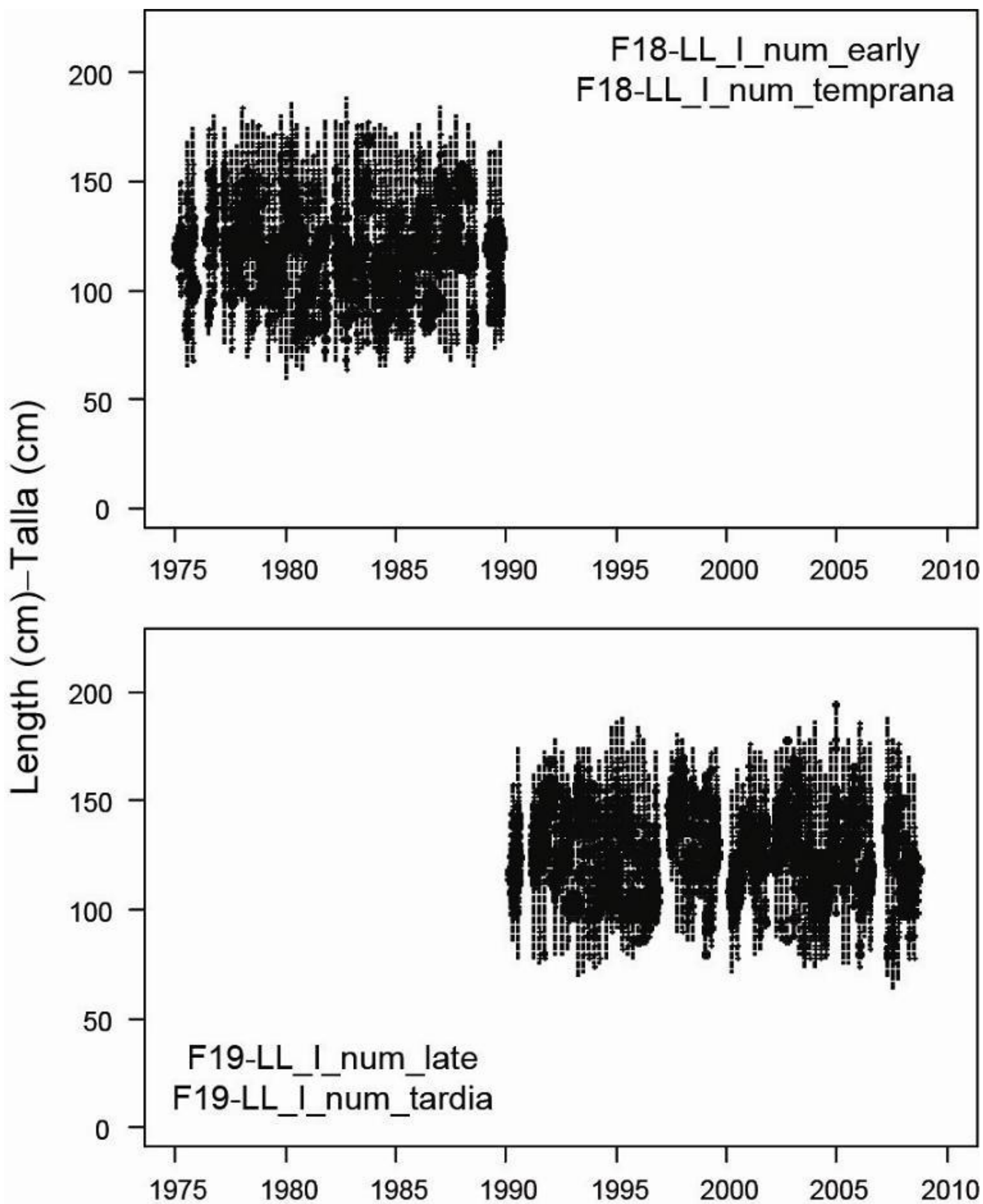

FIGURE 2.6f. Size compositions of the catches of bigeye tuna taken by the inshore longline fisheries (Fisheries 18 and 19), by quarter. The areas of the circles are proportional to the catches. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 2.6f. Composición por talla de las capturas de patudo de las pesquerías de palangre costeras (Pesquerías 18 y 19), por trimestre. El área de los círculos es proporcional a la captura. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

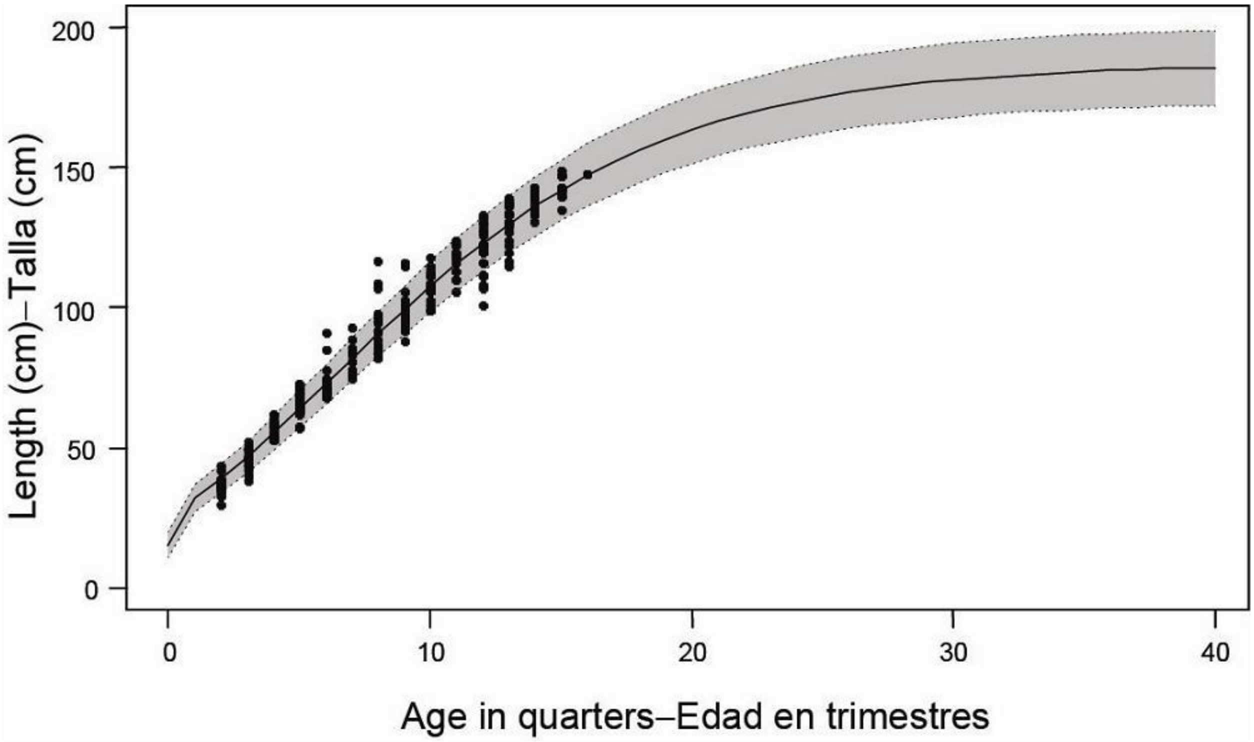

FIGURE 3.1. Estimated average lengths at age for bigeye tuna in the EPO. The dots represent the otolith age-length data from Schaefer and Fuller (2006). The dashed lines indicate the estimated variation of length at age (±2 standard deviations) of the mean lengths at age.

FIGURA 3.1. Talla media estimada por edad del atún patudo en el OPO. Los puntos representan los datos de otolitos de talla por edad de Schaefer y Fuller (2006). Las líneas de trazos indican los intervalos de confianza estimados (±2 desviaciones estándar) de la talla media por edad.

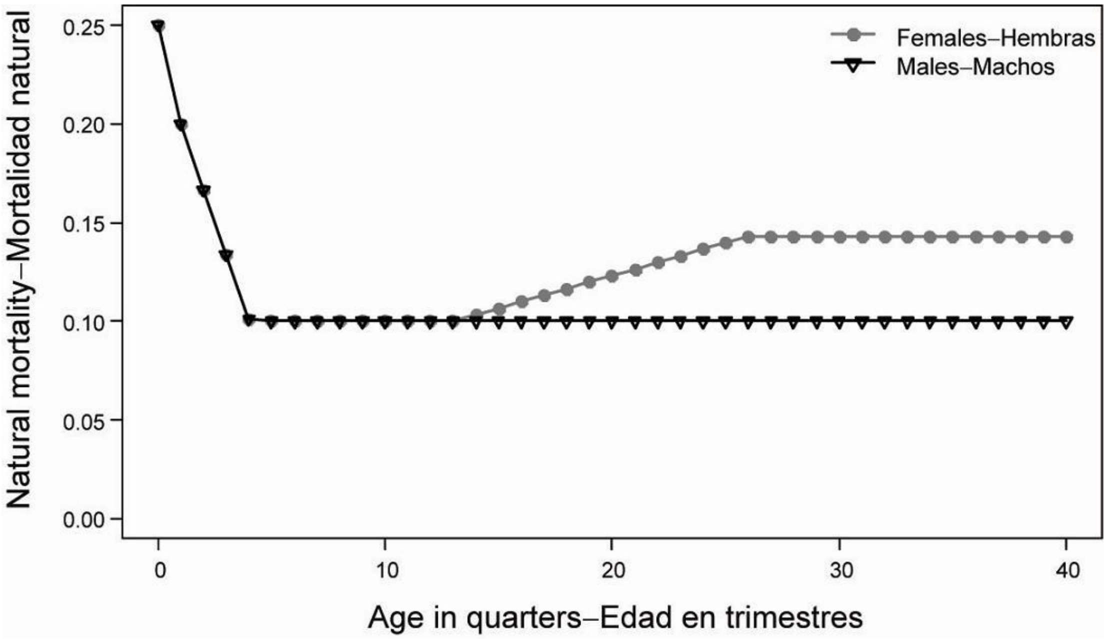

FIGURE 3.2. Quarterly natural mortality (*M*) rates used for the base case assessment of bigeye tuna in the EPO.
FIGURA 3.2. Tasas trimestrales de mortalidad natural (*M*) usadas en la evaluación del caso base del atún patudo en el OPO.

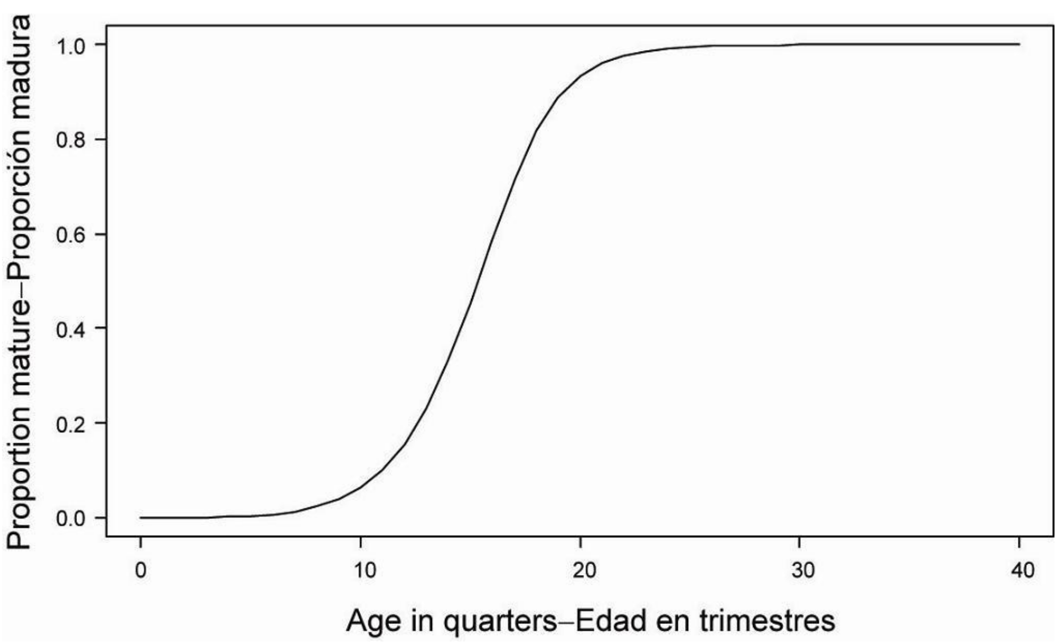

FIGURE 3.3. Age-specific maturity schedule (proportions of mature females) of bigeye tuna as assumed in the base case model.
FIGURA 3.3. Relación de madurez por edad (proporción de hembras maduras) de atún patudo, supuesto en el modelo del caso base.

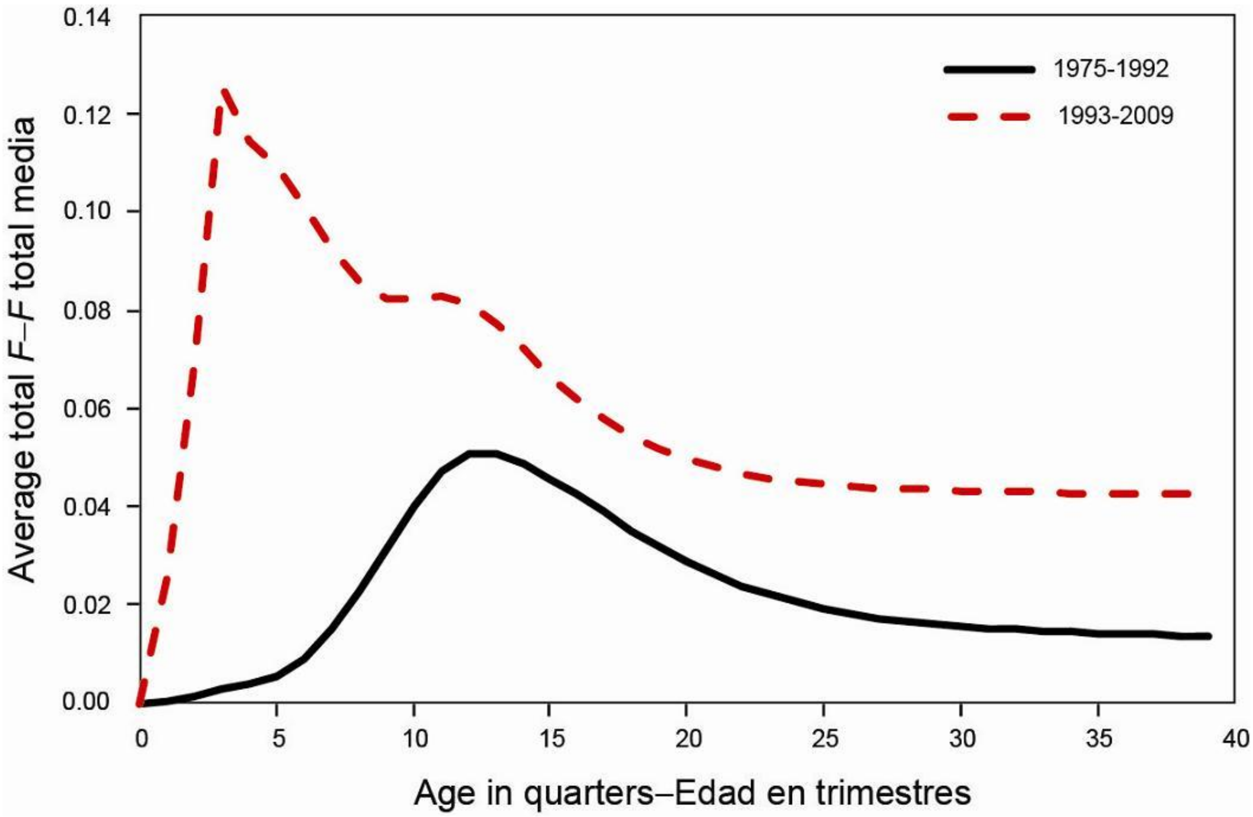

FIGURE 4.1. Average quarterly fishing mortality at age of bigeye tuna, by all gears, in the EPO. The curves for 1975-1992 and 1993-2009 display the averages for the periods before and after the expansion of the floating-object fisheries, respectively.

FIGURA 4.1. Mortalidad por pesca trimestral media por edad de atún patudo en el OPO, por todas las artes. Las curvas de 1975-1992 y 1993-2007 indican los promedios de los períodos antes y después de la expansión de las pesquerías sobre objetos flotantes, respectivamente.

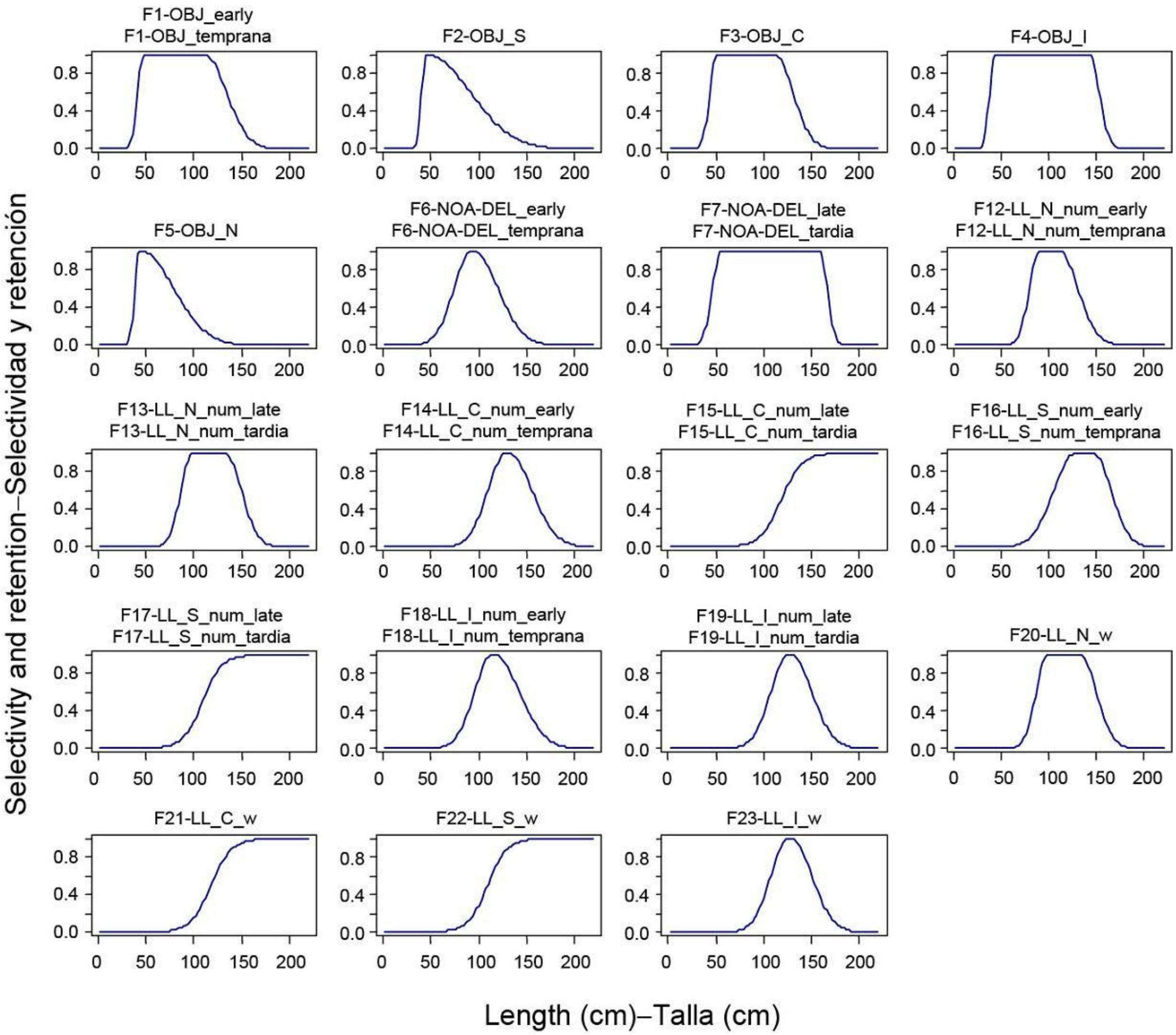

FIGURE 4.2. Size selectivity curves for surface Fisheries 1-7 and longline Fisheries 12-23 estimated with Stock Synthesis. Age 1-3 quarter fish are assumed to be fully selected for the discard fisheries (8-11). The selectivity curves for Fisheries 20-23 are the same as those for Fisheries 13, 15, 17, and 19, respectively. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 4.2. Curvas de selectividad por talla correspondientes a las pesquerías de superficie 1-7 y las pesquerías de palangre 12-23 estimadas con *Stock Synthesis*. En el caso de las pesquerías de descarte (8-11), se supone que los peces de 1 a 3 trimestres de edad son plenamente seleccionados. Las curvas de selectividad de las pesquerías 20-23 son iguales que las de las pesquerías 13, 15, 17, y 19, respectivamente. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

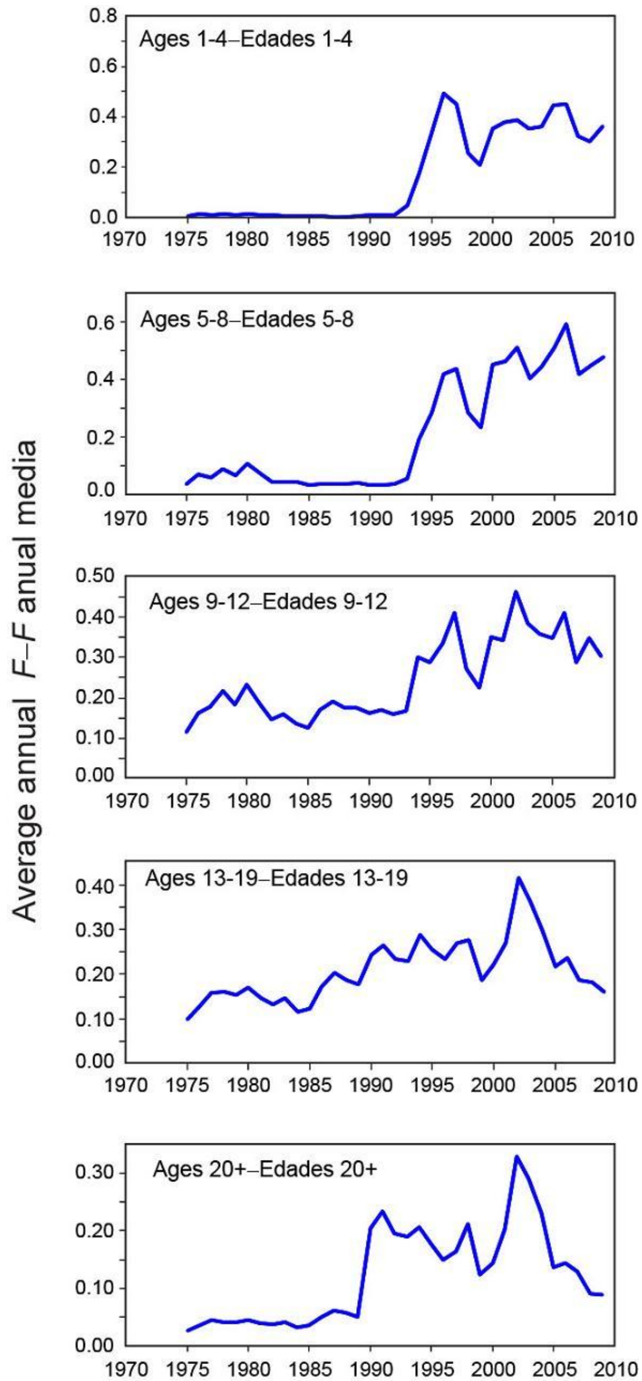

FIGURE 4.3. Average annual fishing mortality, by all gears, of bigeye tuna recruited to the fisheries of the EPO. Each panel illustrates the average fishing mortality rates that affected the fish within the range of ages indicated in the title of each panel. For example, the trend illustrated in the top panel is an average of the fishing mortalities that affected the fish that were 1-4 quarters old.

FIGURA 4.3. Mortalidad por pesca anual media, por todas las artes, de atún patudo reclutado a las pesquerías del OPO. Cada recuadro ilustra las tasas medias de mortalidad por pesca que afectaron a los peces de la edad indicada en el título de cada recuadro. Por ejemplo, la tendencia ilustrada en el recuadro superior es un promedio de las mortalidades por pesca que afectaron a los peces de entre 1 y 4 trimestres de edad.

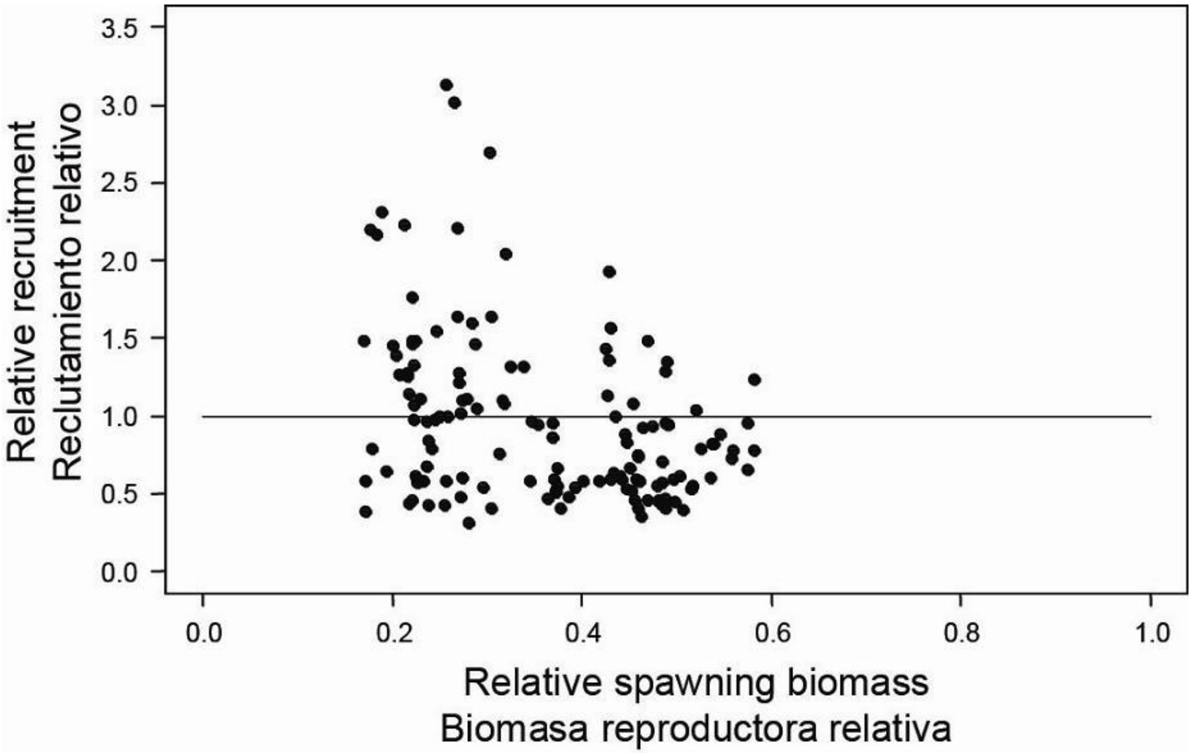

FIGURE 4.4. Estimated relationship between the recruitment and spawning biomass of bigeye tuna. The recruitment is scaled so that the estimate of virgin recruitment is equal to 1.0. Likewise, the spawning biomass is scaled so that the estimate of virgin spawning biomass is equal to 1.0. The horizontal line represents the assumed stock-recruitment relationship.

FIGURA 4.4. Relación estimada entre el reclutamiento y la biomasa reproductora del atún patudo. Se escala el reclutamiento para que la estimación de reclutamiento virgen equivalga a 1,0, y la biomasa reproductora para que la estimación de biomasa reproductora virgen equivalga a 1,0. La línea horizontal representa la relación población-reclutamiento supuesta.

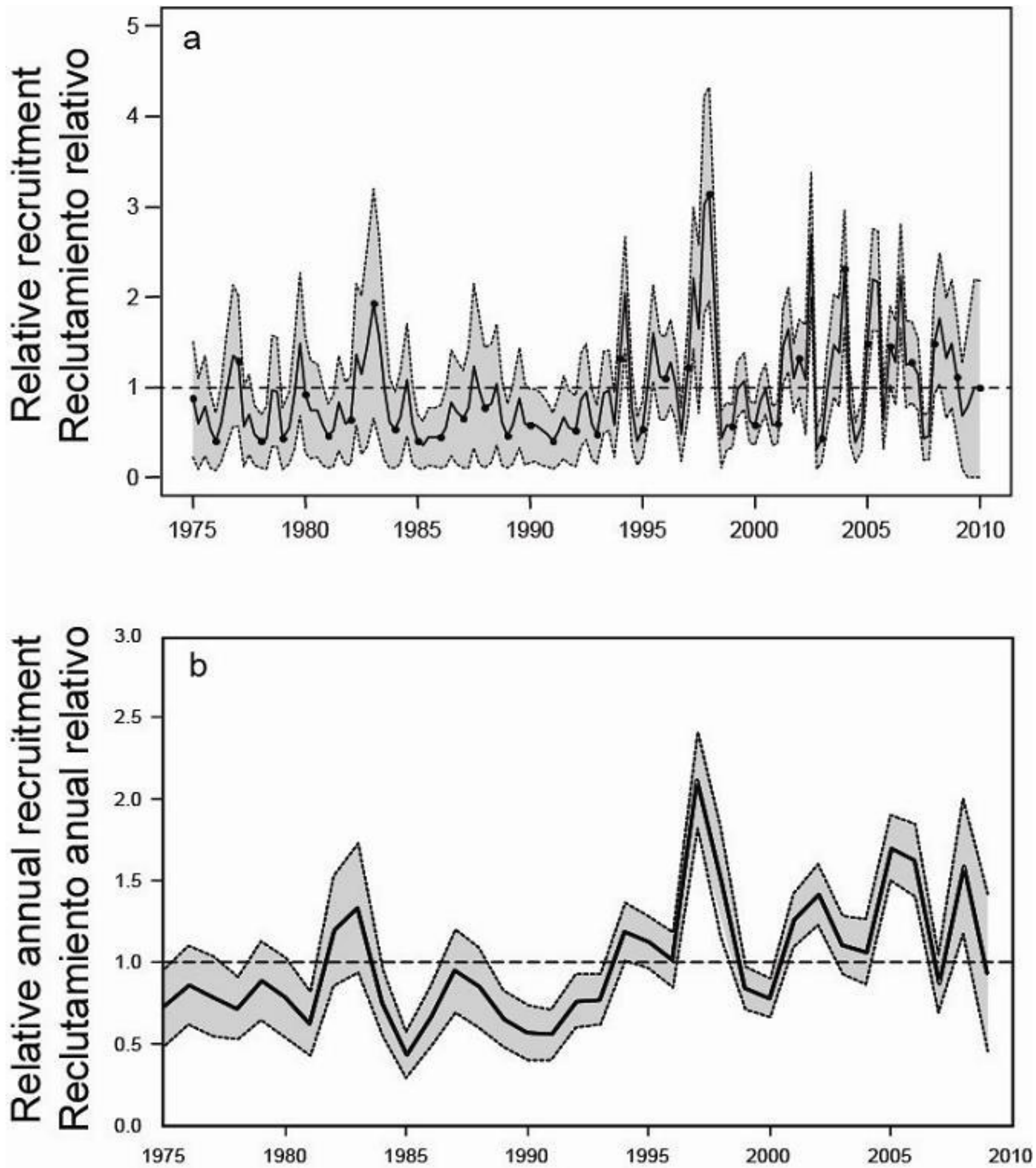

FIGURE 4.5. Estimated recruitment of bigeye tuna to the fisheries of the EPO: a) quarterly recruitment; b) annual recruitment. The estimates are scaled so that the estimate of virgin recruitment is equal to 1.0 (dashed horizontal line). The bold line illustrates the maximum likelihood estimates of recruitment, and the thin dashed lines the confidence intervals (±2 standard deviations) around those estimates.. The labels on the time axis are drawn at the beginning of each year, but, since the assessment model represents time on a quarterly basis, there are four estimates of recruitment for each year.

FIGURA 4.5. Reclutamiento estimado de atún patudo a las pesquerías del OPO: a) reclutamiento trimestral; b) reclutamiento anual. Se escalan las estimaciones para que la estimación de reclutamiento virgen equivalga a 1,0 (línea horizontal de trazos). La línea gruesa ilustra las estimaciones de reclutamiento de verosimilitud máxima, y las líneas delgadas de trazos los intervalos de confianza (±2 desviaciones estándar) alrededor 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.

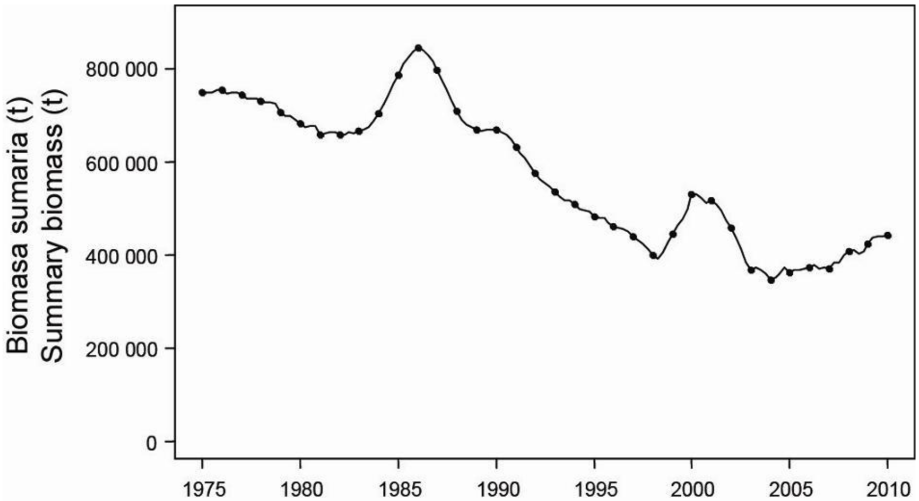

FIGURE 4.6. Maximum likelihood estimates of the biomass of bigeye tuna 3+ quarters old in the EPO (summary biomass). Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year. t = metric tons.
FIGURA 4.6. Estimaciones de verosimilitud máxima de la biomasa de atún patudo de 3+ trimestres de edad en el OPO (biomasa sumaria). Ya que el modelo de evaluación representa el tiempo por trimestre, hay cuatro estimaciones de biomasa para cada año. t = toneladas métricas.

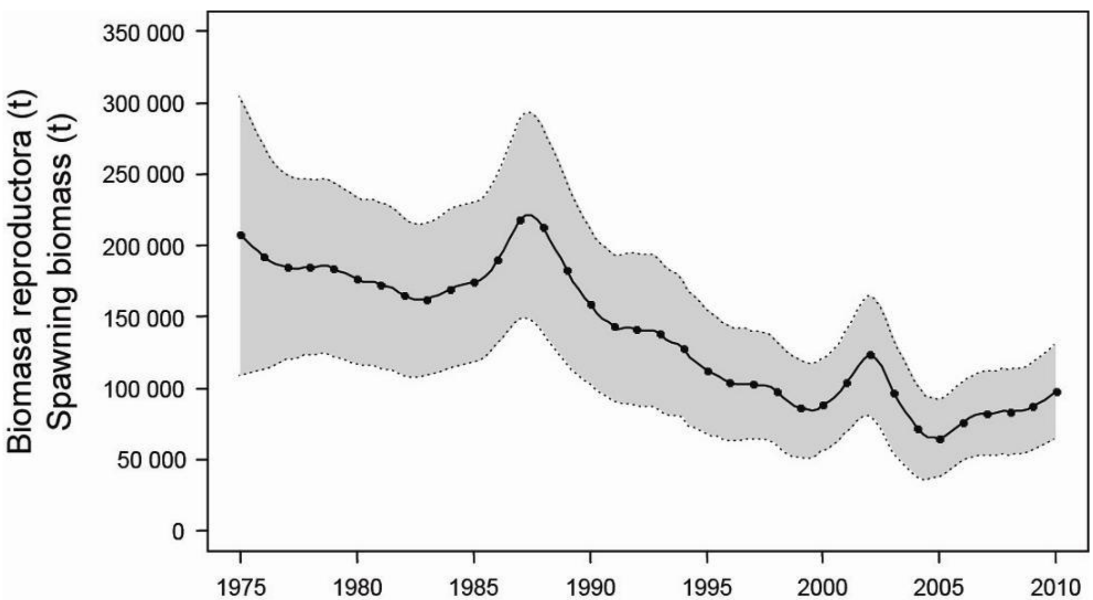

FIGURE 4.7. Maximum likelihood estimates of the spawning biomass (Section 4.1.3) of bigeye tuna in the EPO. The solid line illustrates the maximum likelihood estimates of the biomasses, and the dashed lines the confidence intervals (±2 standard deviations) around those estimates. Since the assessment model represents time on a quarterly basis, there are four estimates of the index for each year. t = metric tons.
FIGURA 4.7. Estimaciones de verosimilitud máxima del índice de biomasa reproductora (Sección 4.1.3) de atún patudo en el OPO. La línea sólida ilustra las estimaciones de verosimilitud máxima de la biomasa, y las líneas de trazos los intervalos de confianza (±2 desviaciones estándar) alrededor de estas estimaciones. Ya que el modelo de evaluación representa el tiempo por trimestre, hay cuatro estimaciones del índice para cada año. t = toneladas métricas.

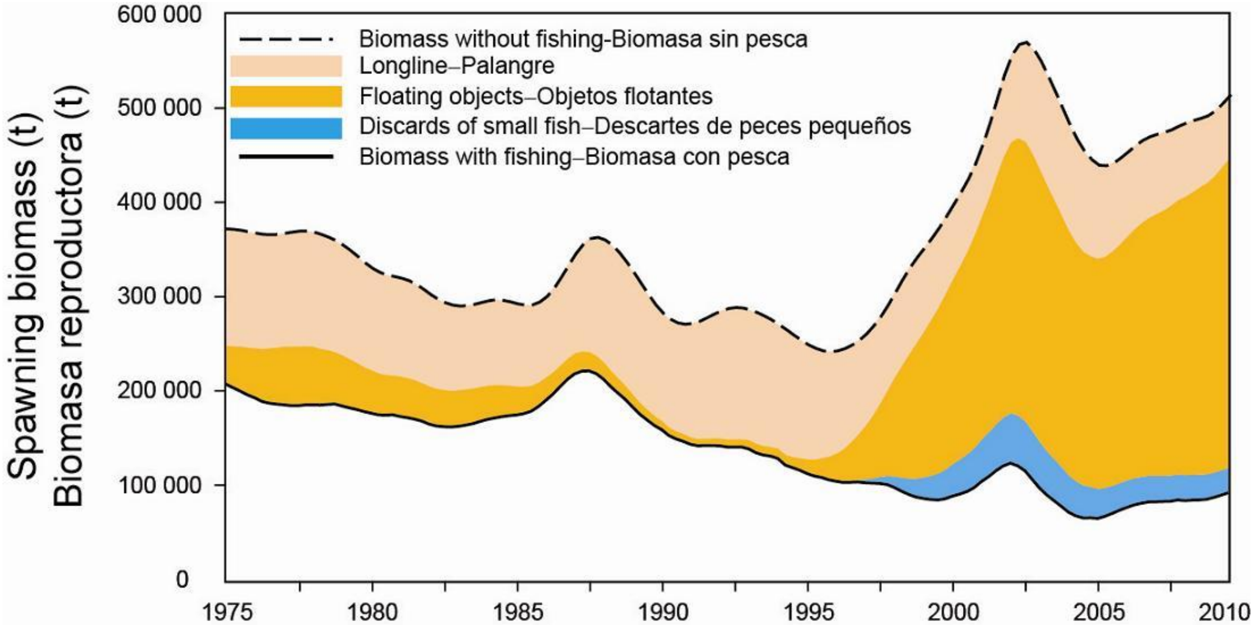

FIGURE 4.8. Trajectory of the spawning biomass of a simulated population of bigeye tuna that was not exploited (top line) and that predicted by the stock assessment model (bottom line). The shaded areas between the two lines show the portions of the impact attributed to each fishing method. t = metric tons.
FIGURA 4.8. Trayectoria de la biomasa reproductora de una población simulada de atún patudo no explotada (línea superior) y la que predice el modelo de evaluación (línea inferior). Las áreas sombreadas entre las dos líneas señalan la porción del efecto atribuida a cada método de pesca. t = toneladas métricas.

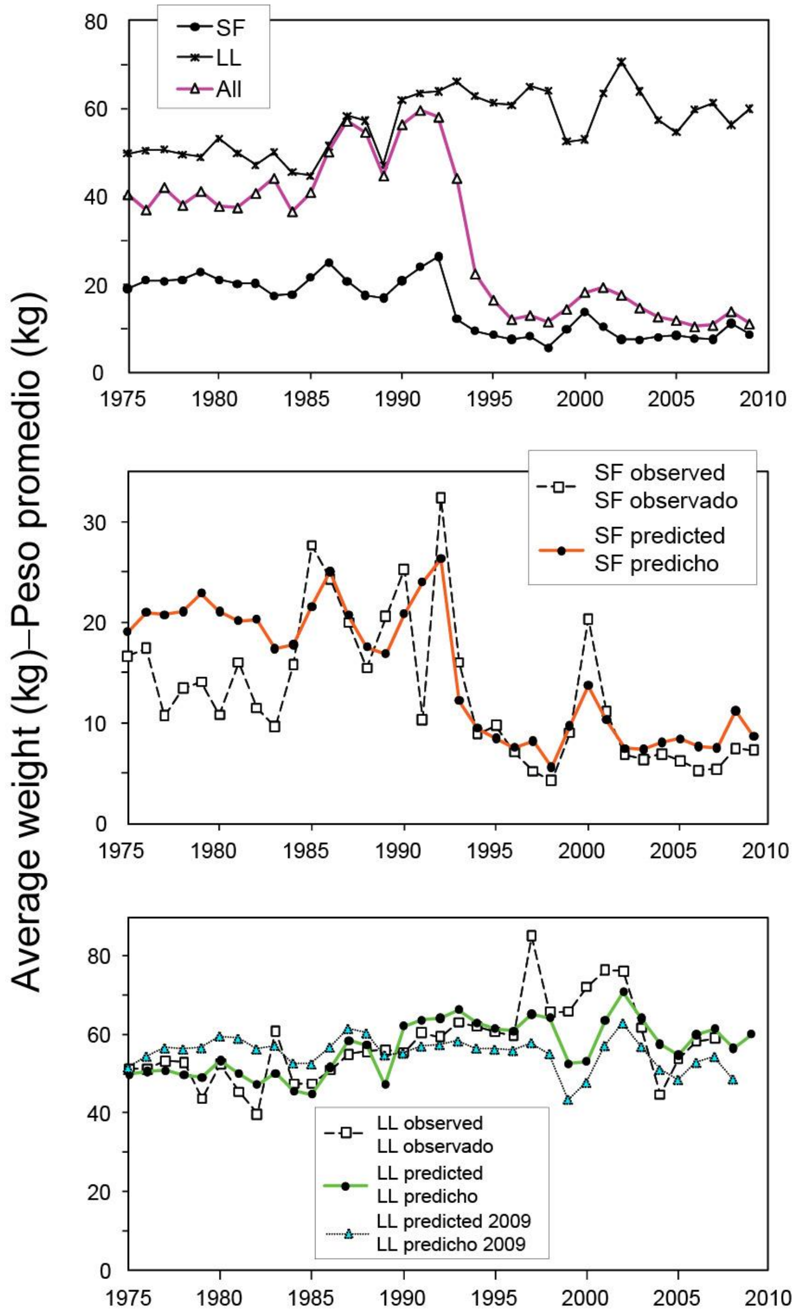

FIGURE 4.9. Average weights of bigeye tuna caught in the EPO, 1975-2009, by the surface fisheries (SF, Fisheries 1-7), longline fisheries (LL, Fisheries 12-23), and all fisheries combined (All). Upper panel: predicted average weights; middle panel: predicted and observed average weights for the surface fisheries; lower panel: predicted (present and last year's assessment SAR10) and observed (Japanese data) average weights for the longline fisheries.

FIGURA 4.9. Peso medio de atún patudo capturado en el OPO, 1975-2009, por las pesquerías de superficie (SF, pesquerías 1-7), de palangre (LL, pesquerías 12-23), y todas las pesquerías combinadas (All). Recuadro superior: pesos medios predichos; recuadro medio: pesos medios predichos y observados de las pesquerías de superficie; recuadro inferior: pesos medios predichos y observados (datos japoneses) de las pesquerías de palangre.

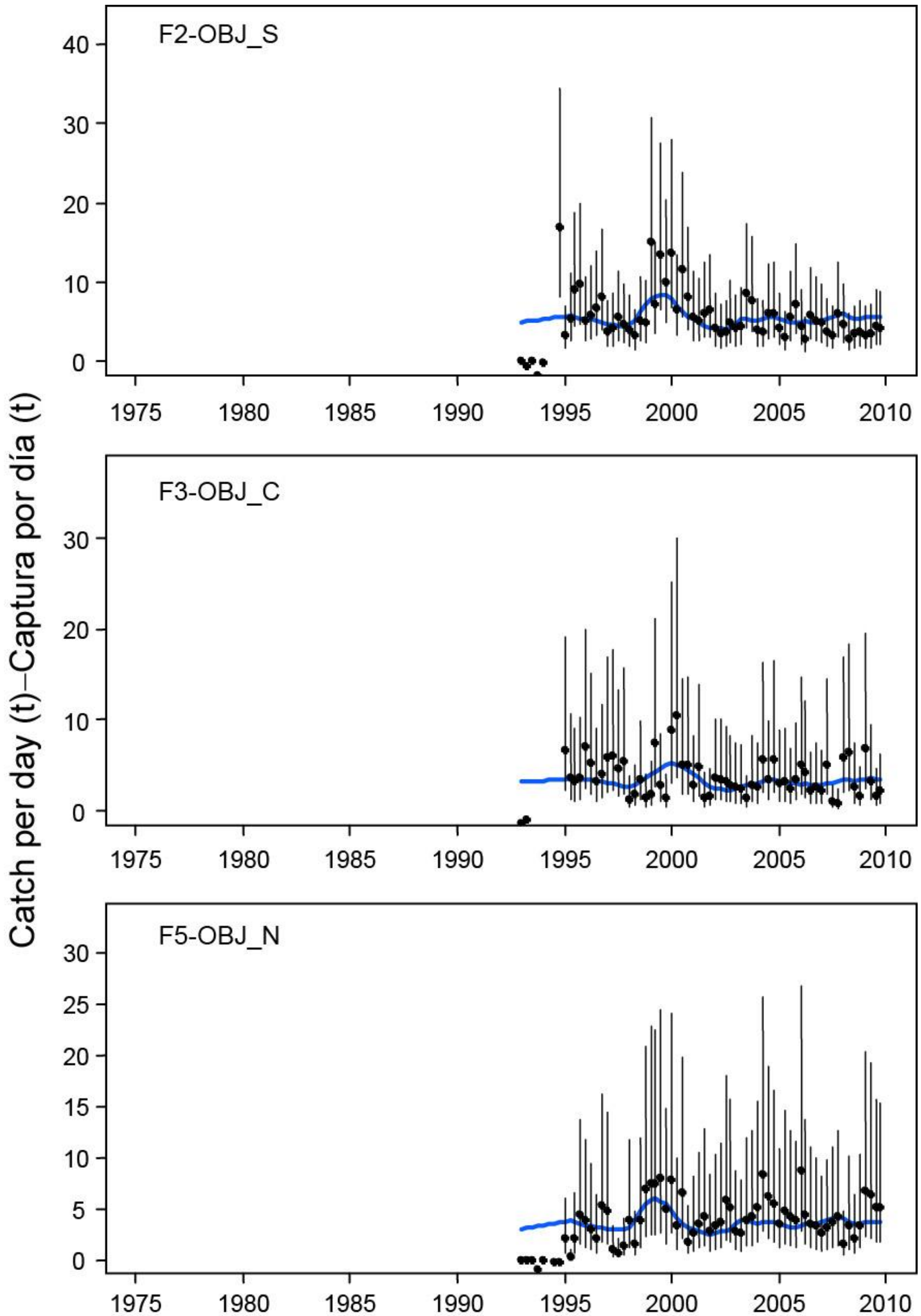

FIGURE 4.10a. Model fit to the CPUE data from different surface fisheries. The CPUEs for surface fisheries 2, 3, and 5 are in tons per day fished. The vertical lines represent the estimated confidence intervals (±2 standard deviations) around the observed CPUE values. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1. t = metric tons.

FIGURA 4.10a. Ajuste del modelo a los datos de CPUE de distintas pesquerías de superficie. Se expresan las CPUE de las pesquerías de superficie 2, 3, y 5 en toneladas por día de pesca. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1. t = toneladas métricas.

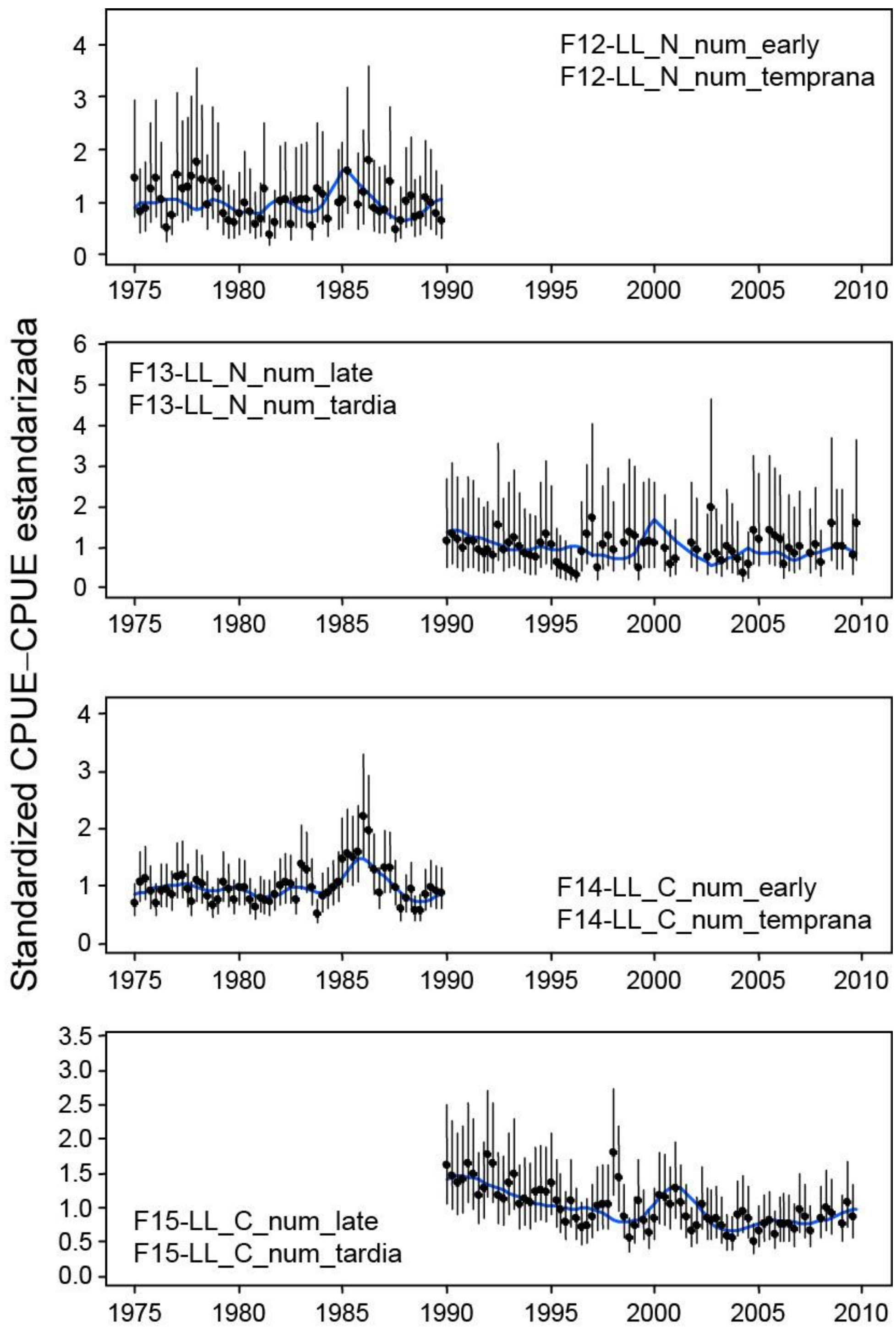

FIGURE 4.10b. Model fit to the CPUE data from different longline fisheries. The CPUEs for longline Fisheries 12-15 are standardized CPUE. The vertical lines represent the estimated confidence intervals (±2 standard deviations) around the CPUE values. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 4.10b. Ajuste del modelo a los datos de CPUE de distintas pesquerías de palangre. Las CPUE de las pesquerías de palangre 12-15 son CPUE estandarizadas. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

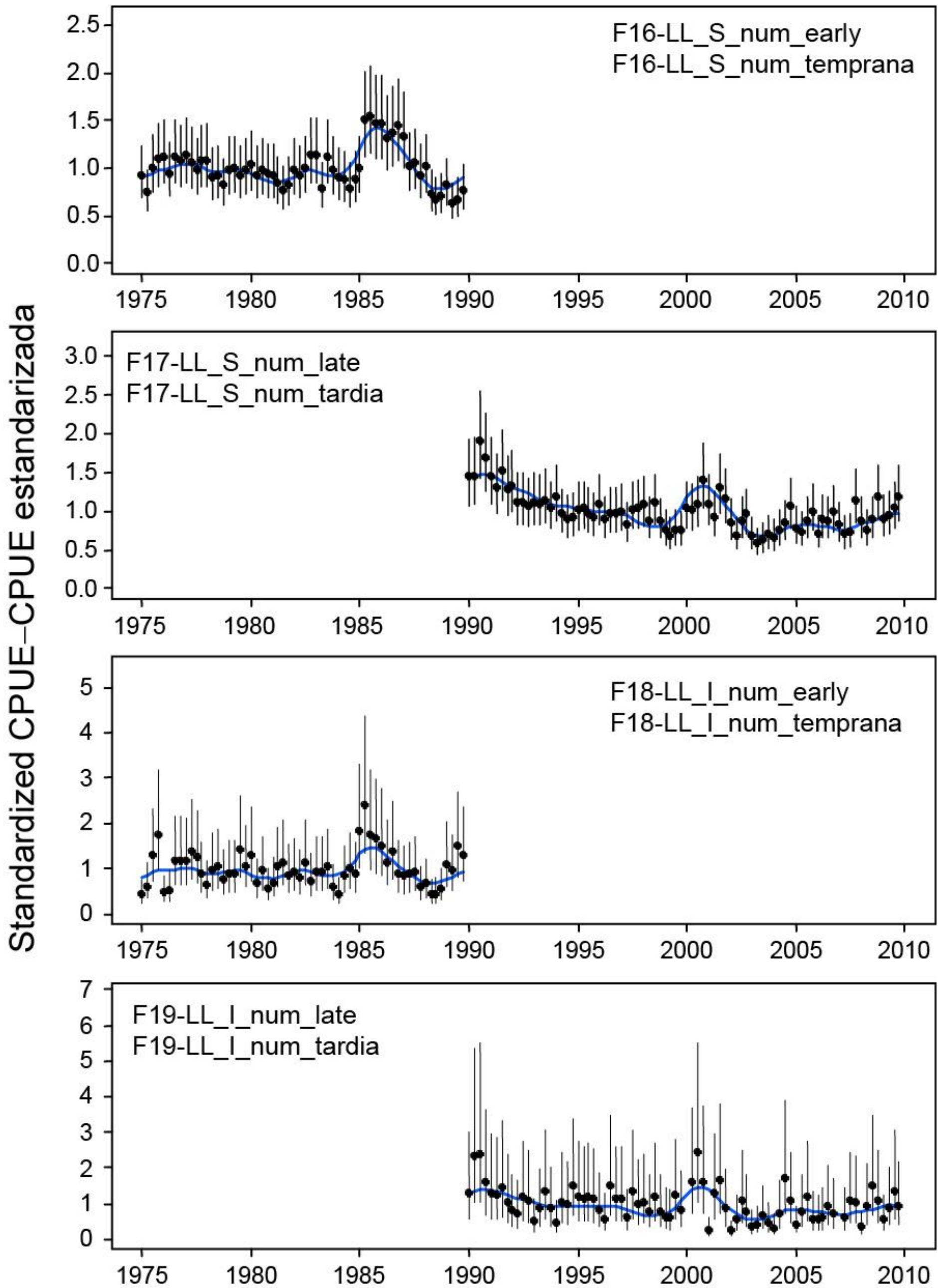

FIGURE 4.10c. Model fit to the CPUE data from different longline fisheries. The CPUEs for longline Fisheries 16-19 are standardized CPUE. The vertical lines represent the fixed and estimated confidence intervals (±2 standard deviations) around the CPUE values for the southern (Fisheries 16 and 17) and inshore (Fisheries 18 and 19) longline fisheries, respectively. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 4.10c. Ajuste del modelo a los datos de CPUE de distintas pesquerías de palangre. Las CPUE de las pesquerías de palangre 16-19 son CPUE estandarizada. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

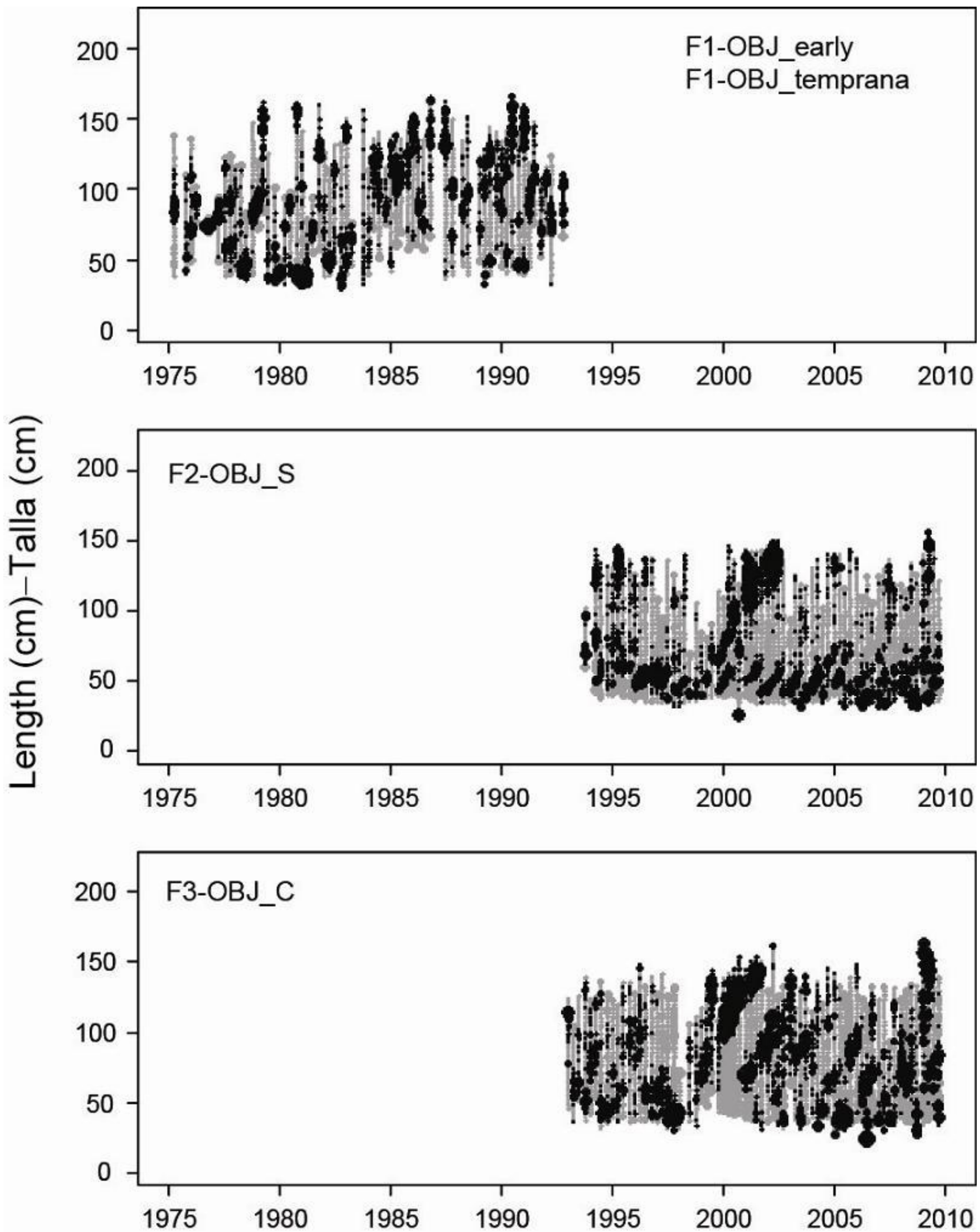

FIGURE 4.11a. Pearson residual plots for the model fits to the length-composition data for Fisheries 1, 2, and 3. The gray and black circles represent observations that are higher and lower, respectively, than the model predictions. The areas of the circles are proportional to the absolute values of the residuals. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 4.11a. Gráficas de residuales de Pearson para los ajustes del modelo a los datos de composición por talla de las pesquerías 1, 2, y 3. Los círculos grises y negros representan observaciones mayores y menores, respectivamente, que las predicciones del modelo. El área de los círculos es proporcional al valor absoluto de los residuales. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

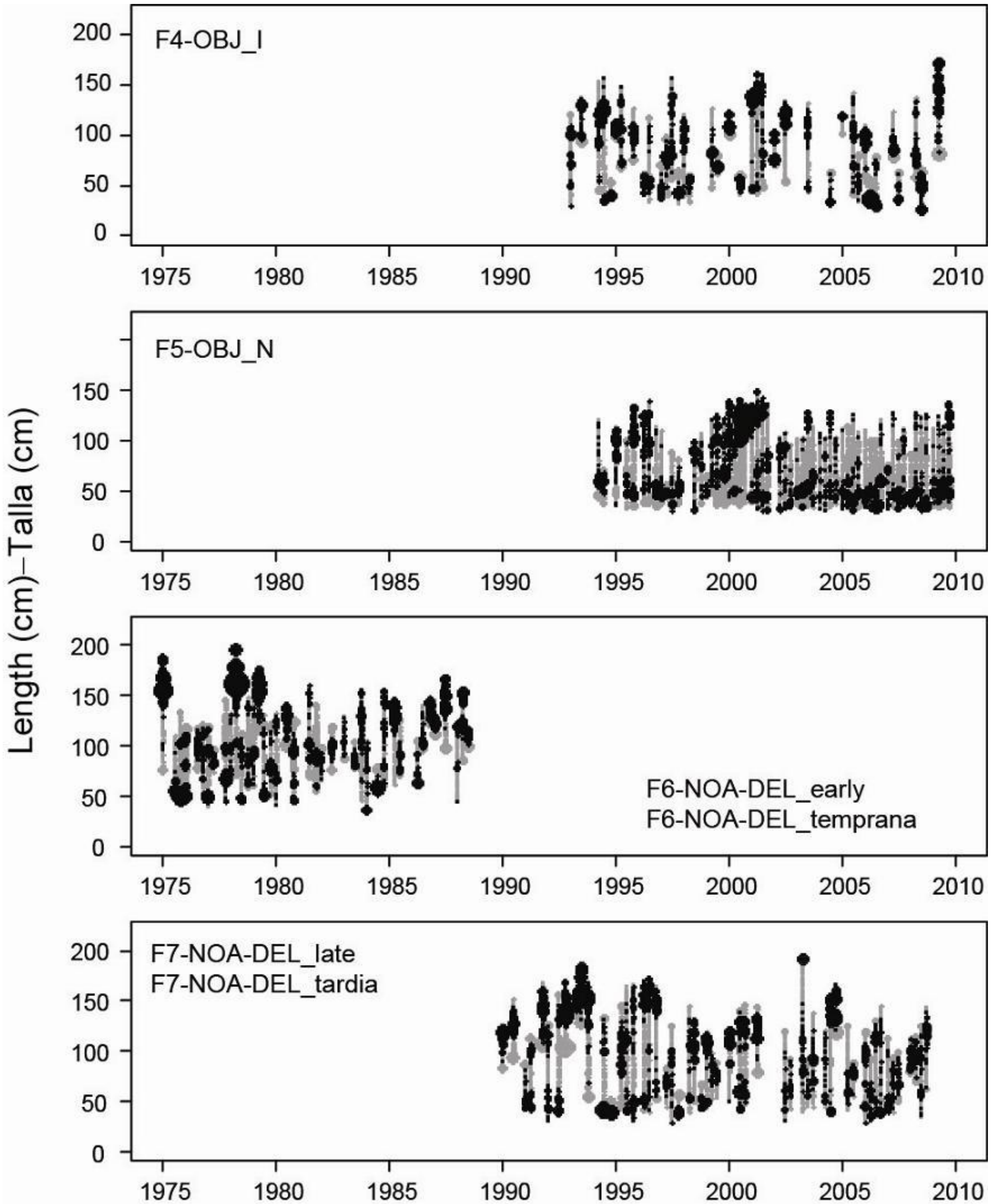

FIGURE 4.11b. Pearson residual plots for the model fits to the length-composition data for Fisheries 4-7. The gray and black circles represent observations that are higher and lower, respectively, than the model predictions. The areas of the circles are proportional to the absolute values of the residuals. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 4.11b. Gráficas de residuales de Pearson para los ajustes del modelo a los datos de composición por talla de las pesquerías 4-7. Los círculos abiertos y sólidos representan observaciones mayores y menores, respectivamente, que las predicciones del modelo. El área de los círculos es proporcional al valor absoluto de los residuales. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

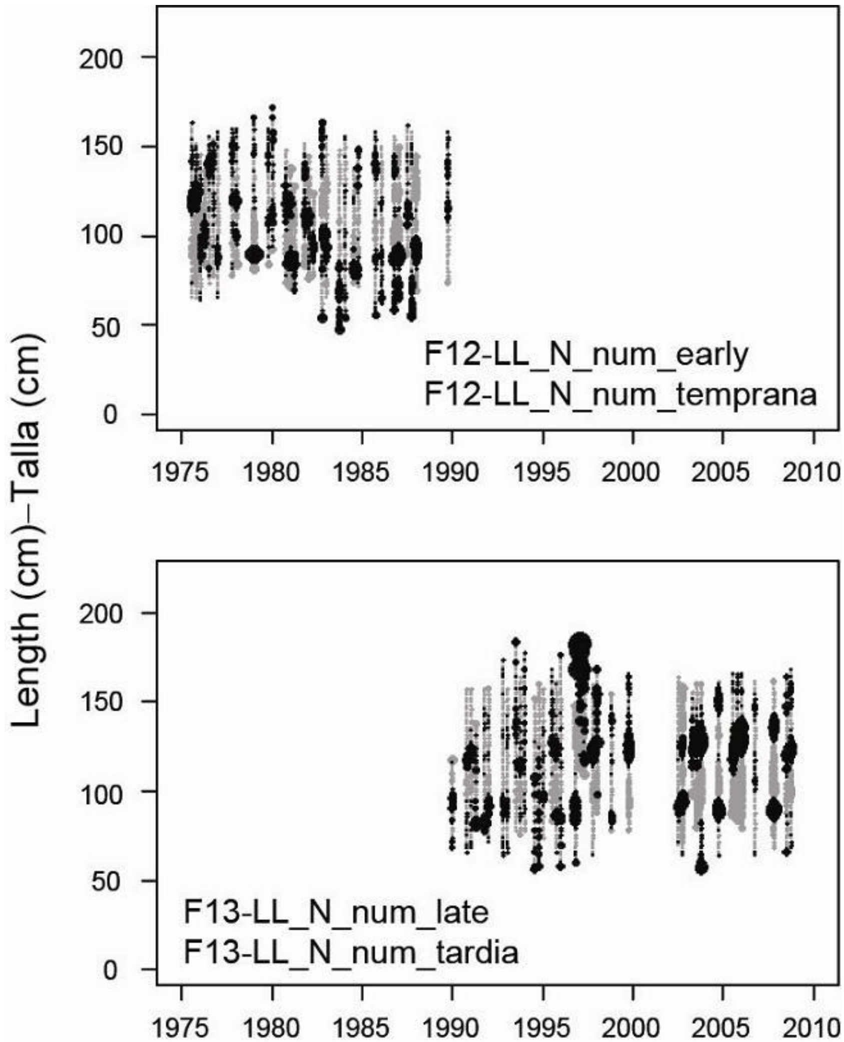

FIGURE 4.11c. Pearson residual plots for the model fits to the length-composition data for Fisheries 12 and 13. The gray and black circles represent observations that are higher and lower, respectively, than the model predictions. The areas of the circles are proportional to the absolute values of the residuals. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 4.11c. Gráficas de residuales de Pearson para los ajustes del modelo a los datos de composición por talla de las pesquerías 12 y 13. Los círculos abiertos y sólidos representan observaciones mayores y menores, respectivamente, que las predicciones del modelo. El área de los círculos es proporcional al valor absoluto de los residuales. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

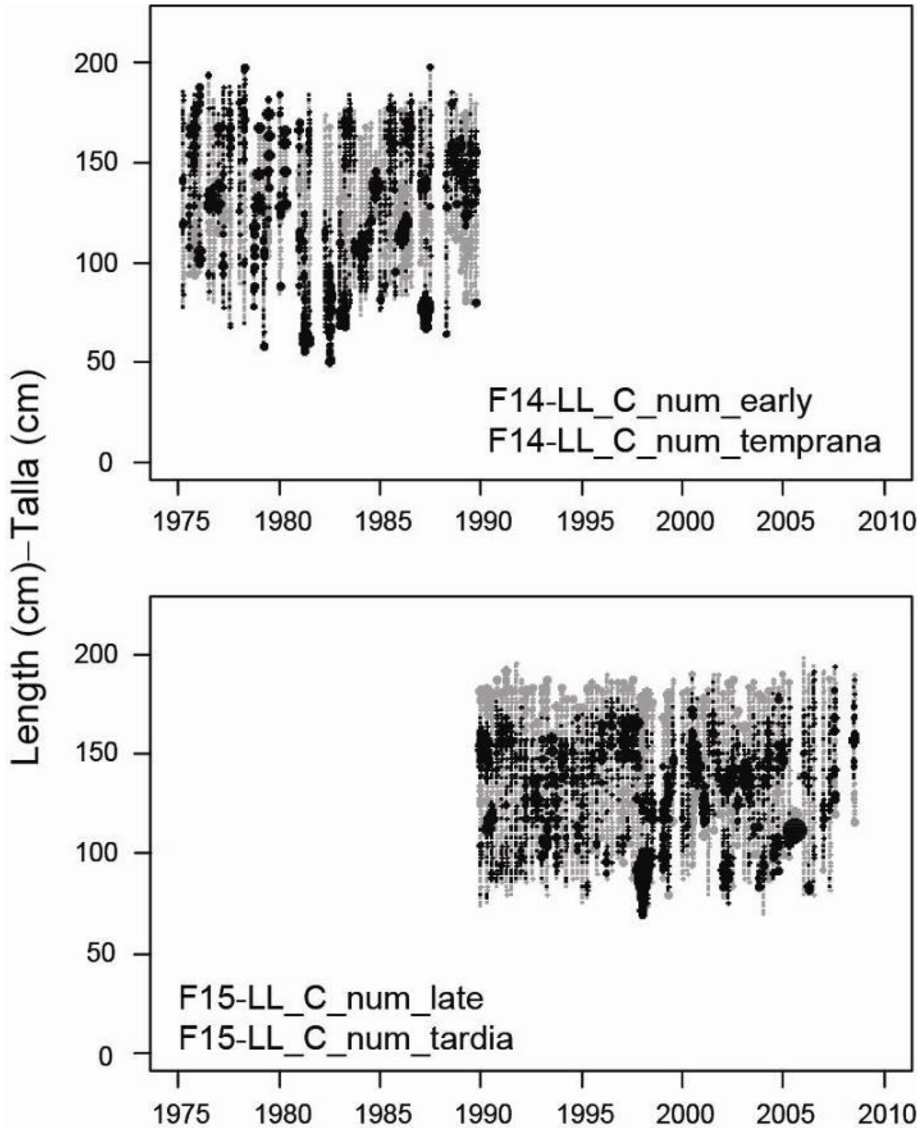

FIGURE 4.11d. Pearson residual plots for the model fits to the length-composition data for Fisheries 14 and 15. The gray and black circles represent observations that are higher and lower, respectively, than the model predictions. The areas of the circles are proportional to the absolute values of the residuals. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 4.11d. Gráficas de residuales de Pearson para los ajustes del modelo a los datos de composición por talla de las pesquerías 14 y 15. Los círculos abiertos y sólidos representan observaciones mayores y menores, respectivamente, que las predicciones del modelo. El área de los círculos es proporcional al valor absoluto de los residuales. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

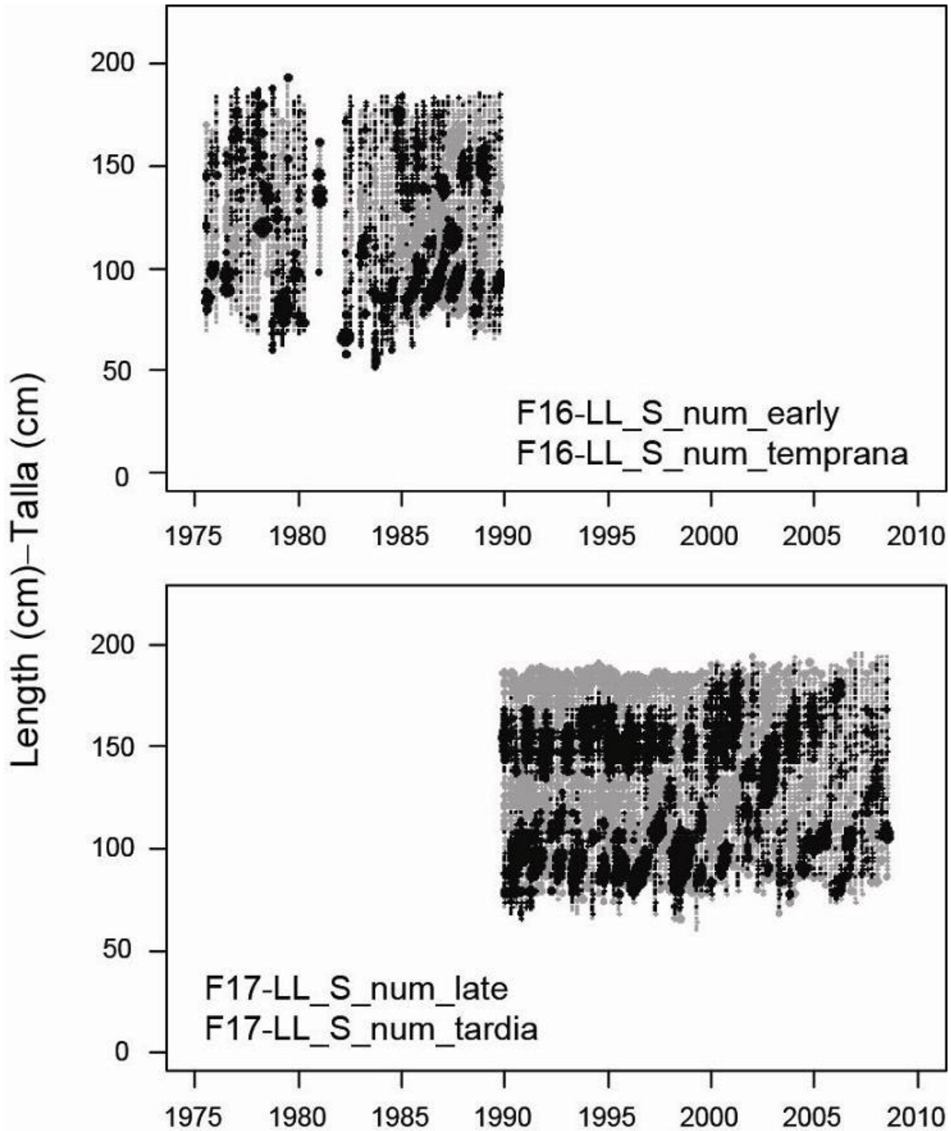

FIGURE 4.11e. Pearson residual plots for the model fits to the length-composition data for Fisheries 16 and 17. The gray and black circles represent observations that are higher and lower, respectively, than the model predictions. The areas of the circles are proportional to the absolute values of the residuals. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 4.11e. Gráficas de residuales de Pearson para los ajustes del modelo a los datos de composición por talla de las pesquerías 16 and 17. Los círculos abiertos y sólidos representan observaciones mayores y menores, respectivamente, que las predicciones del modelo. El área de los círculos es proporcional al valor absoluto de los residuales. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

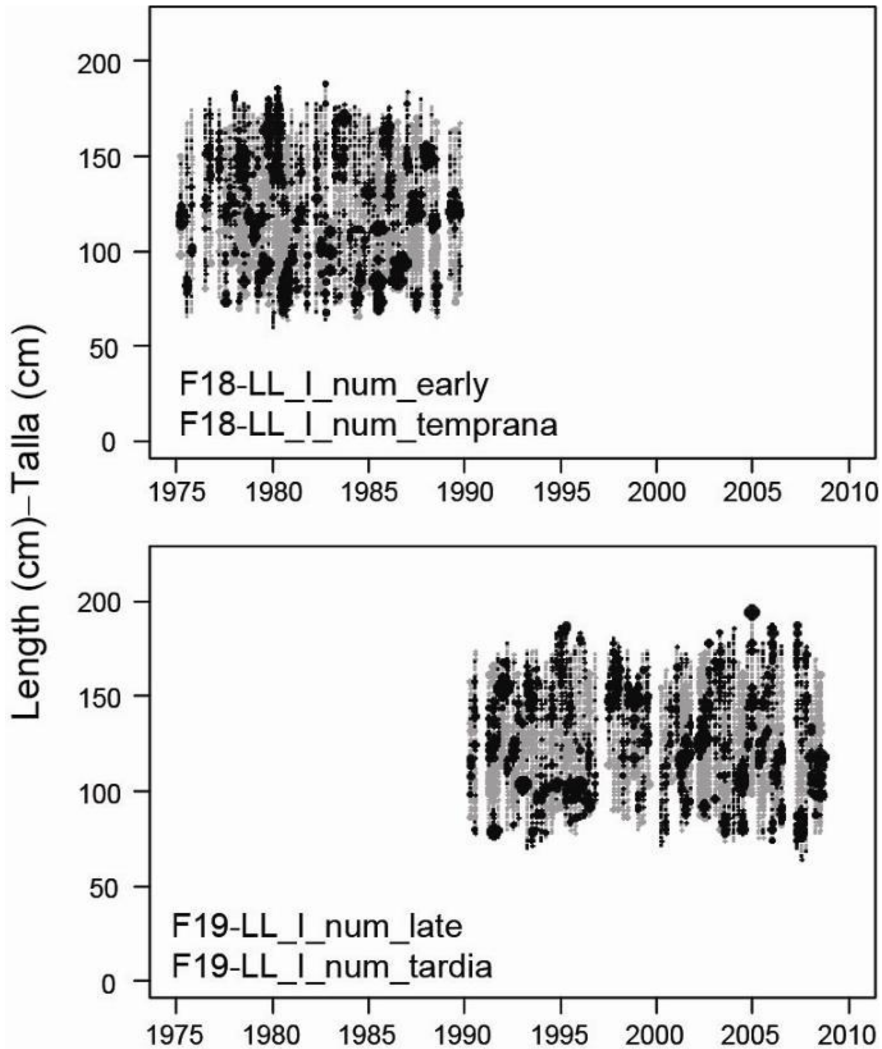

FIGURE 4.11f. Pearson residual plots for the model fits to the length-composition data for Fisheries 18 and 19. The gray and black circles represent observations that are higher and lower, respectively, than the model predictions. The areas of the circles are proportional to the absolute values of the residuals. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 4.11e. Gráficas de residuales de Pearson para los ajustes del modelo a los datos de composición por talla de las pesquerías 18 y 19. Los círculos abiertos y sólidos representan observaciones mayores y menores, respectivamente, que las predicciones del modelo. El área de los círculos es proporcional al valor absoluto de los residuales. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

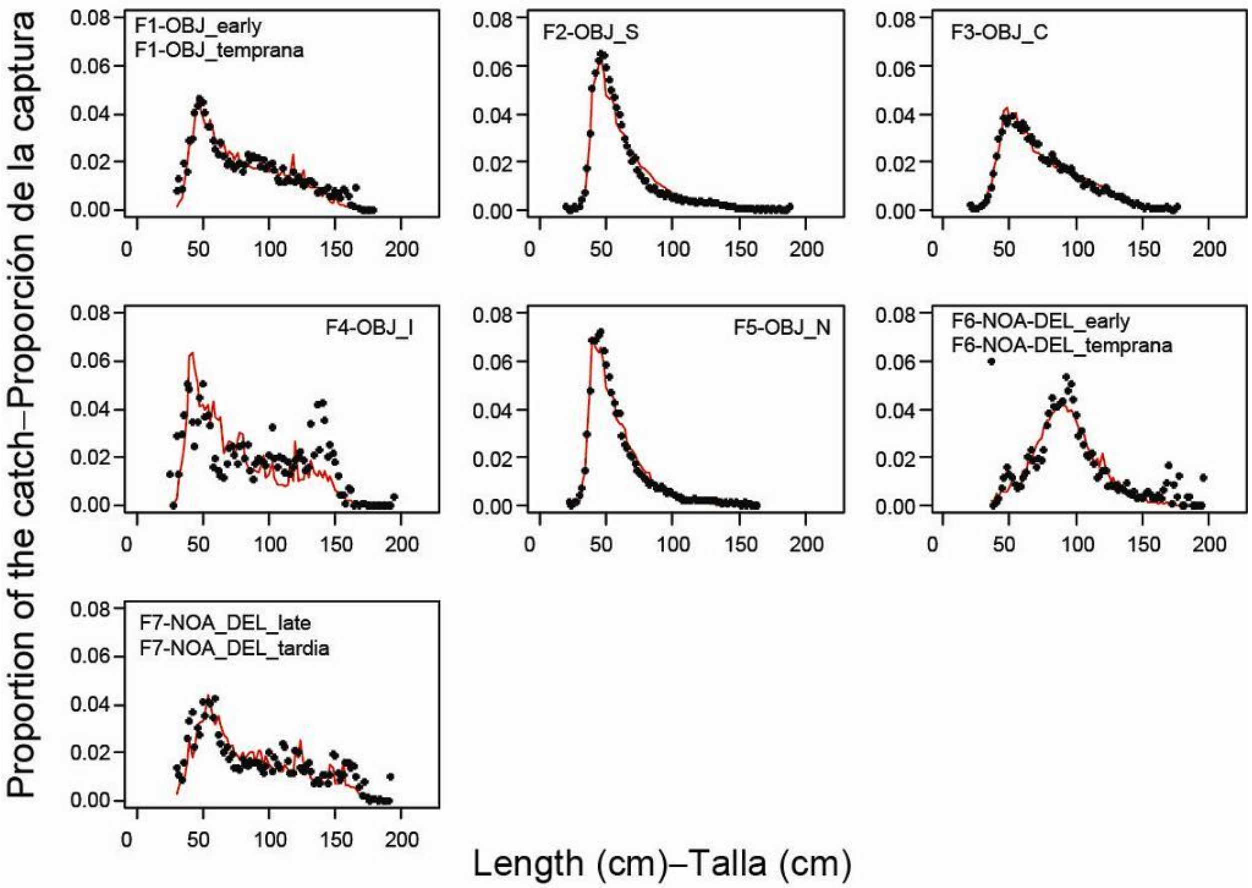

FIGURE 4.11g. Average observed (dots) and predicted (curves) length compositions of the catches taken by surface Fisheries 1-7 defined for the stock assessment of bigeye tuna in the EPO. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 4.11g. Composición por tamaño media observada (puntos) y predicha (curvas) de las capturas realizadas por las pesquerías de superficie 1-7 definidas para la evaluación de la población de atún patudo en el OPO. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

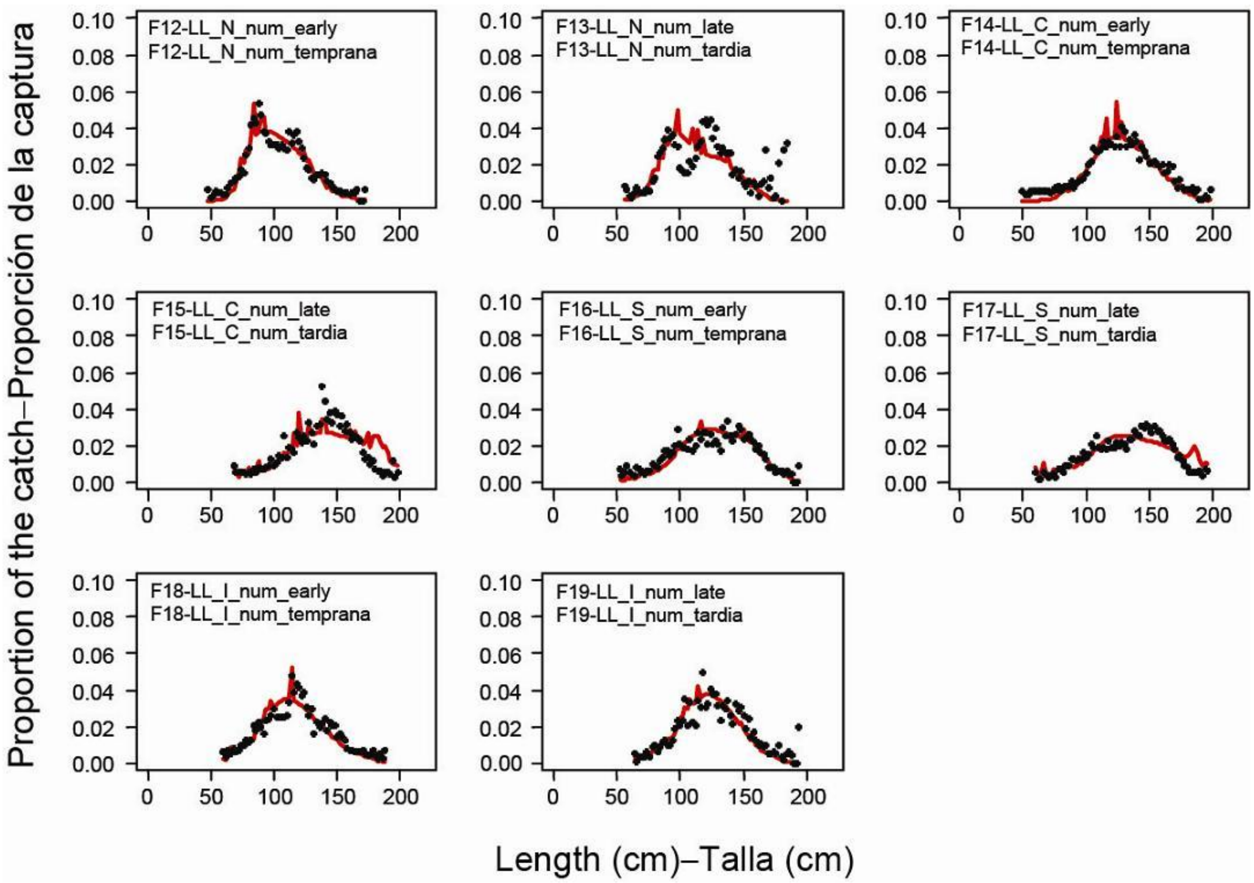

FIGURE 4.11h. Average observed (dots) and predicted (curves) length compositions of the catches taken by the longline Fisheries 12-19 defined for the stock assessment of bigeye tuna in the EPO. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 4.11d. Composición por tamaño media observada (puntos) y predicha (curvas) de las capturas realizadas por las pesquerías de palangre 12-19 definidas para la evaluación de la población de atún patudo en el OPO. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

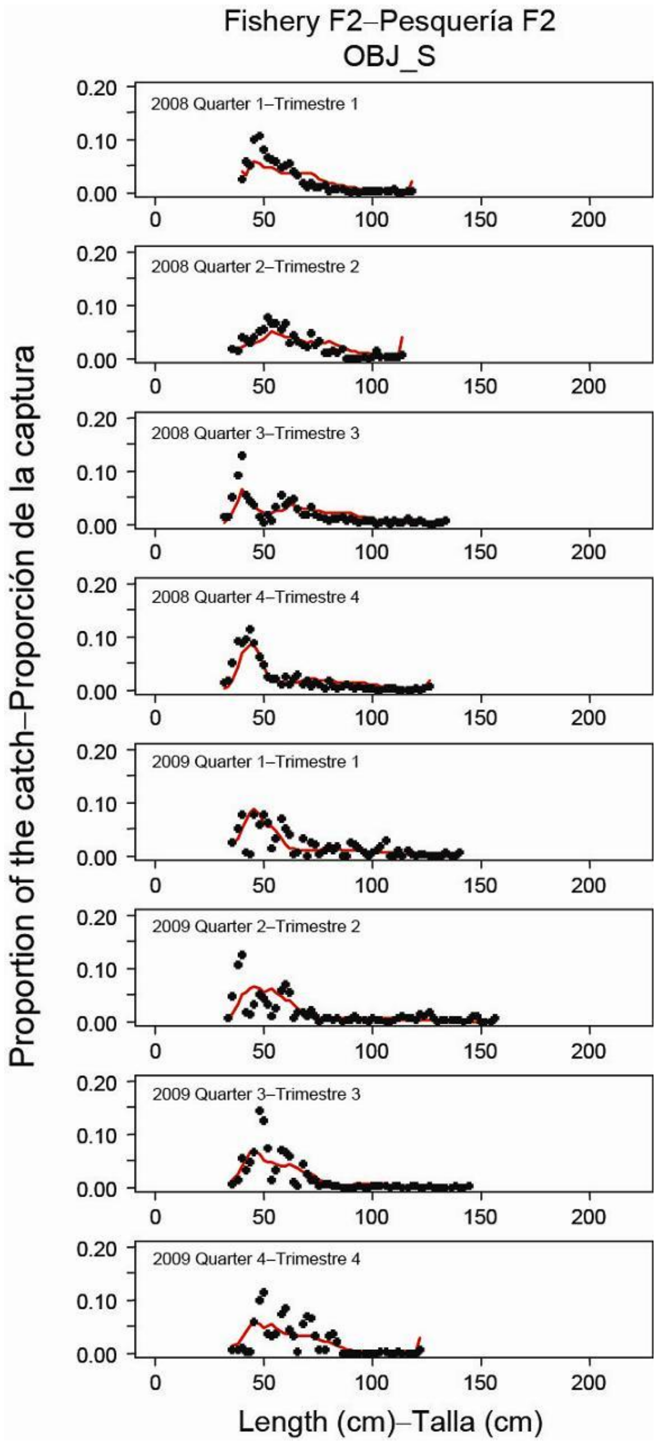

FIGURE 4.11i. Observed (dots) and predicted (curves) length compositions of the recent catches of bigeye tuna by Fishery 2. The tails of the predicted length compositions are accumulated at the length intervals corresponding to the lowest and highest observations.

FIGURA 4.11i. Composición por talla observada (puntos) y predicha (curvas) de las capturas recientes de atún patudo por la Pesquería 2. Las colas de las composiciones por talla predichas se acumulan en los intervalos de talla que corresponden a las observaciones mínimas y máximas.

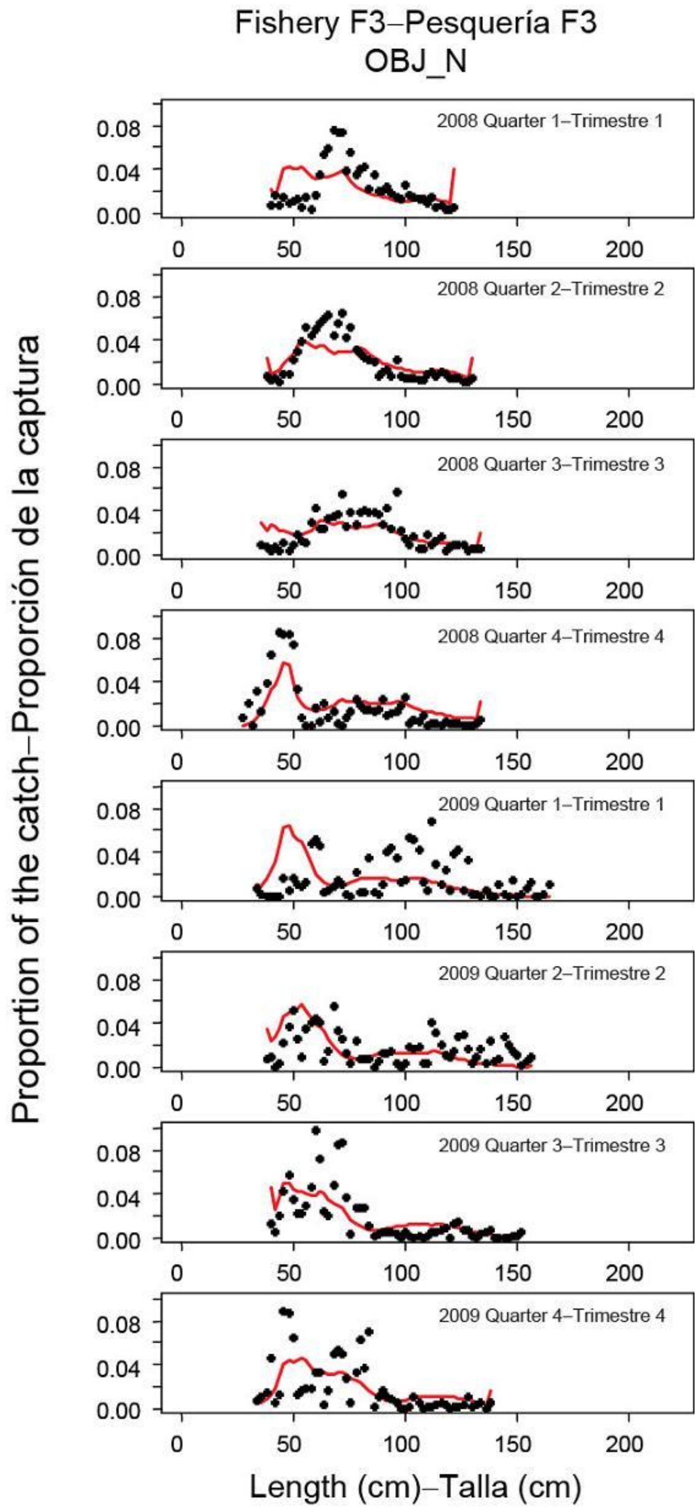

FIGURE 4.11j. Observed (dots) and predicted (curves) length compositions of the recent catches of bigeye tuna by Fishery 3. The tails of the predicted length compositions are accumulated at the length intervals corresponding to the lowest and highest observations.

FIGURA 4.11j. Composición por talla observada (puntos) y predicha (curvas) de las capturas recientes de atún patudo por la Pesquería 3. Las colas de las composiciones por talla predichas se acumulan en los intervalos de talla que corresponden a las observaciones mínimas y máximas.

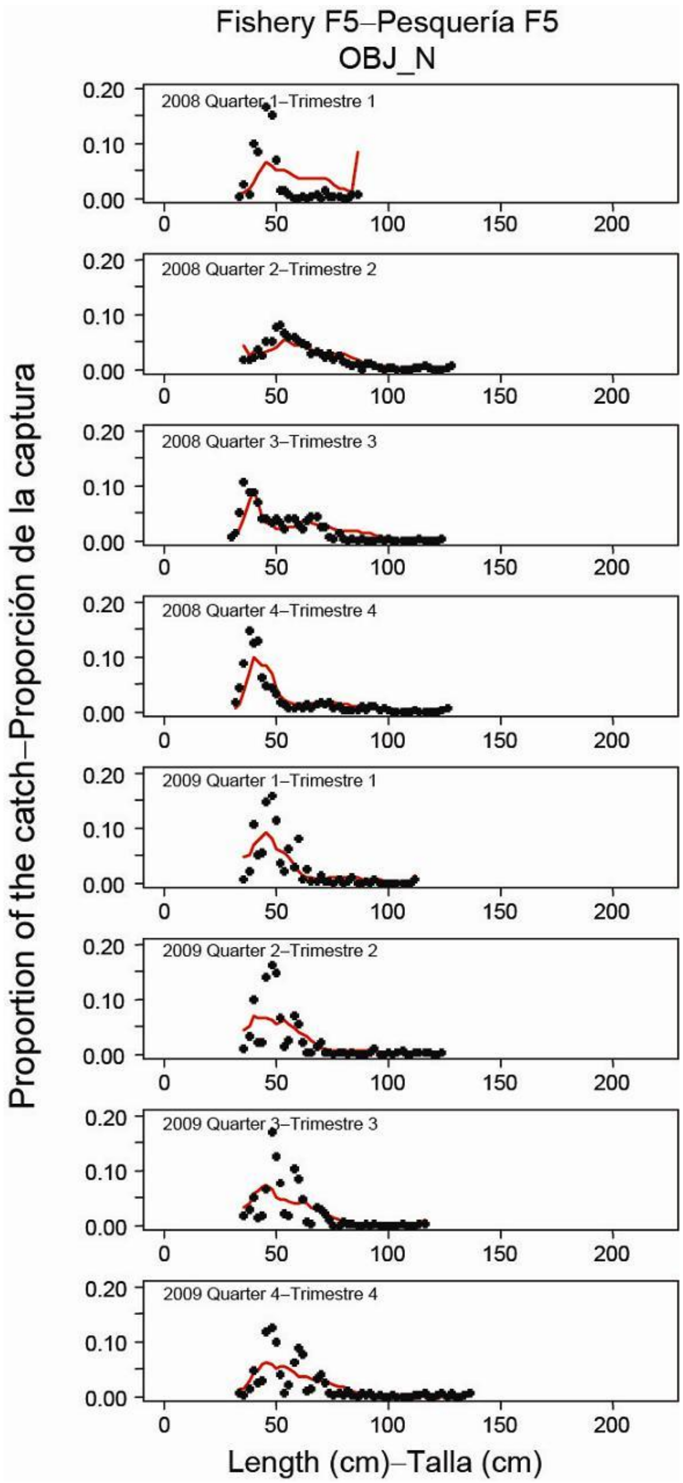

FIGURE 4.11k. Observed (dots) and predicted (curves) length compositions of the recent catches of bigeye tuna by Fishery 5. The tails of the predicted length compositions are accumulated at the length intervals corresponding to the lowest and highest observations.

FIGURA 4.11k. Composición por talla observada (puntos) y predicha (curvas) de las capturas recientes de atún patudo por la Pesquería 5. Las colas de las composiciones por talla predichas se acumulan en los intervalos de talla que corresponden a las observaciones mínimas y máximas.

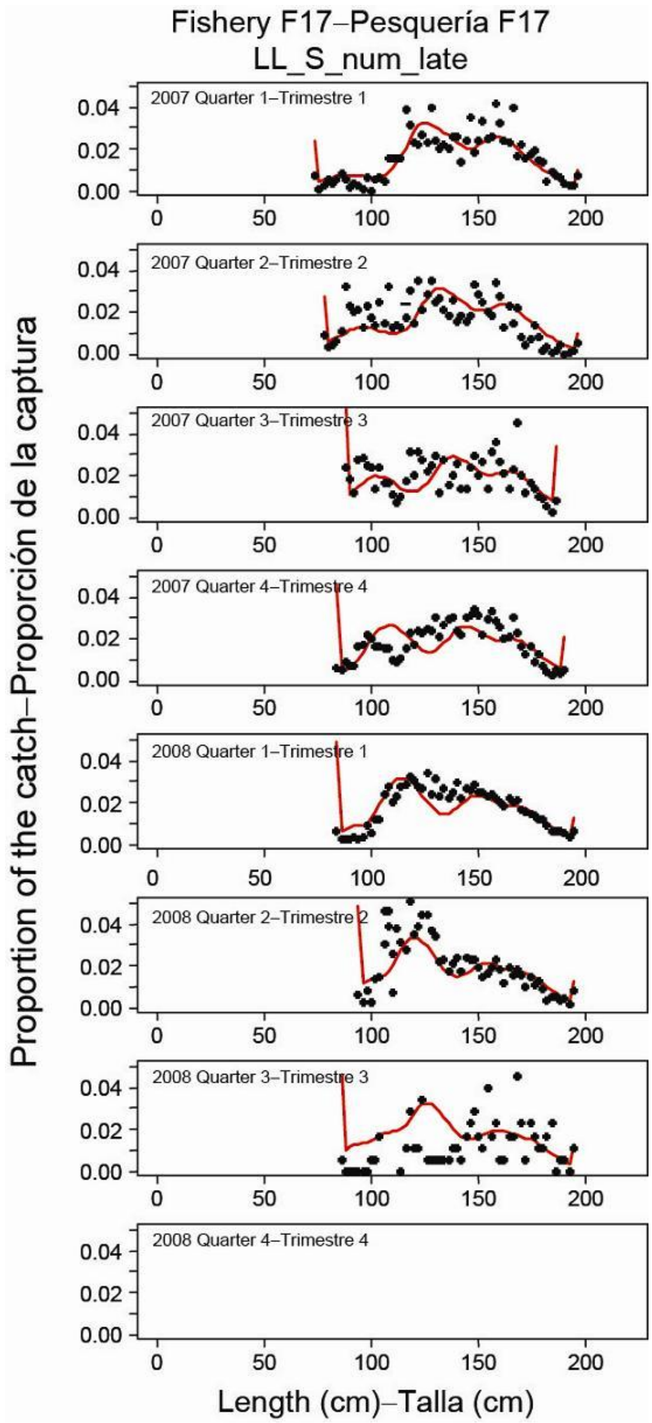

FIGURE 4.11l. Observed (dots) and predicted (curves) length compositions of the recent catches of bigeye tuna by Fishery 17. The tails of the predicted length compositions are accumulated at the length intervals corresponding to the lowest and highest observations.

FIGURA 4.11l. Composición por talla observada (puntos) y predicha (curvas) de las capturas recientes de atún patudo por la pesquería 17. Las colas de las composiciones por talla predichas se acumulan en los intervalos de talla que corresponden a las observaciones mínimas y máximas.

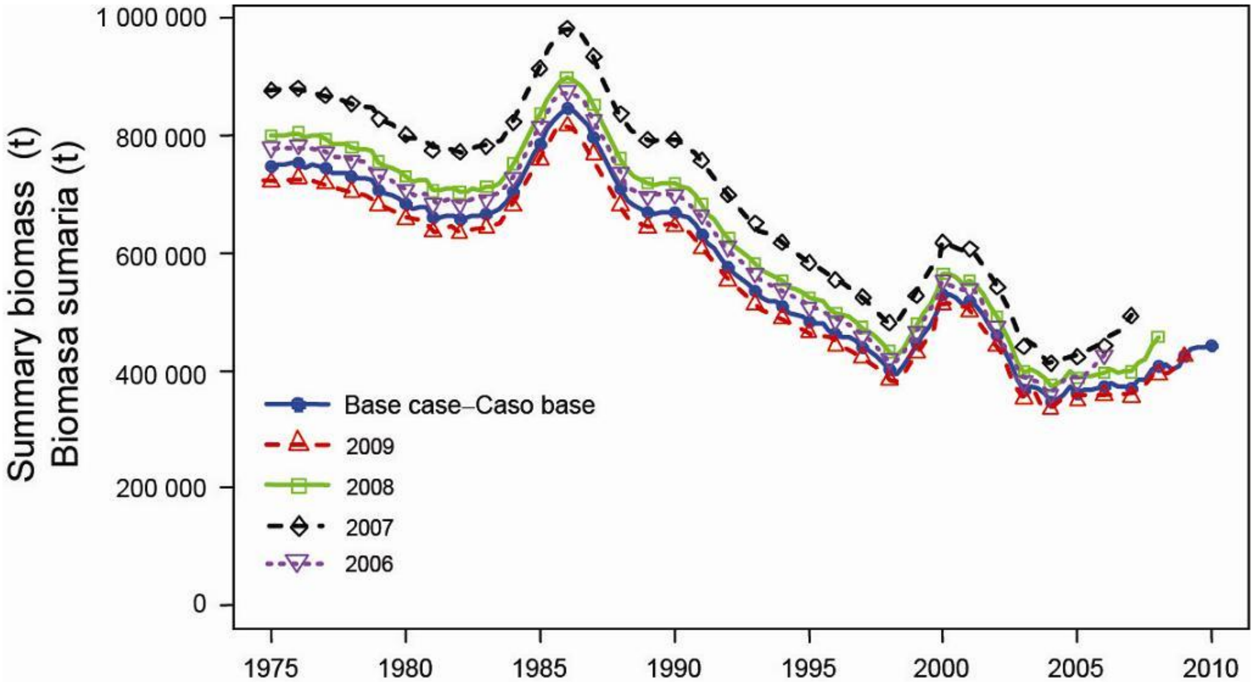

FIGURE 4.12. Retrospective comparisons of estimates of biomass of bigeye tuna 3+ quarters old in the EPO (summary biomass). The estimates from the base case model are compared to the estimates obtained when the most recent year (2009), two years (2009 and 2008), three years (2009, 2008, and 2007) or four years (2009, 2008, 2007, and 2006) of data were excluded. t = metric tons.

FIGURA 4.12. Comparaciones retrospectivas de las estimaciones de la biomasa de atún patudo de 3+ trimestres de edad en el OPO (biomasa sumaria). Se comparan las estimaciones del modelo del caso base con aquéllas obtenidas cuando se excluyeron los datos del año más reciente (2009), o de los dos años (2009 y 2008), tres años (2009, 2008, y 2007), o cuatro años (2009, 2008, 2007, y 2006) más recientes. t = toneladas métricas.

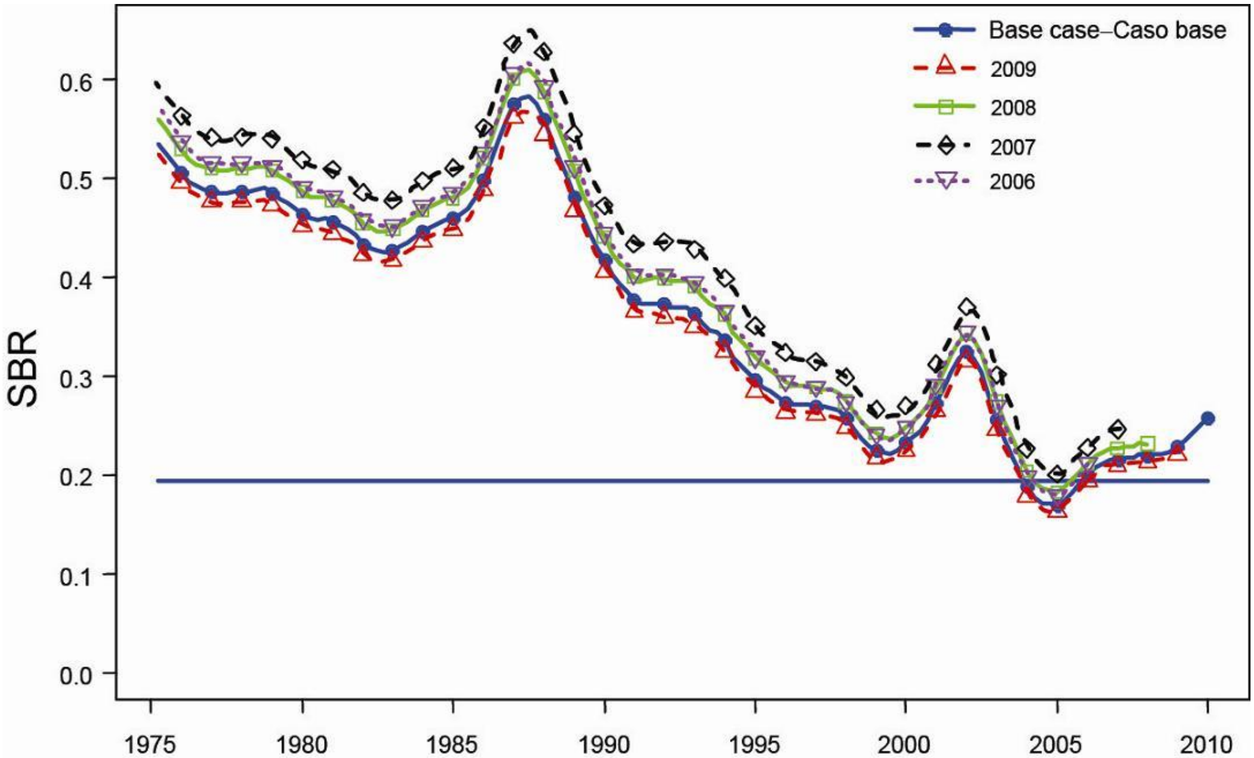

FIGURE 4.13. Retrospective comparisons of estimates of the spawning biomass ratio (SBR) of bigeye tuna in the EPO. The estimates from the base case model are compared with the estimates obtained when the most recent year (2009), two years (2009 and 2008), three years (2009, 2008, and 2007) or four years (2009, 2008, 2007, and 2006) of data were excluded. The horizontal line indicates the SBR at MSY.

FIGURA 4.13. Comparaciones retrospectivas de las estimaciones del cociente de biomasa reproductora (SBR) de atún patudo en el OPO. Se comparan las estimaciones del modelo del caso base con aquéllas obtenidas cuando se excluyeron los datos del año más reciente (2009), o de los dos años (2009 y 2008), tres años (2009, 2008, y 2007), o cuatro años (2009, 2008, 2007, y 2006) más recientes. La línea horizontal indica el SBR en RMS.

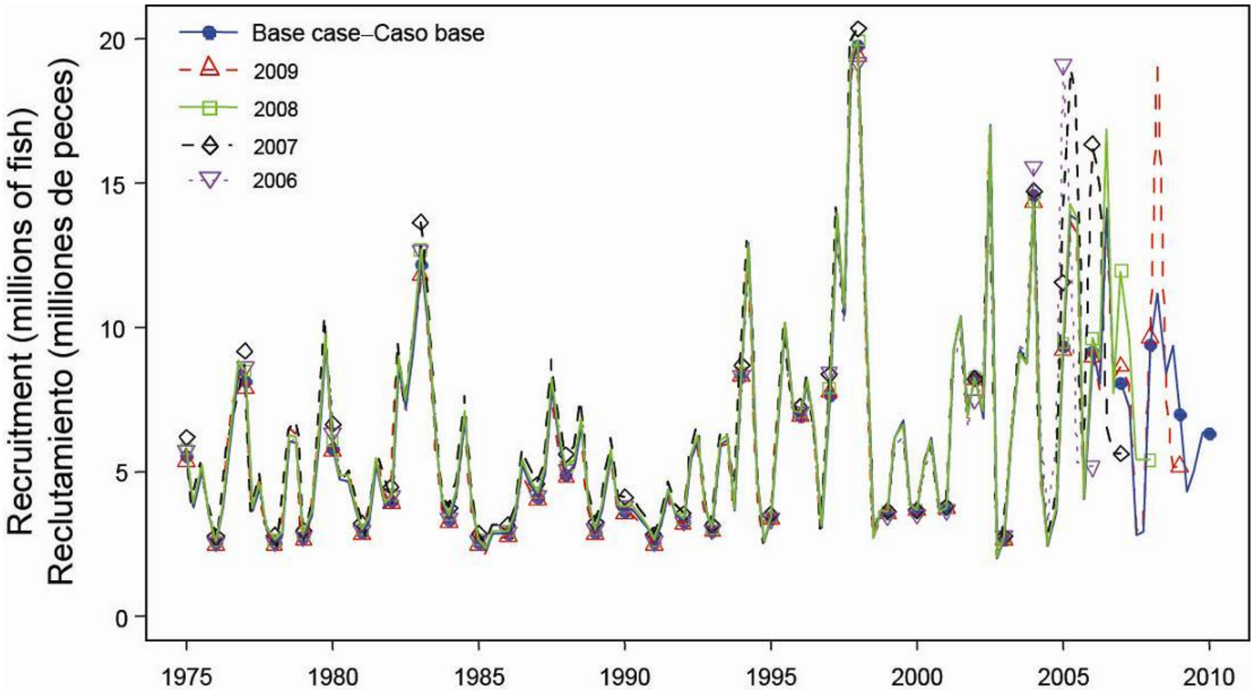

FIGURE 4.14. Retrospective comparisons of estimates of the recruitment of bigeye tuna in the EPO. The estimates from the base case model are compared with the estimates obtained when the most recent year (2009), two years (2009 and 2008), three years (2009, 2008, and 2007) or four years (2009, 2008, 2007, and 2006) of data were excluded.

FIGURA 4.14. Comparaciones retrospectivas de las estimaciones de reclutamiento de atún patudo en el OPO. Se comparan las estimaciones del modelo del caso base con aquéllas obtenidas cuando se excluyeron los datos del año más reciente (2009), o de los dos años (2009 y 2008), tres años (2009, 2008, y 2007), o cuatro años (2009, 2008, 2007, y 2006) más recientes.

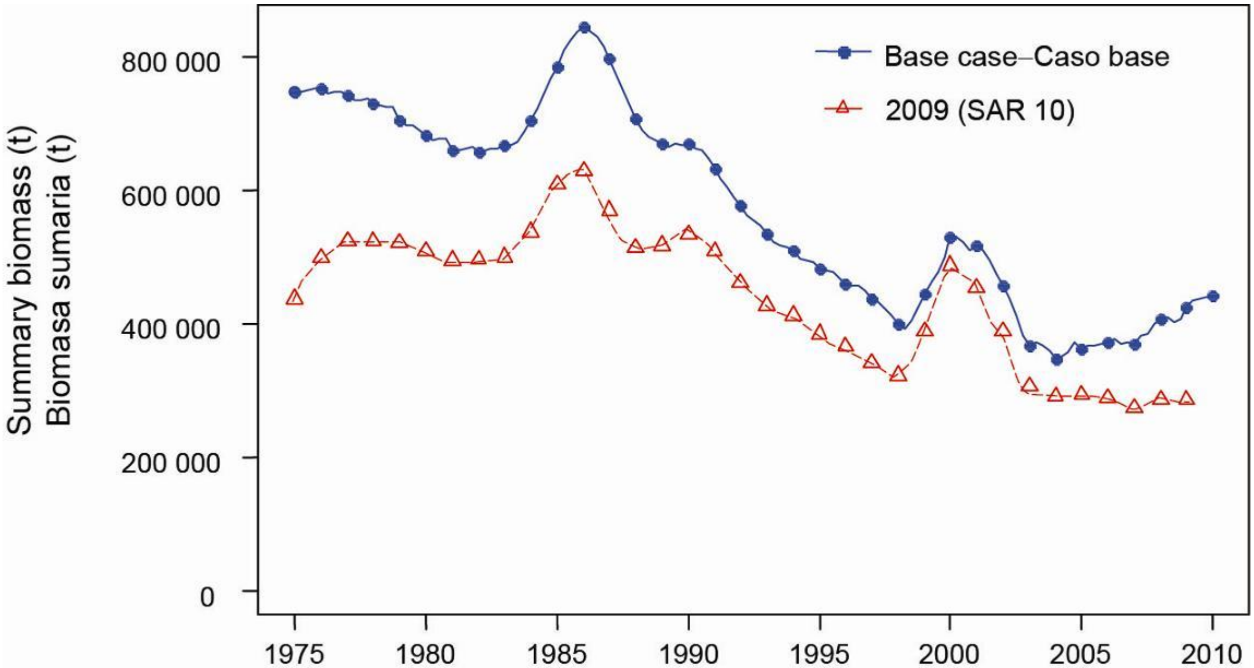

FIGURE 4.15. Comparison of estimates of the biomass of bigeye tuna 3+ quarters old (summary biomass)from the most recent assessment (2009) and the base case model of the current assessment. t = metric tons.

FIGURA 4.15. Comparación de las estimaciones de la biomasa de atún patudo de 3+ trimestres de edad (biomasa sumaria) de la evaluación más reciente (2009) y el modelo de caso base de la evaluación actual. t = toneladas métricas.

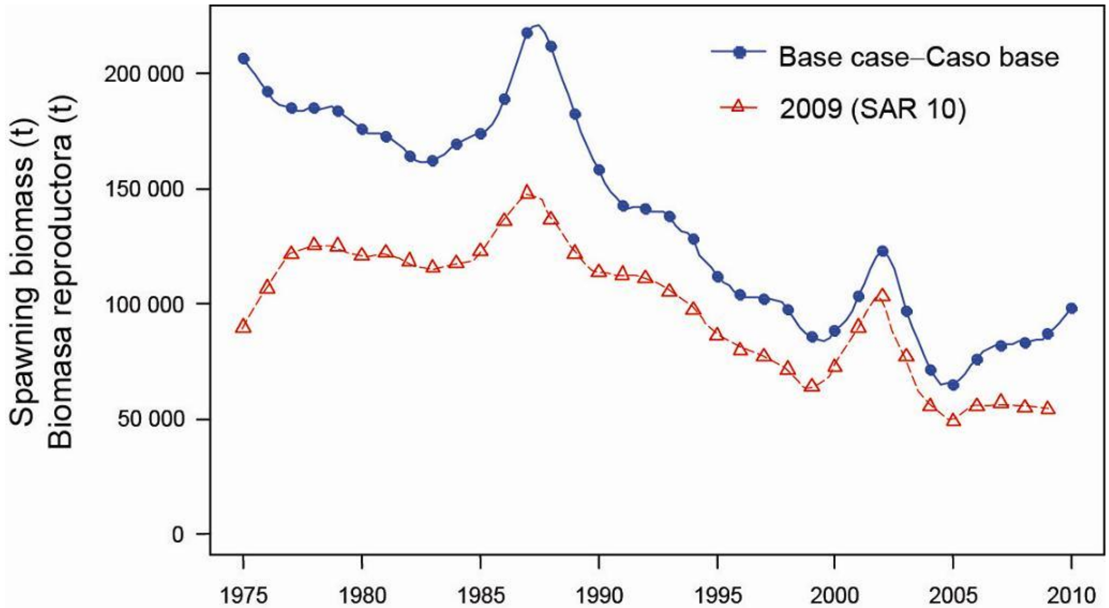

FIGURE 4.16. Comparison of estimates of the spawning biomass of bigeye tuna in the EPO from the most recent assessment (2009) and the base case model of the current assessment. t = metric tons.
FIGURA 4.16. Comparación de la biomasa reproductora estimada de atún patudo en el OPO de la evaluación más reciente (2008) y el modelo de caso base de la evaluación actual. t = toneladas métricas.

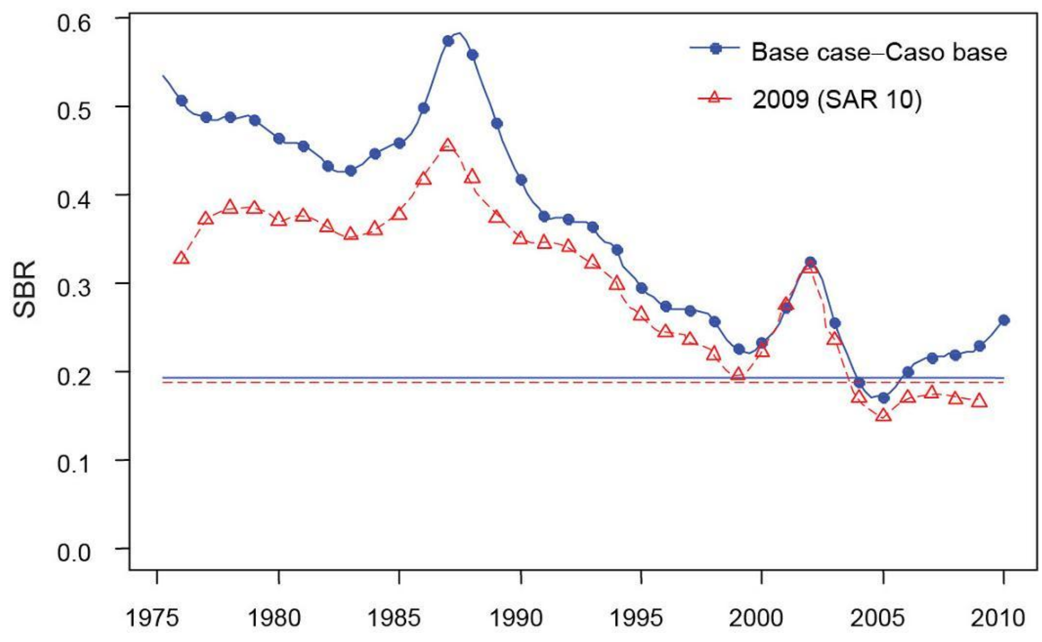

FIGURE 4.17. Comparison of estimated spawning biomass ratios (SBRs) for bigeye tuna in the EPO from the most recent assessment (2008) and the base case model of the current assessment, both using Stock Synthesis. The horizontal lines indicate the SBR at MSY.
FIGURA 4.17. Comparación del cociente de biomasa reproductora (SBR) estimado de atún patudo en el OPO de la evaluación más reciente (2008) y el modelo de caso base de la evaluación actual, ambos con *Stock Synthesis*. Las líneas horizontales indican el SBR en RMS.

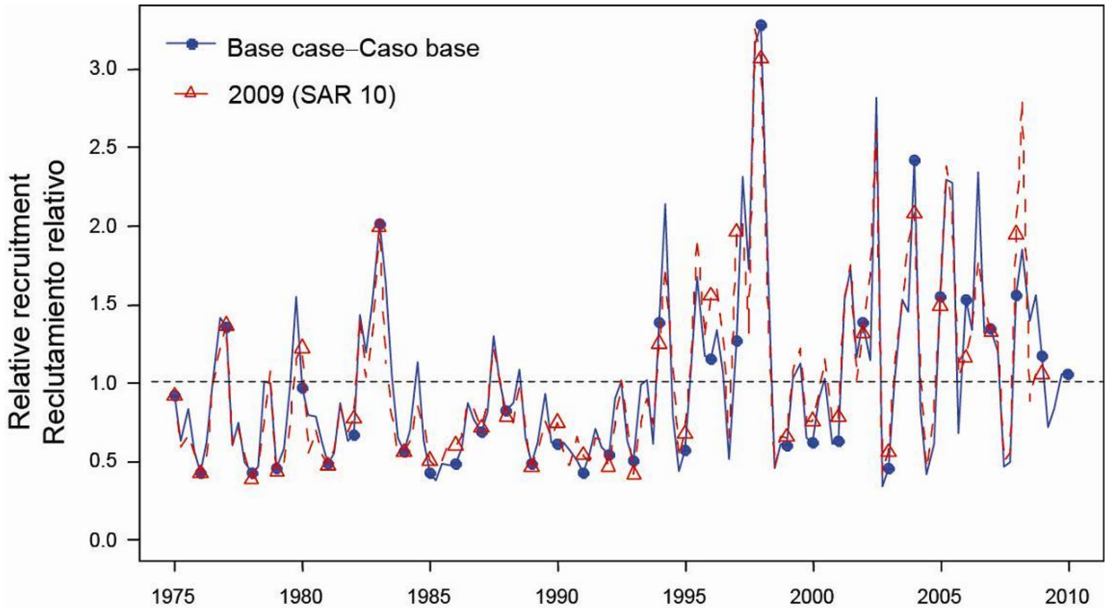

FIGURE 4.18a. Comparison of estimated recruitment of bigeye tuna in the EPO from the most recent assessment (2009) and the base case model of the current assessment, both using Stock Synthesis.
FIGURA 4.18. Comparación del reclutamiento estimado de atún patudo en el OPO de la evaluación más reciente (2009) y del modelo de caso base de la evaluación actual, ambos con *Stock Synthesis*.

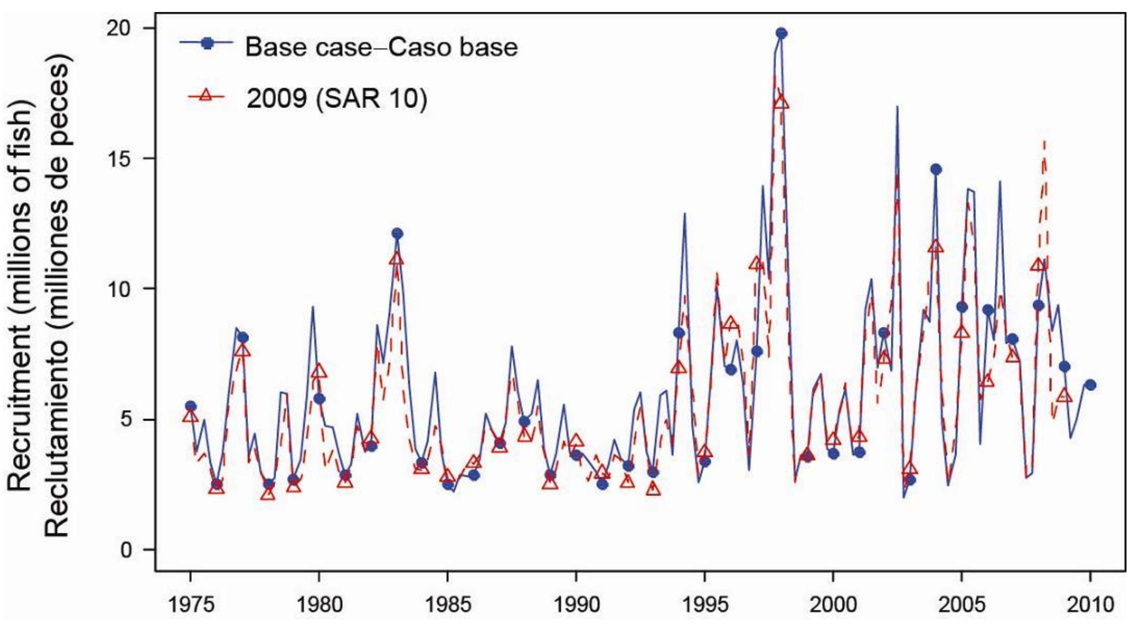

FIGURE 4.18b. Comparison of estimated relative recruitment of bigeye tuna in the EPO from the most recent assessment (2009) and the base case model of the current assessment, both using Stock Synthesis.
FIGURA 4.18b. Comparación del reclutamiento relativo estimado de atún patudo en el OPO de la evaluación más reciente (2008) y del modelo de caso base de la evaluación actual, ambos con *Stock Synthesis*.

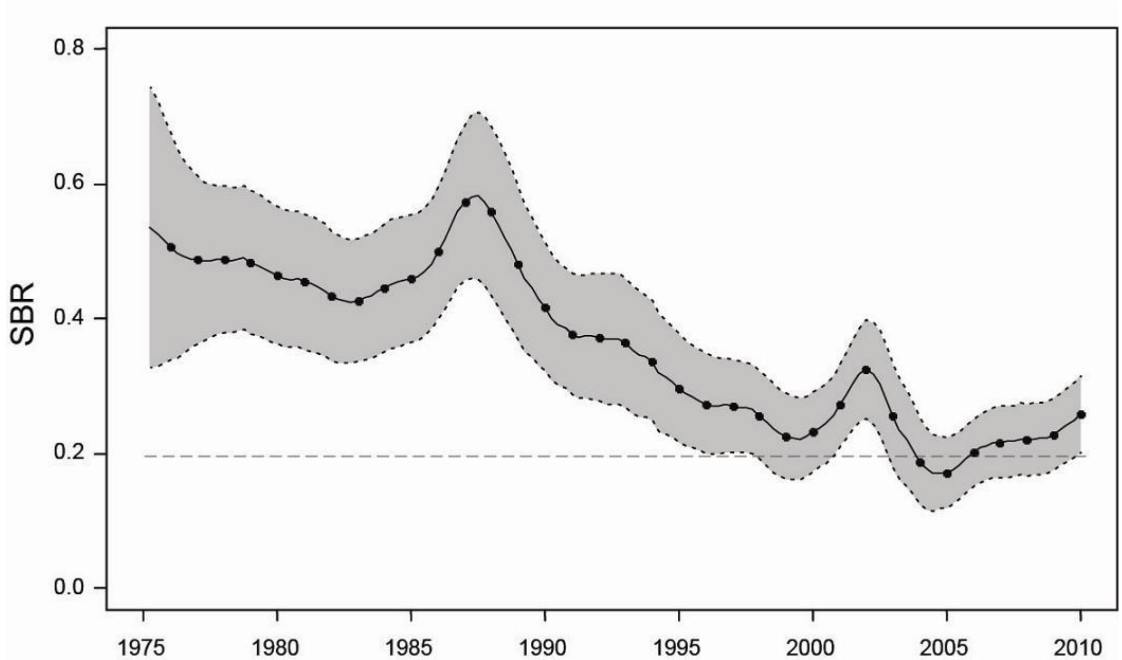

FIGURE 5.1. Estimated spawning biomass ratios (SBRs) for bigeye tuna in the EPO. The dashed horizontal line (at about 0.19) identifies the SBR at MSY. The solid line illustrates the maximum likelihood estimates, and the shaded area represents the confidence intervals (±2 standard deviations) around those estimates.

FIGURA 5.1. Cocientes de biomasa reproductora (SBR) estimados para el atún patudo en el OPO. La línea de trazos horizontal (en aproximadamente 0,19) identifica el SBR en RMS. La línea sólida ilustra las estimaciones de verosimilitud máxima, y el área sombreada representa los intervalos de confianza (±2 desviaciones estándar) alrededor de esas estimaciones.

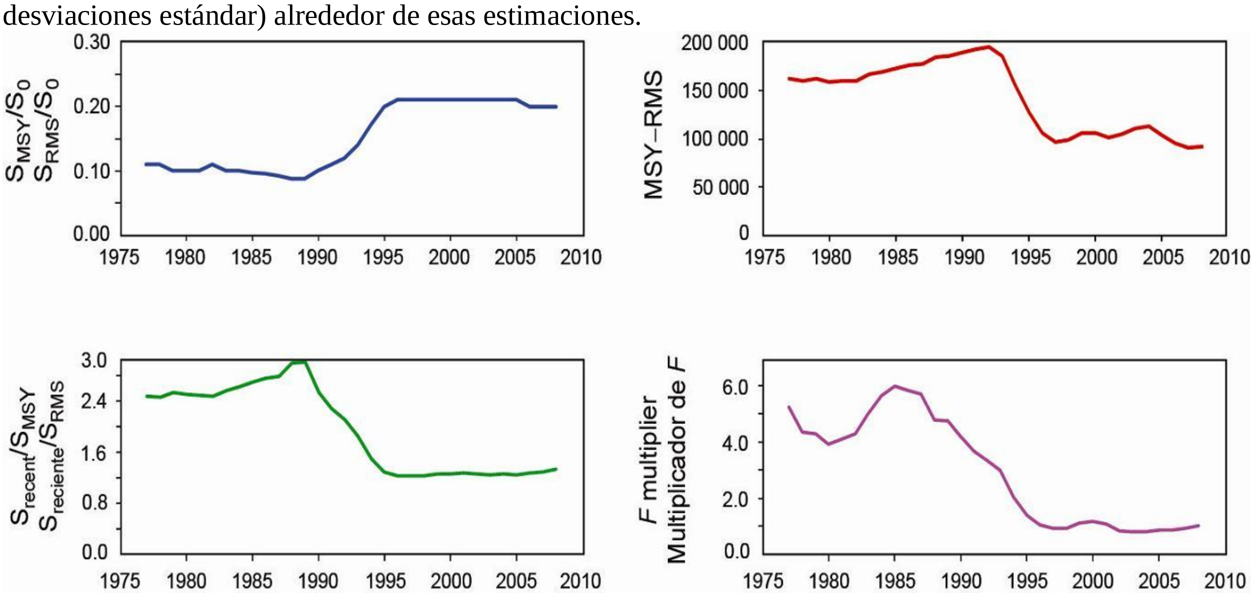

FIGURE 5.2. Estimates of MSY-related quantities calculated using the average age-specific fishing mortality for each year. (S_{recent} is the spawning biomass at the beginning of 2009.)

FIGURA 5.2. Estimaciones de cantidades relacionadas con el RMS calculadas usando la mortalidad por pesca por edad para cada año. ($S_{reciente}$ es la biomasa reproductora al principio de 2009.)

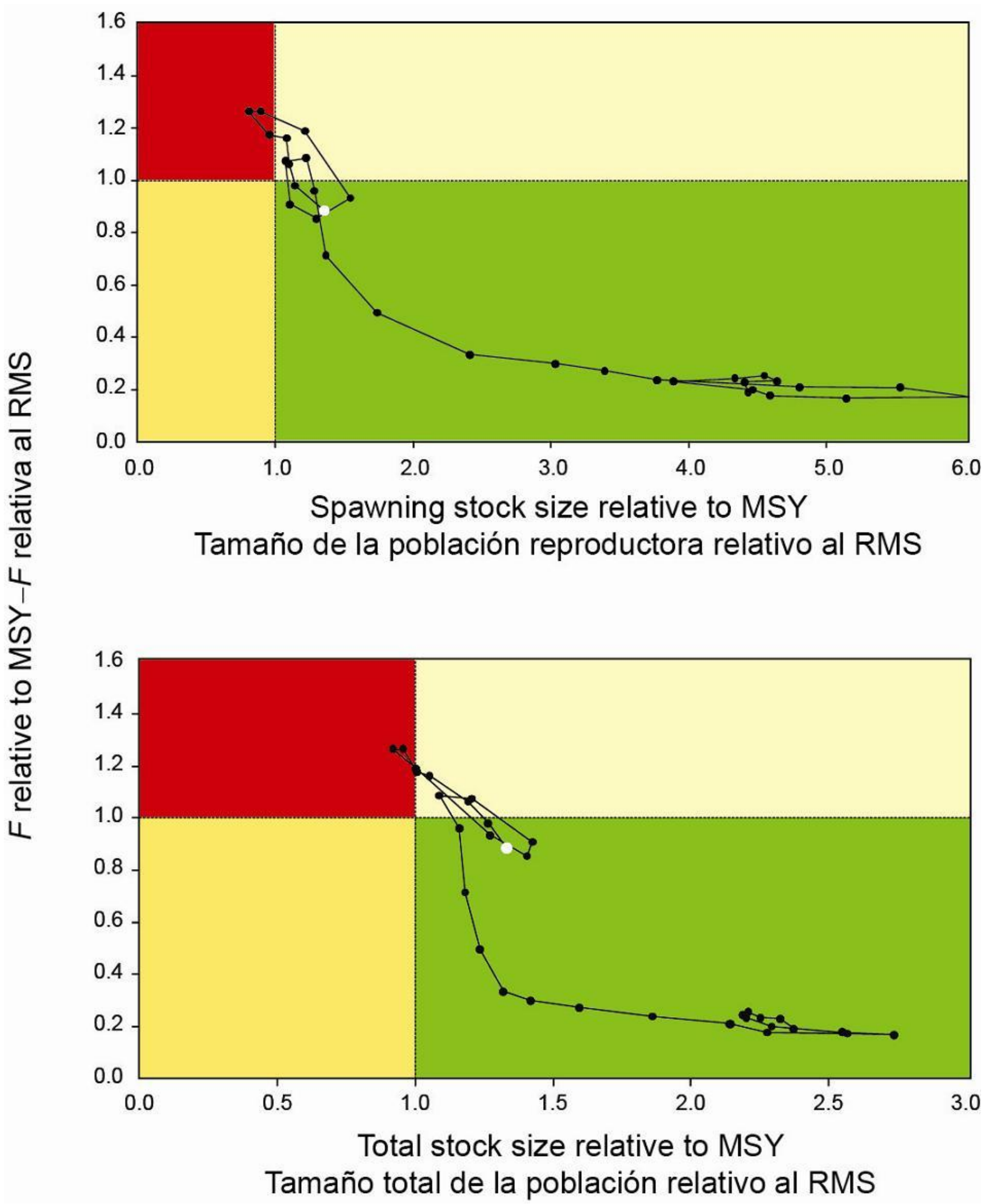

FIGURE 5.3a. Phase plot of the time series of estimates of stock size (top: spawning biomass; bottom: total biomass) and fishing mortality relative to their MSY reference points. Each dot is based on the average fishing mortality rate over three years; the large dot indicates the most recent estimate.

FIGURA 5.3a. Gráfica de fase de la serie de tiempo de las estimaciones del tamaño de la población (arriba: biomasa reproductora; abajo: biomasa total) y la mortalidad por pesca en relación con sus puntos de referencia de RMS. Cada punto se basa en la tasa de explotación media de un trienio; el punto grande indica la estimación más reciente.

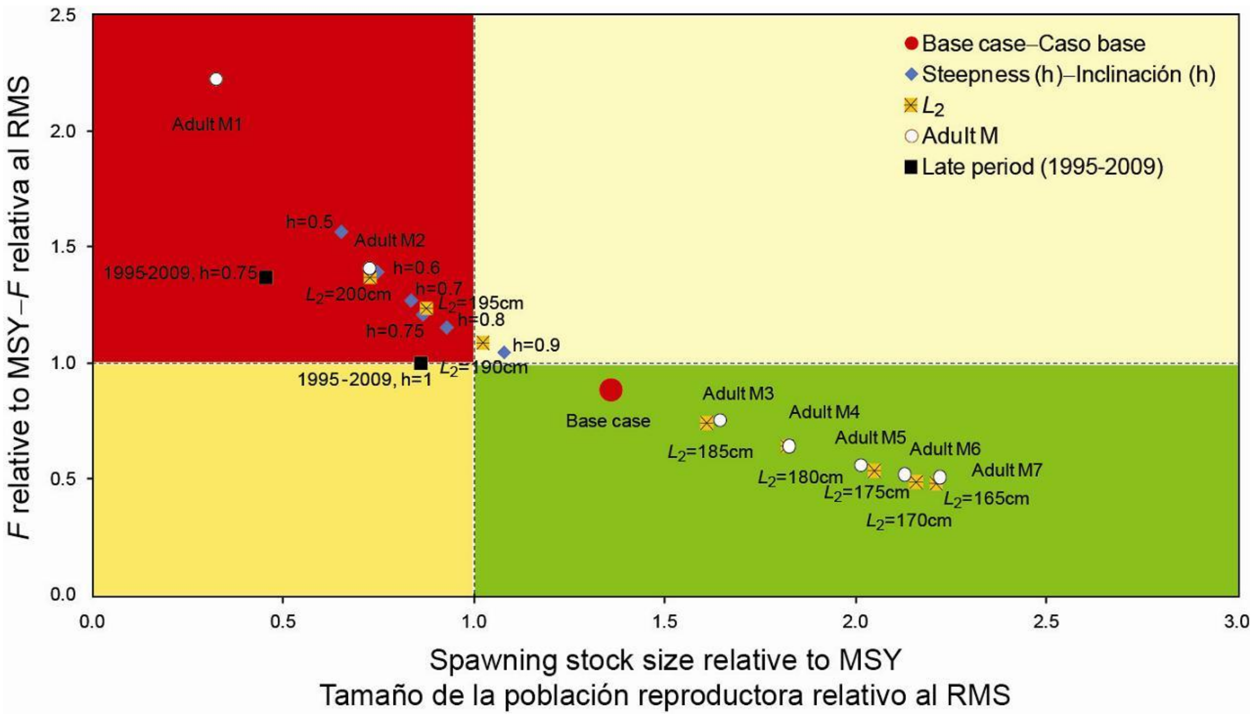

FIGURE 5.3b. Phase plot of the most recent estimate of spawning biomass stock size and fishing mortality relative to their MSY reference points. Each point is based on the average fishing mortality rate over the most recent three years.

FIGURA 5.3b. Gráfica de fase de la estimación más reciente del tamaño de la biomasa reproductora y la mortalidad por pesca en relación con sus puntos de referencia de RMS. Cada punto se basa en la tasa de explotación media de los tres años más recientes.

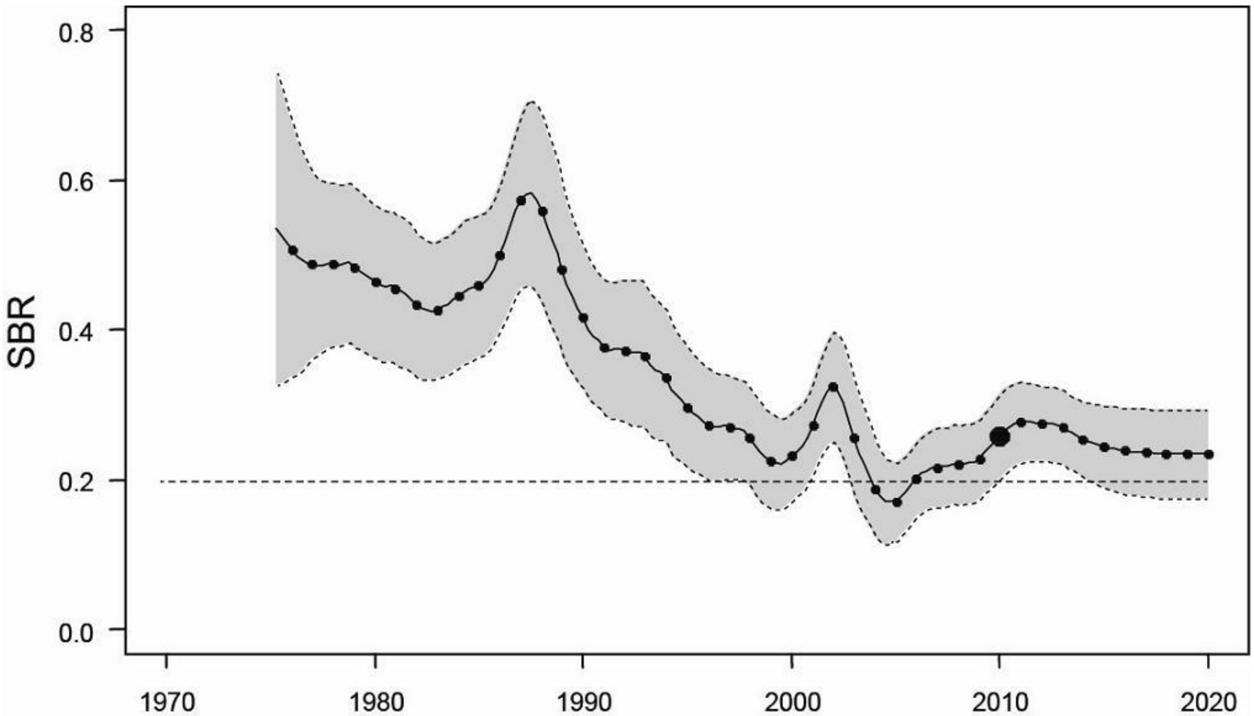

FIGURE 6.1a. Spawning biomass ratios (SBRs) of bigeye tuna in the EPO, including projections for 2011-2020 based on average fishing mortality rates during 2007-2009. The dashed horizontal line (at about 0.19) identifies the SBR at MSY. The solid line illustrates the maximum likelihood estimates, and the estimates after 2010 (the large dot) indicate the SBR predicted to occur if fishing mortality rates continue at the average of that observed during 2007-2009. The dashed lines are the 95-percent confidence intervals around these estimates.

FIGURA 6.1a. Cocientes de biomasa reproductora (SBR) del atún patudo en el OPO, incluyendo proyecciones para 2011-2020 basadas en las tasas medias de mortalidad por pesca durante 2007-2009. La línea sólida ilustra las estimaciones de verosimilitud máxima, y las estimaciones a partir de 2010 (el punto grande) señalan el SBR predicho si las tasas de mortalidad por pesca continúan en el promedio observado durante 2007-2007. Las líneas de trazos representan los intervalos de confianza de 95% alrededor de esas estimaciones.

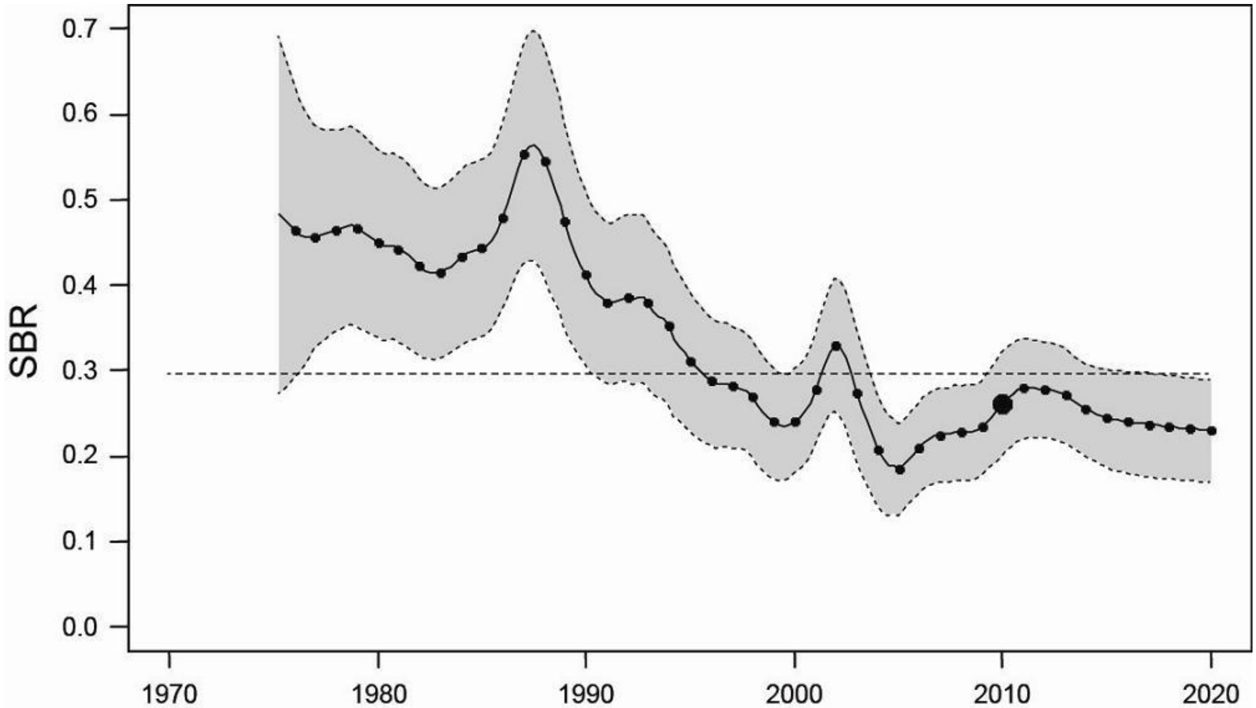

FIGURE 6.1b. Projected spawning biomass ratios (SBRs) of bigeye tuna in the EPO from the stock-recruitment sensitivity analysis. The dashed horizontal line (at about 0.30) identifies the SBR at MSY. The solid line illustrates the maximum likelihood estimates, and the estimates after 2010 (the large dot) indicate the SBR predicted to occur if fishing mortality rates continue at the average of that observed during 2007-2009. The dashed lines are the 95-percent confidence intervals around these estimates.

FIGURA 6.1b. Cocientes de biomasa reproductora (SBR) para el atún patudo en el OPO del análisis de sensibilidad de población-reclutamiento. La línea de trazos horizontal (en aproximadamente 0,30) identifica el SBR en RMS. La línea sólida ilustra las estimaciones de verosimilitud máxima, y las estimaciones a partir de 2010 (el punto grande) señalan el SBR predicho si las tasas de mortalidad por pesca continúa en el promedio observado durante 2007-2009. Las líneas de trazos representan los intervalos de confianza de 95% alrededor de esas estimaciones.

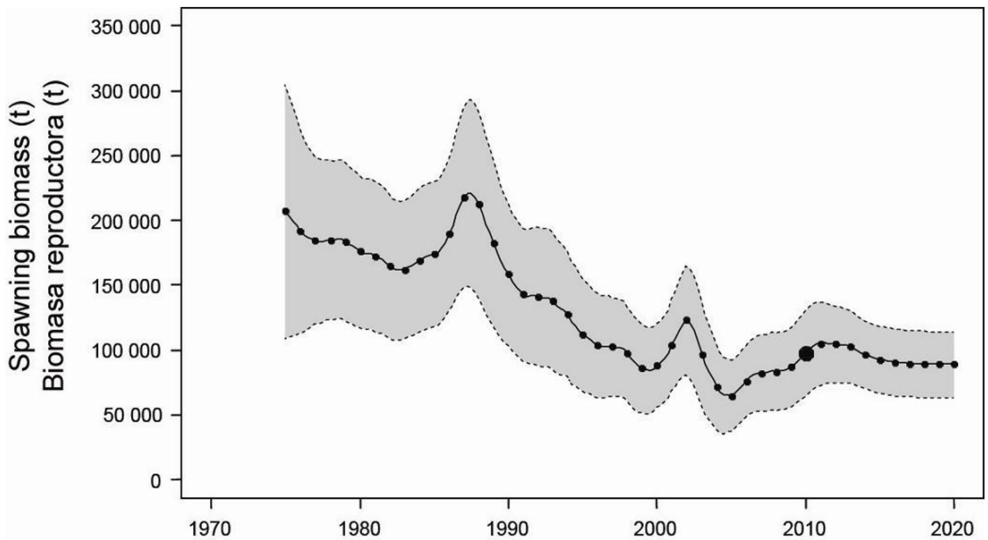

FIGURE 6.2. Spawning biomass of bigeye tuna, including projections for 2011-2020 based on average fishing mortality rates during 2007-2009. The solid line illustrates the maximum likelihood estimates, and the estimates after 2010 (the large dot) indicate the spawning biomass predicted to occur if fishing mortality rates continue at the average of that observed during 2007-2008. The areas between the dashed lines indicate the 95-percent confidence intervals. t = metric tons.

FIGURE 6.2. Biomasa reproductora de atún patudo, incluyendo proyecciones para 2011-2020 basadas en las tasas de mortalidad por pesca media durante 2007-2009. La línea sólida ilustra las estimaciones de verosimilitud máxima, y las estimaciones a partir de 2010 (el punto grande) señalan la biomasa reproductora predicha si las tasas de mortalidad por pesca continúan en el promedio observado durante 2007-2009. La zona sombreada entre las líneas de trazos representa los intervalos de confianza de 95%. t = toneladas métricas.

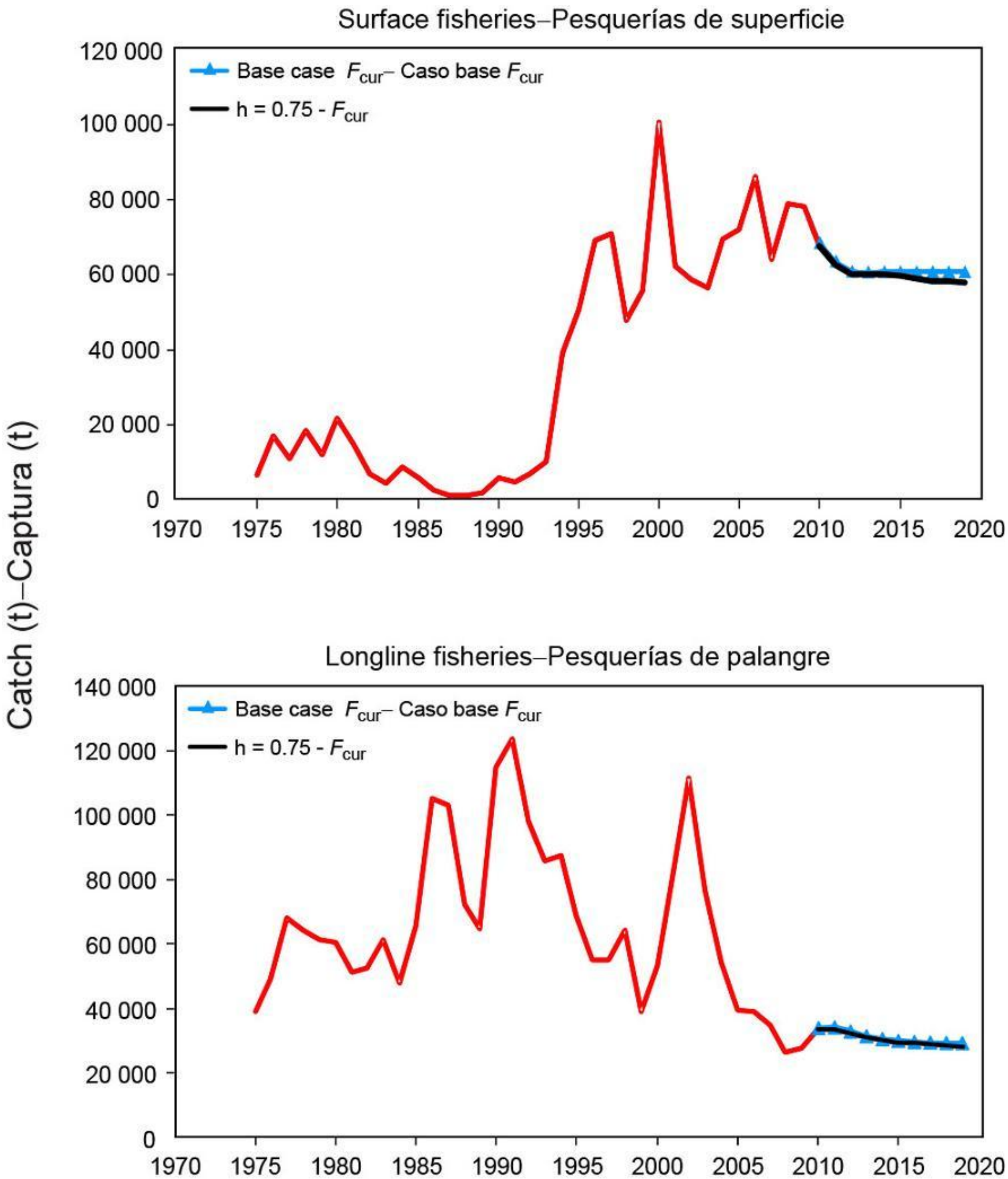

FIGURE 6.3a. Predicted annual catches of bigeye tuna during 2010-2020 for the surface (top panel) and longline (bottom panel) fisheries, based on fishing mortality rates during 2007-2009. Predicted catches are compared between the base case and the analysis in which a stock-recruitment relationship (h = 0.75) was used. t = metric tons.

FIGURA 6.3a. Capturas anuales predichas de atún patudo durante 2010-2020 en las pesquerías de superficie (recuadro superior) y de palangre (recuadro inferior), basadas en las tasas de mortalidad por pesca durante 2007-2009. Se comparan las capturas predichas entre el caso base y el análisis en el que se usa una relación población-reclutamiento (h = 0.75). t = toneladas métricas.

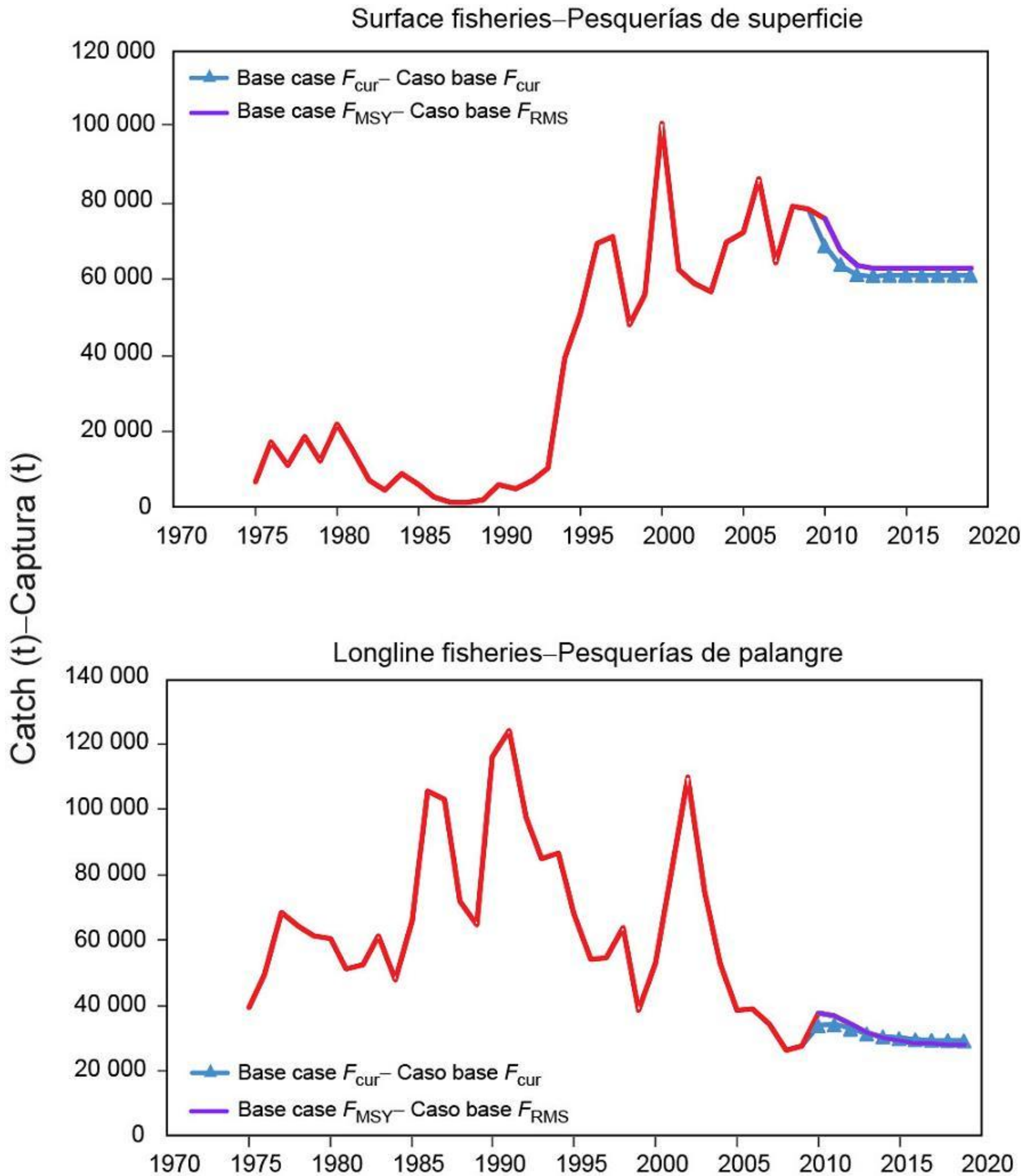

FIGURE 6.3b. Predicted annual catches of bigeye tuna during 2010-2020 for the surface (top panel) and longline (bottom panel) fisheries, based on fishing mortality rates during 2007-2009. Predicted catches are compared between the base case (F_{cur}) and the analysis assuming F_{MSY} (upper panels. t = metric tons).
FIGURA 6.3b. Capturas anuales predichas de atún patudo durante 2010-2020 en las pesquerías de superficie (recuadro superior) y de palangre (recuadro inferior), basadas en las tasas de mortalidad por pesca durante 2007-2009. Se comparan las capturas predichas entre el caso base (F_{cur}) y el análisis que supone F_{MSY}. t = toneladas métricas.

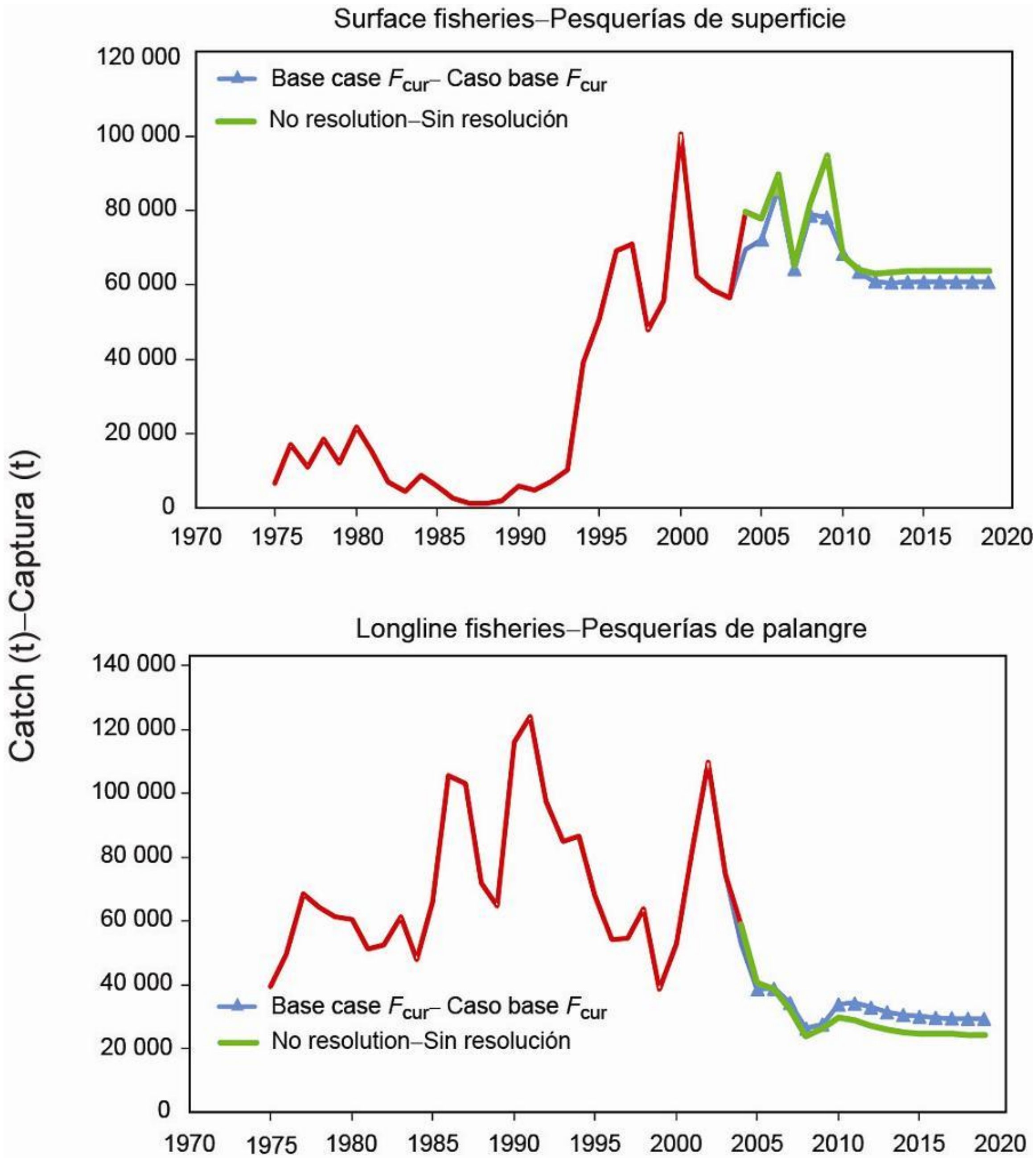

FIGURE 6.3c. Predicted quarterly catches of bigeye tuna during 2004-2020 for the surface (top panel) and longline (bottom panel) fisheries, based on fishing mortality rates that assume that no conservation resolution is in force during that period. Predicted catches are compared between the base case (F_{cur}) and the analysis assuming fishing with no conservation resolution in force (upper panels. t = metric tons).

FIGURA 6.3c. Capturas trimestrales predichas de atún patudo durante 2004-2020 en las pesquerías de superficie (recuadro superior) y de palangre (recuadro inferior), basadas en tasas de mortalidad que suponen que no hay una resolución de conservación en vigor durante ese período. Se comparan las capturas predichas entre el caso base (F_{cur}) y el análisis que supone pesca sin resolución de conservación en vigor. t = toneladas métricas.

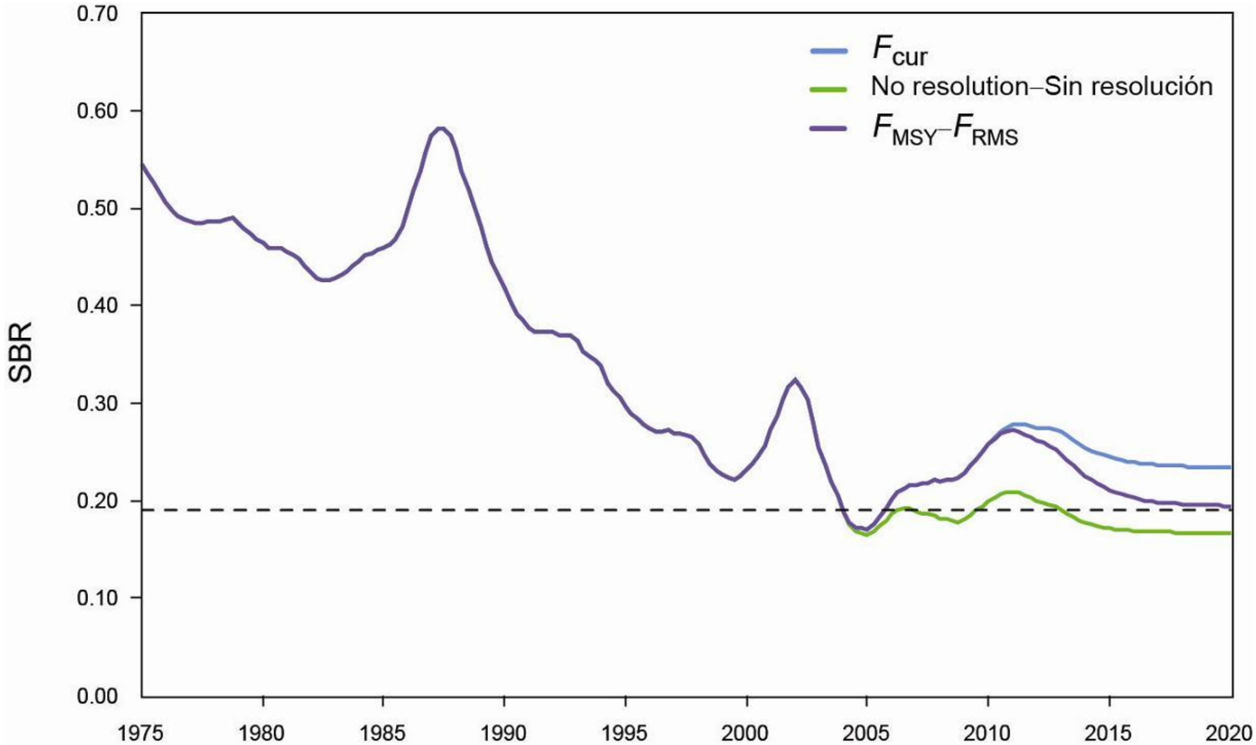

FIGURE 6.4. Projected spawning biomass ratio (SBR) from the base case model assuming a harvesting strategy targeting current fishing mortality rates (status quo), the fishing mortality rate corresponding to MSY (F_{MSY}), and the fishing mortality corresponding to a no conservation resolution scenario.

FIGURA 6.4. Cociente de biomasa reproductora (SBR) proyectado por el modelo de caso base, suponiendo una estrategia de captura que apunta a las tasas actuales de mortalidad por pesca (estatu quo) la mortalidad por pesca correspondiente al RMS (F_{RMS}), y la mortalidad por pesca correspondiente a una situacion sin resolución de conservación.

TABLE 2.1. Fisheries defined for the stock assessment of bigeye 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 dolphins. The sampling areas are shown in Figure 2.1, and the discards are described in Section 2.2.1.

TABLA 2.1. Pesquerías definidas para la evaluación de la población de atún patudo en el OPO. PS = red de cerco; LP = caña; LL = palangre; OBJ = lances sobre objetos flotantes; NOA = lances sobre atunes no asociados; DEL = lances sobre delfines. En la Figura 2.1 se ilustran las zonas de muestreo, y en la Sección 2.2.1 se describen los descartes.

Fishery	Gear	Set type	Years	Sampling areas	Catch data
Pesquería	**Arte**	**Tipo de lance**	**Años**	**Zonas de muestreo**	**Datos de captura**
1	PS	OBJ	1975-1992	1-13	retained catch only–captura retenida solamente
2	PS	OBJ	1993-2008	11-12	retained catch + discards from inefficiencies in fishing process–
3	PS	OBJ	1993-2008	7, 9	captura retenida + descartes de ineficacias en el proceso de pesca
4	PS	OBJ	1993-2008	5-6, 13	
5	PS	OBJ	1993-2008	1-4, 8, 10	
6	PS LP	NOA DEL	1975-1989	1-13	retained catch only–captura retenida solamente
7	PS LP	NOA DEL	1990-2008	1-13	retained catch + discards from inefficiencies in fishing process– captura retenida + descartes de ineficacias en el proceso de pesca
8	PS	OBJ	1993-2008	11-12	discards of small fish from size-sorting the catch by Fishery 2 – descartes de peces pequeños de clasificación por tamaño en la Pesquería 2
9	PS	OBJ	1993-2008	7, 9	discards of small fish from size-sorting the catch by Fishery 3 – descartes de peces pequeños de clasificación por tamaño en la Pesquería 3
10	PS	OBJ	1993-2008	5-6, 13	discards of small fish from size-sorting the catch by Fishery 4 – descartes de peces pequeños de clasificación por tamaño en la Pesquería 4
11	PS	OBJ	1993-2008	1-4, 8, 10	discards of small fish from size-sorting the catch by Fishery 5 – descartes de peces pequeños de clasificación por tamaño en la Pesquería 5
12	LL	-	1975-1989	N of–de 10°N	retained catch only (in numbers)–captura retenida solamente (en número)
13	LL	-	1990-2009	N of–de 10°N	
14	LL	-	1975-1989	N of–de 0° and S of–de 10°N	retained catch only (in numbers)–captura retenida solamente (en número)
15	LL	-	1990-2009	N of–de 0° and S of–de 10°N	
16	LL	-	1975-1989	S of–de 0° and W of–de 100°W	retained catch only (in numbers)–captura retenida solamente (en número)
17	LL	-	1990-2009	S of–de 0° and W of–de 100°W	
18	LL	-	1975-1989	S of–de 0° and E of–de 100°W	retained catch only (in numbers)–captura retenida solamente (en número)
19	LL	-	1990-2009	S of–de 0° and E of–de 100°W	
20	LL	-	1990-2009	N of–de 10°N	retained catch only (in weight) –captura retenida solamente (en peso)
21	LL	-	1990-2009	N of–de 0° and S of–de 10°N	retained catch only (in weight) –captura retenida solamente (en peso)
22	LL	-	1990-2009	S of–de 0° and W of–de 100°W	retained catch only (in weight) –captura retenida solamente (en peso)
23	LL	-	1990-2009	S of–de 0° and E of–de 100°W	retained catch only (in weight) –captura retenida solamente (en peso)

TABLE 3.1. Age-specific maturity schedule (proportion of mature female fish) used to define the spawning biomass.
TABLA 3.1. Relación de madurez por edad (proporción de peces hembra maduros) usada para definir la biomasa reproductora.

Age (quarters)	Proportion mature	Age (quarters)	Proportion mature
Edad (trimestres)	**Proporción madura**	**Edad (trimestres)**	**Proporción madura**
1	0.00	21	0.96
2	0.00	22	0.98
3	0.00	23	0.98
4	0.00	24	0.99
5	0.00	25	0.99
6	0.01	26	1.00
7	0.01	27	1.00
8	0.02	28	1.00
9	0.04	29	1.00
10	0.06	30	1.00
11	0.10	31	1.00
12	0.16	32	1.00
13	0.23	33	1.00
14	0.33	34	1.00
15	0.45	35	1.00
16	0.59	36	1.00
17	0.71	37	1.00
18	0.82	38	1.00
19	0.89	39	1.00
20	0.93	40	1.00

TABLE 4.1. Estimated total annual recruitment (thousands of age-0 quarters fish), summary biomass (fish of age 3+ quarters), spawning biomass (metric tons), and spawning biomass ratio (SBR) of bigeye tuna in the EPO.
TABLA 4.1. Reclutamiento anual total estimado (miles de peces de edad 0), biomasa sumaria (peces de edad 3+ trimestres), biomasa reproductora (toneladas métricas), y cociente de biomasa reproductora (SBR) de atún patudo en el OPO.

Year	Total recruitment Reclutamiento total	Summary biomass Biomasa sumaria	Spawning biomass Biomasa reproductora	SBR SBR
1975	17,661	748,366	206,952	0.55
1976	20,753	753,950	192,262	0.51
1977	19,135	743,472	184,917	0.49
1978	17,332	730,237	184,931	0.49
1979	21,388	706,298	183,757	0.48
1980	18,938	682,809	176,075	0.46
1981	15,149	659,718	172,592	0.46
1982	28,807	657,584	164,442	0.43
1983	32,152	666,978	162,279	0.43
1984	18,112	704,652	169,450	0.45
1985	10,486	786,252	174,177	0.46
1986	16,116	844,767	189,316	0.50
1987	22,882	797,413	217,823	0.57
1988	20,524	708,965	212,174	0.56
1989	15,864	669,483	182,733	0.48
1990	13,745	669,529	158,621	0.42
1991	13,485	632,389	142,975	0.38
1992	18,446	577,253	141,514	0.37
1993	18,669	535,622	138,071	0.36
1994	28,587	510,423	128,099	0.34
1995	27,119	483,170	112,175	0.30
1996	24,464	461,337	103,897	0.27
1997	51,006	439,044	102,307	0.27
1998	35,920	400,426	97,597	0.26
1999	20,386	446,005	85,766	0.23
2000	18,865	529,542	88,211	0.23
2001	30,320	517,867	103,549	0.27
2002	34,175	458,973	123,118	0.32
2003	26,772	367,753	96,814	0.26
2004	25,700	347,245	71,372	0.19
2005	40,954	362,062	64,611	0.17
2006	39,205	372,358	76,264	0.20
2007	20,972	370,403	82,165	0.22
2008	38,298	408,325	83,499	0.22
2009	22,629	424,853	86,839	0.23
2010	-	442,693	98,024	0.26

TABLE 4.2. Estimates of the average sizes and weights of bigeye tuna derived from the base case model. The ages are quarters after hatching.

TABLA 4.2. Estimaciones del tamaño y peso promedio del atún patudo derivados del modelo de caso base. Se expresa la edad 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)**
1	32.1	0.3	21	166.4	102.5
2	39.2	1.1	22	169.0	107.3
3	46.9	2.5	23	171.4	111.6
4	55.1	4.5	24	173.4	115.5
5	63.8	7.3	25	175.2	118.9
6	72.7	10.6	26	176.7	122.0
7	81.6	14.5	27	178.1	124.8
8	90.5	18.9	28	179.3	127.2
9	99.2	23.6	29	180.3	129.3
10	107.5	28.8	30	181.2	131.2
11	115.4	34.1	31	182.0	132.8
12	122.8	39.7	32	182.6	134.2
13	129.8	45.4	33	183.2	135.5
14	136.1	51.2	34	183.7	136.6
15	141.9	57.0	35	184.2	137.5
16	147.2	62.8	36	184.5	138.3
17	152.0	68.6	37	184.9	139.1
18	156.2	74.2	38	185.1	139.7
19	160.0	79.7	39	185.4	140.2
20	163.4	85.1	40	185.6	140.7

TABLE 4.3. Likelihood components obtained for the base case and the sensitivity analyses.
TABLA 4.3. Componentes de verosimilitud obtenidos para el caso base y los análisis de sensibilidad.

Data Datos	Base case Caso base	h = 0.75	L_2		Adult *M* – *M* adultos	
			170 cm	200 cm	Sens *M*1	Sens *M*5
CPUE						
2	-31.13	-30.72	-29.14	-32.93	-33.11	-29.69
3	-7.18	-7.08	-6.55	-7.58	-7.92	-7.15
5	-3.94	-3.56	-3.01	-4.39	-5.12	-2.99
12	-30.92	-30.90	-30.35	-31.25	-30.30	-31.20
13	-24.60	-24.50	-24.45	-26.41	-24.69	-27.51
14	-66.20	-66.04	-66.11	-65.91	-66.71	-66.01
15	-79.23	-80.20	-81.63	-74.68	-74.25	-79.35
16	-95.15	-94.83	-93.82	-95.68	-94.02	-96.24
17	-113.82	-113.85	-113.85	-112.50	-110.26	-116.12
18	-41.41	-41.42	-41.39	-41.57	-43.15	-40.38
19	-28.19	-28.41	-29.39	-26.70	-26.02	-29.05
Total	**-521.76**	**-521.53**	**-519.69**	**-519.59**	**-515.55**	**-525.70**
Size compositions – Composición por talla						
1	164.11	164.09	164.41	164.54	164.84	163.52
2	226.15	226.61	222.73	229.93	222.99	228.20
3	313.81	312.33	313.29	317.77	317.74	313.11
4	79.07	78.57	78.05	80.84	80.36	78.21
5	167.13	167.68	165.95	168.66	162.82	168.15
6	127.41	127.77	127.45	127.67	127.08	127.99
7	134.37	132.80	128.88	142.34	134.44	132.57
12	33.61	33.62	34.16	33.08	33.28	33.93
13	54.29	53.86	54.39	54.84	54.64	66.70
14	32.43	32.53	33.07	32.55	32.50	32.38
15	49.34	51.00	39.60	49.99	49.53	41.97
16	39.13	38.92	36.89	41.61	40.05	38.86
17	129.94	133.10	86.94	142.58	132.29	110.14
18	54.21	54.17	54.29	54.98	54.86	53.75
19	59.69	59.64	60.30	60.48	59.93	60.31
Total	**1664.68**	**1666.68**	**1600.38**	**1701.87**	**1667.34**	**1649.78**
Age at length Talla por edad	278.34	279.71	291.63	270.48	278.55	276.61
Recruitment Reclutamiento	-28.01	-25.80	-31.42	-19.66	8.77	-33.84
Total	**1393.25**	**1399.06**	**1340.90**	**1433.10**	**1439.12**	**1366.85**

TABLE 5.1. Estimates of the MSY and its associated quantities for bigeye tuna for the base case assessment and the sensitivity analyses. All analyses are based on average fishing mortality during 2007-2009. B_{recent} and B_{MSY} are defined as the biomass of fish 3+ quarters old (in metric tons) at the beginning of 2010 and at MSY, respectively. S_{recent} and S_{MSY} are in metric tons. C_{recent} is the estimated total catch in 2009. The F multiplier indicates how many times effort would have to be effectively increased to achieve the MSY in relation to the average fishing mortality during 2007-2009.

TABLA 5.1. Estimaciones del RMS y sus cantidades asociadas para el atún patudo para la evaluación del caso base y los análisis de sensibilidad. Todos los análisis se basan en la mortalidad por pesca promedio de 2007-2009. Se definen B_{recent} y B_{RMS} como la biomasa de peces de 3+ trimestres de edad (en toneladas métricas) al principio de 2010 y en RMS, respectivamente. Se expresan S_{recent} y S_{MSY} en toneladas métricas. C_{recent} es la captura total estimada en 2009. El multiplicador de F indica cuántas veces se tendría que incrementar el esfuerzo para lograr el RMS en relación con la mortalidad por pesca media durante 2007-2009.

		Appendix-Anexo						
		A	**B**		**C**		**D**	
	Base case-Caso base	**h = 0.75**	***L*$_2$**		**Adult *M*-*M* adulto**		**Data-Datos 1995-2009**	
			170 cm	**200 cm**	**Sens *M*1**	**Sens *M*5**	**h=1**	**h=0.75**
MSY-RMS	90,538	86,321	114,492	86,001	88,294	113,917	115,781	141,283
B_{MSY}- B_{RMS}	332,331	582,233	428,532	306,662	516,205	375,778	418,608	928,017
S_{MSY}- S_{RMS}	73,690	145,123	94,287	67,789	145,753	75,696	92,177	230,675
B_{MSY}/B_0- B_{RMS}/B_0	0.25	0.34	0.24	0.27	0.27	0.25	0.25	0.34
S_{MSY}/S_0- S_{RMS}/S_0	0.19	0.30	0.19	0.21	0.26	0.19	0.20	0.30
C_{recent}/MSY- C_{recent}/RMS	1.17	1.23	0.91	1.24	1.21	0.92	0.92	0.75
B_{recent}/B_{MSY}- B_{recent}/B_{RMS}	1.33	0.95	1.93	0.85	0.42	1.86	0.91	0.51
S_{recent}/S_{MSY}- S_{recent}/S_{RMS}	1.33	0.88	2.06	0.74	0.33	2.02	0.87	0.46
F multiplier-Multiplicador de F	1.13	0.83	1.87	0.73	0.45	1.79	1.00	0.73

TABLE 5.2. Estimates of the MSY and its associated quantities for bigeye tuna, obtained by assuming that there is no stock-recruitment relationship (base case), that each fishery maintains its current pattern of age-specific selectivity (Figure 4.5), and that each fishery is the only one operating in the EPO. The estimates of the MSY and B_{MSY} are in metric tons. The F multiplier indicates how many times effort would have to be effectively increased to achieve the MSY in relation to the average fishing mortality during 2007-2009. An analysis of the sensitivity of the management quantities estimates to using the average fishing mortality rates for 2007-2008 is also presented. "only" means that only that gear is used and the fishing mortality for the other gears is set to zero.

TABLA 5.2. Estimaciones del RMS y sus cantidades asociadas para el atún patudo, obtenidas suponiendo que no existe una relación población-reclutamiento (caso base), que cada pesquería mantiene su patrón actual de selectividad por edad (Figura 4.5), y que cada pesquería es la única que opera en el OPO. Se expresan las estimaciones del RMS y B_{RMS} en toneladas métricas. El multiplicador de F indica cuántas veces el esfuerzo necesitaría ser incrementado efectivamente para obtener el RMS en relación con la mortalidad por pesca promedio durante 2007-2009. Se presenta también un análisis de sensibilidad a las estimaciones de las cantidades de ordenación al uso de las tasas medias de mortalidad de pesca durante 2006-2007 "solamente" significa que se usa solamente ese arte, y se fija la mortalidad por pesca de las otras artes en cero.

	Base case Caso base	**Purse-seine only Cerco solamente**	**Longline only Palangre solamente**	**2007-2008**
MSY-RMS	90,538	67,928	208,887	93,412
B_{MSY}- B_{RMS}	332,331	266,626	371,166	335,584
S_{MSY}- S_{RMS}	73,690	62,008	40,302	73,661
B_{MSY}/B_0- B_{RMS}/B_0	0.25	0.20	0.28	0.25
S_{MSY}/S_0- S_{RMS}/S_0	0.19	0.16	0.11	0.19
C_{recent}/MSY- C_{recent}/RMS	1.17	1.56	0.51	1.13
B_{recent}/B_{MSY}- B_{recent}/B_{RMS}	1.33	1.66	1.19	1.32
S_{recent}/S_{MSY}-S_{recent}/S_{RMS}	1.33	1.58	2.43	1.33
F multiplier- Multiplicador de F	1.13	1.60	9.56	1.14

APPENDIX A: SENSITIVITY ANALYSIS FOR STEEPNESS
ANEXO A: ANÁLISIS DE SENSIBILIDAD A LA INCLINACIÓN

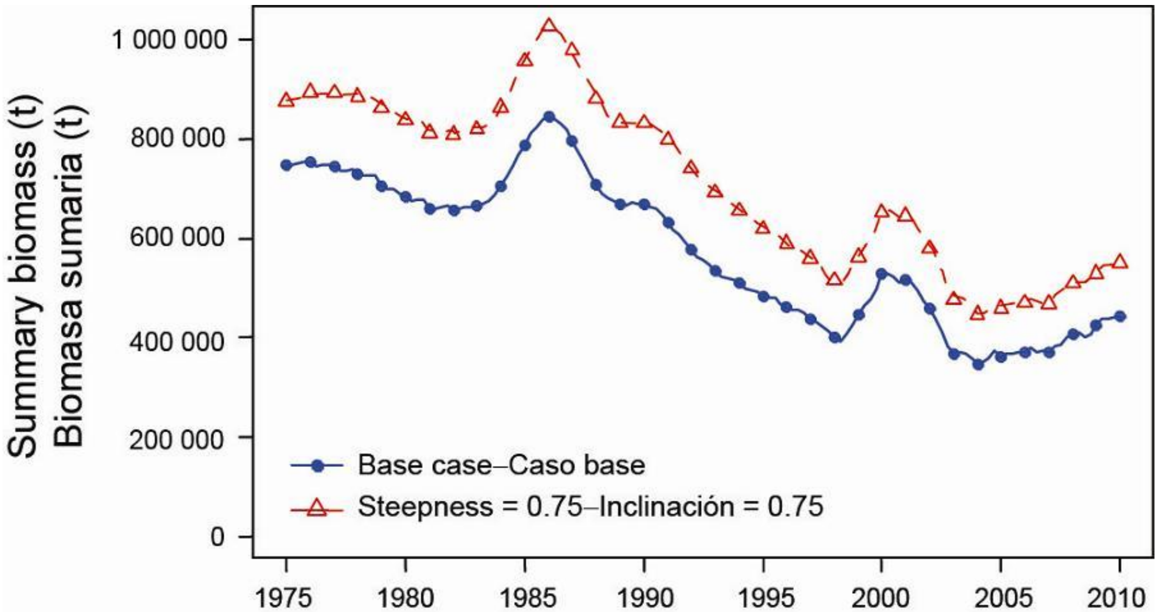

FIGURE A.1. Comparison of estimates of biomass of bigeye tuna 3+ quarters old (summary biomass) from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). t = metric tons.

FIGURA A.1. Comparación de las estimaciones de la biomasa de atún patudo de 3+ trimestres de edad (biomasa sumaria) del análisis sin una relación población-reclutamiento (caso base) y con dicha relación (inclinación = 0.75). t = toneladas métricas.

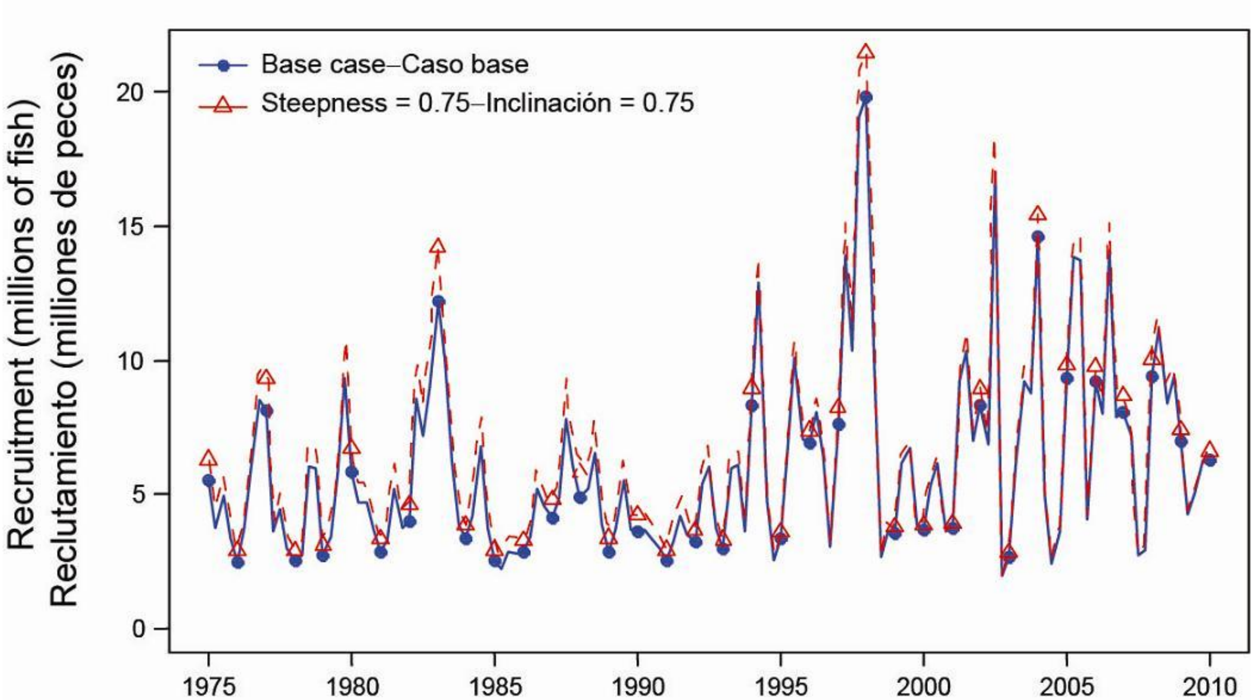

FIGURE A.2a. Comparison of estimates of absolute recruitment for bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).

FIGURA A.2a. Comparación de las estimaciones de reclutamiento absoluto de atún patudo del análisis sin una relación población-reclutamiento (caso base) y con dicha relación (inclinación = 0.75).

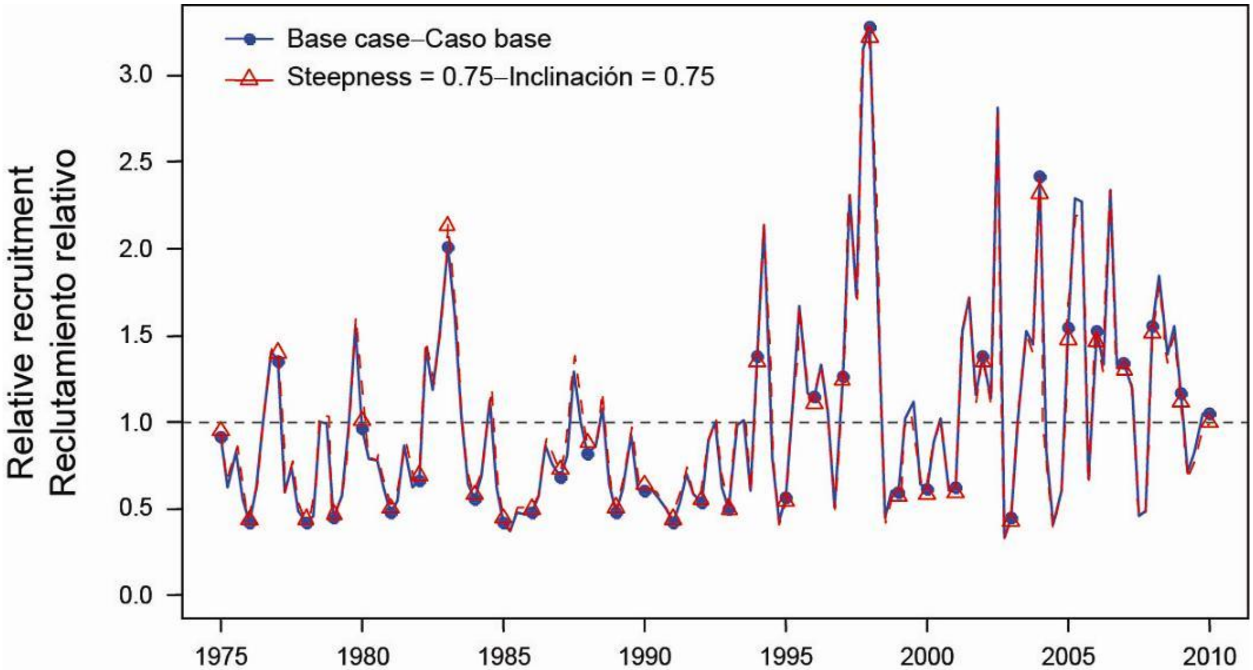

FIGURE A.2b. Comparison of estimates of relative recruitment for bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). The estimates are scaled so that the estimate of average recruitment is equal to 1.0 (dashed horizontal line).

FIGURA A.2b. Comparación de las estimaciones de reclutamiento relativo de atún patudo del análisis sin una relación población-reclutamiento (caso base) y con dicha relación (inclinación = 0.75). Se escalan las estimaciones para que la estimación de reclutamiento medio equivalga a 1,0 (línea de trazos horizontal).

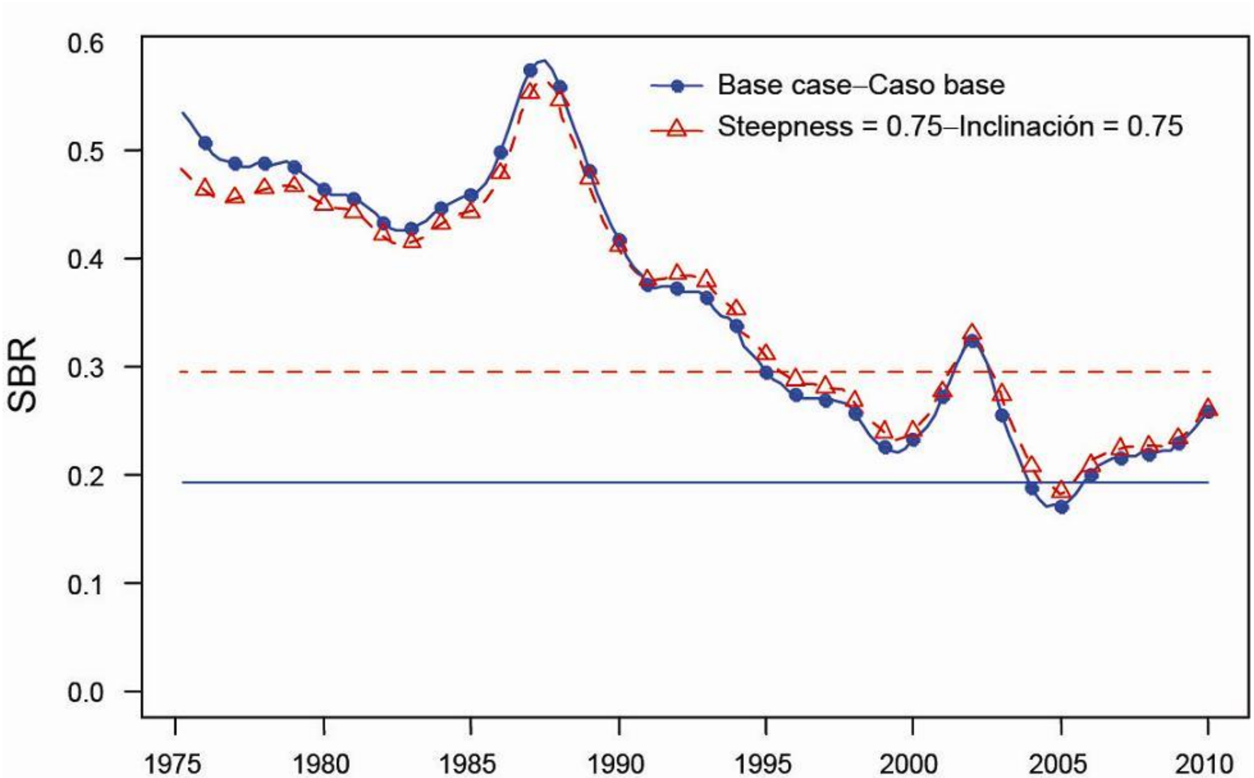

FIGURE A.3. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). The horizontal lines represent the SBRs associated with MSY under the two scenarios.
FIGURA A.3. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún patudo del análisis sin una relación población-reclutamiento (caso base) y con dicha relación (inclinación = 0.75). Las líneas horizontales representan los SBR asociados con el RMS en los dos escenarios.

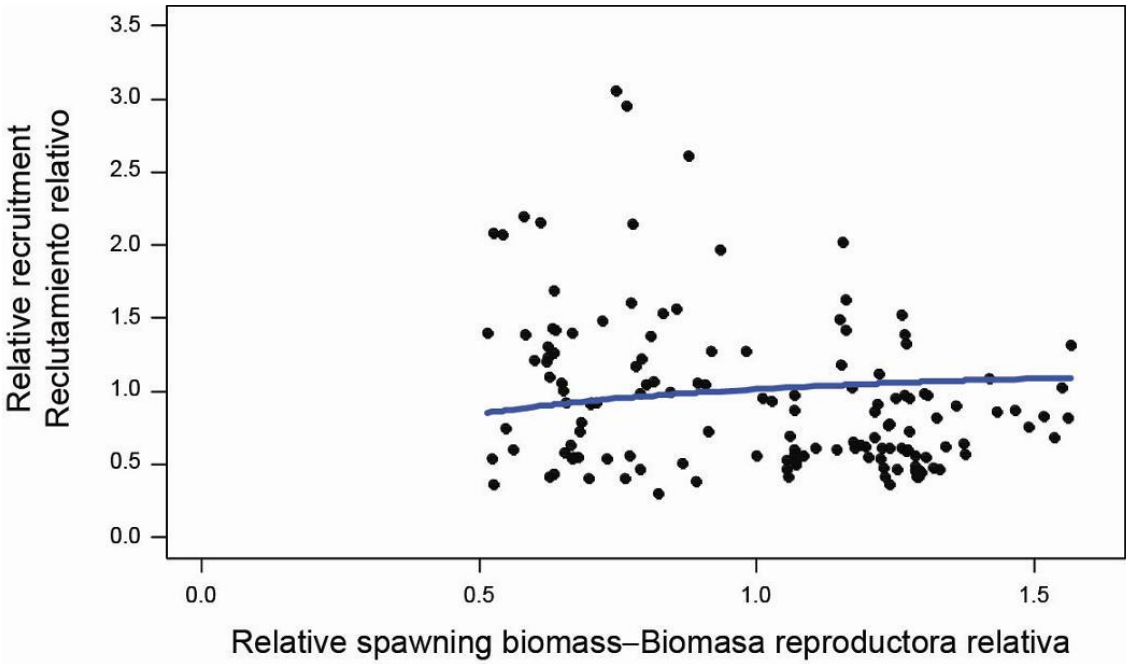

FIGURE A.4. Recruitment of bigeye tuna plotted against spawning biomass when the analysis has a stock-recruitment relationship (steepness = 0.75).
FIGURA A.4. Reclutamiento de atún patudo graficado como función de la biomasa reproductora cuando el análisis incluye una relación población-reclutamiento (inclinación = 0.75).

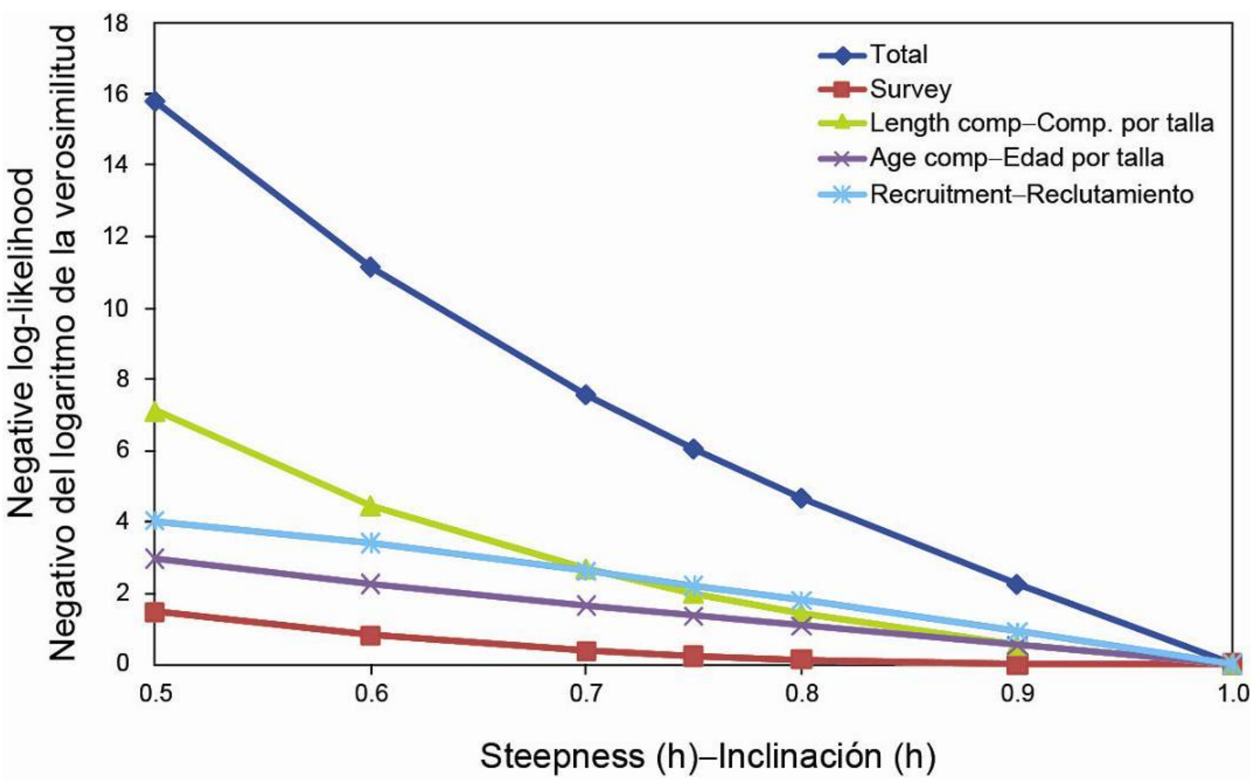

FIGURE A.5. Likelihood profile on steepness.
FIGURA A.5. Perfil de verosimilitud en inclinación.

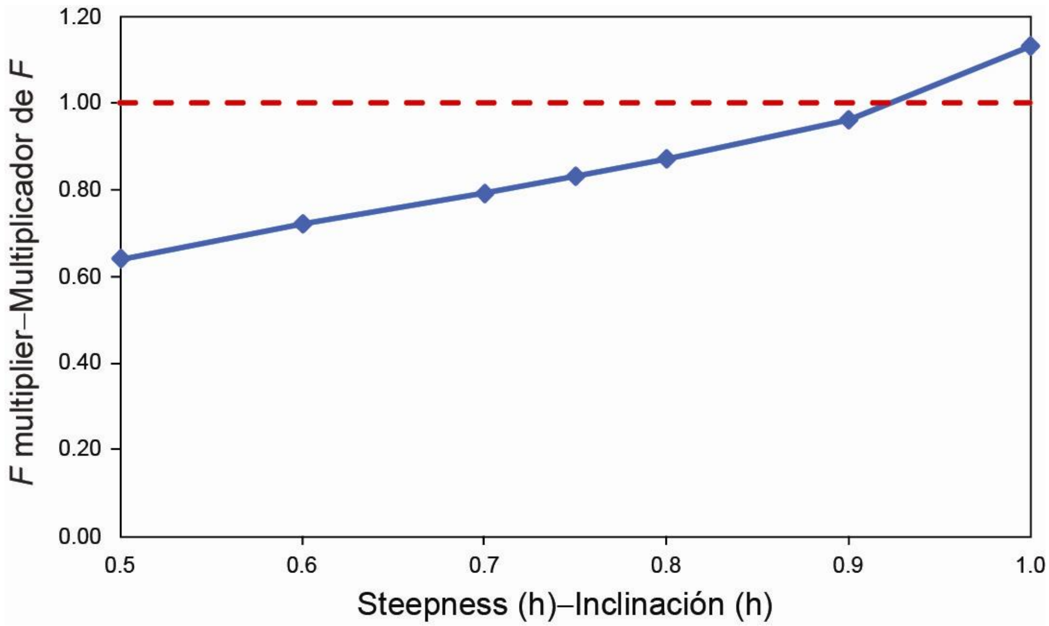

FIGURE A.6. *F* multiplier as a function of steepness.
FIGURA A.6. Multiplicador de *F* como función de la inclinación.

TABLE A.1. Estimates of the MSY and its associated quantities for bigeye tuna, for different assumptions on steepness (*h*).
TABLA A.1. Estimaciones de RMS y sus cantidades asociadas para el atún patudo, correspondientes a distintos supuestos sobre la inclinación (*h*).

	***h* = 0.5**	***h* = 0.6**	***h* = 0.7**	***h* = 0.75**	***h* = 0.8**	***h* = 0.9**	**Base case–Caso base (*h*=1)**
MSY-RMS	86,808	85,646	85,926	86,321	86,833	88,225	90,538
B_{MSY}- B_{RMS}	1,095,940	814,943	646,325	582,233	526,187	428,314	332,331
S_{MSY}- S_{RMS}	290,369	211,127	163,347	145,123	129,152	101,185	73,690
B_{MSY}/B_0- B_{RMS}/B_0	0.40	0.37	0.35	0.34	0.32	0.29	0.25
S_{MSY}/S_0- S_{RMS}/S_0	0.37	0.34	0.31	0.30	0.28	0.24	0.19
C_{recent}/MSY- C_{recent}/RMS	1.22	1.24	1.23	1.23	1.22	1.20	1.17
B_{recent}/B_{MSY}- B_{recent}/B_{RMS}	0.70	0.81	0.90	0.95	1.00	1.12	1.33
S_{recent}/S_{MSY}-S_{recent}/S_{RMS}	0.65	0.74	0.83	0.88	0.93	1.07	1.33
F multiplier- Multiplicador de *F*	0.64	0.72	0.79	0.83	0.87	0.96	1.13

APPENDIX B: SENSITIVITY ANALYSIS TO THE AVERAGE SIZE OF THE OLDEST FISH PARAMETER, L_2

ANEXO B: ANÁLISIS DE SENSIBILIDAD AL PARÁMETRO DE TAMAÑO MEDIO DE LOS PECES DE MAYOR EDAD, L_2

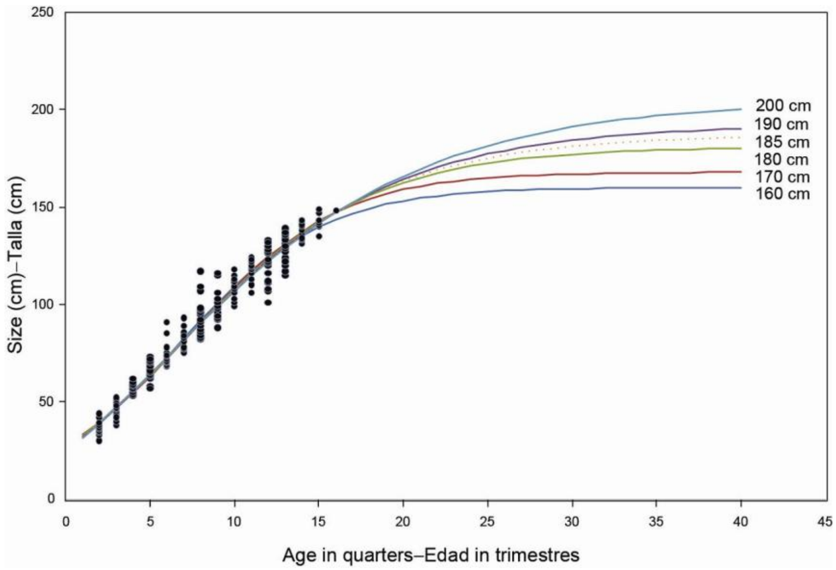

FIGURE B.1. Comparison of the estimated Richards growth curves (sensitivity) for bigeye tuna, assuming different fixed values for the average size of the oldest fish (L_2) parameter.

FIGURA B.1. Comparación de las curvas de crecimiento de Richards (sensibilidad) del atún patudo, con diferentes supuestos de valor fijo del parámetro de tamaño medio de los peces de mayor edad (L_2).

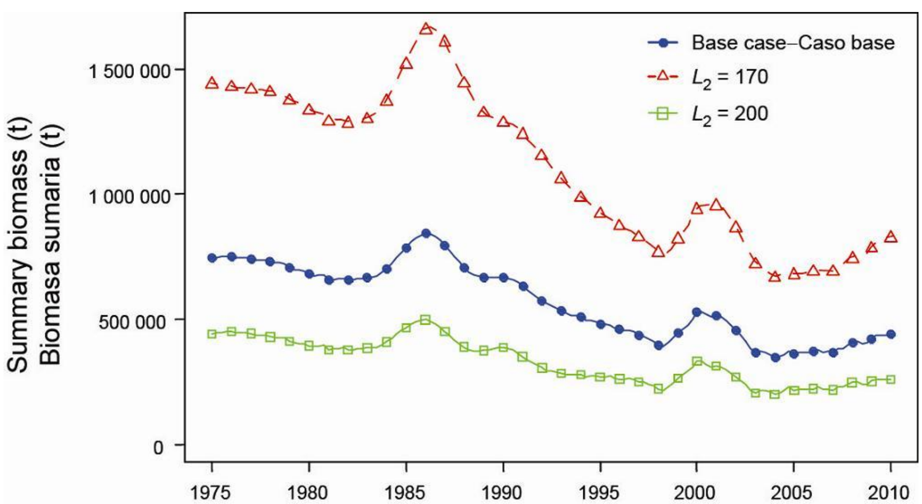

FIGURE B.2. Comparison of estimates of biomass of bigeye tuna from the base case analysis using a Richards growth curve with the average size of the oldest fish (L_2) fixed at 185.5 cm, and two alternative models with L_2 fixed at a lower (170 cm) and a higher value (200 cm). t = metric tons.

FIGURA B.2. Comparación de las estimaciones de biomasa de atún patudo del análisis del caso base que usa una curva de crecimiento de Richards con el tamaño promedio de los peces de mayor edad (L_2) fijado en 185.5 cm, y dos modelos alternativos con L_2 fijado en valores menor (170 cm) y mayor (200 cm). t = toneladas métricas.

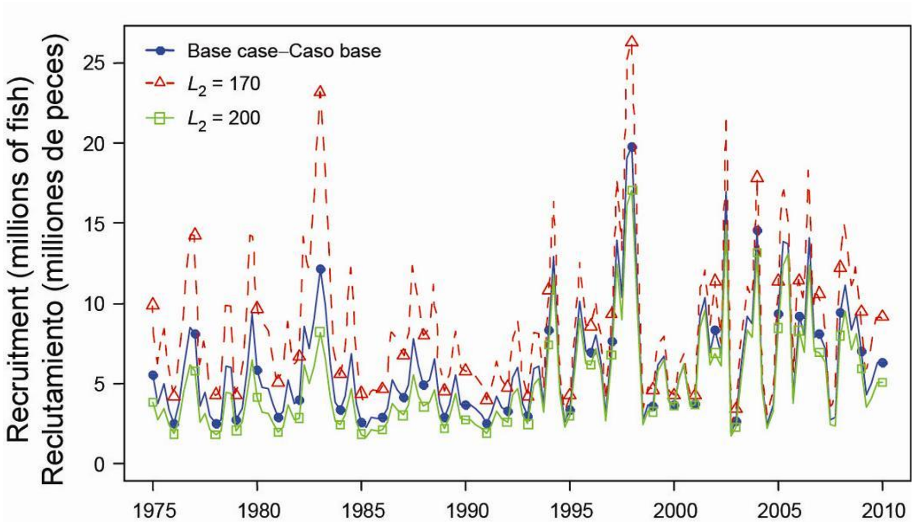

FIGURE B.3a. Comparison of estimates of absolute recruitment (in millions of fish) for bigeye tuna from the base case analysis using a Richards growth curve with the average size of the oldest fish (L_2) fixed at 185.5 cm, and two alternative models with L_2 fixed at a lower (170 cm) and a higher value (200 cm).

FIGURA B.3a. Comparación de las estimaciones de reclutamiento absoluto (en millones de peces) de atún patudo del análisis del caso base que usa una curva de crecimiento de Richards con el tamaño promedio de los peces de mayor edad (L_2) fijado en 185.5 cm, y dos modelos alternativos con L_2 fijado en valores menor (170 cm) y mayor (200 cm).

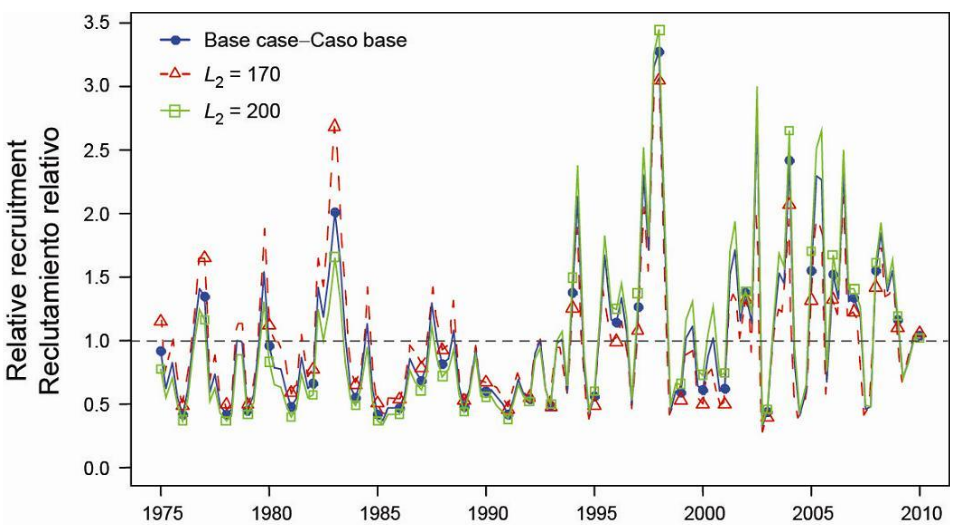

FIGURE B.3b. Comparison of estimates of relative recruitment for bigeye tuna from the base case analysis using a Richards growth curve with the average size of the oldest fish (L_2) fixed at 185.5 cm, and two alternative models with L_2 fixed at a lower (170 cm) and a higher value (200 cm). The estimates are scaled so that the estimate of average recruitment is equal to 1.0 (dashed horizontal line).

FIGURA B.3b. Comparación de las estimaciones de reclutamiento relativo de atún patudo del análisis del caso base que usa una curva de crecimiento de Richards con el tamaño promedio de los peces de mayor edad (L_2) fijado en 185.5 cm, y dos modelos alternativos con L_2 fijado en valores menor (170 cm) y mayor (200 cm). Se escalan las estimaciones para que la estimación de reclutamiento medio equivalga a 1,0 (línea de trazos horizontal).

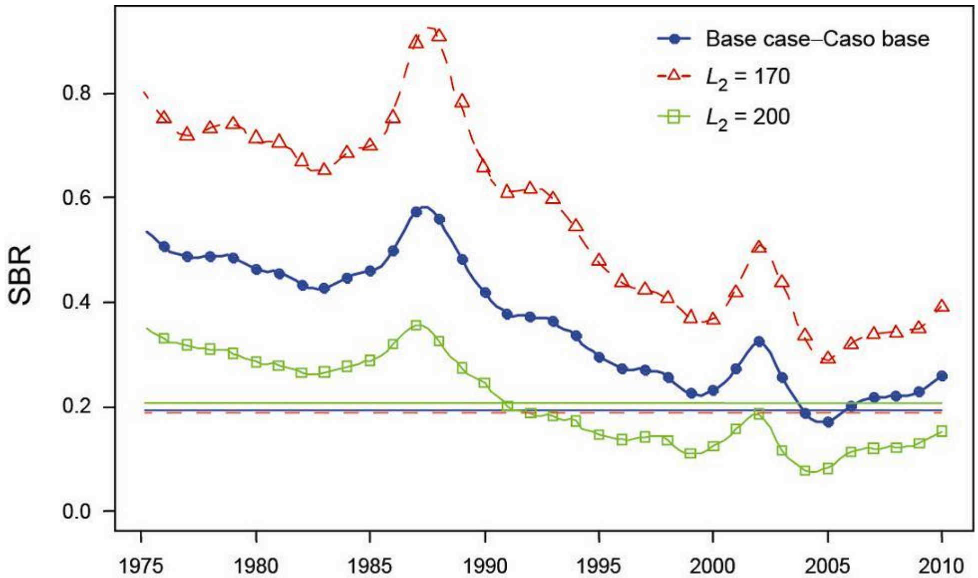

FIGURE B.4. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the base case analysis using a Richards growth curve with the average size of oldest fish (L_2) fixed at 185.5 cm, and two alternative models with L_2 fixed at a lower (170 cm) and a higher value (200 cm). The horizontal lines represent the SBRs associated with MSY under the two scenarios.

FIGURA B.4. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún patudo del análisis del caso base que usa una curva de crecimiento de Richards con el tamaño promedio de los peces de mayor edad (L_2) fijado en 185.5 cm, y dos modelos alternativos con L_2 fijado en valores menor (170 cm) y mayor (200 cm). Las líneas horizontales representan los SBR asociados con el RMS en los dos escenarios.

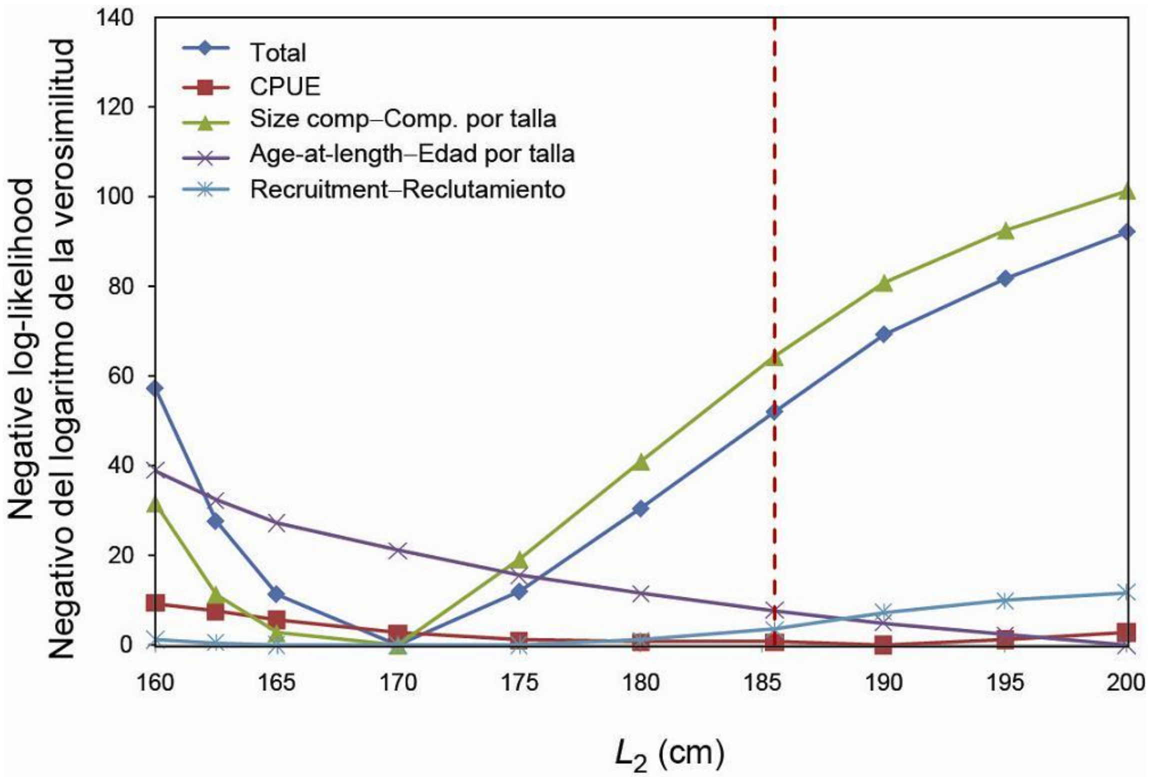

FIGURE B.5. Negative log-likelihood profile on average size of the oldest fish (L_2). Profiles are shown for total likelihood and different data components (subtracted to their respective minimum negative log-likelihood). The vertical dashed line marks the L_2 value fixed in the base case model (185.5 cm).

FIGURA B.5. Perfil del negativo del logaritmo de la verosimilitud en el tamaño medio de los peces de mayor edad (L_2). Se ilustran los perfiles de verosimilitud total y de distintos componentes de los datos (restados a su negativo mínimo respectivo del logaritmo de la verosimilitud). La línea de trazos vertical indica el valor de L_2 fijado en el modelo de caso base (185,5 cm).

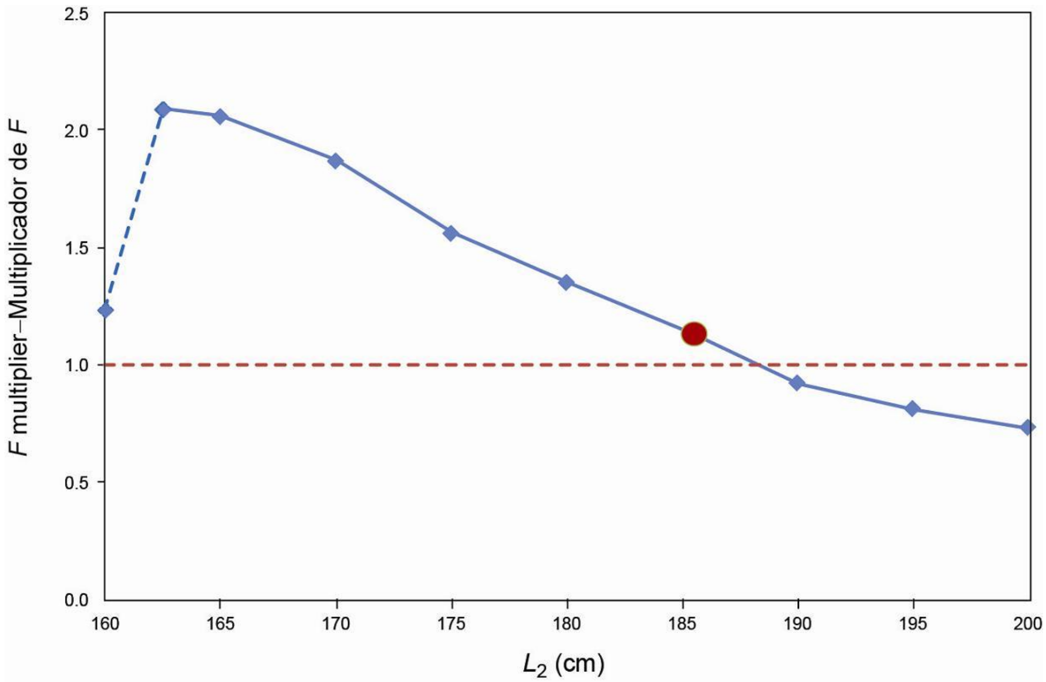

FIGURE B.6. Relationship between the *F* multiplier and the assumed value of L_2. The large dot indicates the L_2 assumption of the base case model (185.5 cm). The horizontal dashed line indicates F_{MSY}. The dashed segment between 160 and 165 cm represents L_2 values for which the relationship apparently deteriorates.
FIGURA B.6. Relación entre el multiplicador de *F* y el valor supuesto de L_2. El punto grande indica el L_2 supuesto en el modelo de caso base (185,5 cm). La línea de trazos horizontal indica F_{MSY}. El segmento de trazos entre 160 y 165 cm representa los valores de L_2 para los cuales la relación aparentemente deteriora.

TABLE B.1. Estimates of management-related quantities for bigeye tuna for the base case and the sensitivity analysis to the average size of the oldest fish (L_2). * = base case.

TABLA B.1. Estimaciones de las cantidades relacionadas con la ordenación para el atún patudo del caso base y del análisis de sensibilidad al tamaño medio de los peces de mayor edad (L_2). * = caso base

	Size – Tamaño								
	160	**165**	**170**	**175**	**180**	**185.5***	**190**	**195**	**200**
MSY-RMS	150,481	122,242	114,492	103,643	96,697	90,538	86,270	85,567	86,001
B_{MSY}- B_{RMS}	516,026	449,643	428,532	386,761	358,835	332,331	309,933	305,640	306,662
S_{MSY}- S_{RMS}	104,352	96,782	94,287	85,636	79,636	73,690	68,176	67,312	67,789
B_{MSY}/B_0- B_{RMS}/B_0	0.25	0.24	0.24	0.24	0.24	0.25	0.26	0.26	0.27
S_{MSY}/S_0- S_{RMS}/S_0	0.19	0.19	0.19	0.19	0.19	0.19	0.2	0.2	0.21
C_{recent}/MSY- C_{recent}/RMS	0.69	0.85	0.91	1.02	1.09	1.17	1.23	1.25	1.24
B_{recent}/B_{MSY}- B_{recent}/B_{RMS}	1.99	2.02	1.93	1.72	1.55	1.33	1.09	0.95	0.85
S_{recent}/S_{MSY}-S_{recent}/S_{RMS}	2.26	2.17	2.06	1.81	1.59	1.33	1.03	0.87	0.74
F multiplier- Multiplicador de *F*	1.23	2.06	1.87	1.56	1.35	1.13	0.92	0.81	0.73

APPENDIX C: SENSITIVITY ANALYSIS TO HIGHER RATES OF ADULT NATURAL MORTALITY
ANEXO C: ANÁLISIS DE SENSIBILIDAD A TASAS MAYORES DE MORTALIDAD NATURAL DE ADULTOS

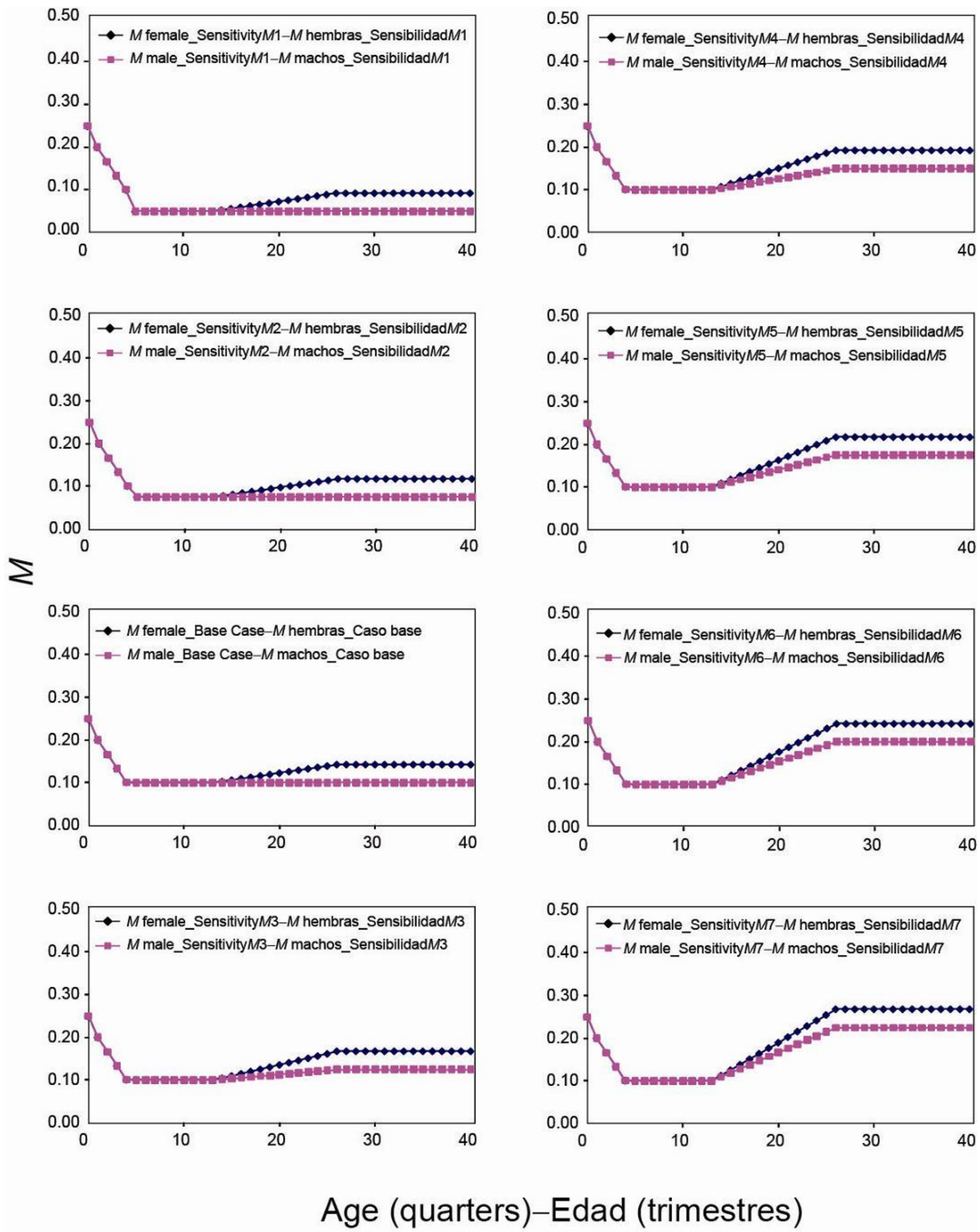

FIGURE C.1. Natural mortality (*M*) schedules for female and male bigeye investigated in the sensitivity analysis to higher *M* values for adults.
FIGURA C.1. Vectores de mortalidad natural (*M*) de patudos hembra y macho investigados en el análisis de sensibilidad a valores mayores de *M* para los adultos.

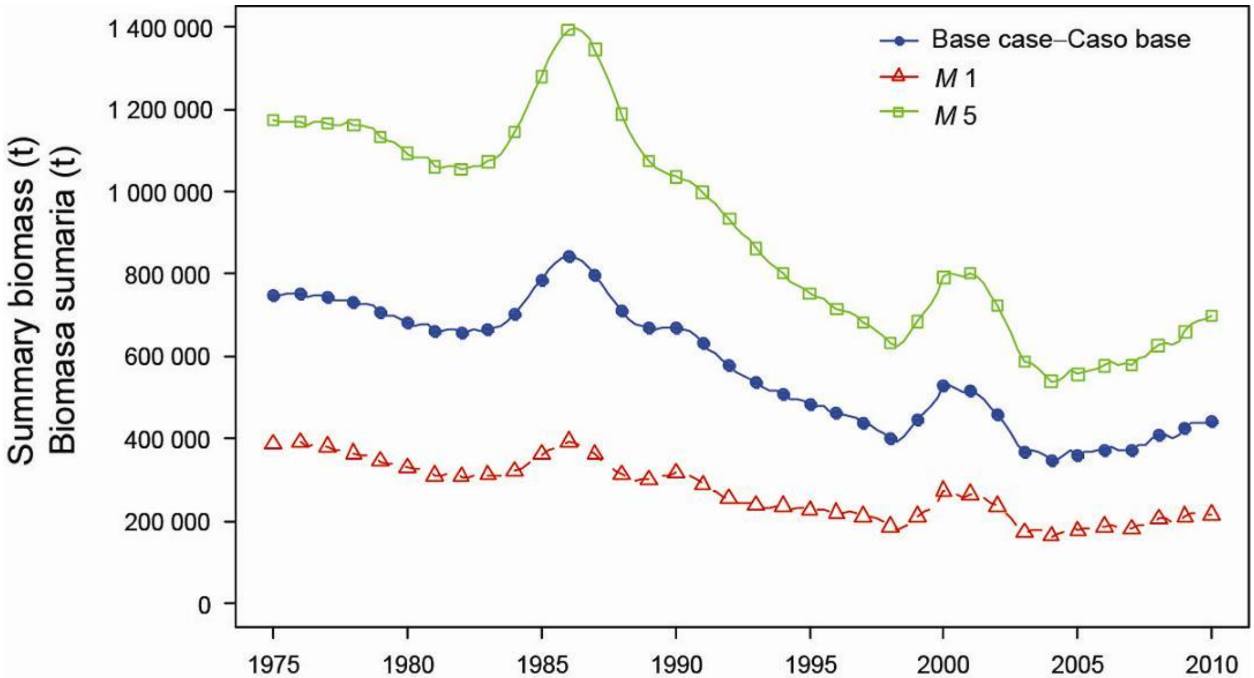

FIGURE C.2. Comparison of estimates of biomass of bigeye tuna 3+ quarters old (summary biomass) from the base case analysis and two sensitivity analyses assuming lower (Sensitivity *M*1) and higher (Sensitivity *M*5) rates of adult natural mortality (*M*), respectively (see Figure C.1 to compare *M* schedules). t = metric tons.

FIGURA C.2. Comparación de las estimaciones de biomasa de atún patudo de 3+ trimestres de edad (biomasa sumaria) del análisis de caso base y de dos análisis de sensibilidad que suponen tasas de mortalidad natural (*M*) de adultos menores (Sensibilidad *M*1) y mayores (Sensibilidad *M*5), respectivamente (ver Figura C.1 para comparar vectores de *M*). t = toneladas métricas.

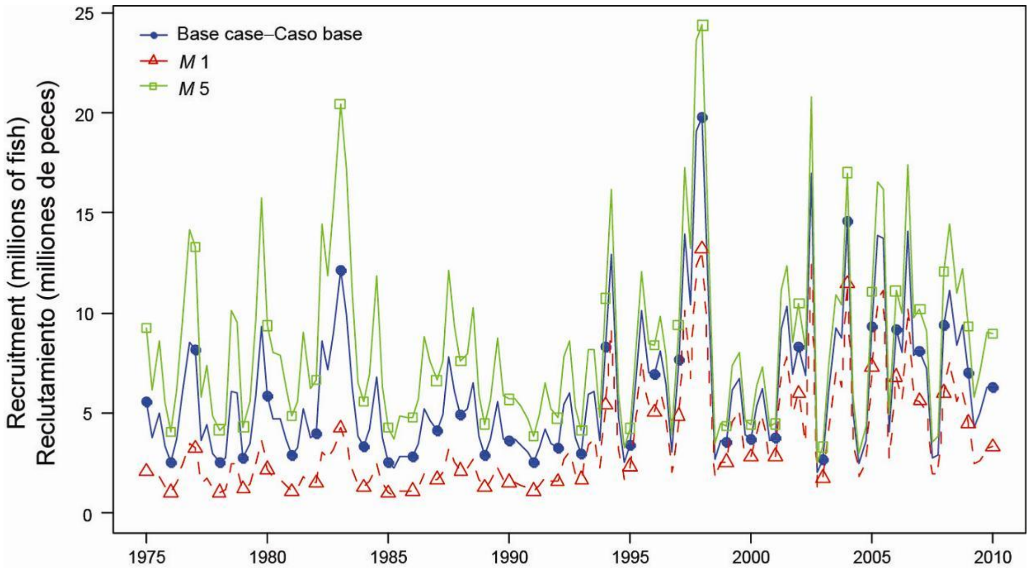

FIGURE C.3a. Comparison of estimates of absolute recruitment (in millions of fish) for bigeye tuna from the base case analysis and two sensitivity analyses assuming lower (Sensitivity *M*1) and higher (Sensitivity *M*5) rates of adult natural mortality (*M*), respectively (see Figure C.1 to compare *M* schedules).

FIGURA C.3a. Comparación de las estimaciones de reclutamiento absoluto (en millones de peces) de atún patudo del análisis de caso base y de dos análisis de sensibilidad que suponen tasas de mortalidad natural (*M*) de adultos menores (Sensibilidad *M*1) y mayores (Sensibilidad *M*5), respectivamente (ver Figura C.1 para comparar vectores de *M*).

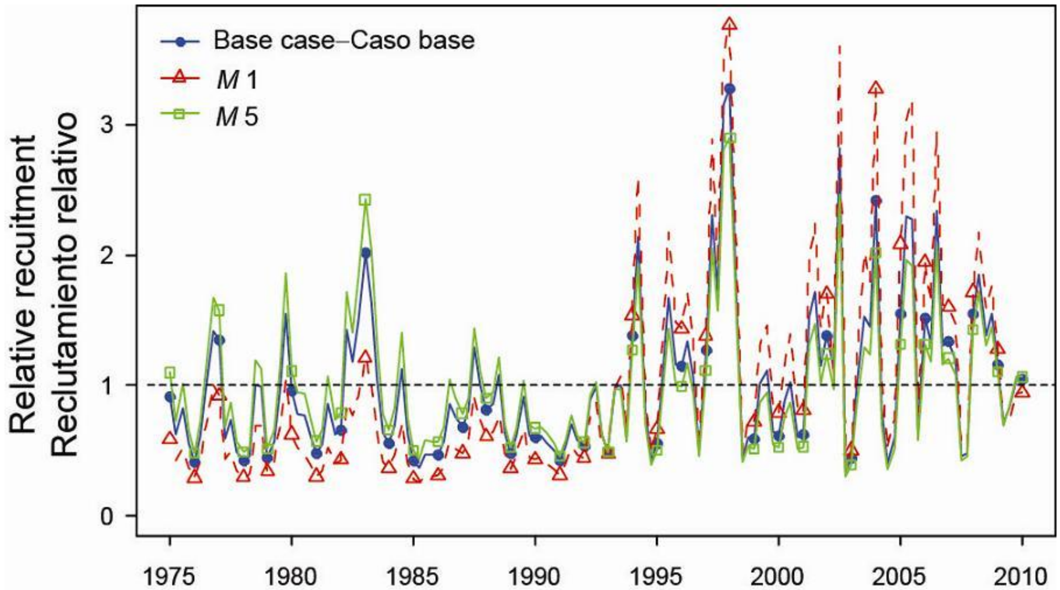

FIGURE C.3b. Comparison of estimates of relative recruitment for bigeye tuna from the base case analysis and from two sensitivity analyses assuming lower (Sensitivity *M*1) and higher (Sensitivity *M*5) rates of adult natural mortality (*M*), respectively (see Figure C.1 to compare *M* schedules). The estimates are scaled so that the estimate of average recruitment is equal to 1.0 (dashed horizontal line).

FIGURA C.3b. Comparación de las estimaciones de reclutamiento relativo de atún patudo del análisis de caso base y de dos análisis de sensibilidad que suponen tasas de mortalidad natural (*M*) de adultos menores (Sensibilidad *M*1) y mayores (Sensibilidad *M*5), respectivamente (ver Figura C.1 para comparar vectores de *M*). Se escala el reclutamiento para que la estimación de reclutamiento medio equivalga a 1,0 (línea de trazos horizontal).

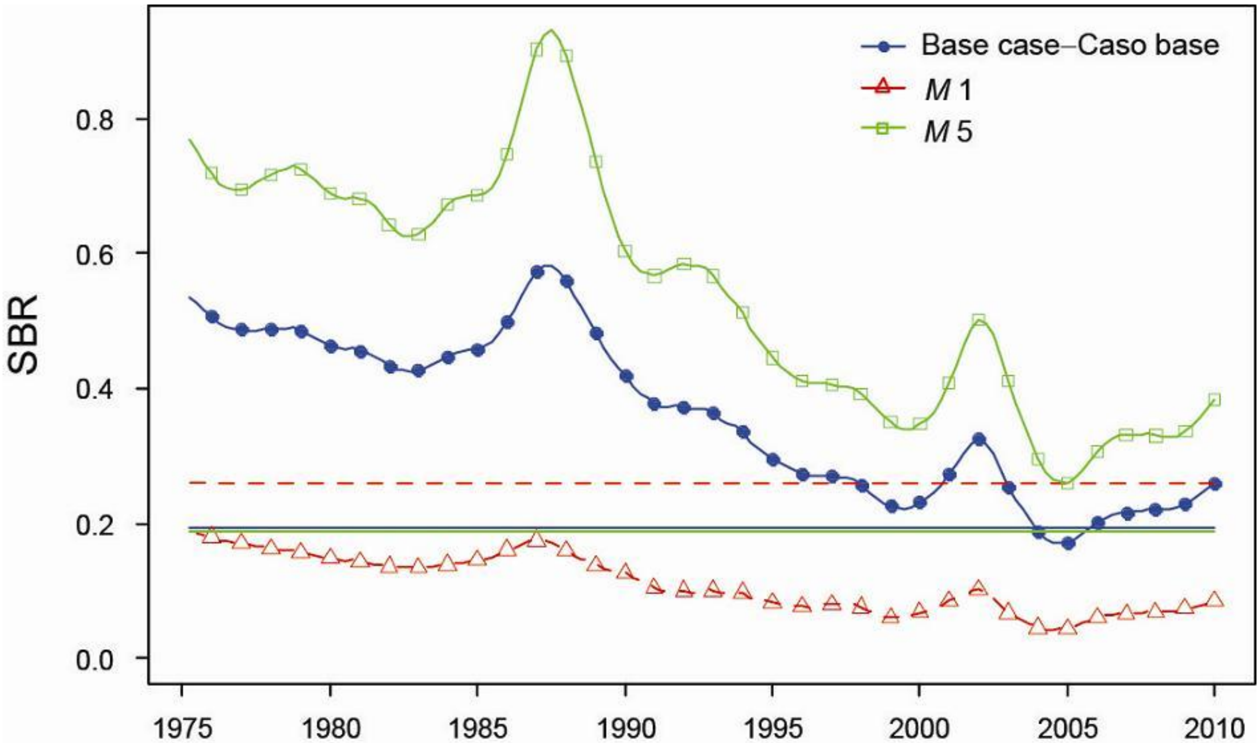

FIGURE C.4. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the base case analysis and from two sensitivity analyses assuming lower (Sensitivity *M*1) and higher (Sensitivity *M*5) rates of adult natural mortality (*M*), respectively (see Figure C.1 to compare *M* schedules). The horizontal lines represent the SBRs associated with MSY under the two scenarios.

FIGURA C.4. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún patudo del análisis de caso base y de dos análisis de sensibilidad que suponen tasas de mortalidad natural (*M*) de adultos menores (Sensibilidad *M*1) y mayores (Sensibilidad *M*5), respectivamente (ver Figura C.1 para comparar vectores de *M*). Las líneas horizontales representan los SBR asociados con el RMS bajo los dos escenarios.

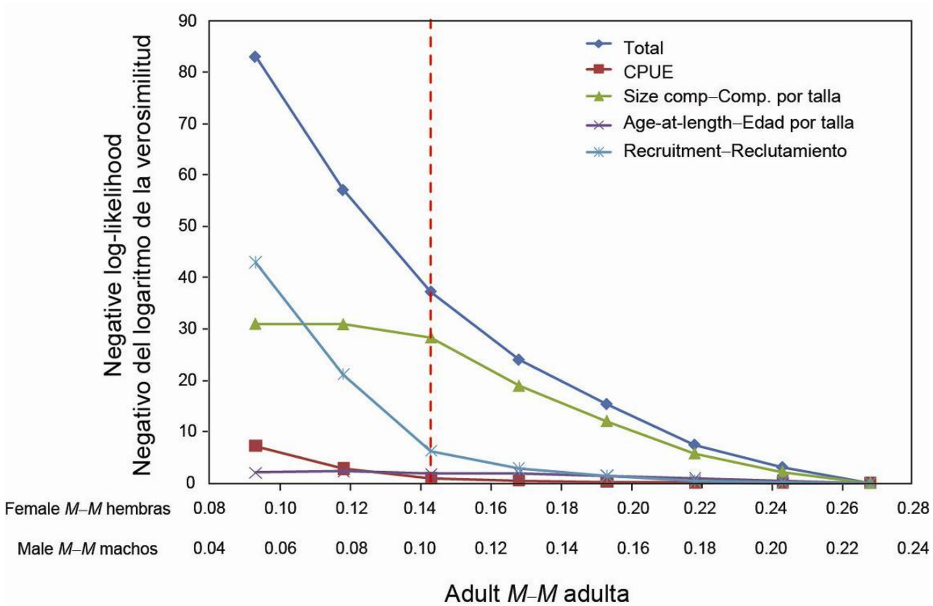

FIGURE C.5. Negative log-likelihood for adult natural mortality (*M*). Profiles are shown for total likelihood and different data components (subtracted to their respective minimum negative log-likelihood). The vertical dashed line represents the *M* values assumed in the base case model.
FIGURA C.5. Negativo del logaritmo de la verosimilitud correspondiente a la mortalidad natural (*M*) de los adultos. Se ilustran los perfiles de verosimilitud total y de distintos componentes de los datos (restados a su negativo mínimo respectivo del logaritmo de la verosimilitud). La línea de trazos vertical representa los supuestos de *M* usados en el modelo de caso base .

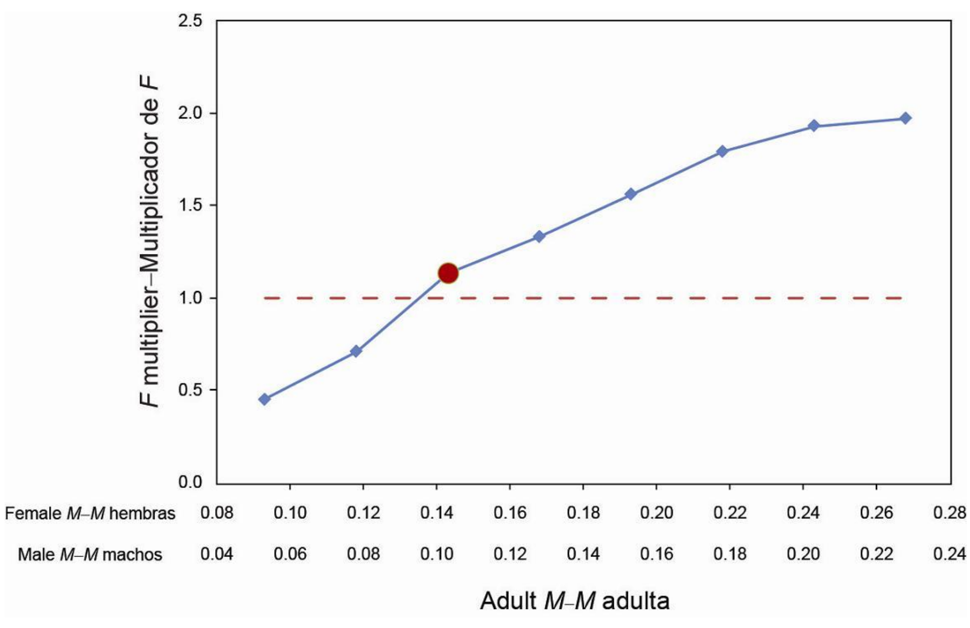

FIGURE C.6. Relationship between the *F* multiplier and the assumed levels of adult natural mortality (*M*) for females and males. The large dot indicates the *M* assumed in the base case model. The horizontal dashed line indicates F_{MSY}.
FIGURA C.6. Relación entre el multiplicador de *F* y los niveles supuestos de mortalidad natural (*M*) de hembras y machos adultos. El punto grande indica la *M* supuesta en el modelo de caso base. La línea de trazos horizontal indica F_{RMS}.

TABLE C.1. Estimates of management-related quantities for bigeye tuna for the base case and adult natural mortality (*M*) sensitivity analysis (see Figure C.1 to compare *M* schedules).
TABLA C.1. Estimaciones de las cantidades relacionadas con la ordenación para el atún patudo del caso base y del análisis de sensibilidad a la mortalidad natural (*M*) de adultos (ver Figura C.1 para comparar vectores de *M*).

			M1	***M*2**	**Base case Caso base**	***M*3**	***M*4**	***M*5**	***M*6**	***M*7**
	M	Female Hembras	0.09	0.12	0.14	0.17	0.19	0.22	0.24	0.27
		Male Machos	0.05	0.08	0.10	0.13	0.15	0.18	0.20	0.23
MSY-RMS			88,294	81,433	90,538	98,876	105,292	113,917	119,786	125,003
B_{MSY}- B_{RMS}			516,205	376,198	332,331	348,678	357,310	375,778	385,455	393,609
S_{MSY}- S_{RMS}			145,753	95,987	73,690	75,012	73,791	75,696	75,457	74,983
B_{MSY}/B_0- B_{RMS}/B_0			0.27	0.26	0.25	0.25	0.25	0.25	0.25	0.25
S_{MSY}/S_0- S_{RMS}/S_0			0.26	0.22	0.19	0.19	0.19	0.19	0.19	0.19
C_{recent}/MSY- C_{recent}/RMS			1.21	1.31	1.17	1.07	1	0.92	0.88	0.84
B_{recent}/B_{MSY}- B_{recent}/B_{RMS}			0.42	0.81	1.33	1.57	1.71	1.86	1.94	2
S_{recent}/S_{MSY}- S_{recent}/S_{RMS}			0.33	0.72	1.33	1.63	1.82	2.02	2.14	2.23
F multiplier- Multiplicador de *F*			0.45	0.71	1.13	1.33	1.56	1.79	1.93	1.97

APPENDIX D: SENSITIVITY ANALYSIS TO USING DATA ONLY FOR THE LATE PERIOD OF THE FISHERY (1995-2009)

ANEXO D: ANÁLISIS DE SENSIBILIDAD ANALYSIS TO USING DATA ONLY FOR THE LATE PERIOD OF THE FISHERY (1995-2009)

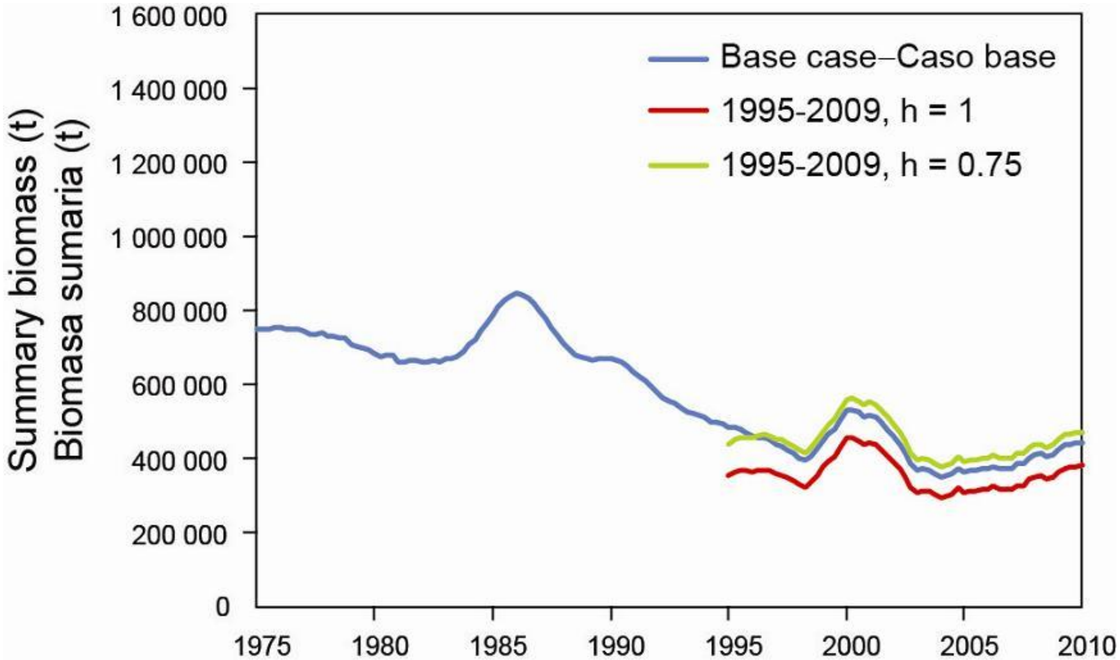

FIGURE D1. Comparison of estimates of the biomass of bigeye tuna 3+ quarters old (summary biomass) from the base case analysis and a stock assessment model using data only for the late period of the fishery (1995-2009).

FIGURA D.1. Comparación de las estimaciones de biomasa de atún patudo de 3+ trimestres de edad (biomasa sumaria) del análisis de caso base y de un modelo de evaluación de la población que usa datos del período tardío de la pesquería (1995-2009) solamente.

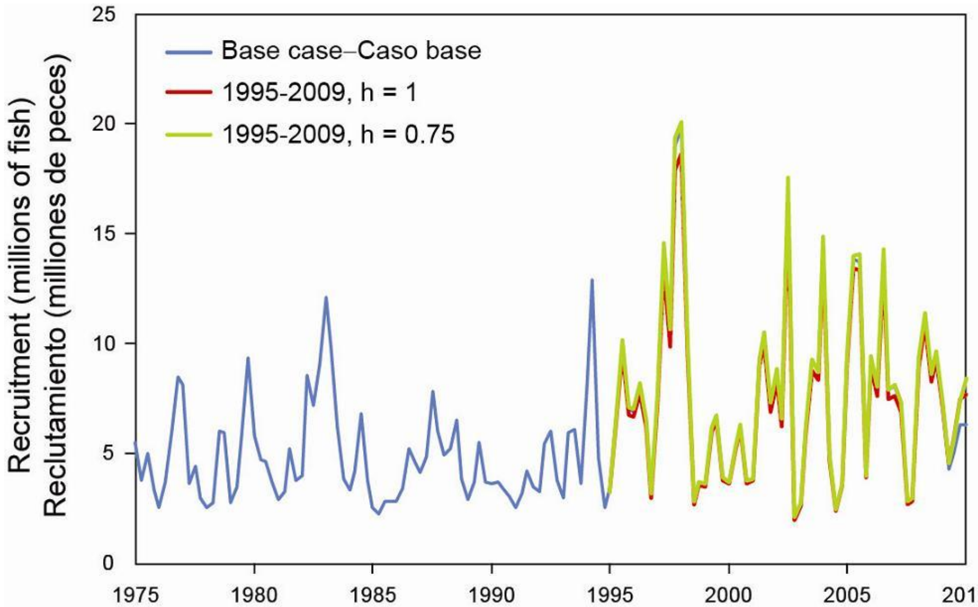

FIGURE D.2a. Comparison of estimates of absolute recruitment (in millions of fish) for bigeye tuna from the base case analysis and a stock assessment model using data only for the late period of the fishery (1995-2009).
FIGURA D.2a. Comparación de estimaciones de reclutamiento absoluto (en millones de peces) de atún patudo, del análisis de caso base y de un modelo de evaluación de la población que usa datos del período tardío de la pesquería (1995-2009) solamente.

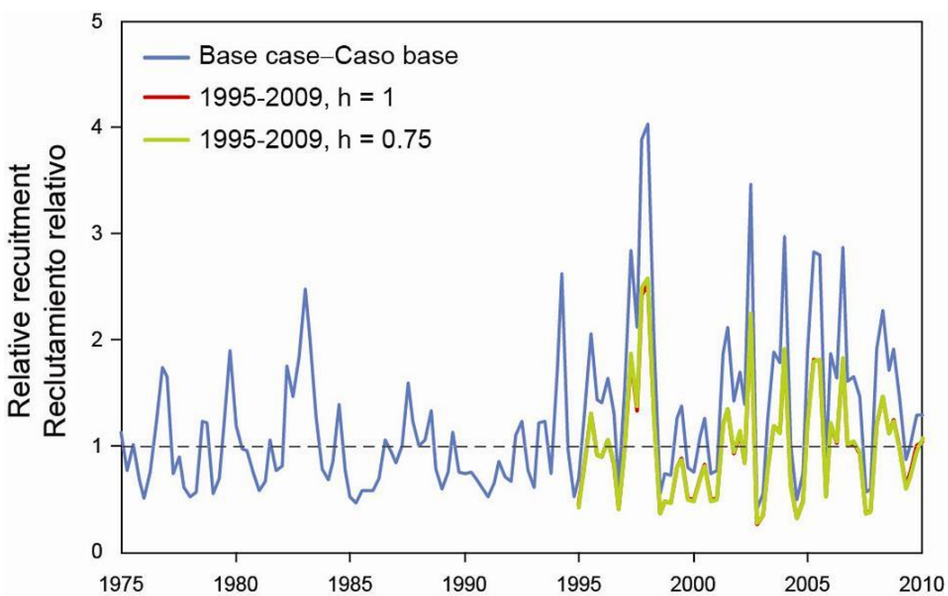

FIGURE D.2b. Comparison of estimates of relative recruitment for bigeye tuna from the base case analysis and a stock assessment model using data only for the late period of the fishery (1995-2009). The estimates are scaled so that the estimate of average recruitment is equal to 1.0 (dashed horizontal line).
FIGURA D.2b. Comparación de estimaciones de reclutamiento relativo de atún patudo, del análisis de caso base y de un modelo de evaluación de la población que usa datos del período tardío de la pesquería (1995-2009) solamente. Se escalan las estimaciones para que la estimación de reclutamiento medio equivalga a 1,0 (línea de trazos horizontal).

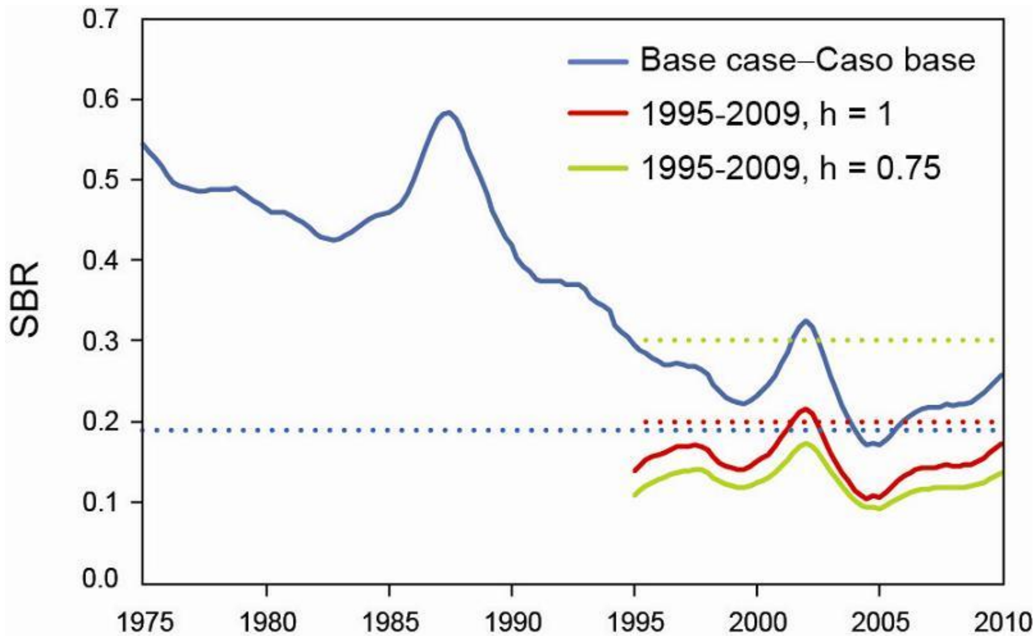

FIGURE D.4. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the base case analysis and a stock assessment model using data only for the late period of the fishery (1995-2009). The horizontal dashed lines represent the SBRs associated with MSY under the different scenarios.

FIGURA D.4. Comparación de estimaciones del cociente de biomasa reproductora (SBR) de atún patudo, del análisis de caso base y de un modelo de evaluación de la población que usa datos del período tardío de la pesquería (1995-2009) solamente. Las líneas de trazos horizontales representan los SBR asociados con el RMS en los distintos escenarios.

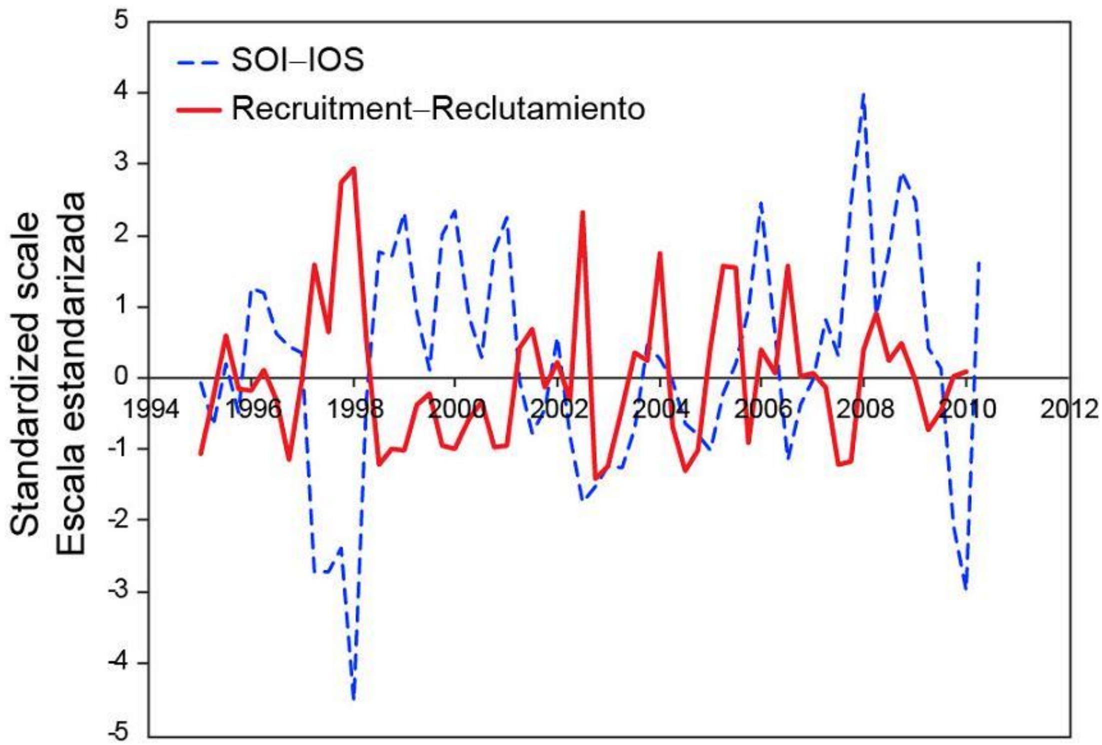

FIGURE D.5. Quarterly time series of bigeye standardized recruitments and the Southern Oscillation Index (SOI).
FIGURA D.5. Series de tiempo trimestrales de reclutamiento estandarizado de patudo y el Índice de Oscilación del Sur (IOS)

APPENDIX E: ADDITIONAL RESULTS FROM THE BASE CASE ASSESSMENT

This appendix contains additional results from the base case assessment of bigeye tuna in the EPO. These results are total fishing mortality rates.

ANEXO E: RESULTADOS ADICIONALES DE LA EVALUACIÓN DEL CASO BASE

Este anexo contiene resultados adicionales de la evaluación de caso base del atún patudo en el OPO. Estos resultados son tasas de mortalidad por pesca total.

TABLE E.1. Average annual fishing mortality rates for bigeye in the EPO for the base case assessment.
TABLA E.1. Tasas medias de mortalidad anual por pesca de patudo en el OPO para la evaluación del caso base.

	1-4	**5-8**	**9-12**	**13-19**	**20+**
1975	0.01	0.04	0.12	0.10	0.03
1976	0.01	0.07	0.16	0.13	0.03
1977	0.01	0.06	0.18	0.16	0.04
1978	0.01	0.09	0.22	0.16	0.04
1979	0.01	0.07	0.18	0.15	0.04
1980	0.01	0.11	0.23	0.17	0.04
1981	0.01	0.07	0.19	0.15	0.04
1982	0.01	0.05	0.15	0.13	0.04
1983	0.01	0.04	0.16	0.15	0.04
1984	0.01	0.05	0.13	0.12	0.03
1985	0.01	0.03	0.13	0.12	0.04
1986	0.00	0.04	0.17	0.17	0.05
1987	0.00	0.04	0.19	0.20	0.06
1988	0.00	0.04	0.17	0.19	0.06
1989	0.00	0.04	0.18	0.18	0.05
1990	0.01	0.03	0.16	0.24	0.20
1991	0.01	0.03	0.17	0.26	0.23
1992	0.01	0.04	0.16	0.23	0.19
1993	0.05	0.06	0.17	0.23	0.19
1994	0.17	0.19	0.30	0.29	0.21
1995	0.34	0.28	0.29	0.26	0.18
1996	0.49	0.42	0.34	0.23	0.15
1997	0.45	0.43	0.41	0.27	0.16
1998	0.26	0.28	0.27	0.28	0.21
1999	0.21	0.23	0.23	0.19	0.12
2000	0.35	0.45	0.35	0.22	0.14
2001	0.38	0.46	0.34	0.27	0.20
2002	0.39	0.51	0.46	0.42	0.33
2003	0.35	0.40	0.38	0.36	0.29
2004	0.36	0.44	0.36	0.30	0.23
2005	0.44	0.51	0.35	0.22	0.14
2006	0.45	0.59	0.41	0.24	0.14
2007	0.32	0.42	0.29	0.19	0.13
2008	0.30	0.45	0.35	0.18	0.09
2009	0.36	0.48	0.30	0.16	0.09

REFERENCES—REFERENCIAS

Aires-da-Silva, A. and M.N. Maunder. 2007. Status of bigeye tuna in the eastern Pacific Ocean in 2006 and outlook. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 8: 105-203.

Aires-da-Silva, A. and M.N. Maunder. 2009. Status of bigeye tuna in the eastern Pacific Ocean in 2007 and outlook for the future. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 9: 101-202.

Aires-da-Silva, A. and M.N. Maunder. 2010a. Status of bigeye tuna in the eastern Pacific Ocean in 2009 and outlook for the future. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 10: 116-228.

Aires-da-Silva, A. and M.N. Maunder. 2010b. An evaluation of spatial structure in the stock assessment of bigeye tuna in the eastern Pacific Ocean. Document BET-01-02b, External review of IATTC bigeye tuna assessment. La Jolla, California, USA; 3-7 May 2010.

Aires-da-Silva, A. and M.N. Maunder. 2010c. Sensitivity analysis of bigeye stock assessment to alternative growth assumptions. Document BET-01-03, External review of IATTC bigeye tuna assessment. La Jolla, California, USA; 3-7 May 2010.

Aires-da-Silva, A., M.N. Maunder and C.E. Lennert-Cody. 2010. An investigation of the longline fishery length-frequency residual pattern in the stock assessment of bigeye tuna in the eastern Pacific Ocean. Document BET-01-05, External review of IATTC bigeye tuna assessment. La Jolla, California, USA; 3-7 May 2010.

Aires-da-Silva, A., M.N. Maunder and P.K. Tomlinson. 2010. An investigation of the trend in the estimated recruitment for bigeye tuna in the eastern Pacific Ocean. Document BET-01-06, External review of IATTC bigeye tuna assessment. La Jolla, California, USA; 3-7 May 2010.

Anonymous. 2006. Report of the Albacore Working Group Meeting (November 28-December 2, 2005, La Jolla, CA, U.S.A.)**:** 30 p. (http://isc.ac.affrc.go.jp/isc6/ISC06_Annex%206_ISC- ALBWG _Report_Final.pdf)

Beddington, J.R. and D.B. Taylor. 1973. Optimum age specific harvesting of a population. Biometrics 29: 801-809.

Beverton, R.J.H. and S.J. Holt. 1957. On the dynamics of exploited fish populations. Minis. Agri. Fish. Food Inves., Ser. 2, 19: 533 p.

Bigelow, K., J. Hampton, and N. Miyabe. 2002. Application of a habitat-based model to estimate effective longline fishing effort and relative abundance of Pacific bigeye tuna (*Thunnus obesus*). Fish. Ocean. 11: 143-155.

Clark, W.G. 1991. Groundfish exploitation rates based on life history parameters. Can. J. Fish. Aquat. Sci. 48: 734-750.

Francis, R.I.C.C. 1993. Monte Carlo evaluation of risks for biological reference points used in New Zealand fishery assessments. Can. Spec. Publ. Fish. Aquat. Sci. 120: 221-230.

Getz, W.M. 1980. The ultimate sustainable yield problem in nonlinear age structured populations. Mathematical Bioscience 48: 279-292.

Hampton J. 2000. Natural mortality rates in tropical tunas: size really does matter. Can. J. Fish. Aquat. Sci. 57: 1002-1010.

Hampton, J. 2002. Stock assessment of bigeye tuna in the western and central Pacific Ocean. Sec. Pacif. Comm., Oceanic Fish. Prog., 15th meeting, Stand. Comm. Tuna Billfish, BET-1: 37 p. (http://www.spc.int/oceanfish/Html/SCTB/SCTB15/BET-1.pdf)

Hampton, J., K. Bigelow, and M. Labelle. 1998. A summary of current information on the biology, fisheries and stock assessment of bigeye tuna (*Thunnus obesus*) in the Pacific Ocean, with recommendations for data requirements and future research. Sec. Pacif. Comm., Oceanic Fish. Prog,, Tech. Rep. 36: 46 p.

Hampton, J. and D.A. Fournier. 2001a. A spatially disaggregated, length-based, age-structured population model of yellowfin tuna (*Thunnus albacares*) in the western and central Pacific Ocean. Mar. Fresh. Res. 52: 937-963.

Hampton, J. and D.A. Fournier. 2001b. A preliminary stock assessment model for bigeye tuna in the Pacific Ocean. Sec. Pacif. Comm., Oceanic Fish. Prog., 14th meeting, Stand. Comm. Tuna Billfish. BET-1: 31 p. (http://www.spc.org.int/OceanFish/Html/SCTB/SCTB14/bet1.pdf)

Hampton, J., P. Kleiber, Y. Takeuchi, H. Kurota, and M. Maunder. 2003. Stock assessment of bigeye tuna in the western and central Pacific Ocean, with comparisons to the entire Pacific Ocean. Sec. Pacif. Comm., Oceanic Fish. Prog., 16th meeting, Stand. Comm. Tuna Billfish, BET-1: 80 p. (http://www.spc.org.int/OceanFish/Html/SCTB/SCTB16/bet1.pdf)

Hampton, J. and M.N. Maunder. 2005. Comparison of Pacific-wide, western and central Pacific, and eastern Pacific assessments of bigeye tuna. WCPFC–SC1 SA WP–2−SUP, 19p. (http://www.spc.int/oceanfish/Html/WCPFC/SC1/pdf/SC1_SA_WP_2_SUP.pdf

Hampton, J. and M.N. Maunder. 2006. An update of Pacific-wide assessment of bigeye tuna with comparisons with eastern Pacific assessment results.(http://www.iattc.org/PDFFiles2/SAR-7-07c.ii-Pacific-wide-BET-assessment.pdf)

Harley, S. J. and M. N. Maunder. 2003. Recommended diagnostics for large statistical stock assessment models. Sec. Pacif. Comm., Oceanic Fish. Prog., 16th meeting, Stand. Comm. Tuna Billfish, MWG-3: 34 p. (http://www.spc.org.int/OceanFish/Html/SCTB/SCTB16/mwg3.pdf)

Harley, S.J. and M.N. Maunder. 2004. Status of bigeye tuna in the eastern Pacific Ocean in 2002 and outlook for 2003. Inter-Amer. Trop. Tuna Comm., Stock Asses. Rep. 4: 120-286.

Harley, S.J. and M.N. Maunder. 2005. Status of bigeye tuna in the eastern Pacific Ocean in 2003 and outlook for 2004. Inter-Amer. Trop. Tuna Comm., Stock Asses. Rep. 5: 168-290.

Hinton, M.G. and H. Nakano. 1996. Standardizing catch and effort statistics using physiological, ecological, or behavioral constraints and environmental data, with an application to blue marlin (*Makaira nigrican*s) catch and effort data from Japanese longline fisheries in the Pacific. Inter-Amer. Trop. Tuna Comm., Bull. 20: 169-200.

Hoyle, S.D. and M.N. Maunder. 2006 Standardization of yellowfin and bigeye CPUE data from Japanese longliners, 1975-2004. IATTC Working Group on Stock Assessments, 7th Meeting, SAR-7-07. (http://www.iattc.org/PDFFiles2/SAR-7-07-LL-CPUE-standardization.pdf)

Kume, S. 1967. Distribution and migration of bigeye tuna in the Pacific Ocean. Rep. Nankai Reg. Fish. Res. Lab. 25: 75-80.

Langley, A., J. Hampton, P. Kleiber and S. Hoyle. 2008. Stock assessment of bigeye tuna in the western and central Pacific Ocean, including an analysis of management options. WCPFC-SC4-2008/SA-WP-1 Rev.1, Port Moresby, Papua New Guinea, 11−22 August 2008.

Lehodey, P., J. Hampton, and B. Leroy. 1999. Preliminary results on age and growth of bigeye tuna (*Thunnus obesus*) from the western and central Pacific Ocean as indicated by daily growth increments and tagging data. Sec. Pacif. Comm., Oceanic Fish. Prog., 12th meeting, Stand. Comm. Tuna Billfish, BET-2: 18 p. (http://www.spc.org.nc/OceanFish/Html/SCTB/SCTB12/WP/SCTB99_WPBET-2.pdf)

Lennert-Cody, C.E., J.J. Roberts, and R.J. Stephenson. 2008. Effects of gear characteristics on the presence of bigeye tuna (*Thunnus obsesus*) in the catches of the purse-seine fishery of the eastern Pacific Ocean. ICES Jour. Mar. Sci., 65: 970-978.

Lennert-Cody, C.E., M.N. Maunder and A. Aires-da-Silva. 2010. Preliminary analysis of spatial-temporal pattern in bigeye tuna length-frequency distributions and catch-per-unit effort trends. Document BET-01-02a, External review of IATTC bigeye tuna assessment. La Jolla, California, USA; 3-7 May 2010.

Mace, P.M. 1994. Relationships between common biological reference points used as thresholds and targets of fisheries management strategies. Can. J. Fish. Aquat. Sci. 51: 110-122.

Matsumoto, T. and W.H. Bayliff. 2008. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1998-2003. Inter-Amer. Trop. Tuna Comm., Bull. 24: 1-187.

Maunder, M.N. 2002a. Status of yellowfin tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 3: 47-134.

Maunder, M.N. 2002b. The relationship between fishing methods, fisheries management and the estimation of MSY. Fish and Fisheries 3: 251-260.

Maunder, M.N. 2004. Status of yellowfin tuna in the eastern Pacific Ocean in 2002 and outlook for 2003. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 4: 5-119.

Maunder, M.N. (compiler) 2006. Report from the workshop on stock assessment methods, IATTC, La Jolla, California (USA), 7-11 November 2005. (http://www.iattc.org/PDFFiles2/Assessment-methods-WS-Nov05-ReportENG.pdf)

Maunder, M.N. (compiler) 2007. Report from the workshop on management strategies, IATTC, La Jolla, California (USA), 17-20 October 2006. (http://www.iattc.org/PDFFiles2/Management-strategies-WS-Oct-06-ReportENG.pdf)

Maunder, M.N. and A. Aires-da-Silva. 2010. Investigation of catch-per-unit-of-effort data used in the eastern Pacific Ocean bigeye assessment model. Document BET-01-04, External review of IATTC bigeye tuna assessment. La Jolla, California, USA; 3-7 May 2010.

Maunder, M.N., A. Aires-da-Silva, R. Deriso, K. Schaefer, and D. Fuller. 2010. Preliminary estimation of age- and sex-specific natural mortality of bigeye tuna in the eastern Pacific Ocean by applying a cohort analysis with auxiliary information to tagging data. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 10: 253-278.

Maunder, M.N. and S.J. Harley. 2002. Status of bigeye tuna in the eastern Pacific Ocean in 2001 and outlook for 2002. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 3: 201-311.

Maunder, M. N. and S. J. Harley. 2003. Methodological improvements to the EPO tuna stock assessments. Sec. Pacif. Comm., Oceanic Fish. Prog., 16th meeting, Stand. Comm. Tuna Billfish, MWG-2: 26 p. (http://www.spc.org.int/OceanFish/Html/SCTB/SCTB16/mwg2.pdf)

Maunder M.N., S.J. Harley, and J. Hampton. 2006. Including parameter uncertainty in forward projections of computationally intensive statistical population dynamic models. ICES Jour. Mar. Sci. 63 (6): 969-979.

Maunder M.N. and S.D. Hoyle. 2006. Status of bigeye tuna in the eastern Pacific Ocean in 2004 and outlook for 2005. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 6: 103-206.

Maunder, M.N. and S.D. Hoyle. 2007. Status of bigeye tuna in the eastern Pacific Ocean in 2005 and outlook for 2006. Inter-Amer. Trop. Tuna Comm., Stock Assessment Report, 7: 117-248.

Maunder, M.N. and G.M. Watters. 2001. Status of yellowfin tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 1: 5-86.

Maunder, M.N. and G.M. Watters. 2003. A-SCALA: an age-structured statistical catch-at-length analysis for assessing tuna stocks in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull. 22: 433-582.

Methot, R. D. 2005. Technical description of the Stock Synthesis II assessment program. NOAA Fisheries. http://www.sefsc.noaa.gov/sedar/download/S16_AW_04.pdf?id=DOCUMENT

Methot, R. D. 2009. User manual for Stock Synthesis. Model Version 3.04b. NOAA Fisheries.

Nakamura, E.L. and J.H. Uchiyama. 1966. Length-weight relations of Pacific tunas. *In* Manar, T.A. (editor), Proc., Governor’s [Hawaii] Conf. Cent. Pacif. Fish. Resources: 197-201.

Okamoto, H. and W.H. Bayliff. 2003. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1993-1997. Inter-Amer. Trop. Tuna Comm., Bull. 22: 219-431.

Philander, S. G. 1990. El Niño, La Niña, and the Southern Oscillation. Academic Press, Inc. 293 pp.Reed, W.J. 1980. Age-specific harvesting in a nonlinear population model. Biometrics 36: 579-593.

Richards, F.J. 1959. A flexible growth function for empirical use. Jour. Exper. Botany, 10: 290-300.

Schaefer, K.M. 2009. Stock structure of bigeye, yellowfin, and skipjack tunas in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 9. 203-221.

Schaefer, K.M. and D.W. Fuller. 2006. Estimates of age and growth of bigeye tuna (*Thunnus obesus*) in the eastern Pacific Ocean, based on otolith increments and tagging data. Inter-Amer. Trop. Tuna Comm., Bull. 23: 33-76.

Schaefer, K. M., and D. W. Fuller. 2009. Horizontal movements of bigeye tuna (*Thunnus obesus*) in the eastern Pacific Ocean, as determined from conventional and archival tagging experiments initiated during 2000-2005. Inter-Am. Trop. Tuna Comm., Bull., 24: 189-248.

Schaefer, K. M., D. W. Fuller, and B. A. Block. 2009. Vertical movements and habitat utilization of skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), and bigeye (*Thunnus obesus*) tunas in the equatorial eastern Pacific Ocean, ascertained through archival tag data. *In* Nielsen, Jennifer L., Haritz Arrizabalaga, Nuno Fragoso, Alistair Hobday, Molly Lutcavage, and John Sibert (editors), 2009, Tagging and Tracking of Marine Animals with Electronic Devices. Springer: 121-144.

Schaefer, K.M., D.W. Fuller, and N. Miyabe. 2005. Reproductive biology of bigeye tuna (*Thunnus obesus*) in the eastern and central Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull. 23: 1-32.

Stocker, M. (editor). 2005. Report of the Ninteenth North Pacific Albacore Workshop. Nanaimo, B.C. Canada, Pacific Biological Station, Nanaimo, B.C.: 127 p. (http://www.dfompo.gc.ca/Library/315833.pdf)

Suda, A. and S. Kume. 1967. Survival and recruitment of bigeye tuna in the Pacific Ocean, estimated by the data of tuna longline catch. Nankai Reg. Fish. Res. Lab, Rep. 25: 91-104.

Sun, C, C. Huang, and S. Yeh. 2001. Age and growth of the bigeye tuna, *Thunnus obesus*, in the western Pacific Ocean. Fish. Bull. 99: 502-509.

Thompson, G.G. 1993. A proposal for a threshold stock size and maximum fishing mortality rate. Can. Spec. Publ. Fish. Aquat. Sci. 120: 303-320.

Tomlinson, P. 2002. Progress on sampling the eastern Pacific Ocean tuna catch for species composition and length-frequency distributions. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 2: 339-365.

von Bertalanffy, L. 1938. A quantitative theory of organic growth. Human Biology, 19(2):181-213.

Wang, S-P., M. Maunder and A. Aires-da-Silva. 2009. Implications of model and data assumptions: an illustration including data for the Taiwanese longline fishery into the eastern Pacific Ocean bigeye tuna (*Thunnus obesus*). Fish. Res. 99 (1-2): 118-126.

Watters, G.M. 1999. Geographical distributions of effort and catches of tunas by purse-seine vessels in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Data Rep. 10: 100 p.

Watters, G.M. and R. Deriso. 2000. Catch per unit of effort of bigeye tuna: a new analysis with regression trees and simulated annealing. Inter-Amer. Trop. Tuna Comm., Bull. 21: 527-571.

Watters, G.M. and M.N. Maunder. 2001. Status of bigeye tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 1: 109-210.

Watters, G.M. and M.N. Maunder. 2002. Status of bigeye tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Stock Assess. Rep. 2: 147-246.