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STATUS OF BIGEYE TUNA IN THE EASTERN PACIFIC OCEAN IN 2008 AND OUTLOOK FOR THE FUTURE

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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; Methot 2005, 2009). 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 stock assessment requires a substantial amount of information. Data on retained catch, discards, catch per unit of effort (CPUE), 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, CPUE, and length-frequency data for the surface fisheries have been updated to include new data for 2008. New or updated longline catch data are available for Chinese Taipei (2005-2007), the Peoples Republic of China (2007), and Japan (2003-2007).

Analyses were carried out to assess the sensitivity of results to: 1) a stock-recruitment relationship; 2) use of a Richards growth curve fit to age at length data derived from otolith data; 3) extending the assumed western limit of the bigeye stock distribution from 150°W to 170°E.

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 slightly. 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.

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 recruitment in 1994-1998, followed by a period of below-average recruitment in 1999-2000. The recruitments have been above average from 2001 to 2006, and were particularly large in 2005 and 2006. The 2007 recruitment was below average, but the recent recruitment in 2008 appears to be particularly high. 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 1975-1986, and reached its peak level of about 630 thousand metric tons (t) in 1986, after which it decreased to an historic low of 287 thousand t at the beginning of 2009. Spawning biomass has generally followed a trend similar to that for the biomass of 3+-quarter-olds, but lagged by 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 nearly stable with no trend for the last six years.

The estimates of biomass are moderately sensitive to the steepness of the stock-recruitment relationship, but the trends are very similar to the base case. The recruitment time series is similar to the base case.

When a Richards growth curve was used, the biomasses were lower than those obtained by base case model which assumes a von Bertalanffy growth function. However, the trends in the biomasses were very similar. The recruitment estimates were also very similar between the two models. The Richards growth curve provided a better fit to the fishery data when compared to the base case model.

When the assumed western limit of the bigeye stock distribution was extended from 150°W to 170°E, and the additional catch taken in the WCPO were included in the model, the recruitments and biomasses were greater than those estimated by the base case. However, the biomass estimates for most years became

lower than the base case when the model was also fit to the additional CPUE and size composition data from the WCPO.

At the beginning of January 2009, the spawning biomass of bigeye tuna in the EPO was near the historic low level. At that time the spawning biomass ratio (the ratio of the spawning biomass at that time to that of the unfished stock; SBR) was about 0.17, which is about 11% less than the level corresponding to the maximum sustainable yield (MSY).

Recent catches are estimated to have been 19% higher than 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 81% of the current (2006-2008) 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 15°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}.

All four scenarios considered suggest that, at the beginning of 2009, the spawning biomass (S) was below S_{MSY}. MSY and the F multiplier are sensitive to how the assessment model is parameterized, the data that are included in the assessment, and the periods assumed to represent average fishing mortality, but under all scenarios considered, fishing mortality is well above F_{MSY}. The management quantities derived from the base case model were the less pessimistic among all scenarios.

Recent spikes in recruitment are predicted to result in stabilized levels of SBR and increased longline catches for the next few years. However, high levels of fishing mortality are expected to subsequently reduce the SBR. Under current effort levels, the population is unlikely to remain at levels that support MSY unless fishing mortality levels are greatly reduced or recruitment is above average for several consecutive years.

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 are similar to the previous assessments;
2. There is uncertainty about recent and future recruitment and biomass levels;
3. The recent fishing mortality rates are well above those corresponding to the MSY and this result is consistent across various modeling scenarios;
4. The results from the base case model are the more optimistic among the various modeling scenarios investigated;
5. The results are more pessimistic if a stock-recruitment relationship is assumed;
6. Assuming a more flexible Richards growth curve improved the model fit to the fishery data. This alternative model could potentially be considered as the base case model in future assessments;
7. The assessment results are more pessimistic if the western limit of the bigeye stock distribution is extended from 150°W to 170°E.

2. DATA

Catch, effort, and size-composition data for January 1975 through December 2008 were used to conduct the stock assessment of bigeye tuna, *Thunnus obesus*, in the eastern Pacific Ocean (EPO). The data for 2008, which are preliminary, include records that had been entered into the IATTC databases as of mid-March 2009. All data are summarized and analyzed on a quarterly basis.

2.1. Definitions of the fisheries

Fifteen fisheries are defined for the stock assessment of bigeye tuna. These fisheries 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 (numbers caught or catch in weight).

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, fisheries are defined so that, over time, there is little change in the average size composition of the catch. Fishery definitions for purse-seine sets on floating objects are also stratified to provide a rough distinction between sets made mostly on 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 ahead in section 4) has the flexibility of including catch data in either numbers or weight, four longline fisheries are defined: two fisheries with catch reported in numbers caught (Fisheries 8 and 9), and two additional longline fisheries that report catch in weight (Fisheries 14 and 15).

2.2. Catch

To conduct the stock assessment of bigeye tuna, the catch and effort data in the IATTC databases are stratified according to the fishery definitions described in Section 2.1 and presented in Table 2.1. The three definitions relating to catch data used in previous reports (landings, discards, and catch) are described by Maunder and Watters (2001). The terminology 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 the document the term "catch" will be used to reflect either total catch (retained catch plus discards) or retained catch, and the reader is referred to the context to determine the appropriate definition.

Three types of catch data are used to assess the stock of bigeye tuna (Table 2.1). Removals by Fisheries 1 and 8-9 are simply retained catch. Removals by Fisheries 2-5 and 7 are retained catch, plus some discards resulting from inefficiencies in the fishing process (see Section 2.2.1). Removals by Fisheries 10-13 are discards resulting only from sorting the catch taken by Fisheries 2-5 (see Section 2.2.1).

Updated and new catch data for the surface fisheries (Fisheries 1-7 and 10-13) 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 8-9 and 14-15) are available for Chinese Taipei (2005-2007), the Peoples Republic of China (2007), and Japan (2003-2007). Catch data for 2008 are available for Chinese Taipei, the Peoples Republic of China, the Republic of Korea, Japan, 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 1975-2008 period are shown in Figure 2.2a. The annual catch trends for the combined surface fleet (Fisheries 1-7 and 10-13) and longline fleet (fisheries 8-9 and 14-15) are also shown (Figure 2.2b). There has been substantial annual variation in the catches of bigeye by all fisheries operating in the EPO (Figure 2.2a). Prior to 1996, the longline fleet (Fisheries 8-9) removed more bigeye (in weight) from the EPO than did the surface fleet (Fisheries 1-7 and 10-13) (Figure 2.2b). 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 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 IATTC or national observers, 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 discard rate for the same quarter of the previous year or, if not available, the closest year.

Discards that result from the process of sorting the catch are treated as separate fisheries (Fisheries 10-13), 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 largest floating-object fisheries (2, 3, and 5 with corresponding discard fisheries 10, 11, 13), 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 the weaker year classes than the 1997 year class. However, recruitments since 1997 have been larger 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.

It is assumed that bigeye tuna are not discarded from longline fisheries (Fisheries 8-9 and 14-15).

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 and 10-13) have been updated and new data included for 2008. New or updated catch and effort data are available for the Japanese longline fisheries (2005-2007). 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.

The CPUE for the purse-seine fisheries (class-6 vessels) was calculated as catch divided by number of days fished. The number of days fished by set type was calculated 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 catch per unit effort (1975-2007) were obtained for the longline fisheries (Fisheries 8 and 9). 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 8 and 9 (longline fisheries). The fisheries excluded were considered inappropriate because the catch rates were extremely low (Fishery 1) or because they combined gears (PS and LP; Fisheries 6 and 7). In addition, the first two years of the purse-seine fisheries were excluded because these fisheries were still expanding.

2.4. Size composition data

New length-frequency data for 2008 and updated data for previous years are available for the surface fisheries. New or updated length-frequency data are available for the Japanese longline fleet (2007-2008). Size composition data for the other longline fleets are not used in the assessment.

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 large fish dominated the catch.

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 long) bigeye have been captured in unassociated schools (Figure 2.6c, Fishery 7). The catches taken by the two longline fisheries (Fisheries 8 and 9) have distinctly different size compositions. In the area north of 15°N (Fishery 8), 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 area south of 15ºN (Fishery 9), longliners catch substantial numbers of both medium-sized and large bigeye (Figure 2.6c). However, there appears to have been a transition from medium to large fish in about 1984.

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). Maunder and Hoyle (2007) conducted a sensitivity analysis, using the Chinese Taipei fleet as a separate fishery. Also, a sensitivity analysis to assuming the Taiwanese fishery as a separate entity, rather than combining data for that fishery with those for other longline fisheries, as in this assessment, was made (Wang *et al.*, 2009).

2.5. Auxiliary data

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

3. ASSUMPTIONS AND PARAMETERS

3.1. Biological and demographic information

3.1.1. Growth

Schaefer and Fuller (2006) used both tag-recapture data and otolith daily increments to estimate growth curves for bigeye tuna in the EPO. The two data sources provided similar estimates, with an apparent bias in the tagging data, which is hypothesized to be due to shrinkage because the recaptured bigeye tuna were measured at unloading (after they had been stored frozen). The growth curve estimated by Schaefer and Fuller (2006) is substantially different from the growth curves used in previous assessments. In particular, it shows growth to be approximately linear, and produces larger fish for a given age. The asymptotic length of the von Bertalanffy growth curve estimated by Schaefer and Fuller (2006) is much greater than any length recorded. This is reasonable as long as no biological meaning is given to the asymptotic length parameter and that the model is used only as a representation of the ages of fish that they sampled. The maximum age of the bigeye tuna in their data set is around 4 years (16 quarters) and their von Bertalanffy growth curve is not considered appropriate for ages greater than this. Maunder and Hoyle (2006) fit a Richards growth curve, using a lognormal likelihood function with constant variance and the asymptotic length parameter set at about the length of the largest-sized bigeye in the data (186.5 cm). Maunder and Hoyle (2007) used the resulting growth curve as a prior for all ages in the stock assessment. .

Previous assessments (*e.g.* Harley and Maunder 2005), the EPO yellowfin tuna assessments (*e.g.* Maunder 2002), and tuna assessments in the western and central Pacific Ocean (Lehodey *et al*. 1999; Hampton and Fournier 2001a, 2001b) suggest that the growth of younger tuna does not follow a von Bertalanffy growth curve. However, this observation may be a consequence of length-specific selectivity for small fish.

In the two previous stock assessments for bigeye (Aires-da-Silva and Maunder 2007, 2009), the length-at-age used in the assessment model was based on the von Bertalanffy growth curve. This was mainly due to a Richards function not being available yet in Stock Synthesis (Version 2). The parameters of the von Bertalanffy growth curve were estimated by obtaining the best correspondence of length-at-age used by Maunder and Hoyle (2007). The current assessment assumes the same von Bertalanffy growth function for bigeye which was adopted in the two previous assessments (Figure 3.1). However, a Richards growth curve is now available in Stock Synthesis (Version 3). Hence, a sensitivity analysis using the recently implemented Richards growth function was made (see Section 4.1 ahead).

Hampton and Maunder (2005) found that the results of the stock assessment are very sensitive to the assumed value for the asymptotic length parameter. Therefore, Maunder and Hoyle (2007) conducted sensitivity analyses to investigate the influence of the assumed value of that parameter. A lower value of 171.5 cm, which is around the value estimated by stock assessments for the western and central Pacific Ocean (Adam Langley, Secretariat of the Pacific Community, pers. com.), and an upper value of 201.5 cm were investigated. A sensitivity analysis of the bigeye assessment to these same two values was also conducted by Aires-da-Silva and Maunder (2007). A lesser value of the asymptotic length parameter produced greater biomasses and recruitments.

Another important component of growth used in age-structured statistical catch-at-length models is the variation in length at age. Age-length information contains information about variation of length-at-age, in addition to information about mean length-at-age. Variation in length-at-age was taken from the previous assessment. .

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 the previous assessment, 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 age-specific proportions of females, maturity at age, and natural mortality estimates 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) (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, a series of sensitivity analyses evaluating the effect of various alternative scenarios of natural mortality on the bigeye stock assessment was conducted in 2008 (SARM-9-INF-B[1]). The management quantities showed little sensitivity when higher levels of *M* were assumed for young fish 0-5 quarters of age. In contrast, the management quantities showed higher sensitivity to the assumption made about the oldest of the young ages included in the early high levels of *M*. However, high levels of *M* assumed for bigeye 5-12 quarters (60-120 cm) old seem unrealistic.

An ongoing investigation on natural mortality rates for bigeye tuna based on an integrated analysis including tagging and sex ratio data indicate higher levels of *M* for adult bigeye than previously assumed. Preliminary results of this research, and a sensitivity analysis to assuming different *M* levels for adult fish, are presented elsewhere (SARM-10-11).

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. We also present a sensitivity analysis with steepness = 0.75. In addition to the assumptions required for the stock-recruitment relationship, a constraint on quarterly recruitment deviates with a standard deviation of 0.6 is applied. Recruitment is modeled at age-0

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

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. A spatially-structured framework will be considered in future stock assessments.

3.1.5. Stock structure

Document SARM-9-08 provides 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 2008). 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, and that there is no net exchange of fish between these regions. The IATTC staff currently 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).

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 conduced (see section 4.1.5 ahead).

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. 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 Fishery 3 only. It was found that including this effect did not greatly improve 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 to 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).

Considering the results from previous sensitivities described above, no environmental index was incorporate into this assessment. However, an external correlation analysis was made between various environmental indices and the estimated time series of quarterly recruitments (see Section 4.1.2 ahead)

4. STOCK ASSESSMENT

The Stock Synthesis method (SS - Version 3; 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 10-13) one quarter after hatching, and these discard fisheries catch only fish of the first few age classes.
2. As bigeye tuna age, they become more vulnerable to longlining in the area south of 15°N (Fisheries 9 and 14) and Fishery 7, and the oldest fish are the most vulnerable to these gears.
3. The data for fisheries that catch bigeye tuna from 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 10-13) provide relatively little information about biomass levels, because they 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
2. Recruitment in every quarter from the first quarter of 1975 through the fourth quarter of 2008 (includes estimation of virgin recruitment and temporal recruitment anomalies);
3. Catchability coefficients for the five CPUE time series that are used as indices of abundance (floating-object Fisheries 2, 3, 5 and longline Fisheries 8 and 9).
4. Coefficient of variation (CV) for the five CPUE indices that are used as indices of abundance (Fisheries 2,3, 5, 8 and 9)
5. Selectivity curves for 9 of the 15 fisheries (Fisheries 10-13 have an assumed selectivity curve, and the selectivities of Fisheries 14 and 15 are the same as those of Fisheries 8 and 9, respectively);
6. Initial population size and age structure.

The parameters in the following list 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 10-13);
4. The steepness of the stock-recruitment relationship;
5. Parameters of a linear model relating the standard deviations in length at age to the mean lengths-at-age.

The estimates of management quantities and future projections were computed based on 3-year average fishing mortality rates, by gear, for 2006-2008. The sensitivity of estimates of key management quantities to including the last year (2007) in the 3-year average fishing mortality rate estimate was tested. For this purpose, a 2-year (2006-2007) 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 coefficients of variation (CVs). The confidence intervals and CVs have been estimated under the assumption that the stock assessment model perfectly represents the dynamics of the system. Since it is unlikely that this assumption is satisfied, these values may underestimate the amount of uncertainty in the results of the current assessment.

4.1. Assessment results

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

1. Base case assessment: steepness of the stock-recruitment relationship equals 1 (no relationship between stock and recruitment), CPUE time series for the floating-object Fisheries 2-5 and the longline Fisheries 8-9, time-invariant size selectivities for the different fisheries.
2. Sensitivity to the steepness of the stock-recruitment relationship. The base case assessment included an assumption that recruitment was independent of stock size, and a Beverton-Holt (1957) stock-recruitment relationship with a steepness of 0.75 was used for the sensitivity analysis.
3. Sensitivity to the assumed growth function. The base case assessment assumed a von Bertalanffy growth equation for bigeye in which the parameters were fixed. New features in Stock Synthesis (Version 3) allow more flexibility in modeling growth and a Richards curve is now available. A sensitivity analysis was made to estimating growth by fitting the Richards curve to age-at-length observations derived from otolith readings. The parameters of the Richards curve equation were estimated from the otolith data. The asymptotic length parameter was fixed at about the largest-sized bigeye observed in the data (186.5 cm, Maunder and Hoyle 2007).
4. Sensitivity to an alternative assumption about the western limit of the bigeye stock distribution. As in the previous assessments, the base case model assumed a western limit of 150° W for the bigeye stock distribution. This limit was extended to 170°E. As a result, this sensitivity analysis included the additional bigeye catch taking place in regions 2, 4 and 6 of the WCPO (Langley *et al.* 2008; see also Figure C.1). Two analyses were made with the additional WCPO data: 1) fit to the CPUE and size composition data from the WCPO; 2) do not fit to the WCPO, share selectivities of the WCPO fisheries with EPO fisheries catching fish of similar sizes.

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 since 1993, and that on fish more than about 15 quarters old has increased slightly since then (Figure 4.1). The increase in average fishing mortality on younger fish can be attributed to the expansion of the fisheries that catch bigeye in association with floating objects. These fisheries (Fisheries 2-5) 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 (see 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, and only slightly for older fish, since about 1993. An annual summary of the estimates of total fishing mortality is presented in Appendix D (Table D.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 4.4a). 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 produces a model with a weak 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 moderately related to stock size (steepness = 0.75).

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. There was a period of above-average recruitment in 1994-1998, followed by a period of below-average recruitment in 1999-2000. The recruitments have been above average from 2001 to 2006, and were particularly large in 2005 and 2006. The recruitment in 2007 was below average recruitment. The 2008 recruitment estimate is above the average recruitment level. 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.

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-present). This shift coincided with the expansion of the fisheries that catch bigeye in association with floating objects. A series of possible hypothesis explaining this pattern is presented elsewhere (SARM-9-INF-B[2]). The impact on the bigeye assessment results from 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).

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 1983-1984, and reached its peak level of about 630,249 t in 1986, after which it

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

decreased to an historic low of about 287,090 t at the beginning of 2009.

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 for 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 were estimated to have been stable with no trend over the last six years.

There is uncertainty in the estimated biomasses of spawners. The average CV of the spawning biomass estimates is 0.13.

Given the amount of uncertainty in the estimates of both biomass and recruitment (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 fishing mortality or recruitment. Nevertheless, the assessment suggests two conclusions. First, 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, using the time series of estimated recruitment anomalies, and the estimated environmental effect, in the absence of fishing. The simulated biomass estimates are always greater than the biomass estimates from the base case assessment (Figure 4.8). Second, 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).

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 is done in the no-fishing simulation. The results of this analysis are also provided 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 17% of that expected had no fishing occurred.

4.1.4. Average weights of fish in the catch

Trends in the average weights of bigeye captured 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 (see Maunder and Hoyle 2007). The average weight of bigeye taken by the longline fisheries (Fisheries 8 and 9) has been around the critical weight, which indicates that this fishery tends to maximize the yield per recruit (see Maunder and Hoyle 2007). The average weight for all fisheries combined declined substantially after 1993 as the amount of purse-seine effort on floating objects increased.

The average weight in both 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 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. 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 fixed selectivity curves and estimated harvest rates for each fishery to estimate the average weight.

4.2. Comparisons to external data sources

No comparisons to external data were made in this assessment.

4.3. Diagnostics

Diagnostics are discussed in two sections: residual and retrospective analysis.

4.3.1. Residual analysis

The model fits to the CPUE data from different fisheries are presented in Figure 4.10. As expected, the model fits the southern longline CPUE observations closely. The fits to the other CPUE data series are less satisfactory.

Pearson residual plots are presented for the model fits to the length composition data (Figures 4.11a to 4.11c). The gray and black circles represent observations that are less and greater than the model predictions, respectively. The area of the circles is proportional to the absolute value of the residuals. There are several notable characteristics of the residuals. The model overestimates the large and small fish for the post-1993 floating-object fisheries. In particular, it overestimates the large fish during 1999-2002, when a strong cohort moved through the fishery. Conversely, the model overestimates medium-sized fish for the southern longline fishery (Fishery 8). This overestimation is centered around 80 cm prior to 1988 and then increases to 180 cm, indicating a change in selectivity. Aires-da-Silva and Maunder (2007) conducted a sensitivity analysis in which two time blocks were considered for the selectivity and catchability of the southern longline fishery. The residual pattern of the model fit to the size composition data for this fishery was improved. The model fitted the southern longline CPUE index of abundance very closely. However, the biomasses during the early part of the historical period were less than those estimated by the base case assessment. The described residual pattern for the southern longline fishery may also be attributed to a spatial misspecification issue. Alternative spatial definitions should be explored.

The average fits to the observed size compositions of the catches taken by fisheries defined in the stock assessment model are shown in Figure 4.11d. The mode fits to the size 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 Fishery 9 better (CV = 0.17) than those for other fisheries. The worst fits to the CPUE data are those for Fisheries 3 (CV = 0.54) and 5 (CV = 0.55), followed by Fishery 2 (CV = 0.30). With respect to the length-frequency data, and except for Fisheries 6 and 7, 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 the last 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 analysis, and the assumption that the use of more data improves the estimates, can be used to determine if there are consistent biases in the estimates.

Retrospective analyses were conducted by removing one year (2008), two years (2008 and 2007), three years (2008, 2007, 2006) and four years (2008, 2007, 2006, 2005) of data (Figures 4.12-4.14). The retrospective analyses show an increase in the summary biomass over 2005, 2006, 2007, and 2008 whereas the base case shows a nearly stable trend over the same period (Fig 4.12). This corroborates the results of previous retrospective analyses, which show that the recent estimates of biomass are subject to retrospective bias (Harley and Maunder 2004; Aires-da-Silva and Maunder 2007). In contrast, the recent levels of the spawning biomass ratio (SBR) show little effect of retrospective bias (Fig 4.13). The higher levels bias found for the summary biomass are not surprising given the strong dependence of this quantity on recent recruitment levels, which are also found to be highly subject to recent retrospective bias (Figure 4.14). Although the trends in the biomasses are the same, in general, the retrospective analysis shows that the biomass estimates from the base case model are lower than those estimated when the last years of data are not incorporated in the model. Retrospective bias does not necessarily indicate the magnitude and direction of the bias in the current assessment, just that the model may be misspecified.

4.4. Sensitivity analyses

The results from the three sensitivity analyses are presented in the appendices: sensitivity to the stock–recruitment relationship (Appendix A), use of a Richards growth function to model growth (Appendix B), and extending the assumed western limit of the bigeye stock distribution from 150°W to 170°E (Appendix C). Here we describe differences in model fit and model prediction, and defer our discussion of differences in stock status until Section 5. A comparison table 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 equal to 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. The recruitment time series is similar to the base case (Figure A.2). The trends in the SBR are very similar between the base case and the model assuming a stock recruitment relationship, but the SBR levels are slightly higher for the base case (Figure A.3). The estimated stock-recruitment relationship is presented in Figure A.4.

The base case model used a von Bertalanffy growth function fitted to length at age data derived from otolith readings. A sensitivity run was conducted in which a Richards growth curve was fitted to length at age data (Figure B.1). There was an improvement in the model fit to all data components when a Richards growth curve was assuming (total likelihood improvement of 87.26 units; Table 4.3a). The estimated summary biomass trends for the sensitivity analysis and the base case model are very similar, but the biomass levels obtained when assuming a Richards growth were lower (Figure B.2). The recruitment estimates are also very similar for both models (Figure B.3). The trends in the SBR are very similar between the base case and the model assuming a Richards growth curve, but the SBR levels are slightly higher for the base case (Figure B.3)

The assumed western limit of the bigeye stock distribution was extended from 150°W to 170°E (Figure C.1). When the stock assessment model was fit the CPUE and size composition data of the fisheries operating in regions 2, 4, and 6 of the WCPO, in addition to fitting to the EPO data, the summary biomasses were slightly lower in most years than those estimated by the base case model (Figure C.3). Not fitting to the data from the WCPO fisheries resulted in higher biomass levels, but the relative trends are very similar to the base case estimates (Figure C.3). The sensitivity analyses resulted in higher estimates of recruitment (Figure C.4.a) when compared to the base case. This result is expected given the higher catch levels which resulted from addition of the WCPO catch data. The relative recruitment trends, however, are very similar (Figure C.4b). Although with similar relative trends, the SBR levels obtained when fitting to the WCPO fishery data are much lower than those derived from the base case and the model not fitting to the WCPO data (Figure C.5). This result is likely due to differences in the selectivity curves which resulted from fitting to the size composition data of the WCPO rather than sharing selectivities with the EPO fisheries (Figure 6). Also shown in Appendix C are the estimated average model fits to size composition data (Figures C7.a,b), and the model fits to CPUE time series (Figures

C8.a,b) for both WCPO data sensitivity analyses.

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).

4.5. Comparison to previous assessments

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 2008) are very similar in absolute terms. The minor absolute differences in the biomasses in the more recent years are likely due to the new data. The trends in the SBRs are also very similar, with absolute differences that are very minor during the post-2000 period (Fig. 4.17).

The recruitments estimated by the current assessment are slightly lower than the estimates from the previous assessment, particularly in 2006 and 2007 (Figure 4.18a). The differences found for relative recruitment were also minor(Figure 4.18b).

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 slightly since then. 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 recruitment in 1994-1998, followed by a period of below-average recruitment in 1999-2000. The recruitments have been above average from 2001 to 2006, and were particularly large in 2005 and 2006. The most recent recruitment of 2008 appears to be above 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 1975-1986, and reached its peak level of 630,249 t in 1986, after which it decreased to an historic low of 287,090 t at the beginning of 2009. Spawning biomass has generally followed a trend similar to that for the biomass of 3+-quarter-olds, but lagged by 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 were estimated to have been stable with no trend for the last six years.

The estimates of summary biomass are only 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 recruitment time series is similar to the base case.

When a Richards growth curve was assumed, the summary biomasses were lower than those obtained by base case model which assumes a von Bertalanffy growth curve. However, the relative trends in the summary biomasses were very similar. The recruitment estimates are also very similar for both models. The trends in the SBR are very similar between the base case and the model assuming a Richards growth curve, but the SBR levels are slightly higher for the base case. Assuming a Richards curve improved the model fit to the data.

When the assumed western limit of the bigeye stock distribution was extended from 150°W to 170°E, and the catch by the fisheries in the corresponding regions of the WCPO were included in the model, the recruitments and summary biomasses were higher than those estimated by the base case. The SBR trajectories were very similar. The SBR levels decreased substantially when the stock assessment model was also fitted to CPUE and size composition data from the WCPO regions added to the base case model.

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.

Precautionary reference points, as described in the FAO Code of Conduct for Responsible Fisheries and the United Nations Fish Stocks Agreement, are being widely developed as guides for fisheries management. 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 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 spawning biomass at that time 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 of 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 (1975-2008) 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 2009, the spawning biomass of bigeye tuna in the EPO was near the historical low level (Figure 4.7). At that time the SBR was about 0.17, 10% less than the level corresponding to the MSY (Figure 5.1).

At the beginning of 1975, the SBR was about 0.27 (Figure 5.1), which is consistent with the fact that bigeye was being 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 increased, particularly during 1984-1986, and by the beginning of 1987 was 0.46. 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 time (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, Fishery 9). 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 and the large catches from surface fisheries and increased longline catches. Over time, the SBR shows a trend similar to that of the previous assessment (Figure 4.17).

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 2006 and 2008. Therefore, while these MSY-based results are currently presented as point estimates, there are uncertainties in the results.

At the beginning of January 2008, the spawning biomass of bigeye tuna in the EPO appears to have been about 10% less than S_{MSY}, and the recent catches are estimated to have been about 8% 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 81% of 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 recruiting cohorts. 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 (calculated 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 22% less. If bigeye were caught only by the longline fishery the MSY would about 111% greater than that estimated for all gears combined. To achieve this MSY level longline effort would need to be increased by 320%.

The MSY-related quantities vary as the size composition of the catch varies. The evolution of four of these over the course of 1975-2007 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 2005-2006, it is 416 t (0.5%) less than the base case.

Figure 5.3 shows the historical time series of exploitation rates, spawning biomass and summary biomasses relative to the MSY reference points. Overall, the reference points have not been exceeded until recent years. The five most recent estimates indicate that the bigeye stock in the EPO is probably overexploited ($S < S_{MSY}$) and that overfishing is taking place ($F > F_{MSY}$); the confidence intervals on spawning biomass straddle the MSY level.

5.3. Sensitivity to alternative parameterizations and data

Yields and reference points are moderately 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 model with a steepness of 0.75 estimated the SBR required to support the MSY to be at 0.29, compared to 0.19 for the base case assessment (Table 5.1). The sensitivity analysis for steepness estimates an F multiplier (0.54) considerably less than that for the base case assessment (0.81). All analyses estimate the current SBR to be less than SBR_{MSY} and F multipliers that are less that 1 ($F > F_{MSY}$). The management quantities derived from the base case model (S_{recent}/S_{MSY} and Fmultiplier) provide the less pessimistic scenario among different analyses.

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 2008, the spawning biomass of bigeye tuna in the EPO was near the historic low level (Figure 5.1). At that time the SBR was about 0.17, about 10% less than the level corresponding to the MSY.

Recent catches are estimated to have been about 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 81% of the current (2006-2008) 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 15°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).

All analyses indicate that, at the beginning of 2009, the spawning biomass was probably below S_{MSY} (Tables 5.1 and 5.2). The MSY and the F multiplier are sensitive to how the assessment model is parameterized, the data that are included in the assessment, and the periods assumed to represent average fishing mortality, but under all scenarios considered, fishing mortality is well above F_{MSY}.

6. SIMULATED EFFECTS OF FUTURE FISHING OPERATIONS

A simulation study was conducted to gain further understanding as to how, in the future, hypothetical changes in the amount of fishing effort exerted by the tuna fisheries in the EPO might simultaneously affect the stock of bigeye tuna in the EPO and the catches of bigeye by the various fisheries. Different scenarios were constructed to define how the various fisheries that take 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 with exploitation rates equal to the average for 2006-2008. 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.

6.1. Assumptions about fishing operations

6.1.1. Fishing effort

Future 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 mortality rates for each year in the future were set equal to the average rates from 2006 to 2008, to simulate that fishing mortality rates are maintained at current levels (F_{cur}) – a *status quo* exploitation strategy.
2. An additional analysis was carried out that estimates the population status if fishing effort is reduced 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 8-9 and 14-15). There is probably more uncertainty in the future levels of these outcome variables than is suggested by the results presented in Figures 6.1-6.4. 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 and 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 2006-2008 levels.

SBR is estimated to have increased slightly and remained stable since 2005 (Figure 5.1). This increase is attributed to two spikes in recent recruitment (Figure 4.5b). If recent levels of effort and catchability continue, the SBR is predicted to remain nearly stable at about 0.16 within the next few years (2009-2012), and then to decline to around 0.12 in 2019. During that period (2009-2019), SBR would not increase above the level that would support MSY (0.19) under a *status quo* strategy (Figure 6.1a). Similarly, the spawning biomass is estimated to remain stable within the next couple of years, but it will probably decline in the future (Figure 6.2). These results are similar to the projections for the “no resolution” scenario obtained in the two most recent assessments (Aires-da-Silva and Maunder 2007, 2009).

Under the *status quo* scenario and the assumption of no stock-recruitment relationship, purse-seine catches are predicted to decline from 2009-2012 and then stabilize around 60,000 t in 2013 (Figure 6.3, left panels). Under current effort, longline catches are predicted to increase moderately to around 30,000 t within 2009-2011, but then decline to around 22,000 t in 2018 (Figure 6.3, right panels). The catches would not stabilize and continuously decline if a stock-recruitment relationship was included, due to reductions in the levels of recruitment that contribute to purse-seine catches.

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 from an exploitation strategy targeting MSY, we projected the population forward 10 years, assuming the fishing mortality rates (fishing effort) corresponding to MSY (F_{MSY}). Projected catches at F_{MSY} are lower to the levels obtained at F_{cur} in 2009 and 2010 (Figure 6.3, lower panels). Afterwards, the catches would stabilize at levels that are very similar to those obtained at F_{cur} (around 60,000 t and 25,000 t for the surface and longline fisheries, respectively). However, the SBR levels corresponding to MSY which would be attained (0.19), are much higher than those attained if the current fishing mortality rates persist in the future (0.12) (Figure 6.4).

6.2.3. 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 result in stabilized levels of SBR and increased longline catches for the next few years (2009-2011). However, high levels of fishing mortality are expected to subsequently reduce SBR. Under current effort levels, the population is unlikely to remain at levels that support MSY unless fishing mortality levels are greatly reduced or recruitment is above average for several consecutive years.

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 longline catch and effort data for 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. Make it easier to run projections with fixed harvest rates.
2. Re-evaluate the definitions of fisheries.
3. Determine appropriate weighting of the different data sets.
4. Include available tagging data in the assessment.
5. Explore alternative assumptions on stock structure (spatial analysis)

Collaboration with staff members of the Secretariat of the Pacific Community on the Pacific-wide bigeye model will continue.

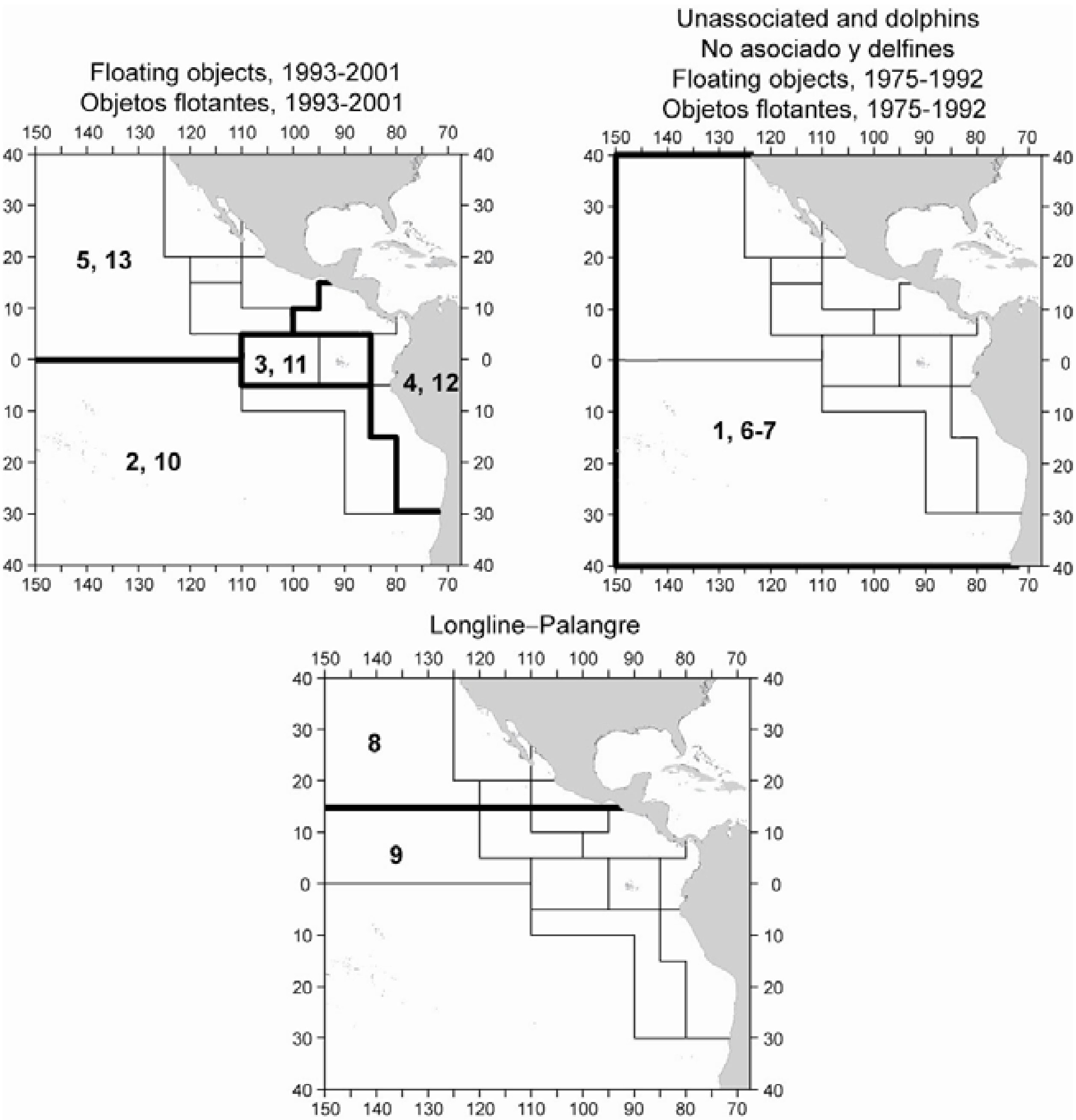

FIGURE 2.1. Spatial extents of the fisheries defined for the stock assessment of bigeye tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the bold numbers the fisheries to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

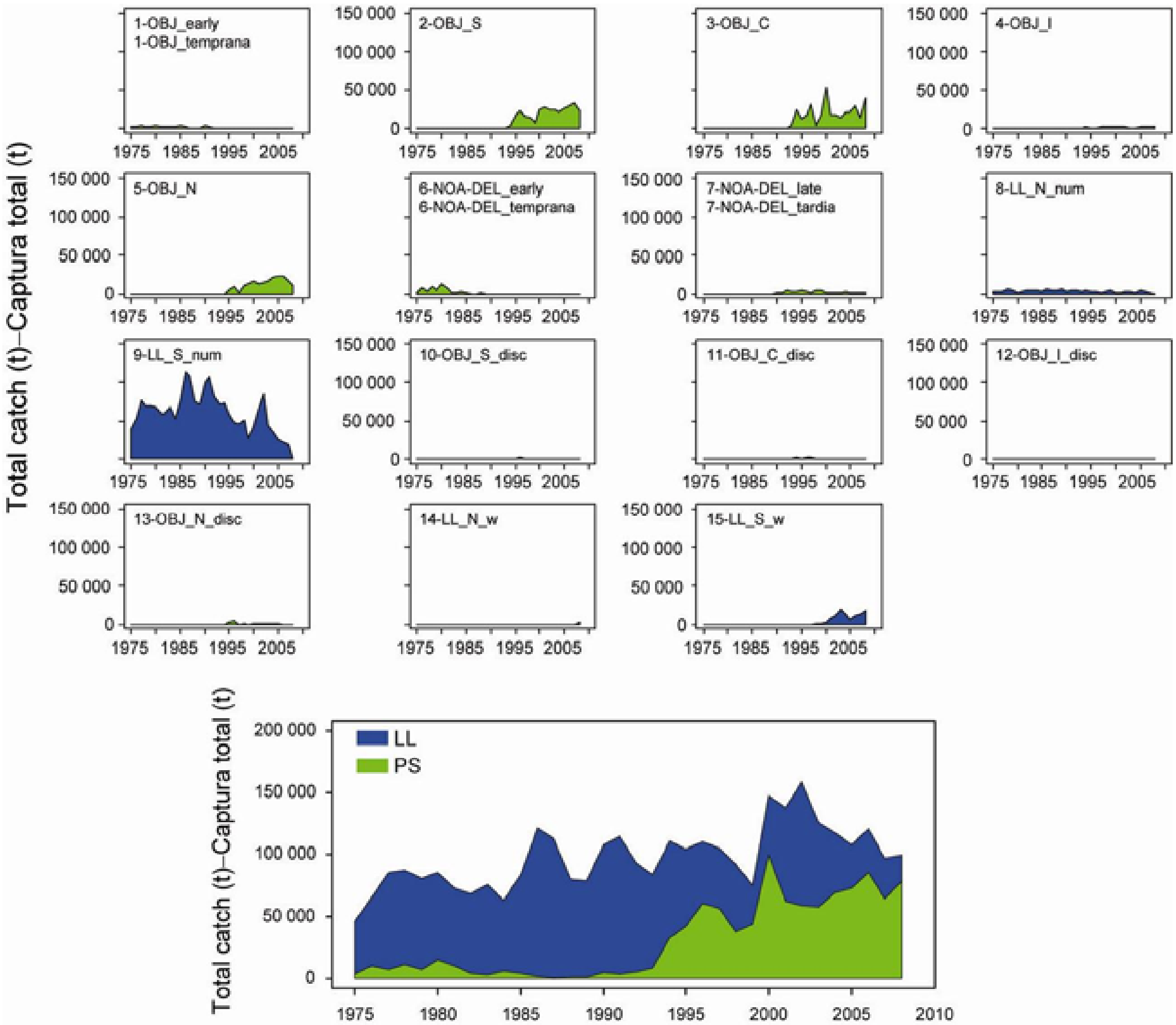

FIGURE 2.2. Annual catches of bigeye tuna taken by the fisheries defined for the stock assessment of that species in the EPO (Table 2.1). Although all the catches are displayed as weights, the stock assessment model uses catches in numbers of fish for Fisheries 8 and 9. Catches in weight for Fisheries 8 and 9 were estimated by the stock assessment model. LL = longline; PS = purse seine; t = metric tons.

FIGURA 2.2. Capturas anuales de atún patudo realizadas por las pesquerías definidas para la evaluación de la población de esa especie en el OPO (Tabla 2.1). Aunque se presentan todas las capturas como pesos, el modelo de evaluación usa capturas en número de peces para las Pesquerías 8 y 9. Se estimaron las capturas en peso para las Pesquerías 8 y 9 multiplicando las capturas en número de peces por estimaciones del peso medio. LL = palangre; PS = red de cerco; t = toneladas métricas.

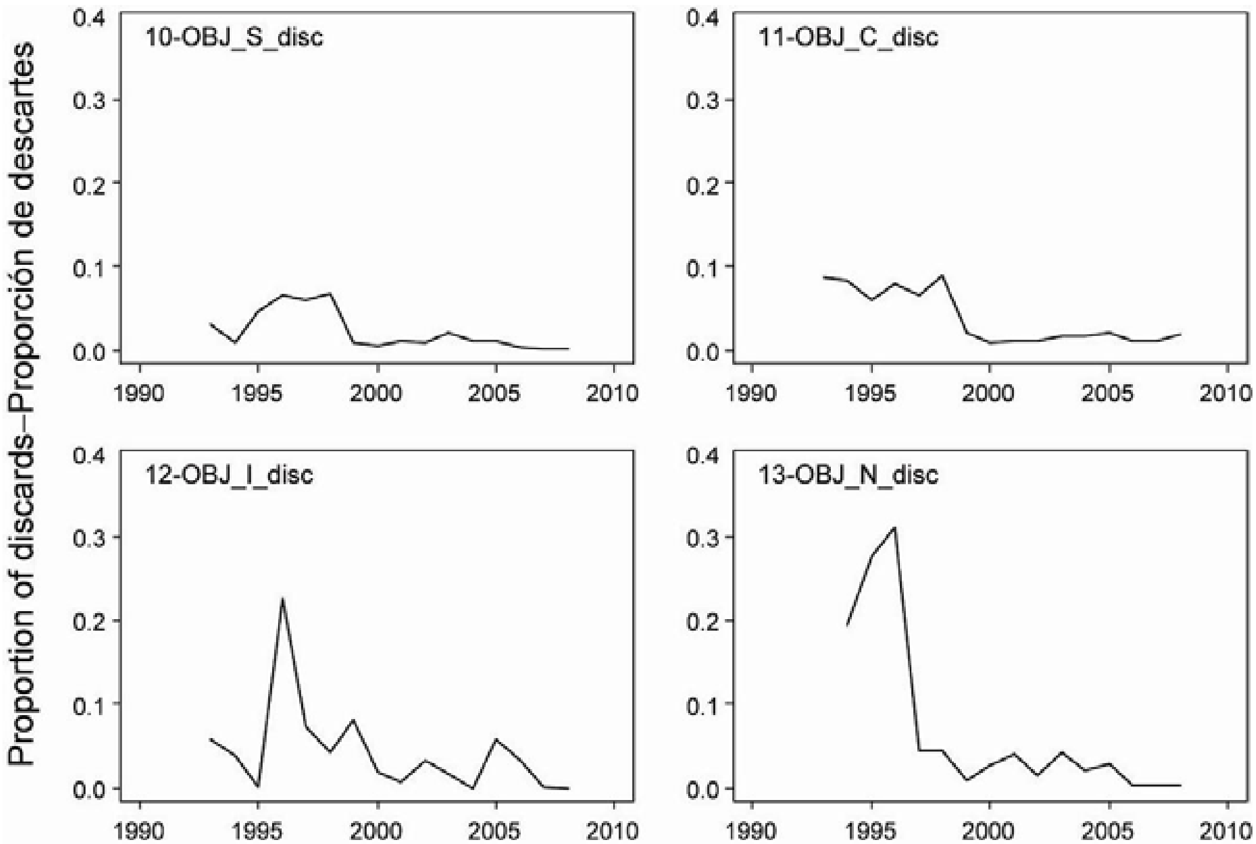

FIGURE 2.3. Weights of discarded bigeye tuna as proportions of the total (retained plus discarded) annual catches for the four floating-object fisheries. Fisheries 2-5 are the "real" fisheries, and Fisheries 10-13 are the corresponding discard fisheries.

FIGURA 2.3. Pesos de atún patudo descartado como proporción de las capturas anuales retenidas de las cuatro pesquerías sobre objetos flotantes. Las pesquerías 2-5 son las pesquerías "reales", y las Pesquerías 10-13 las pesquerías de descarte correspondientes.

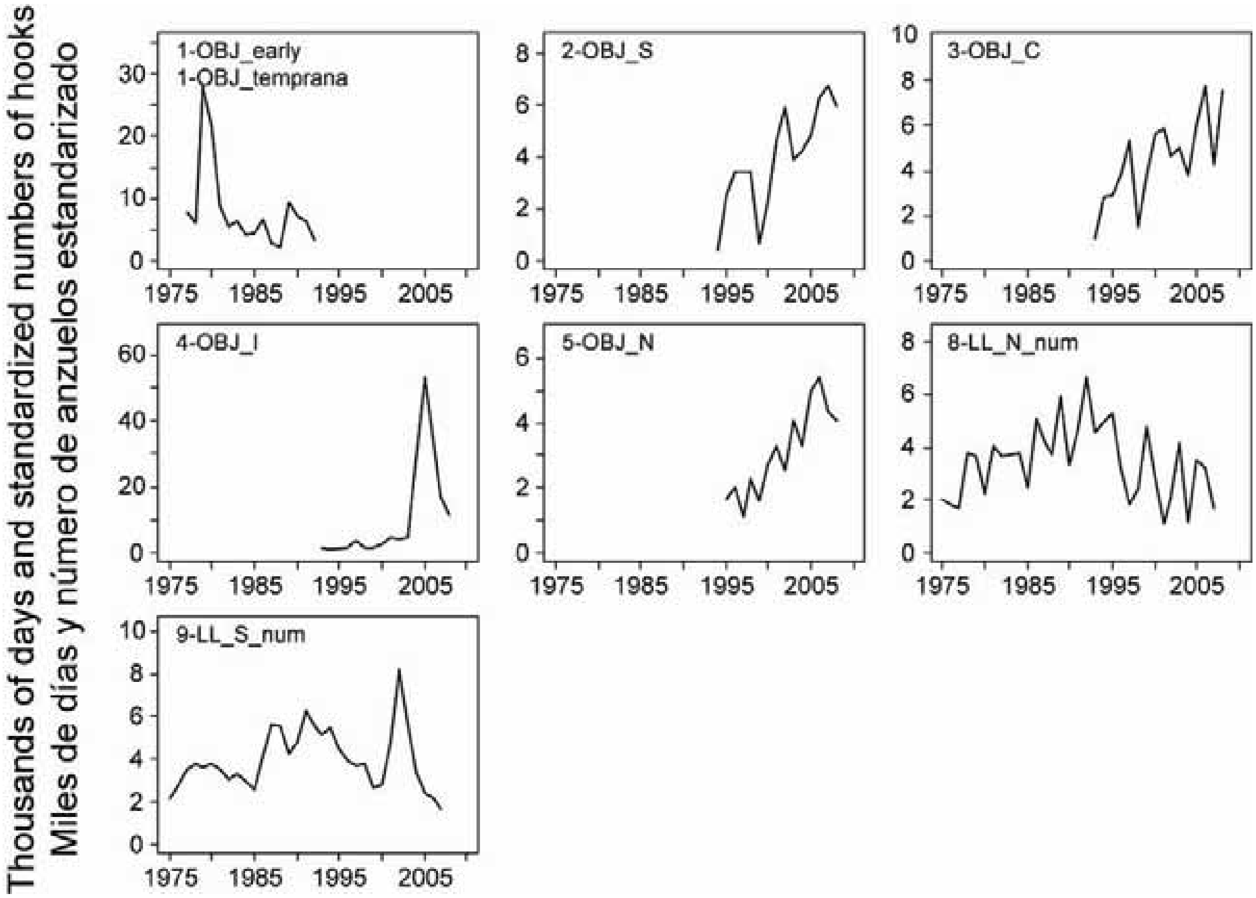

FIGURE 2.4a. Annual fishing effort by class-6 vessels in the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). The effort for Fisheries 1-5 is in days fished, and that for Fisheries 8-9 in standardized numbers of hooks. Fishing effort is not shown for Fisheries 6 and 7, since two gears (purse seine and pole-and-line) were combined for these fisheries. Fishing effort for the discard fisheries (10-13) is that of their corresponding 'real' fisheries (2-5). Note that the vertical scales of the panels are different.

FIGURA 2.4a. Esfuerzo de pesca anual por buques de clase 6 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 1-5I en días de pesca, el de las Pesquerías 8-9 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 (10-13) es aquél de sus pesquerías 'reales' correspondientes (2-5). Nótese que las escalas verticales de los recuadros son diferentes.

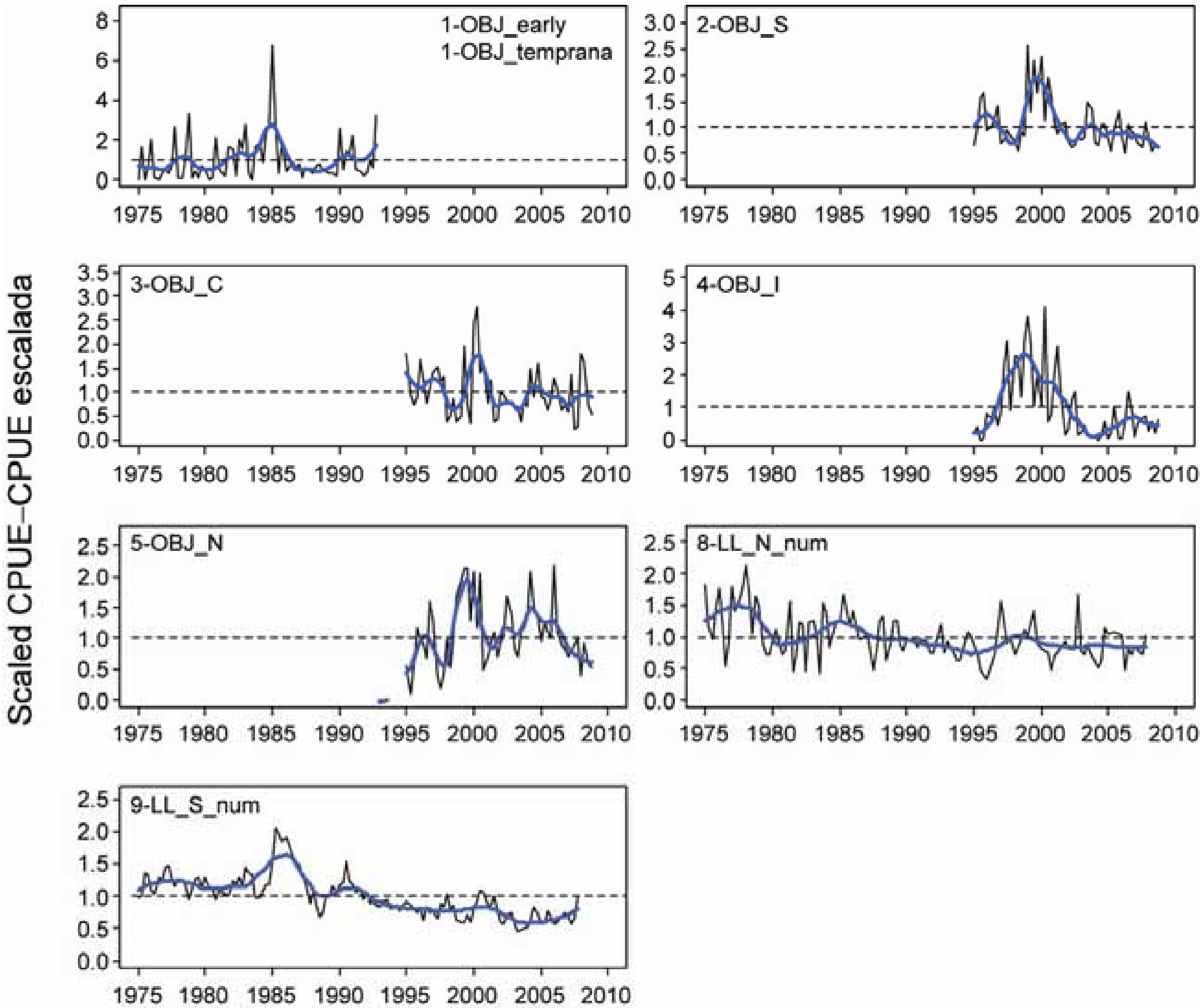

FIGURE 2.5. Four-quarterly running average CPUEs of the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). The CPUEs for the floating-object fisheries (1-5) are in kilograms per day fished, and those for the longline fisheries (8 and 9) in standardized CPUE. The data are adjusted so that the mean of each time series is equal to 1.0. Note that the vertical scales of the panels are different.

FIGURA 2.5. Promedio móvil de cuatro trimestres de las 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 (8 y 9) 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.

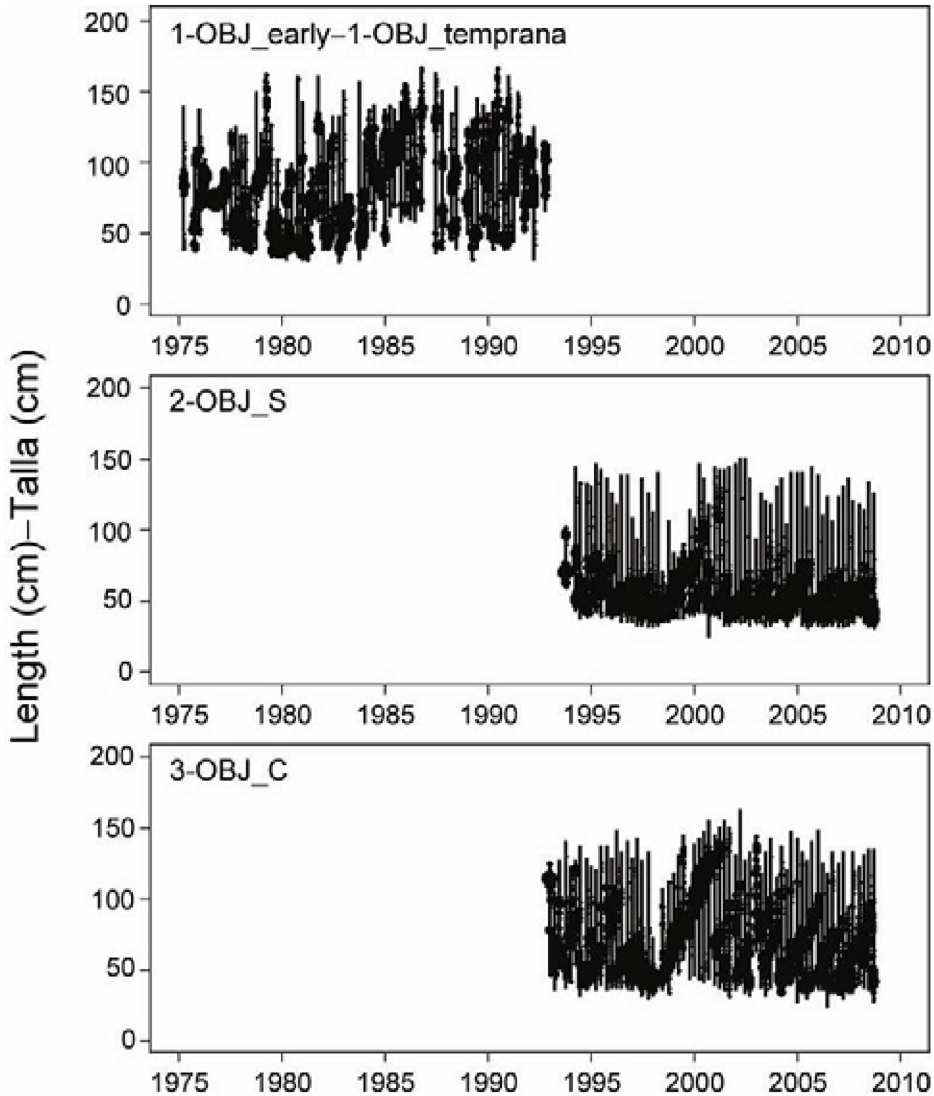

FIGURE 2.6a. Size compositions of the catches of bigeye tuna taken by Fishery 1, by quarter. The sizes of the circles are proportional to the catches.

FIGURA 2.6a. Composición por talla de las capturas de patudo de la Pesquería 1, por trimestre. El tamaño de los círculos es proporcional a la captura.

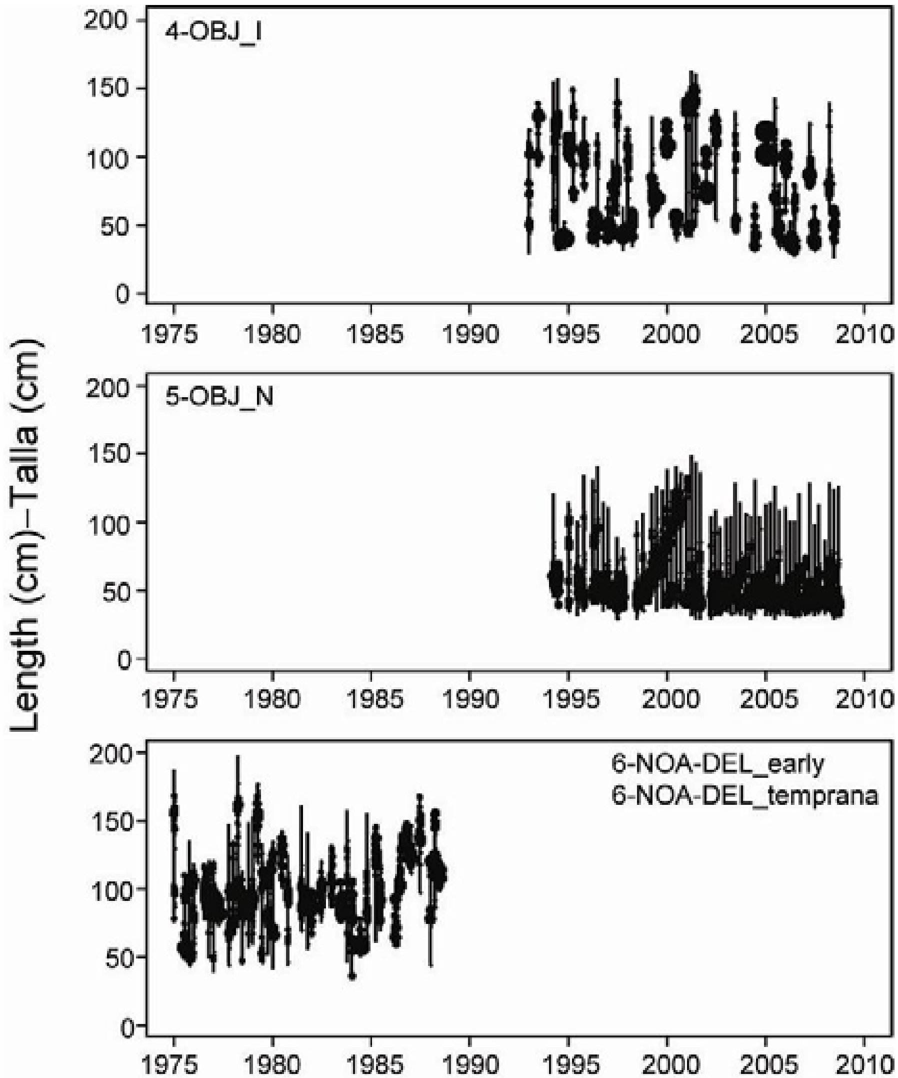

FIGURE 2.6b. Size compositions of the catches of bigeye tuna taken by Fishery 2, by quarter. The sizes of the circles are proportional to the catches.
FIGURA 2.6b. Composición por talla de las capturas de patudo de la Pesquería 2, por trimestre. El tamaño de los círculos es proporcional a la captura.

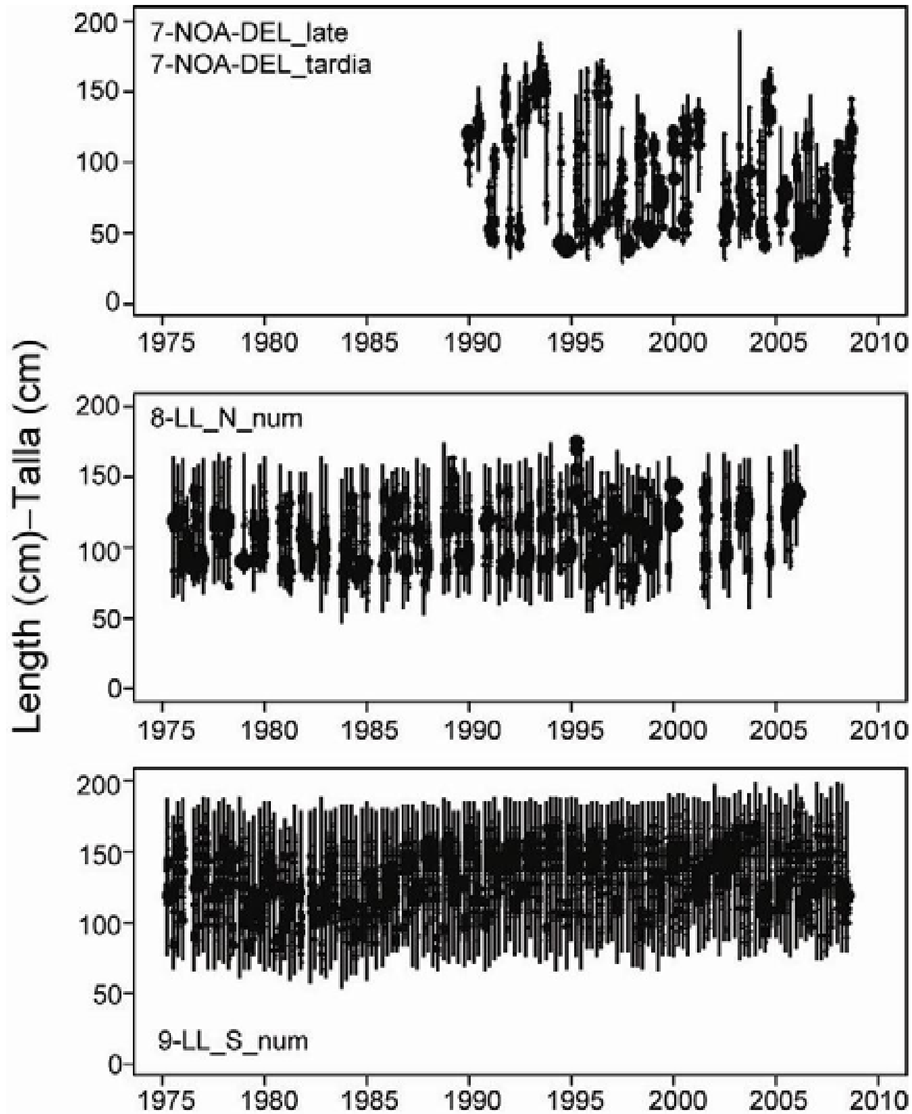

FIGURE 2.6c. Size compositions of the catches of bigeye tuna taken by Fishery 3, by quarter. The sizes of the circles are proportional to the catches.

FIGURA 2.6c. Composición por talla de las capturas de patudo de la Pesquería 3, por trimestre. El tamaño de los círculos es proporcional a la captura.

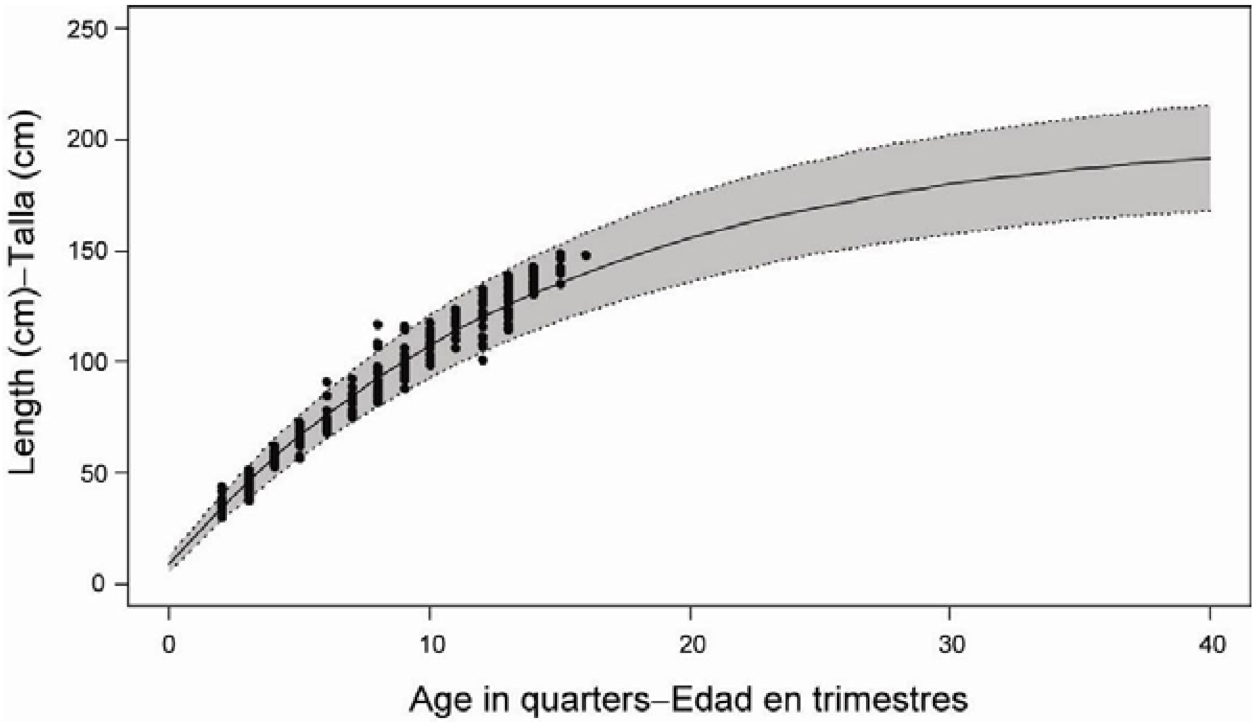

FIGURE 3.1. Estimated average lengths at age for bigeye tuna in the EPO. The dots represent the otolith age-length data from Schaefer and Fuller (2006). The dashed lines indicate the estimated confidence intervals (±2 standard deviations) of the mean lengths at age.

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.

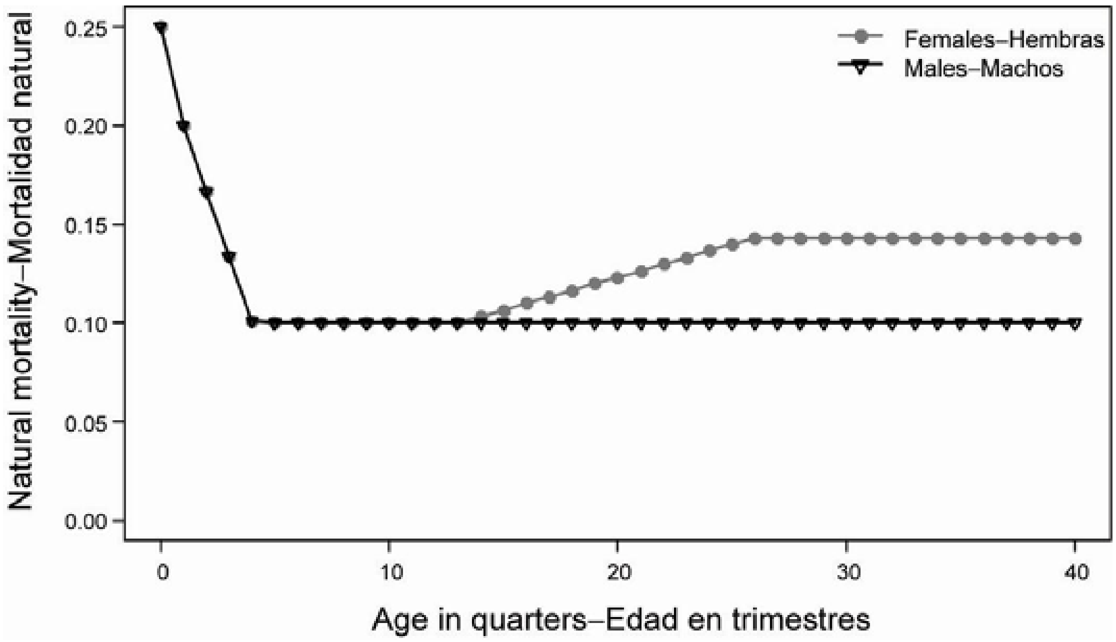

FIGURE 3.2. Quarterly natural mortality (*M*) rates used for the base case assessment of bigeye tuna in the EPO.
FIGURA 3.2. Tasas trimestrales de mortalidad natural (*M*) usadas en la evaluación del caso base del atún patudo en el OPO.

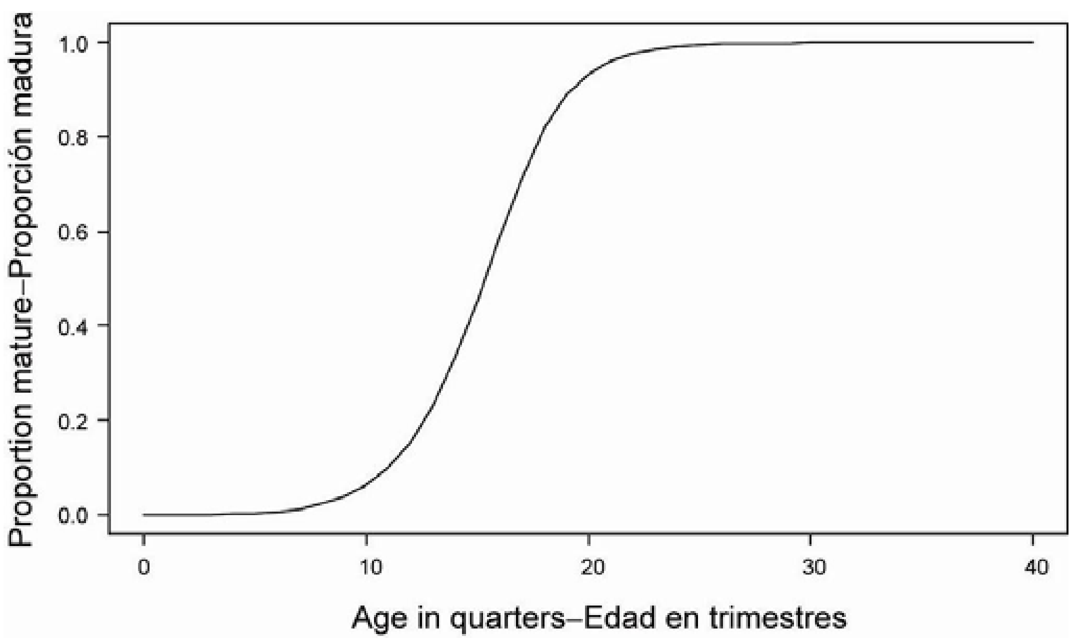

FIGURE 3.3. Age-specific maturity schedule (proportions of mature females) of bigeye tuna as assumed in the base case model.
FIGURA 3.3. Relación de madurez por edad (proporción de hembras maduras) de atún patudo, supuesto en el modelo del caso base.

FIGURE 4.1. Average quarterly fishing mortality (approximated by exploitation rate) at age of bigeye tuna, by all gears, in the EPO. The curves for 1975-1992 and 1993-2007 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 (aproximada por la tasa de explotación) por edad de atún patudo en el OPO, por todas las artes. Las curvas de 1975-1992 y 1993-2007 muestran los promedios de los períodos antes y después de la expansión de las pesquerías sobre objetos flotantes, respectivamente.

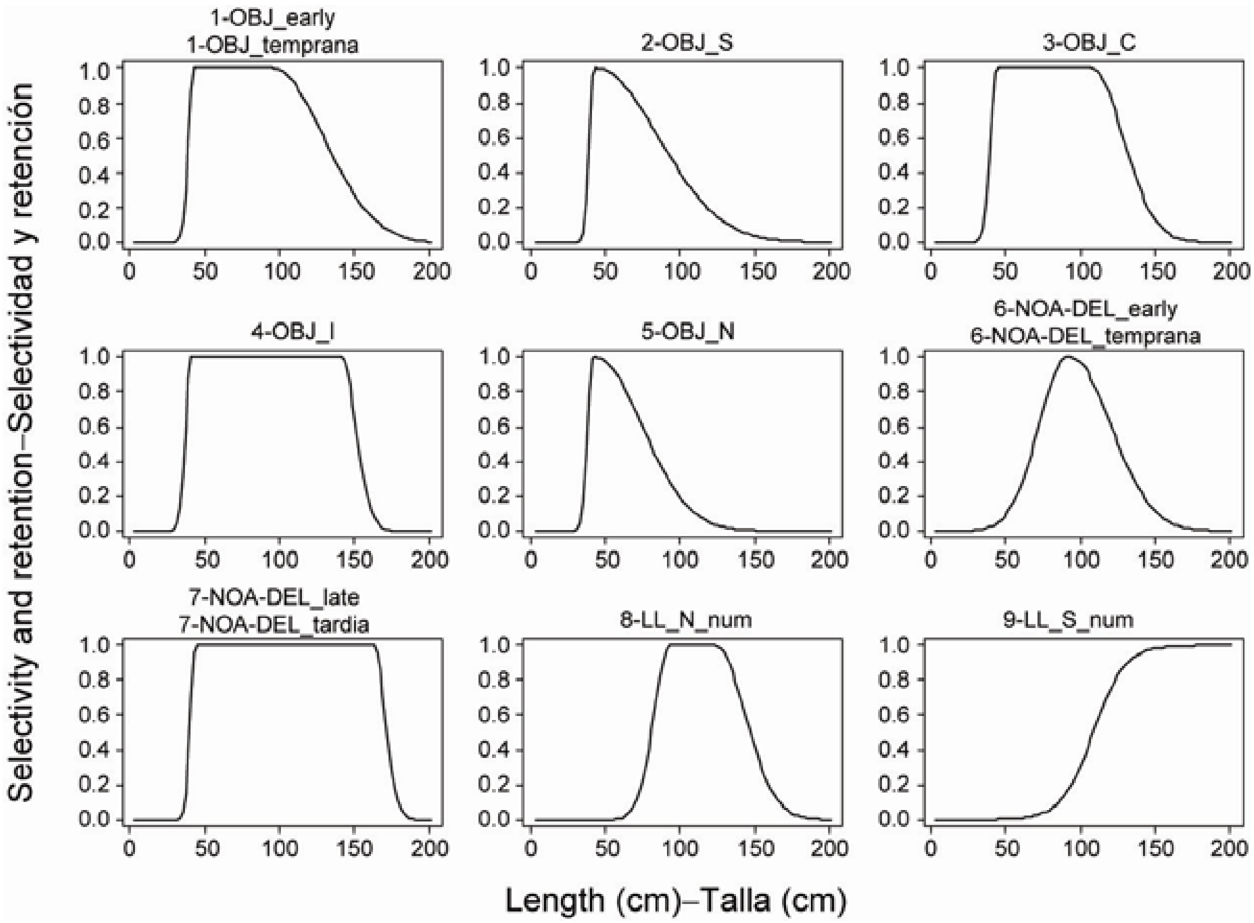

FIGURE 4.2. Size selectivity curves for Fisheries 1-9, estimated with SS2. Fish are assumed to be fully selected for the discard fisheries (10-13). The selectivity curves for Fisheries 14 and 15 are the same as those for Fisheries 8 and 9, respectively.

FIGURA 4.2. Curvas de selectividad por talla correspondientes a las Pesquerías 1 a 9, estimadas con SS2. En el caso de las pesquerías de descarte (10-13), se supone que el pescado es plenamente seleccionado. Las curvas de selectividad de las Pesquerías 14 y 15 son iguales que las de las Pesquerías 8 y 9, respectivamente.

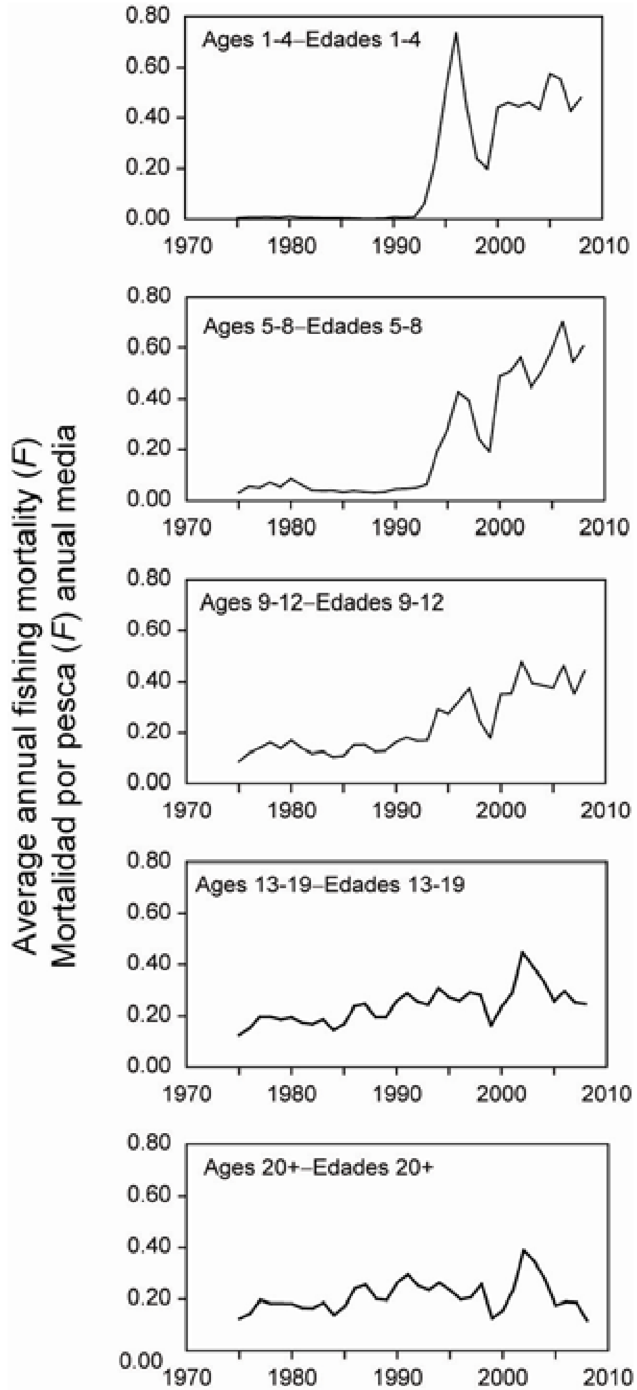

FIGURE 4.3. Average annual fishing mortality, by all gears, of bigeye tuna recruited to the fisheries of the EPO. Each panel illustrates an average of four annual fishing mortality vectors that affected the fish within the range of ages indicated in the title of each panel. For example, the trend illustrated in the 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 un promedio de cuatro vectores anuales de mortalidad por pesca que afectaron los peces de la edad indicada en el título de cada recuadro. Por ejemplo, la tendencia ilustrada en el recuadro superior es un promedio de las mortalidades por pesca que afectaron a los peces de entre 1-4 trimestres de edad.

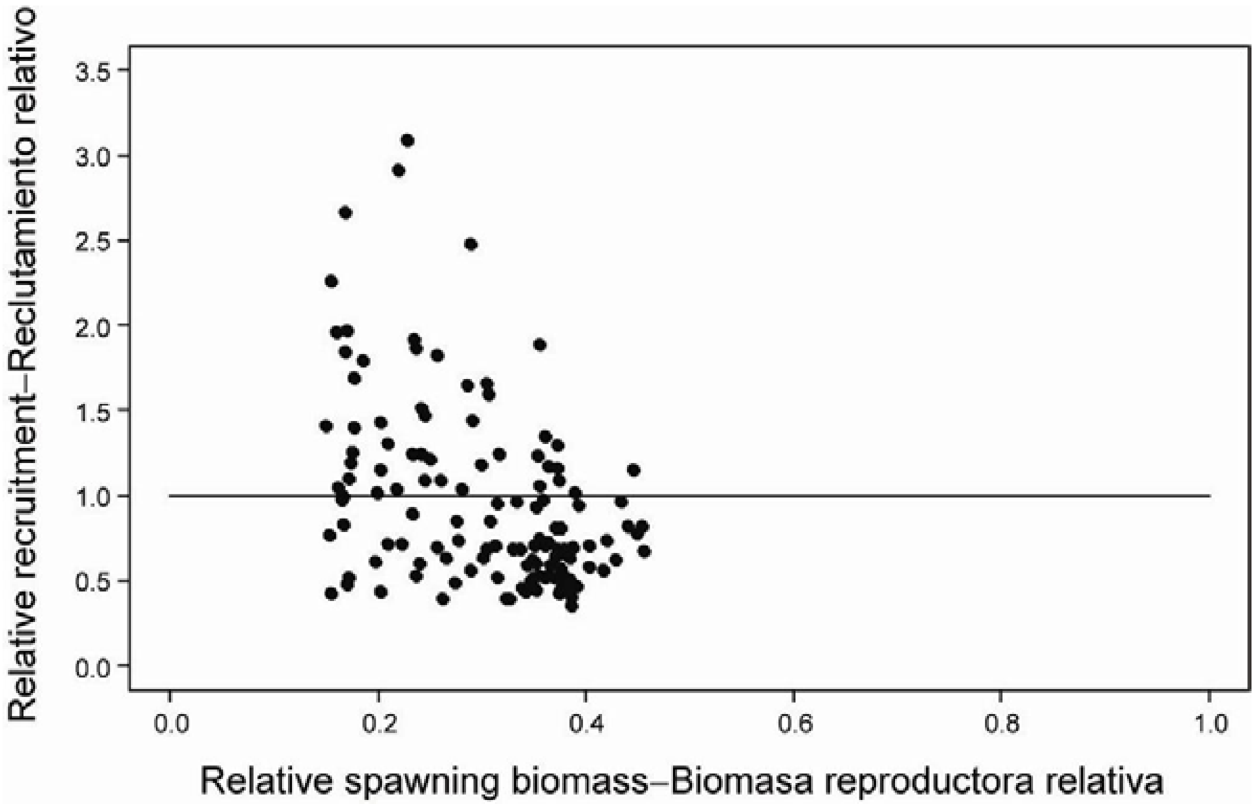

FIGURE 4.4a. Estimated relationship between the recruitment of bigeye tuna and spawning biomass. The recruitment is scaled so that the estimate of virgin recruitment is equal to 1.0. Likewise, the spawning biomass is scaled so that the estimate of virgin spawning biomass is equal to 1.0. The horizontal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

FIGURA 4.4b. Relación estimada entre el reclutamiento y la biomasa reproductora de 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.

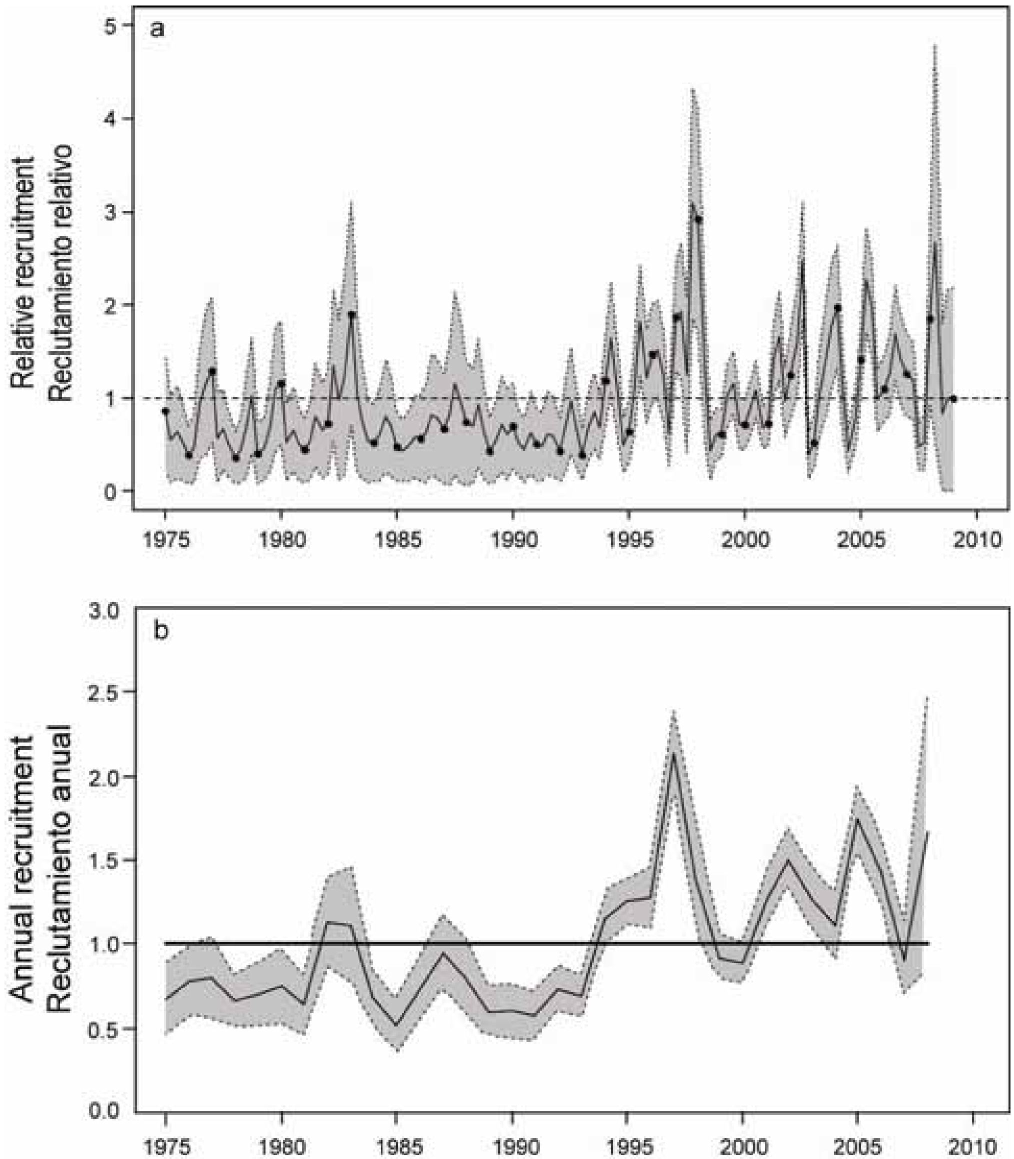

FIGURE 4.5. Estimated recruitment of bigeye tuna to the fisheries of the EPO: a) quarterly recruitment; b) annual recruitment. The estimates are scaled so that the estimate of virgin recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the thin dashed lines the confidence intervals (±2 standard deviations) around those estimates. The dashed horizontal line represents the average recruitment for the period. 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. 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. La línea horizontal de trazos representa el reclutamiento promedio del período. 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.

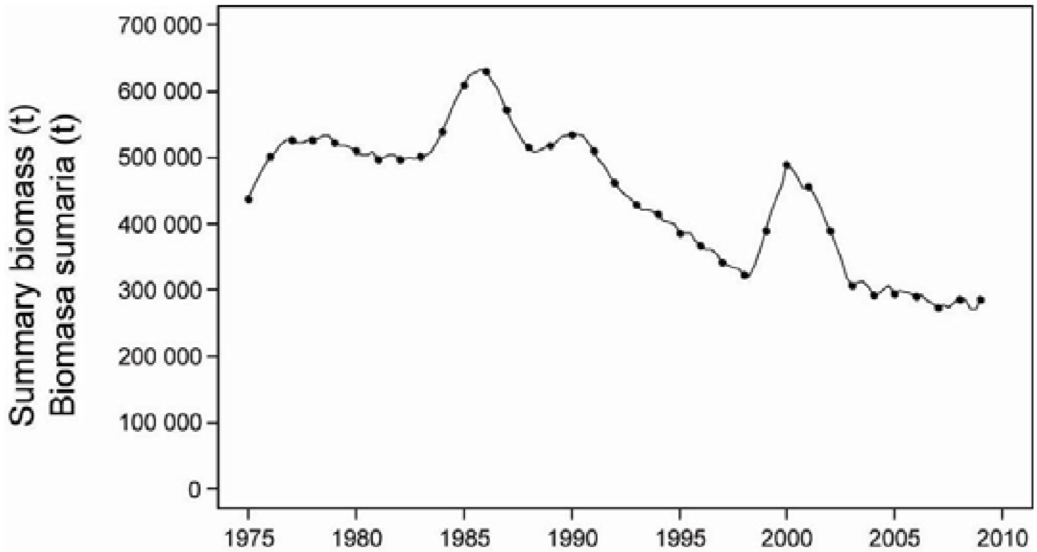

FIGURE 4.6. Maximum likelihood estimates of the biomass of bigeye tuna 3+ quarters old in the EPO (summary biomass). Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year. t = metric tons.

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.

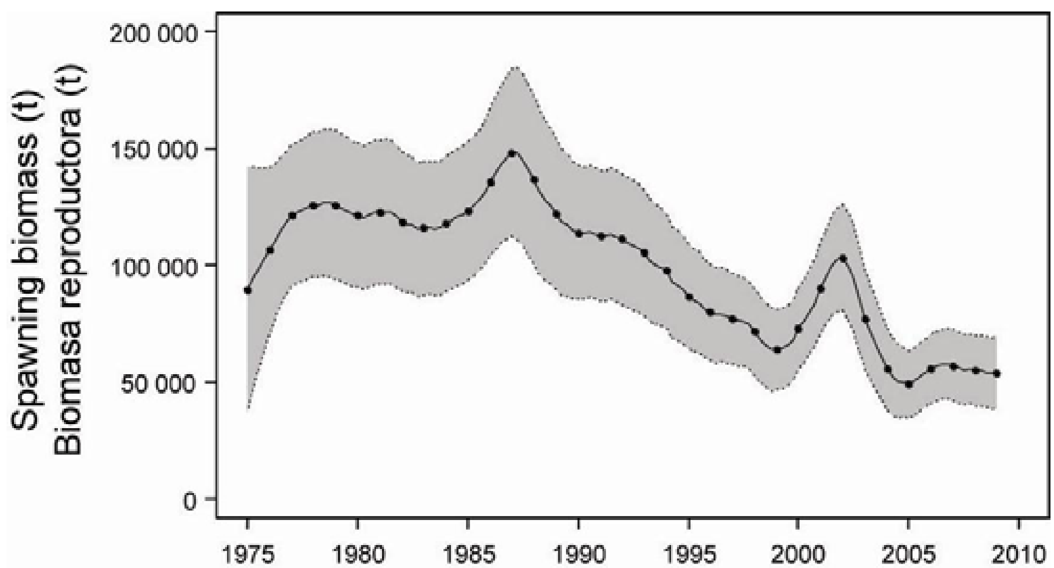

FIGURE 4.7. Maximum likelihood estimates of the spawning biomass (see Section 4.1.3) of bigeye tuna in the EPO. The solid line illustrates the maximum likelihood estimates of the biomasses, and the dashed lines the confidence intervals (±2 standard deviations) around those estimates. Since the assessment 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 (ver 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.

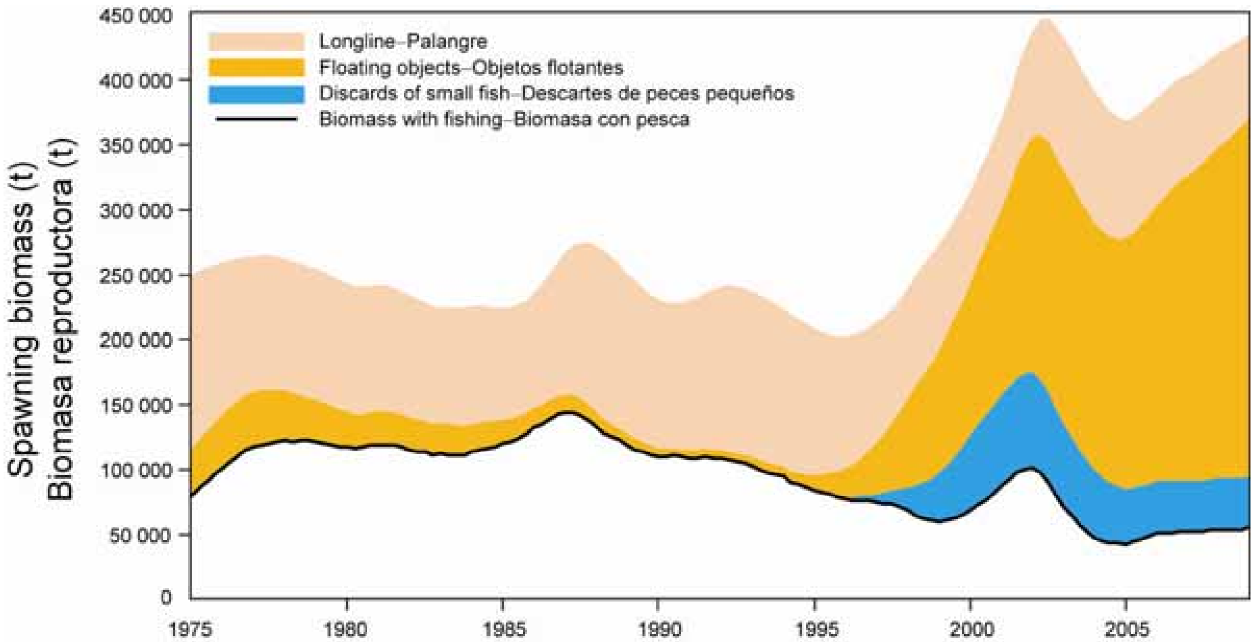

FIGURE 4.8. Trajectory of the spawning biomass of a simulated population of bigeye tuna that was not exploited (top line) and that predicted by the stock assessment model (bottom line). The shaded areas between the two lines show the portions of the impact attributed to each fishing method. t = metric 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.

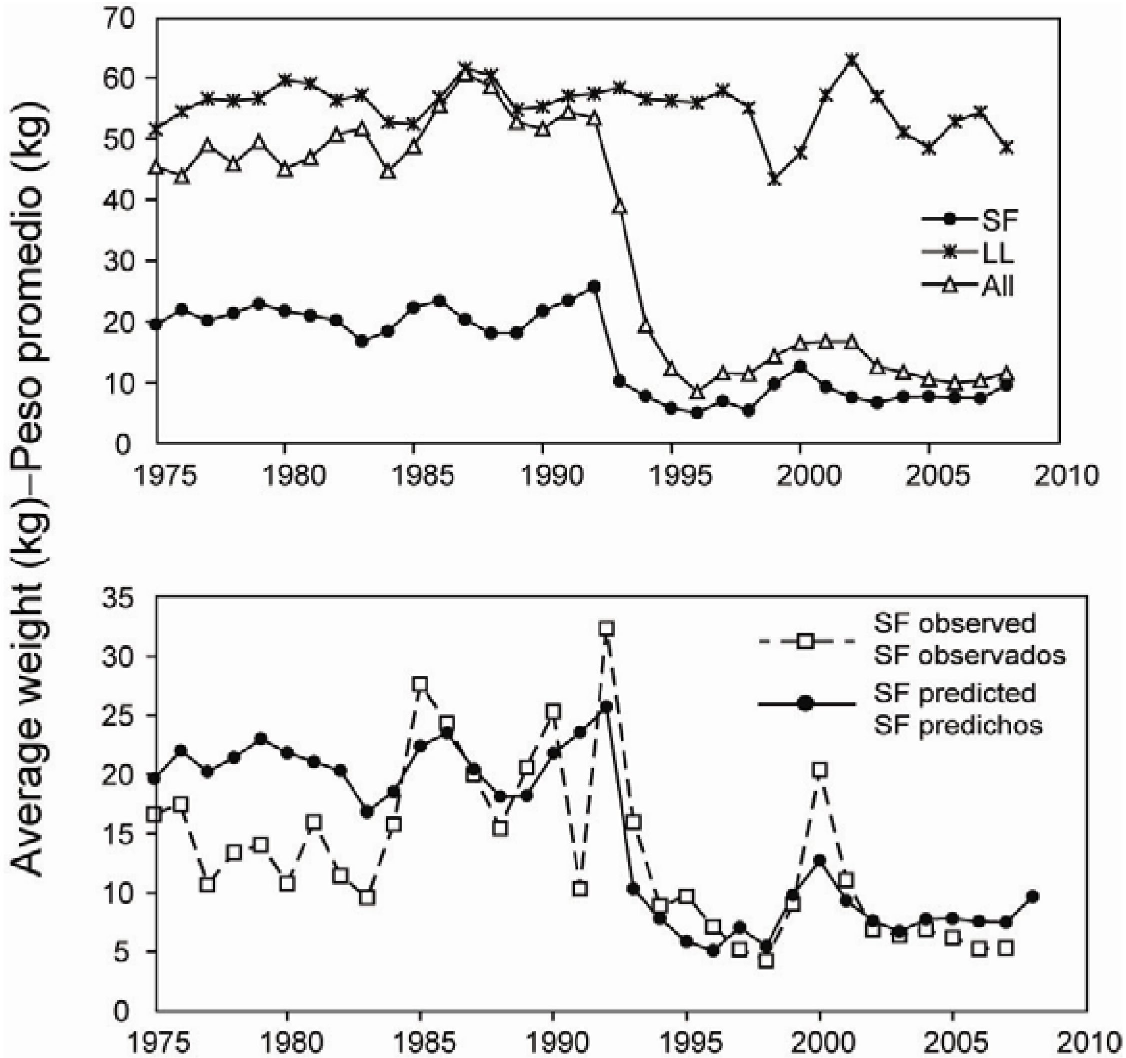

FIGURE 4.9. Average weights of bigeye tuna caught in the EPO, 1975-2008, by the surface fisheries (SF, Fisheries 1-7), longline fisheries (LL, Fisheries 8-9 and 14-15), and all fisheries combined (All). Upper panel: predicted average weights; lower panel: predicted and observed average weights for the surface fisheries.

FIGURA 4.9. Peso medio estimado de atún patudo capturado en el OPO, 1975-2008,por las pesquerías de superficie (SF, Pesquerías 1-7), de palangre (LL, Pesquerías 8, 9 y 14-15), y todas las pesquerías combinadas (All). Recuadro superior: pesos medios predichos; recuadro inferior: pesos medios predichos y observados de las pesquerías de superficie.

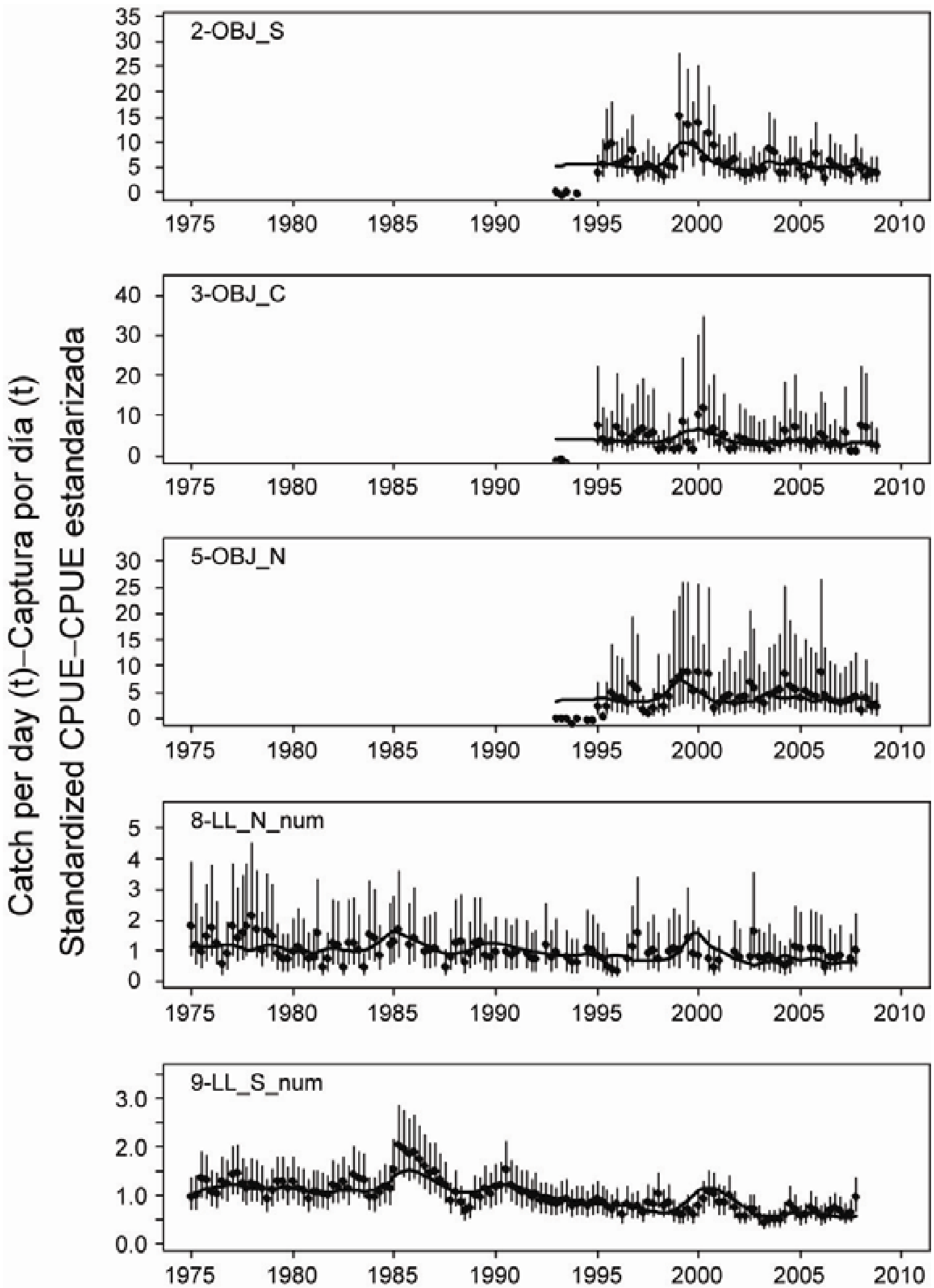

FIGURE 4.10. Model fit to the CPUE data from different fisheries. The CPUEs for surface fisheries 2, 3 and 5 are in kilograms per day fished, and those for longline fisheries 8 and 9 in standardized CPUE.
FIGURA 4.10. Ajuste del modelo a los datos de CPUE de varias pesquerías. Se expresan las CPUE de las pesquerías de superficie 2, 3 y 5 en kilogramos por día de pesca, y aquéllas de las pesquerís de palangre (8 y 9) en CPUE estandarizada.

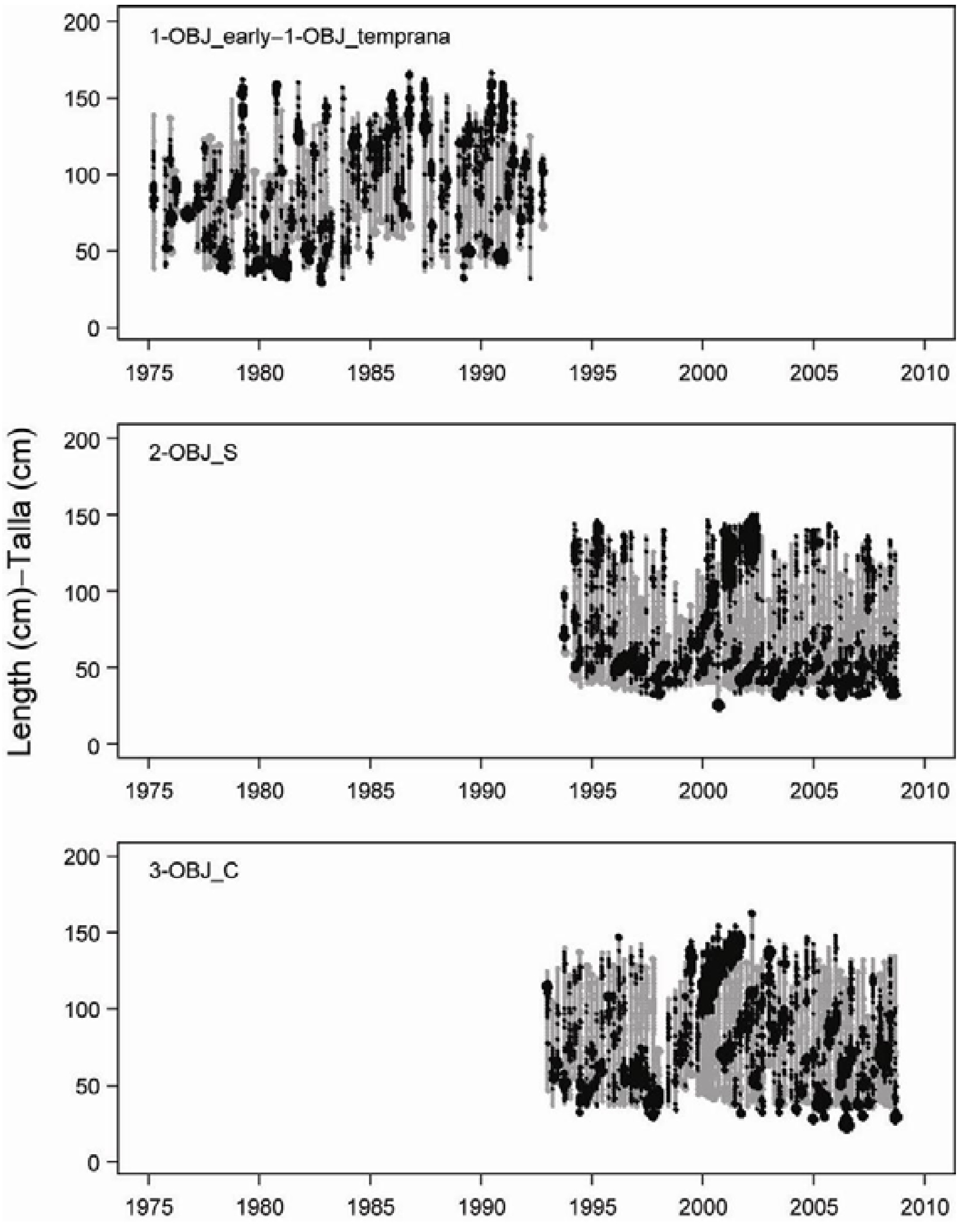

FIGURE 4.11a. Pearson residual plots for the model fits to the length composition data for Fishery 1. The gray and black circles represent observations that are higher and lower, respectively, than the model predictions. The sizes of the circles are proportional to the absolute values of the residuals.

FIGURA 4.11a. Gráficas de residuales de Pearson para los ajustes del modelo a los datos de composición por talla de la Pesquería 1. Los círculos abiertos y sólidos representan observaciones mayores y menores, respectivamente, que las predicciones del modelo. El tamaño de los círculos es proporcional al valor absoluto de los residuales.

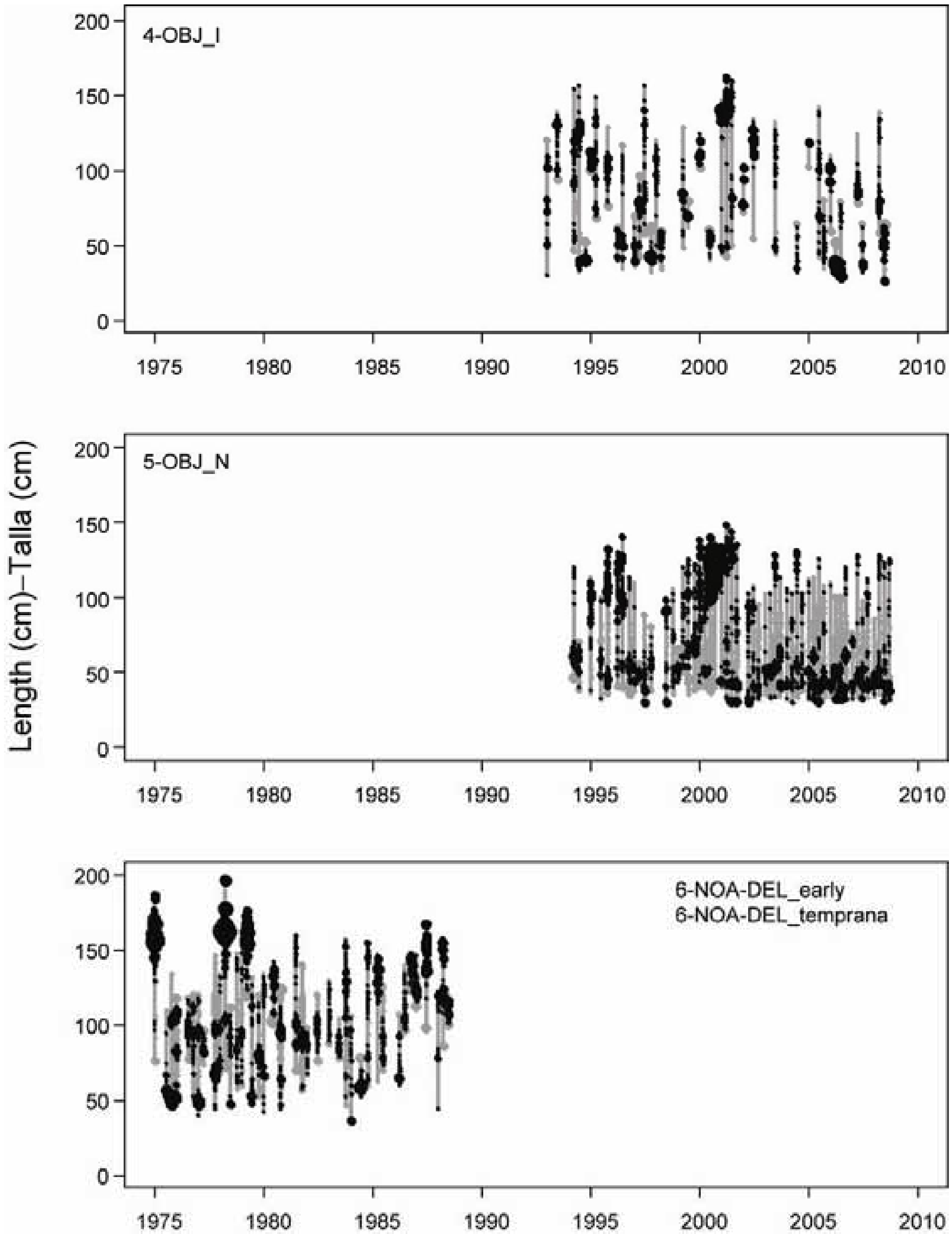

FIGURE 4.11b. Pearson residual plots for the model fits to the length composition data for Fishery 2. The gray and black circles represent observations that are higher and lower, respectively, than the model predictions. The sizes of the circles are proportional to the absolute values of the residuals.

FIGURA 4.11b. Gráficas de residuales de Pearson para los ajustes del modelo a los datos de composición por talla de la Pesquería 2. Los círculos abiertos y sólidos representan observaciones mayores y menores, respectivamente, que las predicciones del modelo. El tamaño de los círculos es proporcional al valor absoluto de los residuales.

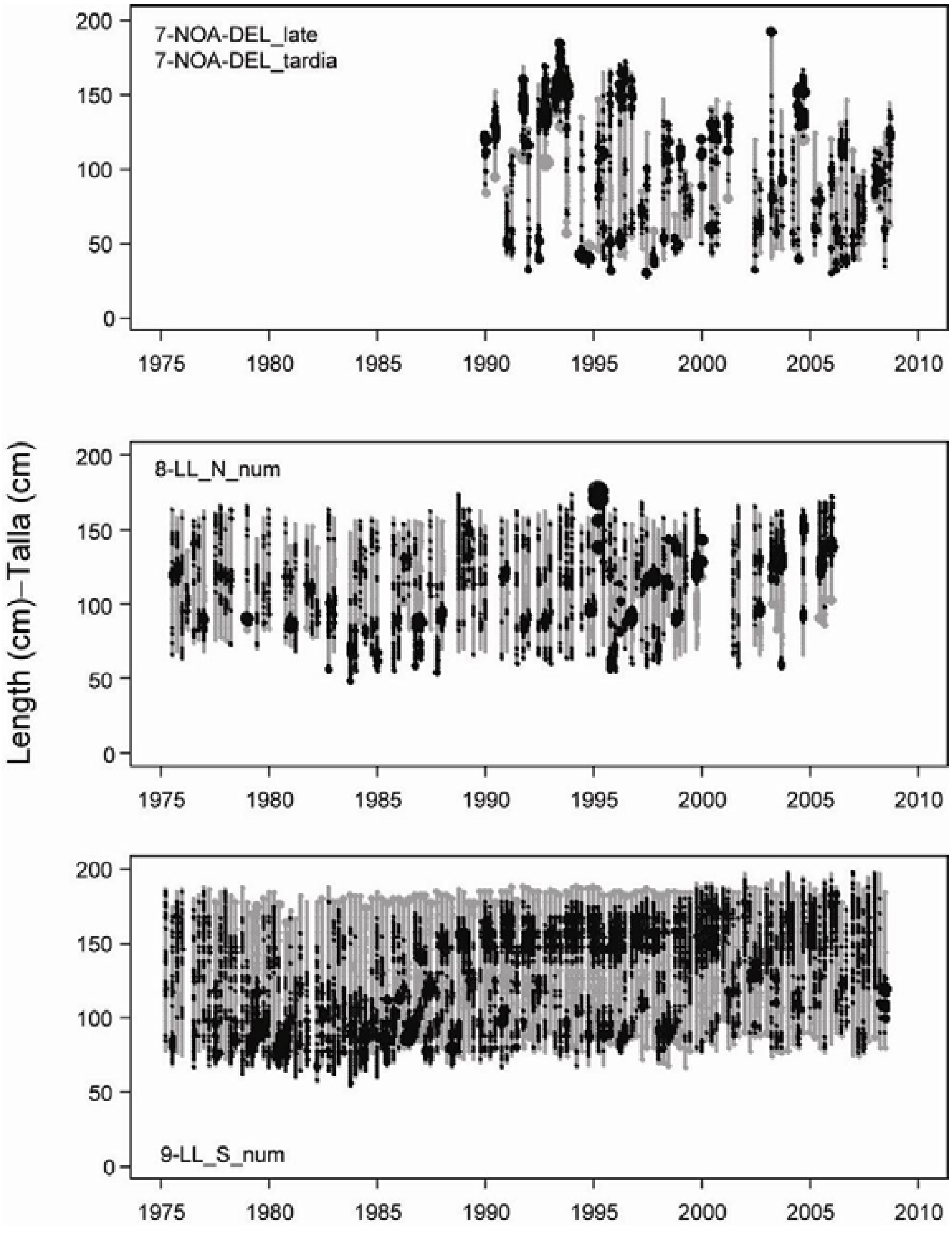

FIGURE 4.11c. Pearson residual plots for the model fits to the length composition data for Fishery 3. The gray and black circles represent observations that are higher and lower, respectively, than the model predictions. The sizes of the circles are proportional to the absolute values of the residuals.

FIGURA 4.11c. Gráficas de residuales de Pearson para los ajustes del modelo a los datos de composición por talla de la Pesquería 3. Los círculos abiertos y sólidos representan observaciones mayores y menores, respectivamente, que las predicciones del modelo. El tamaño de los círculos es proporcional al valor absoluto de los residuales.

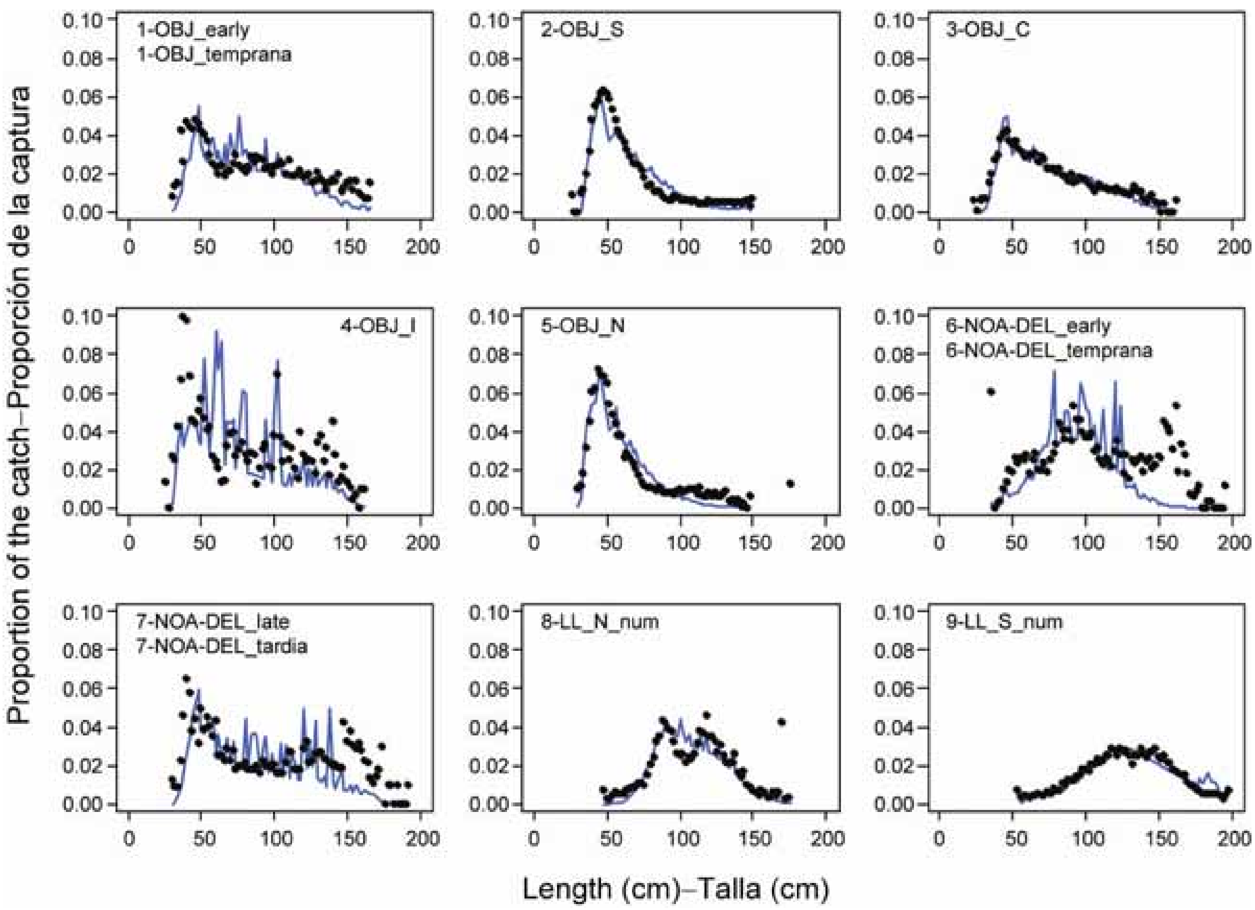

FIGURE 4.11d. Average observed (dots) and predicted (curves) size compositions of the catches taken by the fisheries defined for the stock assessment of bigeye tuna in the EPO.

FIGURA 4.11d. Composición por tamaño media observada (puntos) y predicha (curvas) de las capturas realizadas por las pesquerías definidas para la evaluación de la población de atún patudo en el OPO.

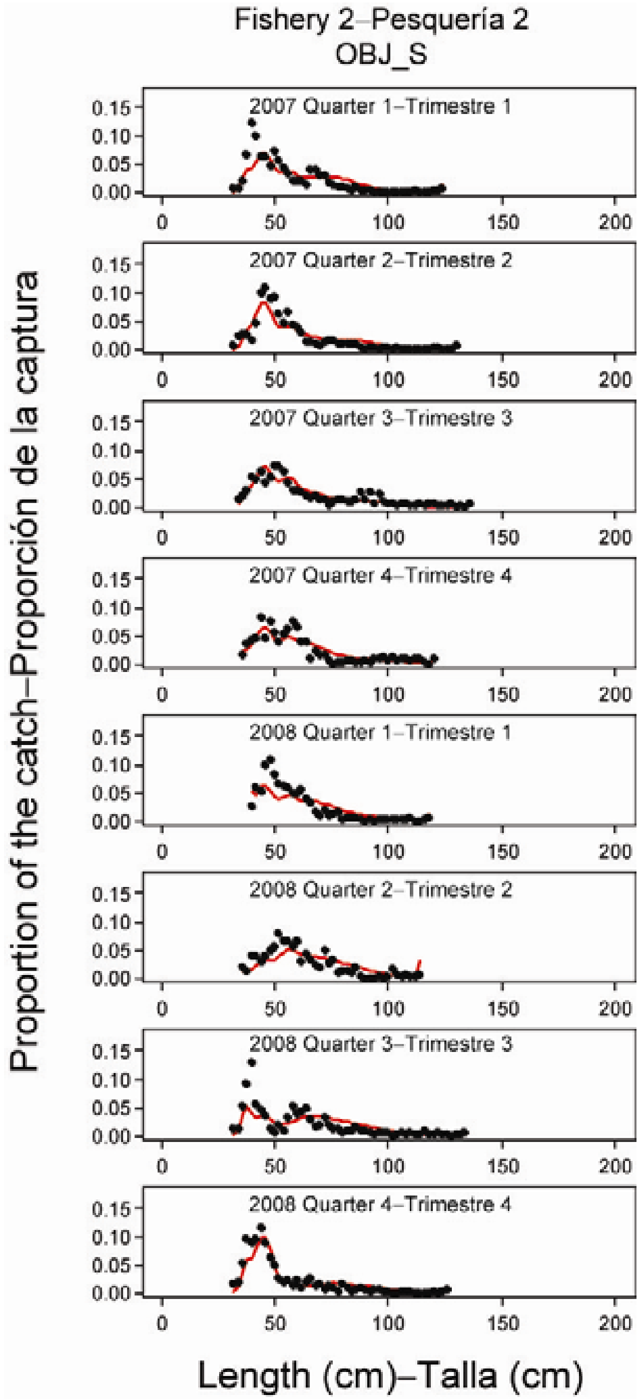

FIGURE 4.11e. Observed (dots) and predicted (curves) size compositions of the recent catches of bigeye tuna by Fishery 2.

FIGURA 4.11e. Composición por talla observada (puntos) y predicha (curvas) de las capturas recientes de atún patudo por la Pesquería 2.

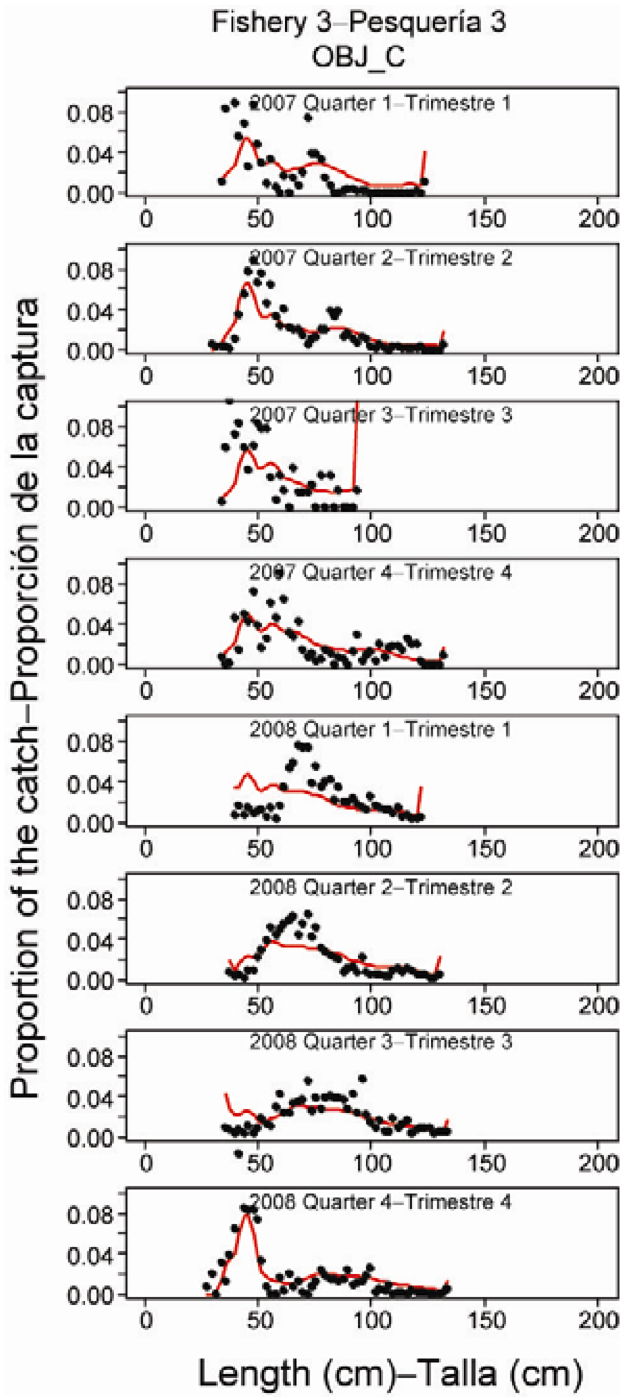

FIGURE 4.11f. Observed (dots) and predicted (curves) size compositions of the recent catches of bigeye tuna by Fishery 3.

FIGURA 4.11f. Composición por talla observada (puntos) y predicha (curvas) de las capturas recientes de atún patudo por la Pesquería 3.

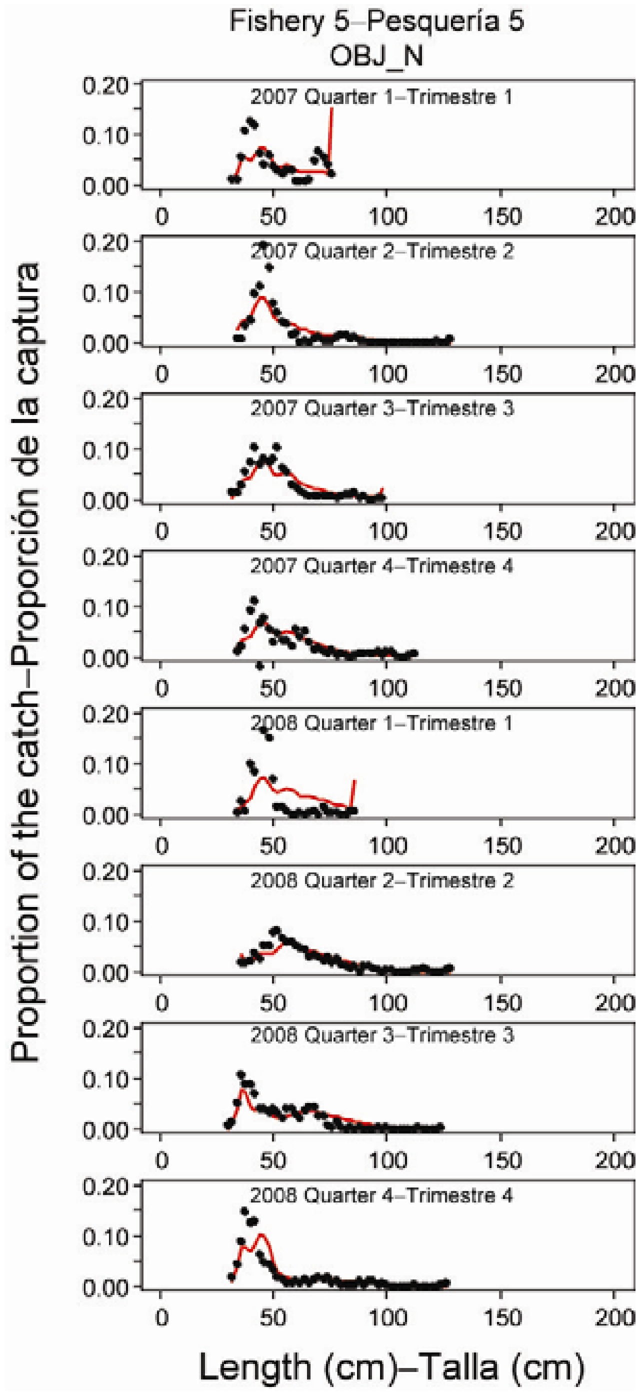

FIGURE 4.11g. Observed (dots) and predicted (curves) size compositions of the recent catches of bigeye tuna by Fishery 5.

FIGURA 4.11g. Composición por talla observada (puntos) y predicha (curvas) de las capturas recientes de atún patudo por la Pesquería 5.

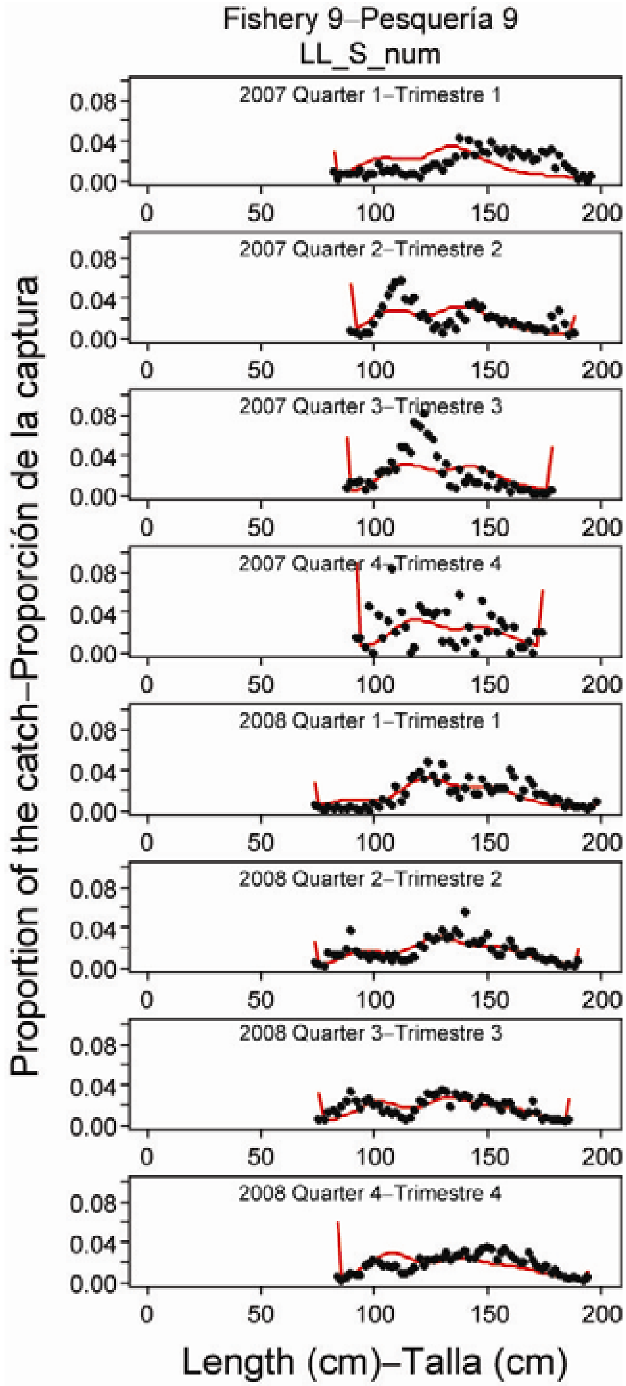

FIGURE 4.11h. Observed (dots) and predicted (curves) size compositions of the recent catches of bigeye tuna by Fishery 9.

FIGURA 4.11h. Composición por talla observada (puntos) y predicha (curvas) de las capturas recientes de atún patudo por la Pesquería 9.

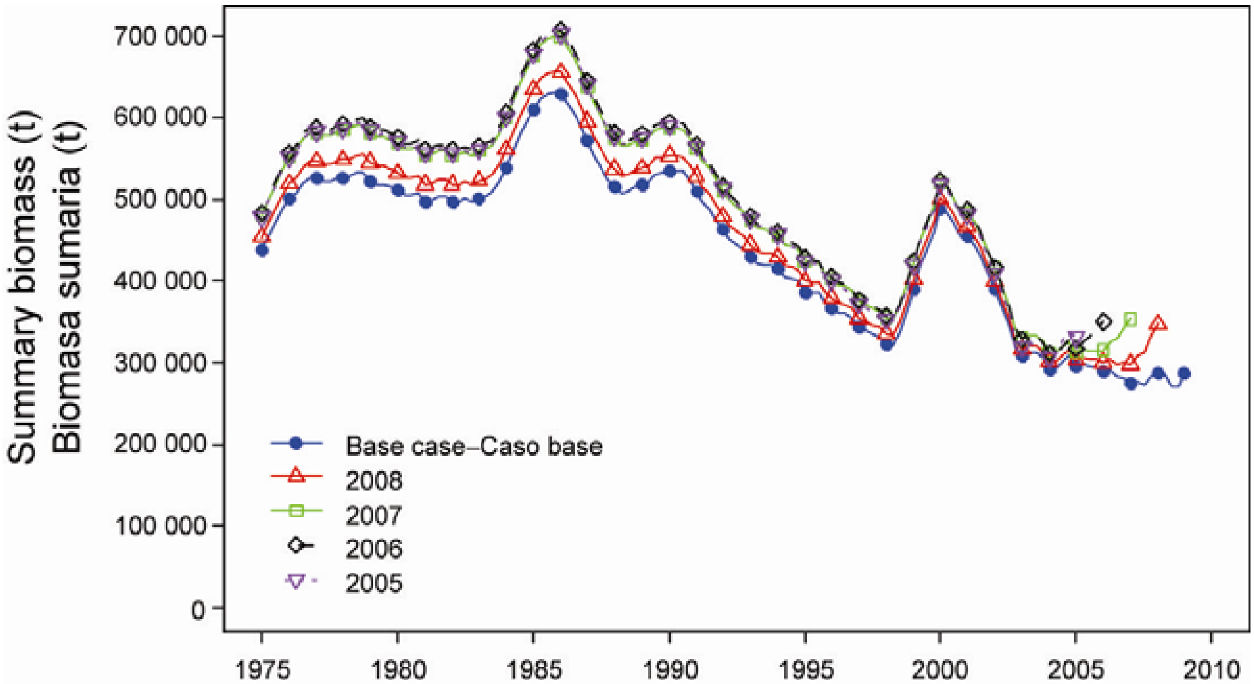

FIGURE 4.12. Retrospective comparisons of estimates of the summary biomass (fish of age 3 quarters and older) of bigeye tuna in the EPO. The estimates from the base case model are compared with the estimates obtained when the most recent year (2008), two years (2008 and 2007), three years (2008, 2007 and 2006) or four years (2008, 2007, 2006 and 2004) of data were excluded. t = metric tons.

FIGURA 4.12. Comparaciones retrospectivas de las estimaciones de la biomasa sumaria (peces de 3 trimestres y más de edad) 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 (2008), o de los dos años (2008 y 2007), tres años (2008, 2007, y 2006), o cuatro años (2008, 2007, 2006, y 2005) más recientes. t = toneladas métricas.

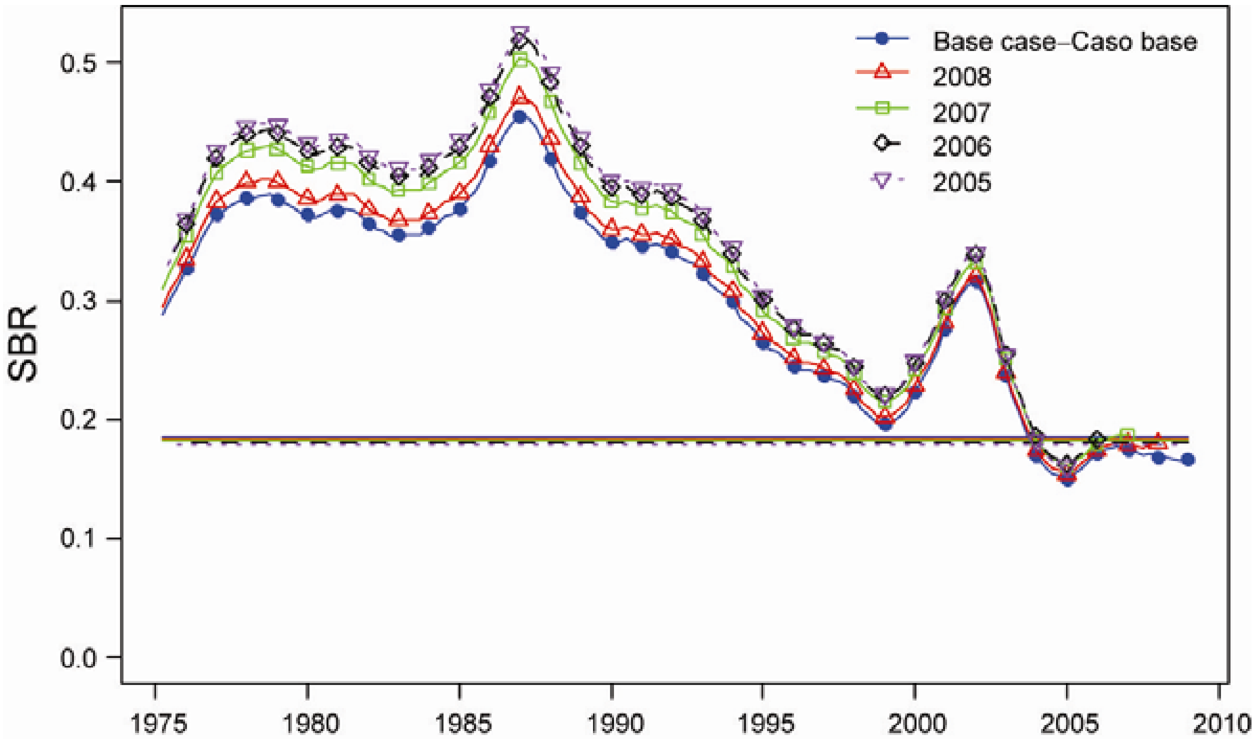

FIGURE 4.13. Retrospective comparisons of estimates of the spawning biomass ratio (SBR) of bigeye tuna in the EPO. The estimates from the base case model are compared with the estimates obtained when the most recent year (2008), two years (2008 and 2007), three years (2008, 2007 and 2006) or four years (2008, 2007, 2006 and 2004) of data were excluded.

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 (2008), o de los dos años (2008 y 2007), tres años (2008, 2007, y 2006), o cuatro años (2008, 2007, 2006, y 2005) más recientes.

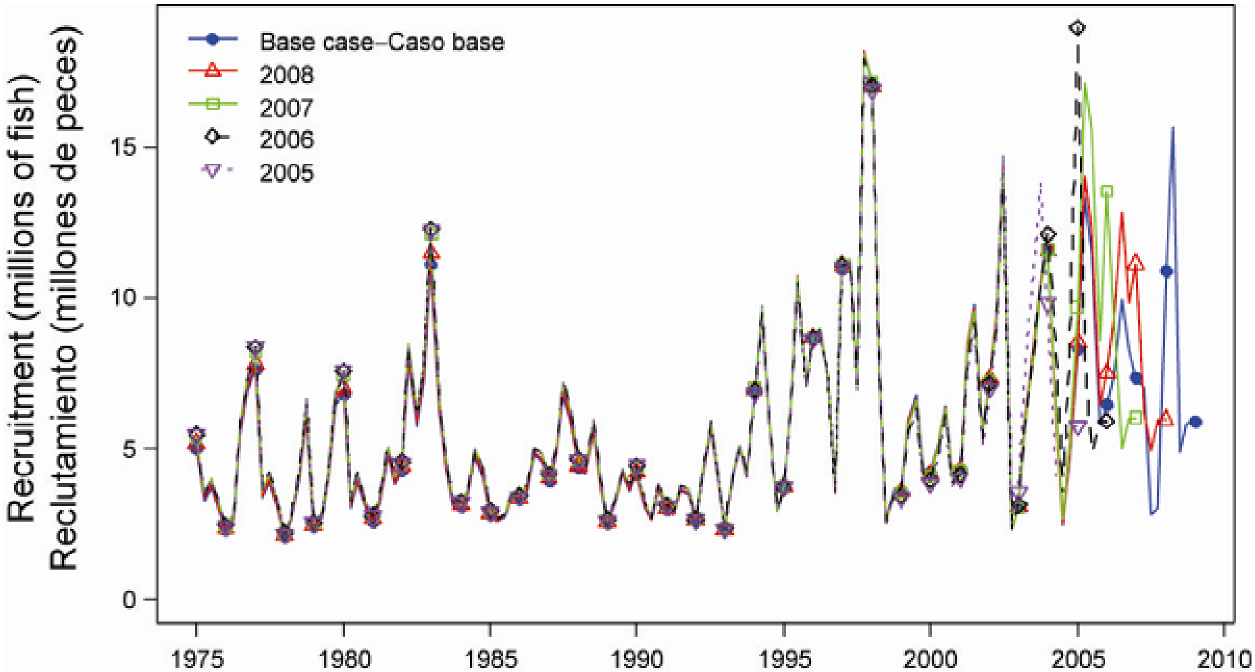

FIGURE 4.14. Retrospective comparisons of estimates of the recruitment of bigeye tuna in the EPO. The estimates from the base case model are compared with the estimates obtained when the most recent year (2008), two years (2008 and 2007), three years (2008, 2007 and 2006) or four years (2008, 2007, 2006 and 2004) 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 (2008), o de los dos años (2008 y 2007), tres años (2008, 2007, y 2006), o cuatro años (2008, 2007, 2006, y 2005) más recientes.

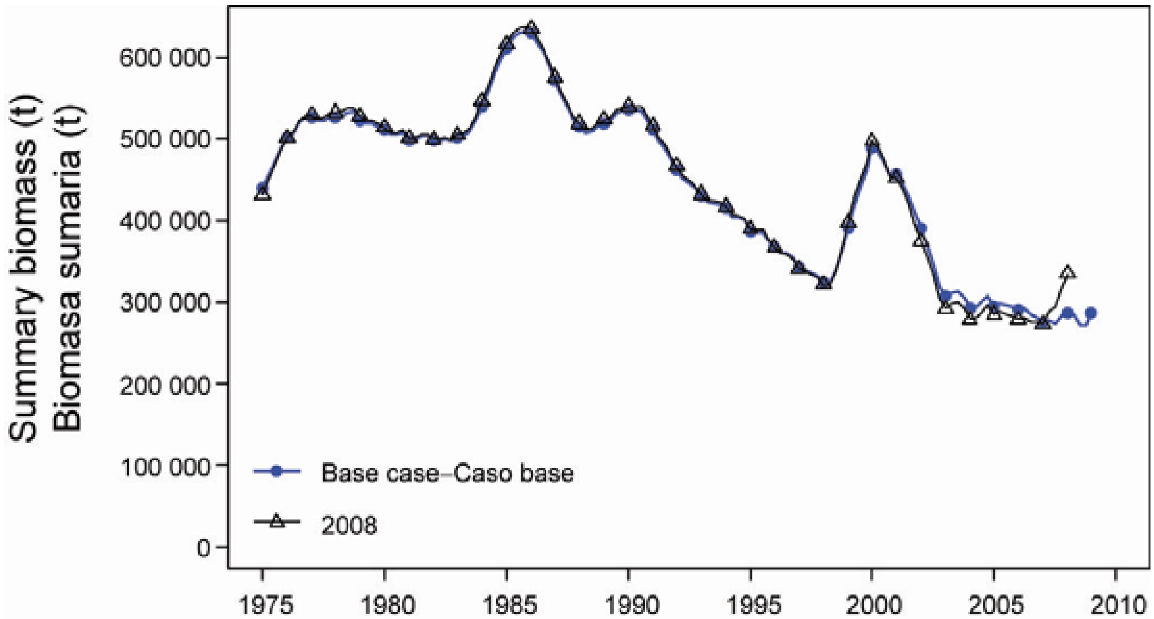

FIGURE 4.15. Comparison of estimates of the summary biomass (fish of age 3 quarters and older) of bigeye tuna from the most recent assessment (2008) and the base case model of the current assessment. t = metric tons.
FIGURA 4.15. Comparación de las estimaciones de la biomasa sumaria (peces de 3 trimestres y más de edad) de atún patudo de la evaluación más reciente (2008) y el modelo de caso base de la evaluación actual. t = toneladas métricas.

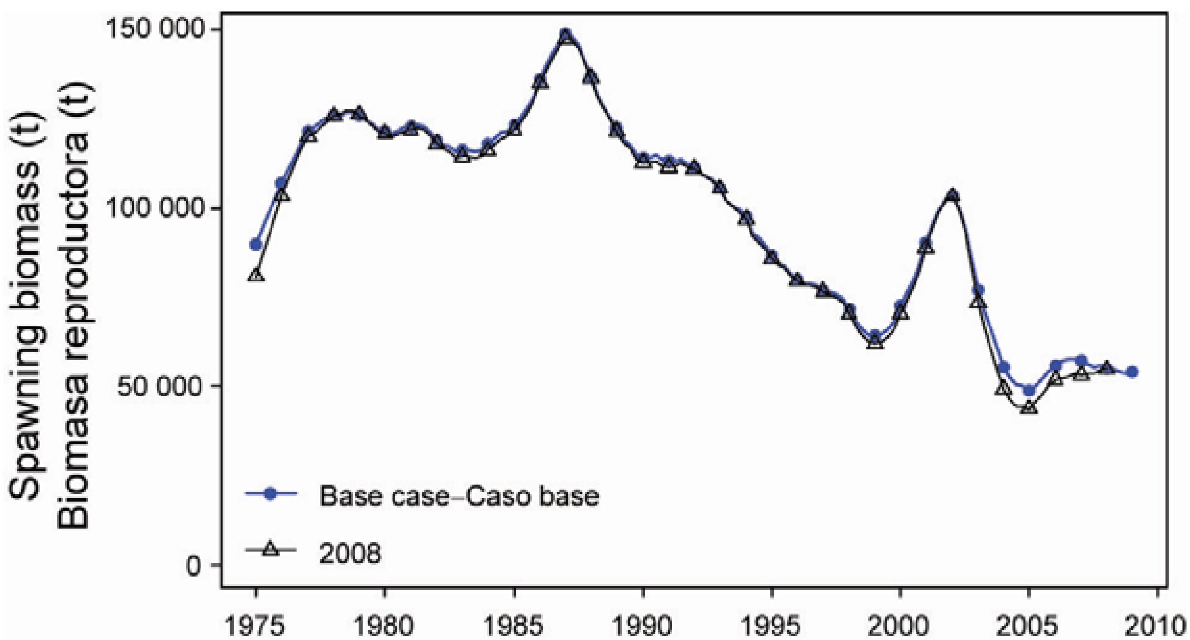

FIGURE 4.16. Comparison of estimates of the spawning biomass for bigeye tuna in the EPO from the most recent assessment (2008) and the base case model of the current assessment. t = metric tons.
FIGURA 4.16. Comparación del índice de biomasa reproductora estimada del atún patudo en el OPO de la evaluación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

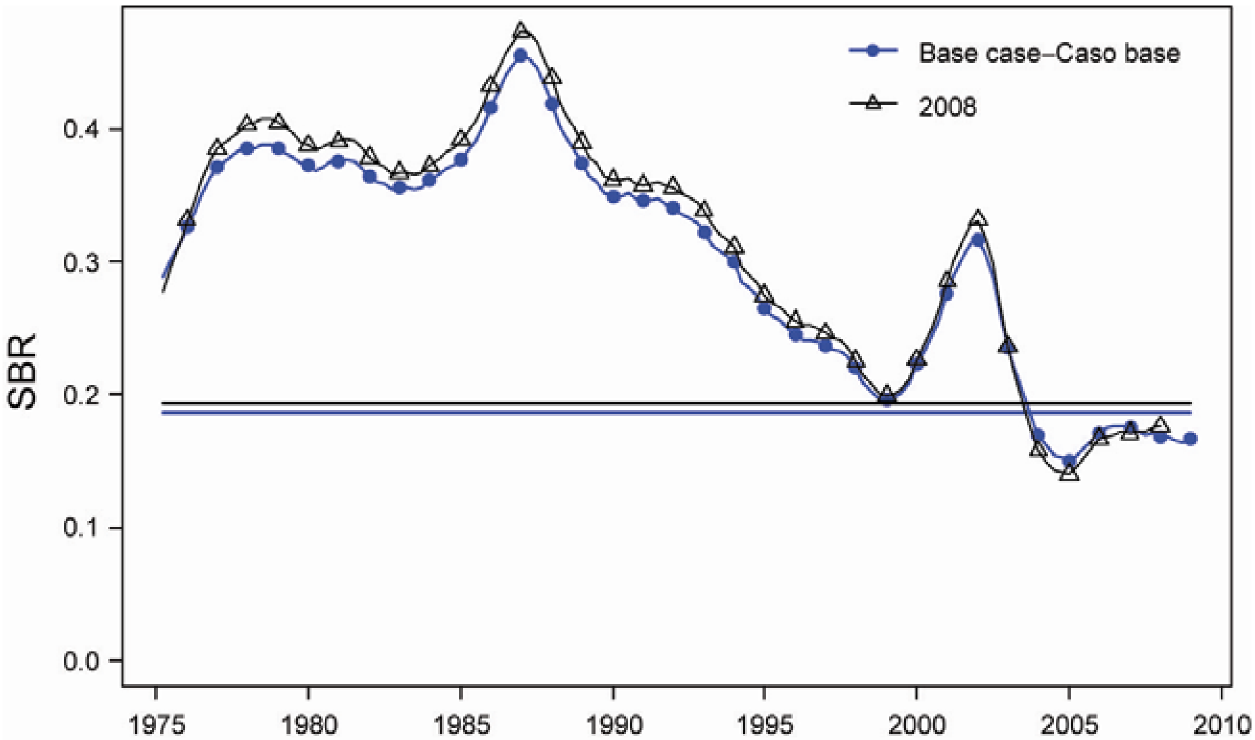

FIGURE 4.17. Comparison of estimated spawning biomass ratios (SBRs) for bigeye tuna in the EPO from the most recent assessment (2008) and the base case model of the current assessment, both using SS2. The horizontal lines indicate the SBR at MSY.

FIGURA 4.17. Comparación del cociente de biomasa reproductora (SBR) estimado del atún patudo en el OPO de la evaluación más reciente (2008) y el modelo de caso base de la evaluación actual, ambas con SS2. Las líneas horizontales indican el SBR en RMS.

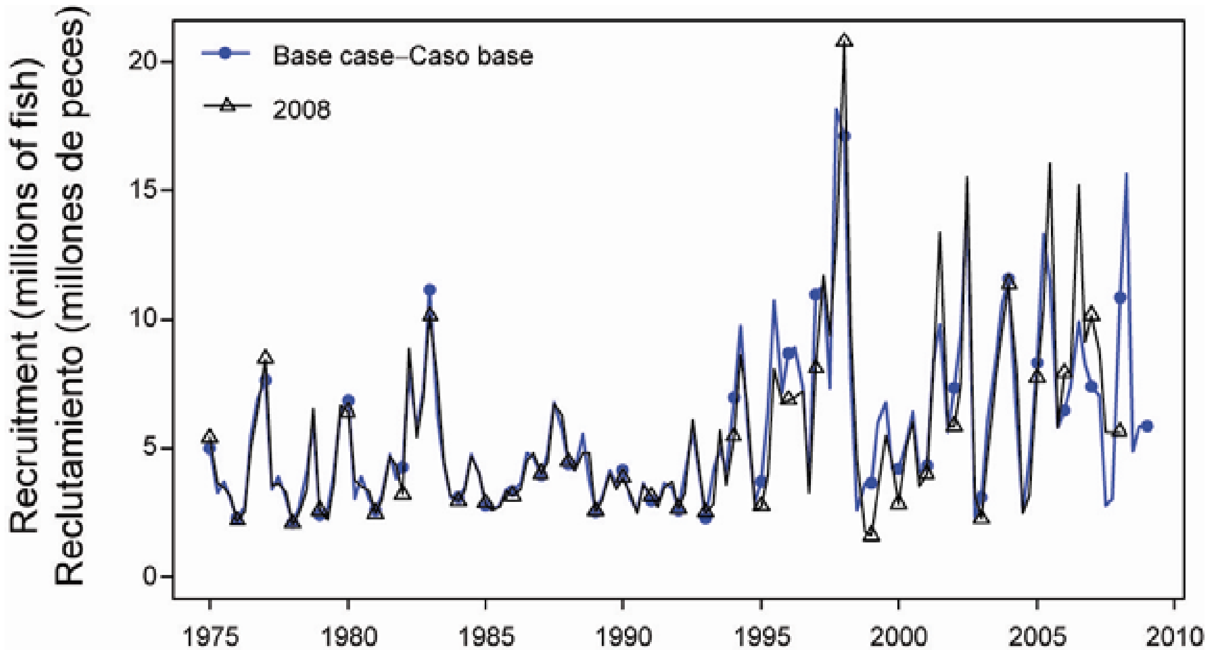

FIGURE 4.18a. Comparison of estimated recruitment of bigeye tuna in the EPO from the most recent assessment (2008) and the base case model of the current assessment (SS2), both using SS2.
FIGURA 4.18. Comparación del reclutamiento estimado del atún patudo en el OPO de la evaluación más reciente (2008) y del modelo de caso base de la evaluación actual (SS2), ambas con SS2.

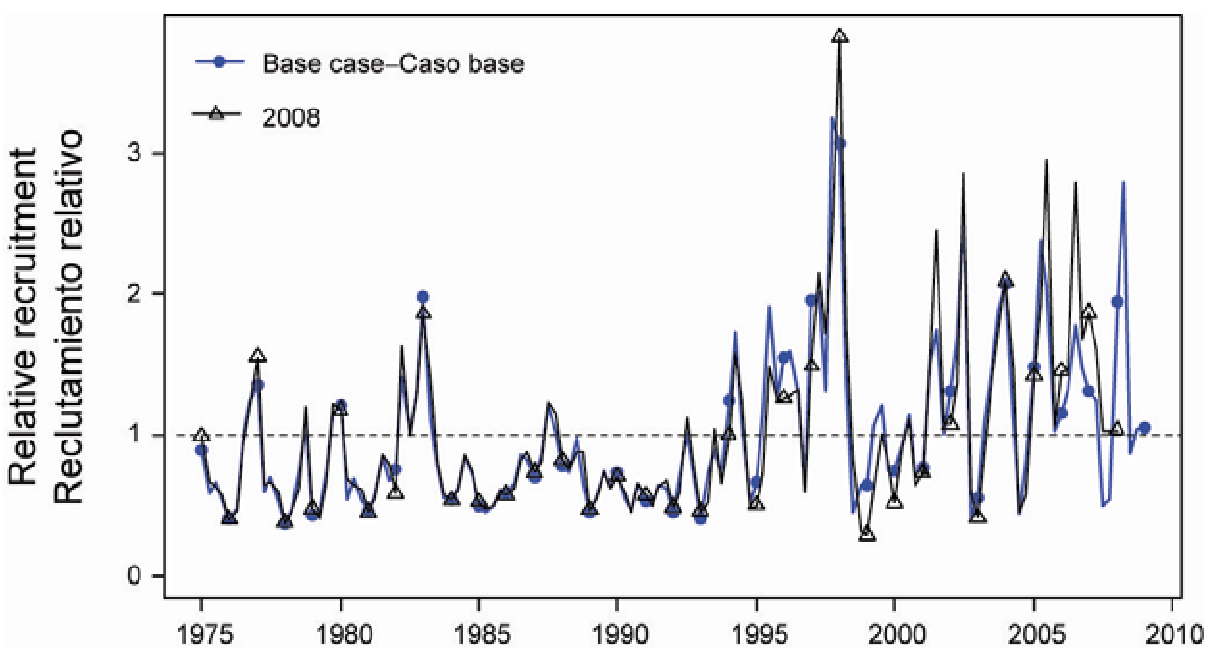

FIGURE 4.18b. Comparison of estimated relative recruitment of bigeye tuna in the EPO from the most recent assessment (2008) and the base case model of the current assessment (SS2), both using SS2.
FIGURA 4.18b. Comparación del reclutamiento relativo estimado del atún patudo en el OPO de la evaluación más reciente (2008) y del modelo de caso base de la evaluación actual (SS2), ambas con SS2.

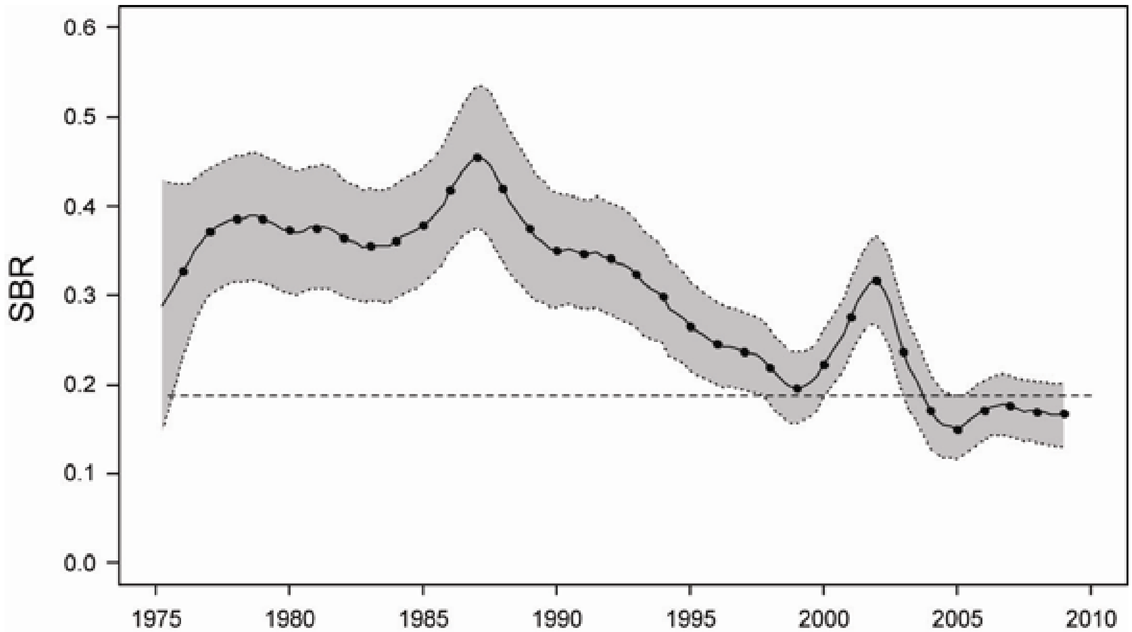

FIGURE 5.1. Estimated spawning biomass ratios (SBRs) for bigeye tuna in the EPO. The dashed horizontal line (at about 0.19) identifies the SBR at MSY. The curve illustrates the maximum likelihood estimates, and the shaded area represents the confidence intervals (±2 standard deviations) around those 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 curva ilustra las estimaciones de verosimilitud máxima, y el área sombreada representa los intervalos de confianza (±2 desviaciones estándar) alrededor de esas estimaciones.

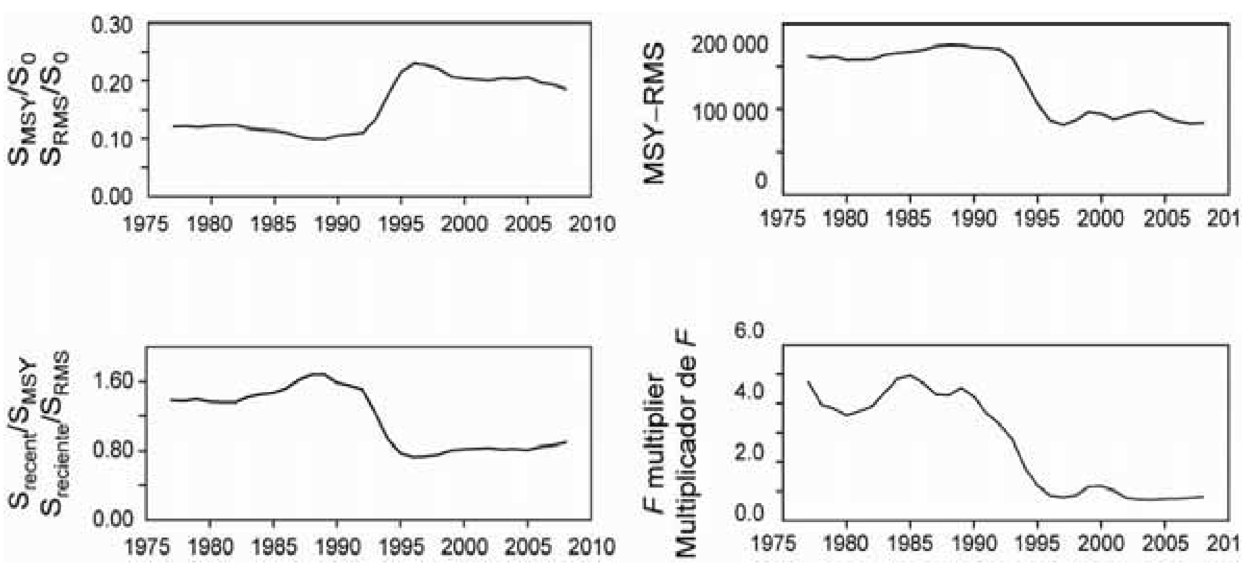

FIGURE 5.2. Estimates of MSY-related quantities calculated using the average age-specific fishing mortality for each year. (S_{recent} is the spawning biomass at the beginning of 2009.)
FIGURA 5.2. Estimaciones de cantidades relacionadas con el RMS calculadas usando la mortalidad por pesca por edad para cada año. ($S_{reciente}$ es la biomasa reproductora al principio de 2009.)

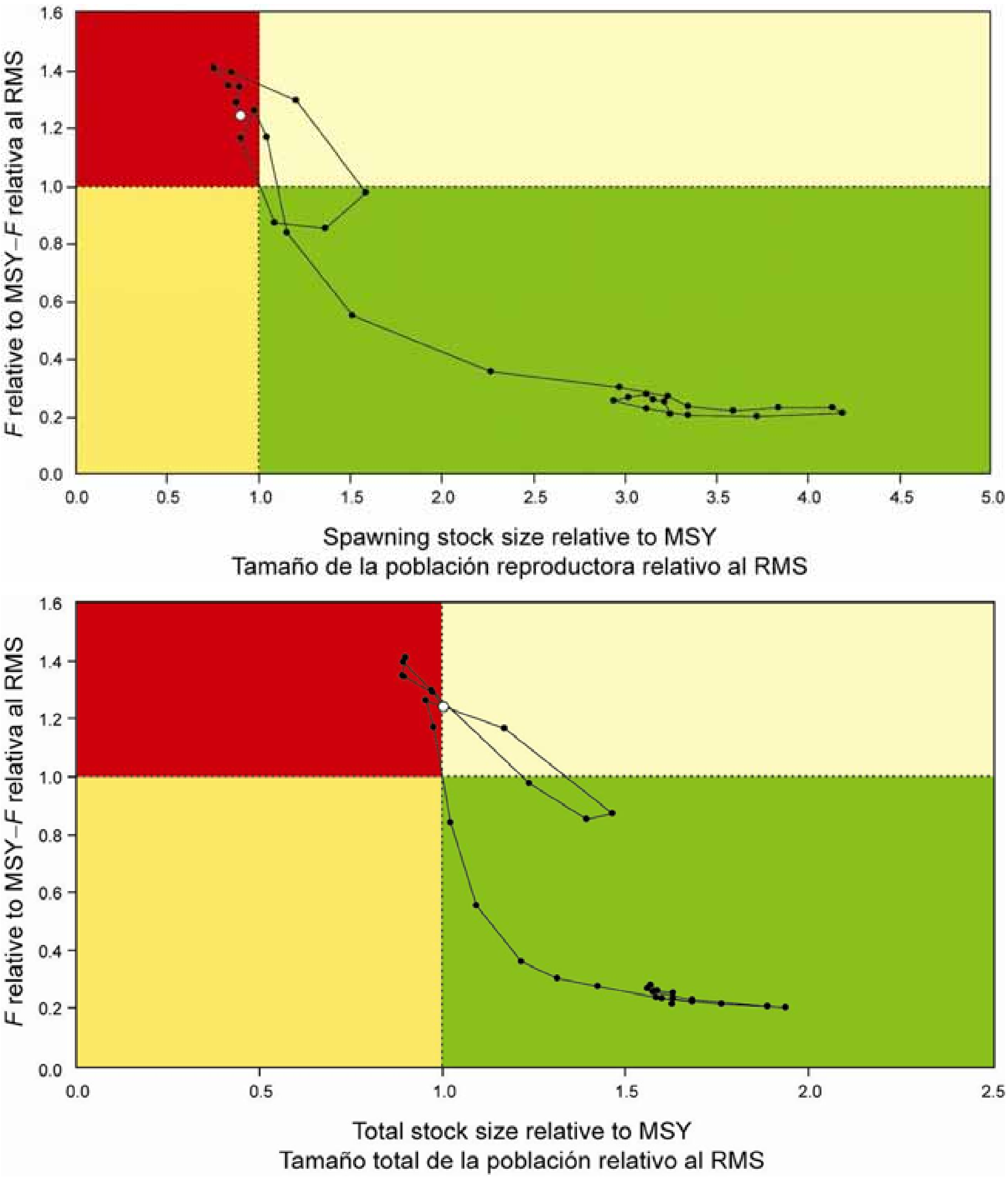

FIGURE 5.3. Phase plot of the time series of estimates of stock size (top: spawning biomass; bottom: total biomass) and fishing mortality relative to their MSY reference points. Each dot is based on the average exploitation rate over three years; the large dot indicates the most recent estimate.

FIGURA 5.3. 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.

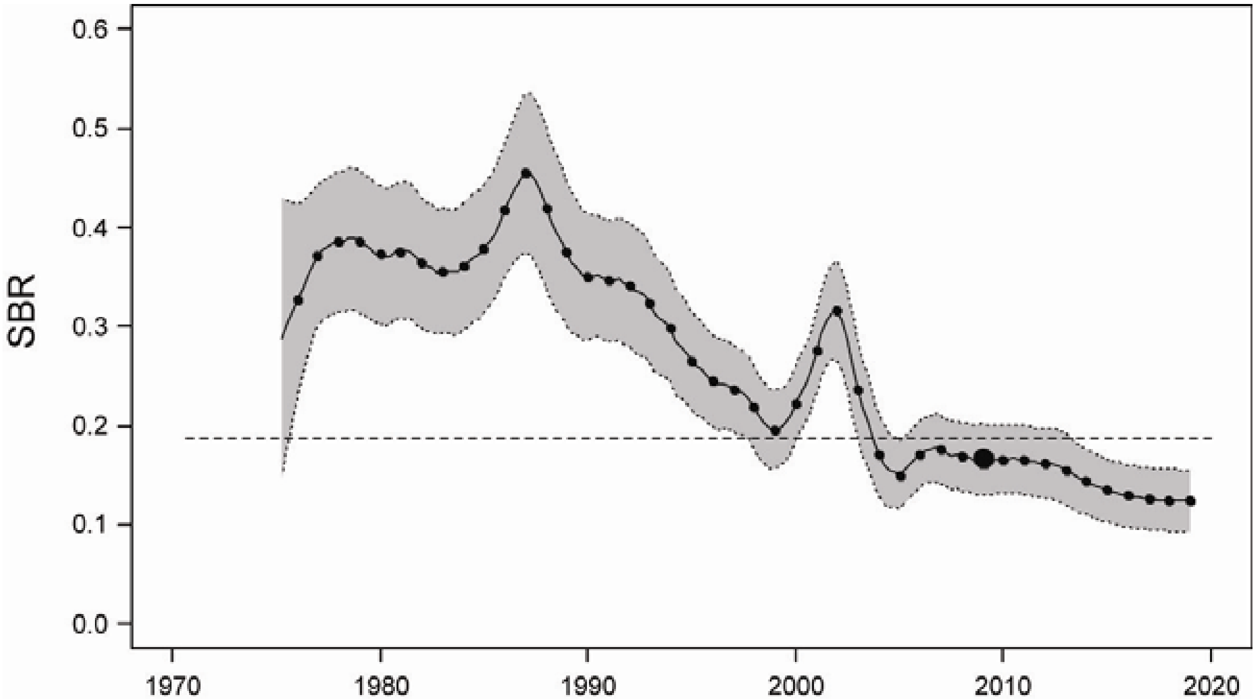

FIGURE 6.1a. Spawning biomass ratios (SBRs) of bigeye tuna in the EPO, including projections for 2010-2019 based on average fishing mortality rates during 2006-2008. The dashed horizontal line (at about 0.19) identifies the SBR at MSY. The solid curve illustrates the maximum likelihood estimates, and the estimates after 2009 (the large dot) indicate the SBR predicted to occur if fishing mortality rates continue at the average of that observed during 2006-2008. 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 2010-2019 basadas en las tasas medias de mortalidad por pesca durante 2006-2008. La línea de trazos horizontal (en aproximadamente 0.19) identifica el SBR en RMS. La curva sólida ilustra las estimaciones de verosimilitud máxima, y las estimaciones a partir de 2009 (el punto grande) señalan el SBR predicho si las tasas de mortalidad por pesca continúa en el promedio observado durante 2006-2008. Las líneas de trazos representan los intervalos de confianza de 95% alrededor de esas estimaciones.

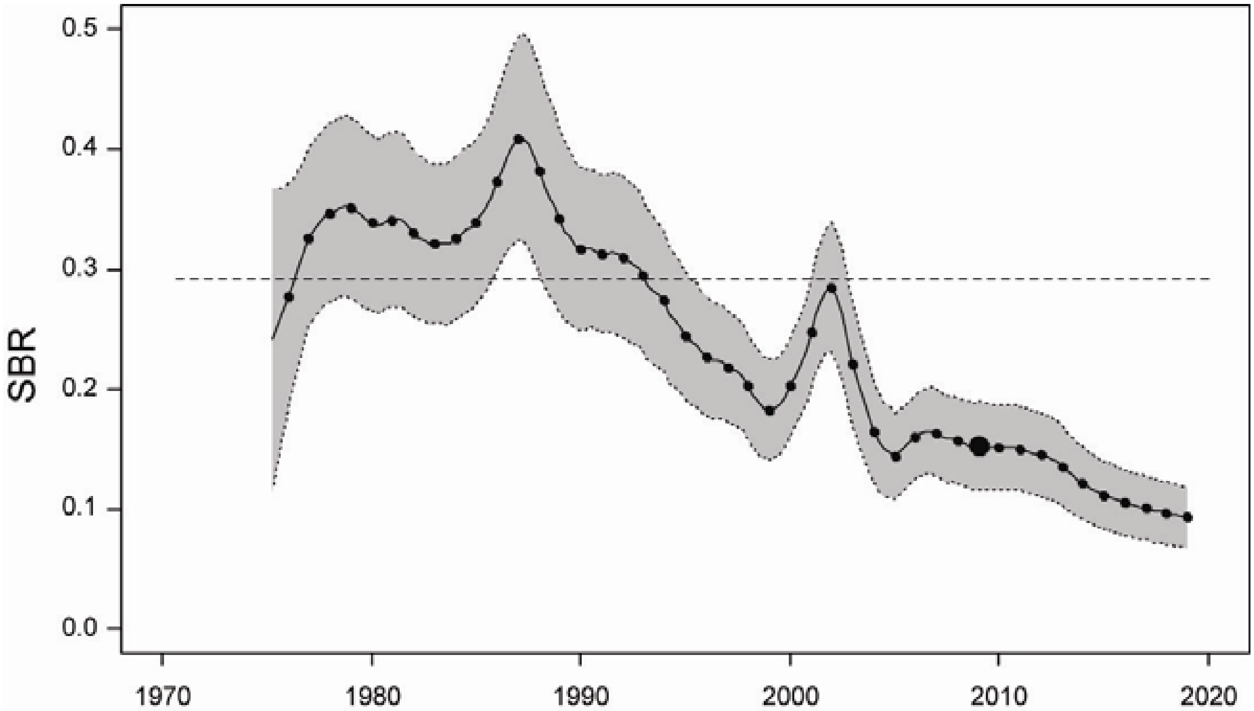

FIGURE 6.1b. Projected spawning biomass ratios (SBRs) of bigeye tuna in the EPO from the stock-recruitment sensitivity analysis. The dashed horizontal line (at about 0.29) identifies the SBR at MSY. The solid curve illustrates the maximum likelihood estimates, and the estimates after 2009 (the large dot) indicate the SBR predicted to occur if fishing mortality rates continue at the average of that observed during 2006-2008. 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 0,29) identifica el SBR en RMS. La curva sólida ilustra las estimaciones de verosimilitud máxima, y las estimaciones a partir de 2009 (el punto grande) señalan el SBR predicho si las tasas de mortalidad por pesca continúa en el promedio observado durante 2006-2008. Las líneas de trazos representan los intervalos de confianza de 95% alrededor de esas estimaciones.

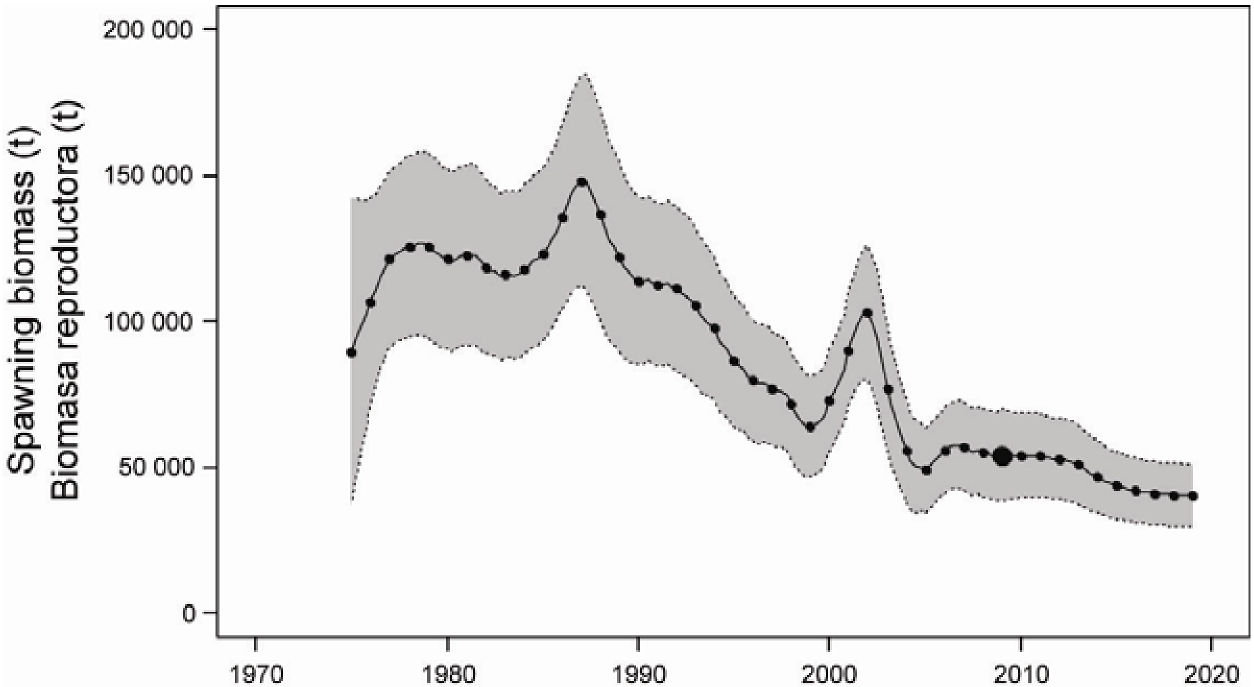

FIGURE 6.2. Spawning biomass of bigeye tuna, including projections for 2010-2019 based on average fishing mortality rates during 2006-2008. The solid curve illustrates the maximum likelihood estimates, and the estimates after 2009 (the large dot) indicate the spawning biomass predicted to occur if fishing mortality rates continue at the average of that observed during 2006-2008.. 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 2010-2019 basadas en las tasas de mortalidad por pesca media durante 2006-2008. La curva sólida ilustra las estimaciones de verosimilitud máxima, y las estimaciones a partir de 2009 (el punto grande) señalan la biomasa reproductora predicha si las tasas de mortalidad por pesca continúan en el promedio observado durante 2006-2008. La zona sombreada entre las líneas de trazos representa los intervalos de confianza de 95%. t = toneladas métricas.

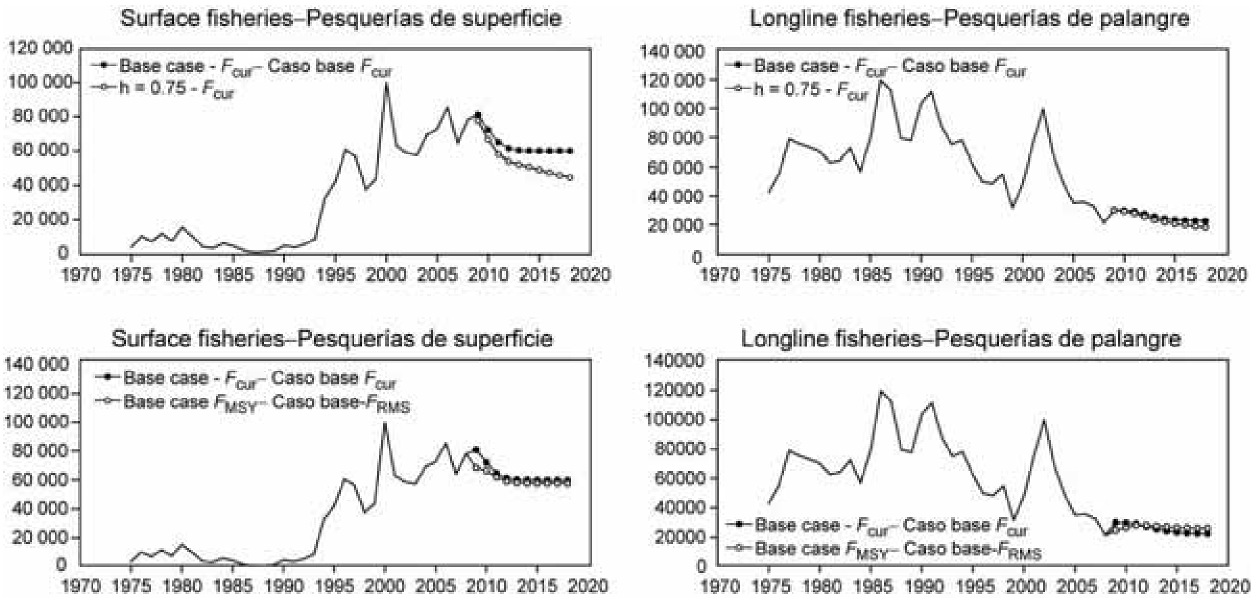

FIGURE 6.3. Predicted quarterly catches during 2009-2018 of bigeye tuna for the purse-seine and pole-and-line (left panels) and longline (right panels) fisheries, based on fishing mortality rates during 2006-2008. Predicted catches are compared between the base case (F_{cur}) and the analysis in which a stock-recruitment relationship was used (upper panels), and the analysis assuming F_{MSY} (lower panels). t = metric tons.

FIGURA 6.3. Capturas trimestrales predichas durante 2009-2018 de atún patudo en las pesquerías de cerco y caña (recuadros izquierdos) y de palangre (recuadros derechos), basadas en las tasas de mortalidad por pesca durante 2006-2008. Se comparan las capturas predichas entre el caso base (F_{cur}) y el análisis en el que se usó una relación población-reclutamiento (recuadros superiores), y el análisis que supuso F_{RMS} (recuadros inferiores). t = toneladas métricas.

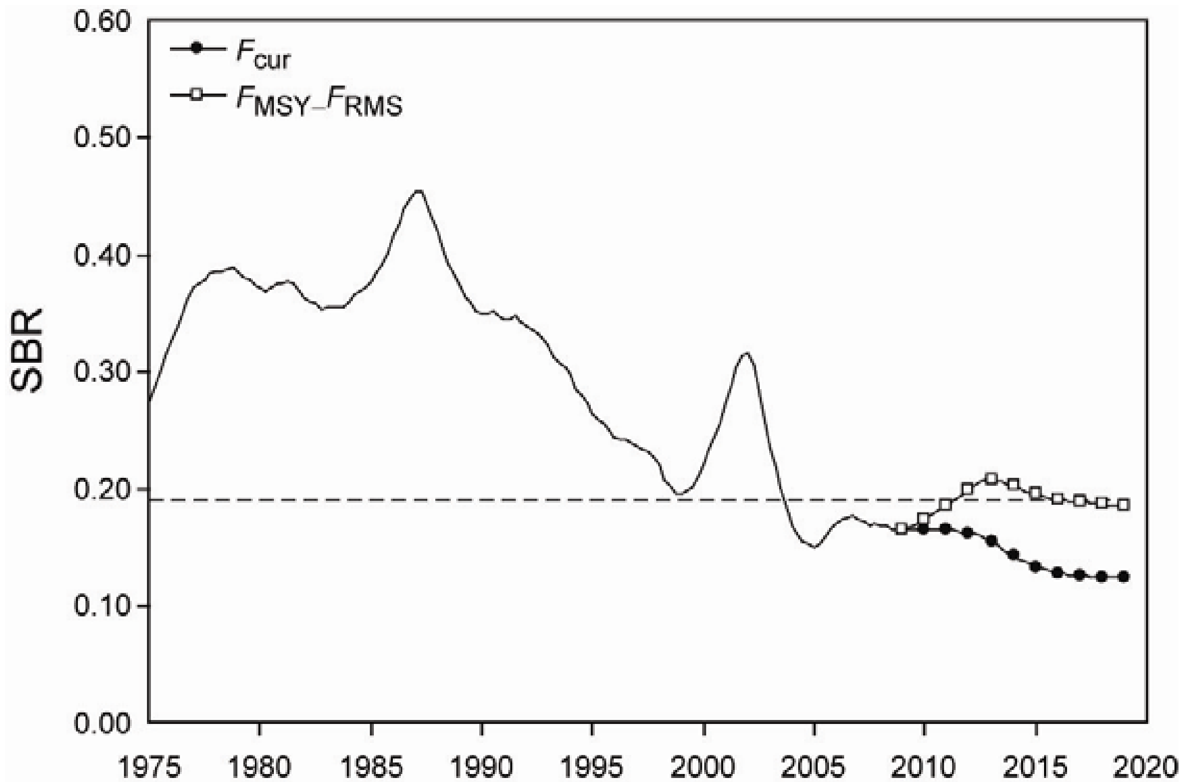

FIGURE 6.4. Projected spawning biomass ratio (SBR) from the base case model assuming a harvesting strategy targeting current fishing mortality rates (status quo) and the fishing mortality rate corresponding to MSY (F_{MSY}).

FIGURA 6.4. Cociente de biomasa reproductora (SBR) predicho del modelo de caso base y sin la restricción de la Resolución C-04-09 de la CIAT.

TABLE 2.1. Fishery definitions used 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 descriptions of the discards are provided 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 objeto flotante; 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–captura retenida + descartes de ineficacias en el proceso de pesca
3	PS	OBJ	1993-2008	7, 9	
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	LL		1975-2008	N of–de 15°N	retained catch only (in numbers)–captura retenida solamente (en número)
9	LL		1975-2008	S of–de 15°N	retained catch only (in numbers) –captura retenida solamente (en número)
10	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
11	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
12	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
13	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
14	LL		1975-2008	N of–de 15°N	retained catch only (in weight) –captura retenida solamente (en peso)
15	LL		1975-2008	S of–de 15°N	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) usados 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 and older), 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 3 trimestres o más de edad), biomasa reproductora (toneladas métricas), y cociente de biomasa reproductora (SBR) de atún patudo en el OPO.

Year Año	Total recruitment Reclutamiento total	Summary biomass Biomasa sumaria	Spawning biomass Biomasa reproductora	SBR SBR
1975	15,055	438,689	89,496	0.27
1976	17,404	501,172	106,657	0.33
1977	17,889	525,812	121,371	0.37
1978	14,856	526,818	125,914	0.39
1979	15,577	523,071	125,729	0.39
1980	16,753	510,801	121,424	0.37
1981	14,339	497,416	122,570	0.38
1982	25,193	497,459	118,792	0.36
1983	24,831	502,199	116,007	0.36
1984	15,301	539,620	117,744	0.36
1985	11,537	610,112	123,189	0.38
1986	16,386	630,249	135,999	0.42
1987	21,232	572,012	148,381	0.46
1988	17,782	515,683	136,886	0.42
1989	13,369	519,028	122,095	0.37
1990	13,458	535,144	114,055	0.35
1991	12,835	510,387	112,824	0.35
1992	16,290	462,666	111,266	0.34
1993	15,498	429,478	105,356	0.32
1994	25,688	414,420	97,648	0.30
1995	28,007	386,837	86,413	0.27
1996	28,460	367,577	79,999	0.25
1997	47,778	343,123	77,133	0.24
1998	31,013	323,754	71,600	0.22
1999	20,571	390,803	64,027	0.20
2000	19,907	488,763	72,672	0.22
2001	28,187	455,889	90,043	0.28
2002	33,601	390,765	103,310	0.32
2003	28,206	307,771	77,068	0.24
2004	24,807	292,493	55,532	0.17
2005	38,890	295,246	48,967	0.15
2006	32,031	290,452	55,689	0.17
2007	20,221	274,923	57,199	0.18
2008	37,256	287,383	55,089	0.17
2009		287,090	54,256	0.17

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. La edad es 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	22.21	0.31	21	158.92	90.35
2	34.50	1.08	22	161.94	95.41
3	45.95	2.48	23	164.76	100.30
4	56.62	4.54	24	167.38	105.00
5	66.57	7.26	25	169.83	109.50
6	75.85	10.59	26	172.11	113.80
7	84.49	14.48	27	174.23	117.89
8	92.56	18.85	28	176.21	121.76
9	100.07	23.64	29	178.06	125.41
10	107.08	28.76	30	179.78	128.84
11	113.61	34.15	31	181.39	132.03
12	119.70	39.73	32	182.89	135.01
13	125.38	45.44	33	184.28	137.76
14	130.67	51.22	34	185.58	140.30
15	135.60	57.03	35	186.79	142.63
16	140.20	62.82	36	187.93	144.77
17	144.49	68.55	37	188.98	146.72
18	148.49	74.20	38	189.96	148.50
19	152.21	79.72	39	190.88	150.13
20	155.69	85.11	40	191.73	151.62

TABLE 4.3a. Likelihood components obtained for the base case and sensitivity analyses. The likelihood components for the western and central Pacific Ocean (WCPO) data sensitivities are presented separately (see Table 4.3b), since the likelihood values are not comparable to those obtained from analyses which included data for the EPO only.

TABLA 4.3a. Componentes de verosimilitud obtenidos para los análisis del caso base y de sensibilidad. Se presentan por separado los componentes de verosimilitud para la sensibilidad a los datos del Pacífico occidental y central (WCPO; ver Tabla 4.3b), ya que los valores de verosimilitud no son comparables con aquéllos obtenidos de análisis que incluyeron datos del OPO solamente.

Data		**Base case**	**h = 0.75**	**Richards growth curve**
Datos		**Caso base**	**h = 0.75**	**Curva de crecimiento de Richards**
CPUE				
Fishery Pesquería	2	-38.69	-38.50	-40.65
	3	-6.55	-6.50	-7.19
	5	-5.31	-5.07	-7.01
	8	-50.39	-50.45	-48.78
	9	-168.12	-168.68	-170.18
	Sum	-269.06	-269.20	-273.81
Size composition Composición por tamaño				
Fishery Pesquería	1	163.86	163.73	165.14
	2	240.11	240.75	204.78
	3	295.99	295.80	284.54
	4	75.03	75.03	74.25
	5	173.68	174.29	146.17
	6	131.44	131.74	130.74
	7	138.27	137.14	138.97
	8	135.70	135.16	138.19
	9	294.22	296.92	297.92
	Sum	1648.30	1650.55	1580.71
Age composition Composición por edad		307.64	309.71	287.72
Recruitment Reclutamiento		-29.99	-25.46	-24.99
Total		**1656.89**	**1665.61**	**1569.63**

TABLE 4.3b. Likelihood components obtained from the two sensitivity analyses in which the western limit of the bigeye stock distribution was extended from 150°W to 170°E. Two sensitivity analyses were made: 1) fitted to CPUE and size composition data from WCPO fisheries in regions 2, 4, and 6 (see Figure C.1); 2) not fitted to WCPO data, and removing catch from the population by sharing selectivities with EPO fisheries catching fish of similar size.

TABLA 4.3b. Componentes de verosimilitud obtenidos para los dos análisis de sensibilidad en los que el límite occidental de la distribución de la población de patudo fue extendido de 150ºO a 170°E. Se realizaron dos análisis de sensibilidad: 1) con ajuste a los datos de CPUE y composición de tallas de las pesquerías del Pacífico occidental y central (WCPO) en las regiones 2, 4, y 6 (ver Figura C.1); 2) sin ajuste a los datos del WCPO, y eliminando la captura de la población, compartiendo la selectividad con las pesquerías del OPO que capturan peces de tamaño similar.

	CPUE		**Size composition Composición por tamaño**	
Fishery	**Fitted**	**Not fitted**	**Fitted**	**Not fitted**
Pesquería	**Ajustada**	**No ajustada**	**Ajustada**	**No ajustada**
1	-	-	172.12	163.833
2	-35.95	-37.9716	277.77	245.529
3	-6.86	-6.73673	340.35	296.067
4	-	-	79.57	75.0905
5	-5.06	-5.30383	179.39	177.755
6	-	-	132.94	131.308
7	-	-	156.11	138.863
8	-60.95	-52.3959	122.43	137.596
9	-169.07	-168.849	316.62	306.824
10	-	-	-	-
11	-	-	-	-
12	-	-	-	-
13	-	-	-	-
14	-	-	-	-
15	-	-	-	-
16	-12.50	-	268.81	-
17	-	-	79.21	-
18	-30.50	-	269.97	-
19	-	-	102.98	-
20	-	-	75.31	-
21	7.97	-	76.46	-
22	-	-	150.65	-
23	-	-	233.64	-
24	-	-	95.39	-
25	-	-	0.00	-
Sum	**-312.93**	**-271.26**	**3129.70**	**1672.87**
Age composition Composición por edad				
	327.54	308.161		
Recruitment Reclutamiento				
	-22.70	-32.7558		
TOTAL LIKELIHOOD VEROSIMILITUD TOTAL				
	3121.62	1677.01		

TABLE 5.1. Estimates of the MSY and its associated quantities for bigeye tuna for the base case assessment and sensitivity analyses. All analyses are based on average fishing mortality during 2006-2008. B_{recent} and B_{MSY} are defined as the biomass of fish 3+ quarters old (in metric tons) at the beginning of 2009 and at MSY, respectively. S_{recent} and S_{MSY} are in metric tons. C_{recent} is the estimated total catch in 2008. 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 from 2006-2008. WCPO: western and central Pacific Ocean.

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 2006-2008. Se definen B_{recent} y B_{RMS} como la biomasa de peces de 3+ trimestres de edad (en toneladas métricas) al principio de 2009 y en RMS, respectivamente. Se expresan S_{recent} y S_{MSY} en toneladas métricas. C_{recent} es la captura total estimada en 2008. 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 de 2006-2008. WCPO: Océano Pacífico occidental y central

				Add WCPO regions 2,4,6	
	Base case	**h = 0.75**	**Richards growth**	**Fitted to WCPO data**	**Not fitted to WCPO data**
				Añadir regiones 2,4,6 del WCPO	
	Caso base	**h = 0.75**	**Crecimiento de Richards**	**Ajuste a los datos del WCPO**	**Sin ajuste a los datos del WCPO**
MSY-RMS	83,615	81,482	79,122	119,638	124,002
B_{MSY}- B_{RMS}	289,475	521,888	278,030	365,335	388,243
S_{MSY}- S_{RMS}	60,631	125,008	60,166	68,783	76,824
B_{MSY}/B_0- B_{RMS}/B_0	0.25	0.34	0.25	0.27	0.25
S_{MSY}/S_0- S_{RMS}/S_0	0.19	0.29	0.19	0.19	0.18
C_{recent}/MSY- C_{recent}/RMS	1.19	1.22	1.26	1.38	1.29
B_{recent}/B_{MSY}- B_{recent}/B_{RMS}	0.99	0.62	0.91	0.73	0.95
S_{recent}/S_{MSY}-S_{recent}/S_{RMS}	0.89	0.52	0.80	0.53	0.86
F multiplier- Multiplicador de *F*	0.81	0.54	0.73	0.59	0.79

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 fishery 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 from 2006-2008. A sensitivity of the management quantities estimates to using the average fishing mortality rates for the period 2006-2007, 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 de 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 2003-2004, 2005-2006 y 2004-2006. "solamente" significa que se usa solamente ese arte, y se fija la mortalidad por pesca de las otras artes en cero.

	Base case	**Purse seine only**	**Longline only**	**2006-2007**
	Caso base	**Cerco solamente**	**Palangre solamente**	
MSY-RMS	83,615	65,209	176,218	89,657
B_{MSY}- B_{RMS}	289,475	235,483	314,523	299,400
S_{MSY}- S_{RMS}	60,631	51,508	30,556	61,367
B_{MSY}/B_0- B_{RMS}/B_0	0.25	0.20	0.27	0.25
S_{MSY}/S_0- S_{RMS}/S_0	0.19	0.16	0.09	0.19
C_{recent}/MSY- C_{recent}/RMS	1.19	1.53	0.56	1.11
B_{recent}/B_{MSY}- B_{recent}/B_{RMS}	0.99	1.22	0.91	0.96
S_{recent}/S_{MSY}-S_{recent}/S_{RMS}	0.89	1.05	1.78	0.88
F multiplier- Multiplicador de *F*	0.81	1.22	5.97	0.81

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

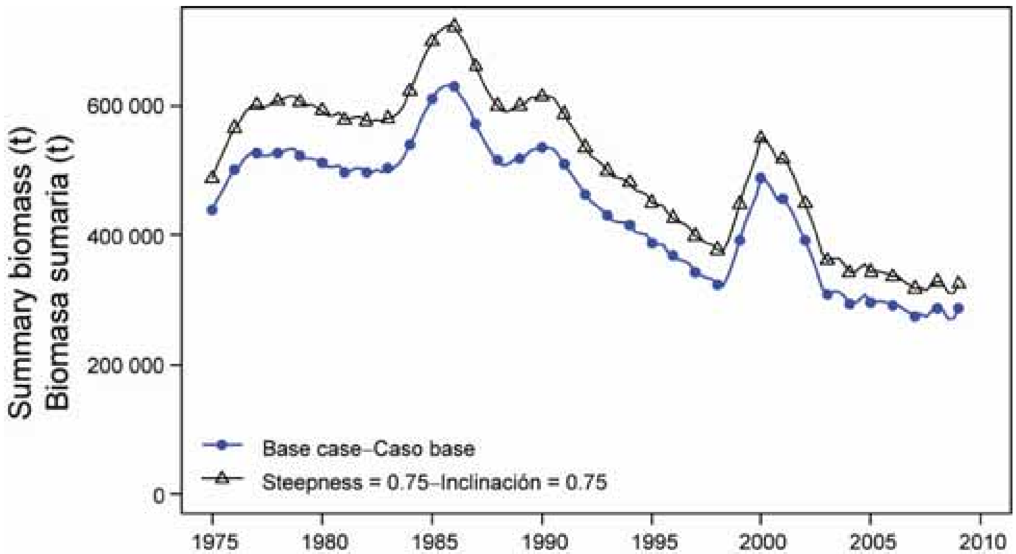

FIGURE A.1. Comparison of estimates of biomass of bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). t = metric tons.
FIGURA A.1. Comparación de las estimaciones de la biomasa de atún patudo del análisis sin una relación población-reclutamiento (caso base) y con dicha relación (inclinación = 0.75). t = toneladas métricas.

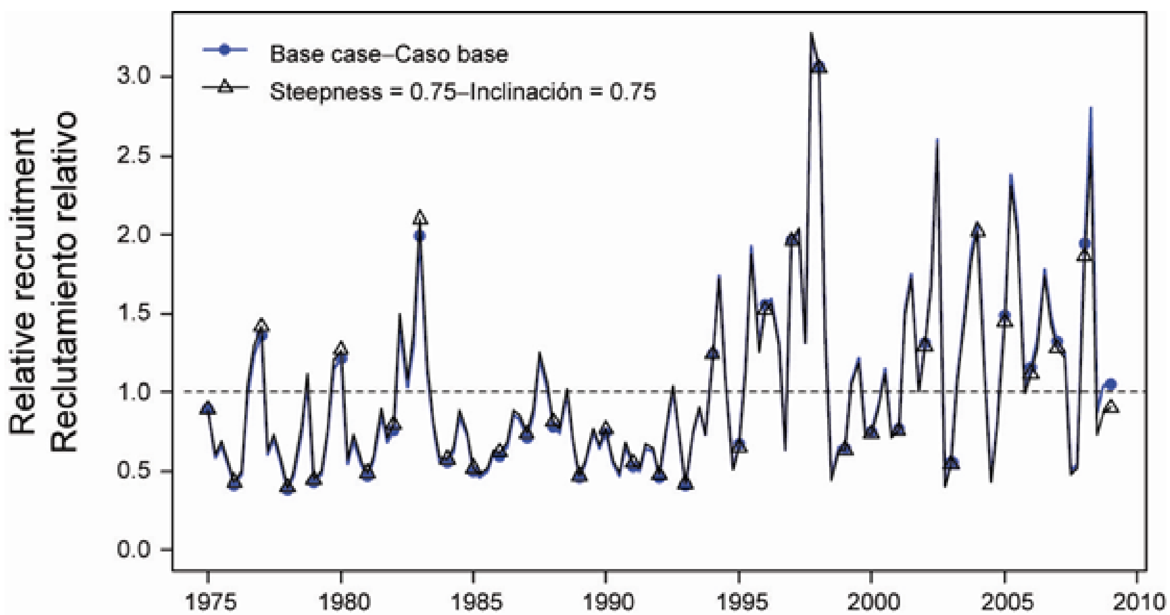

FIGURE A.2. Comparison of estimates of relative recruitment for bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).
FIGURA A.2. Comparación de las estimaciones de reclutamiento relativo de atún patudo del análisis sin una relación población-reclutamiento (caso base) y con dicha relación (inclinación = 0.75).

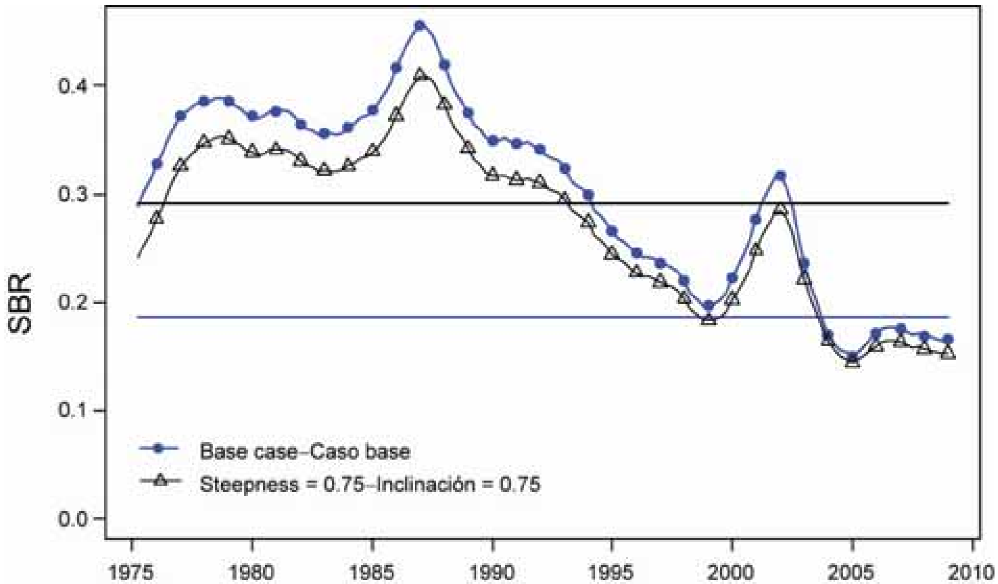

FIGURE A.3. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). The horizontal lines represent the SBRs associated with MSY under the two scenarios.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

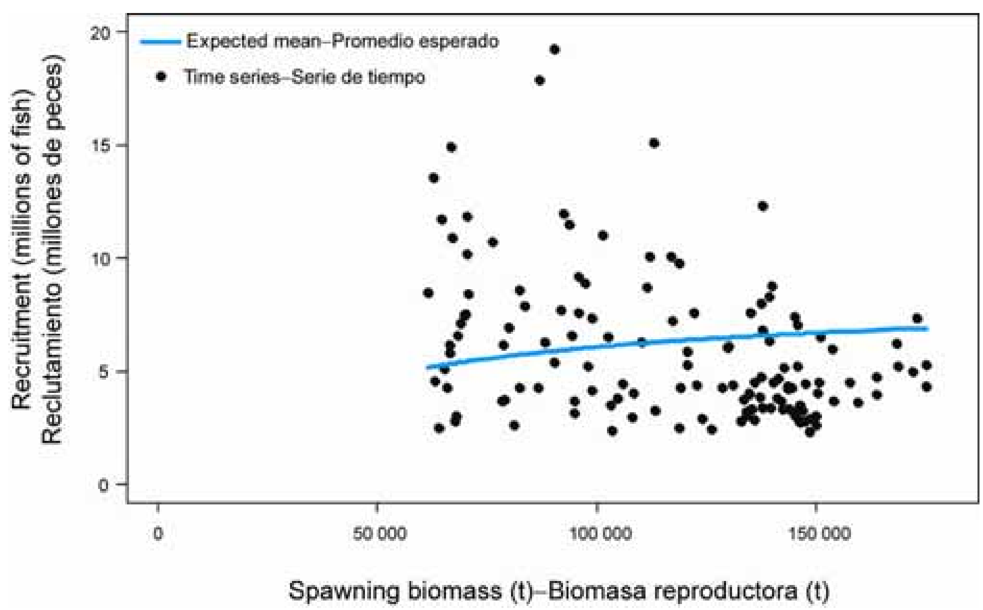

FIGURE A.4. Recruitment of bigeye tuna plotted against spawning biomass when the analysis has a stock-recruitment relationship (steepness = 0.75).
FIGURA A.4. Reclutamiento de atún patudo graficado contra biomasa reproductora cuando el análisis incluye una relación población-reclutamiento (inclinación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

APPENDIX B: SENSITIVITY ANALYSIS TO USING A RICHARDS GROWTH CURVE
ANEXO B: ANÁLISIS DE SENSIBILIDAD USANDO DATOS DE CPUE DE LA PESQUERÍA DE PALANGRE DEL SUR SOLAMENTE

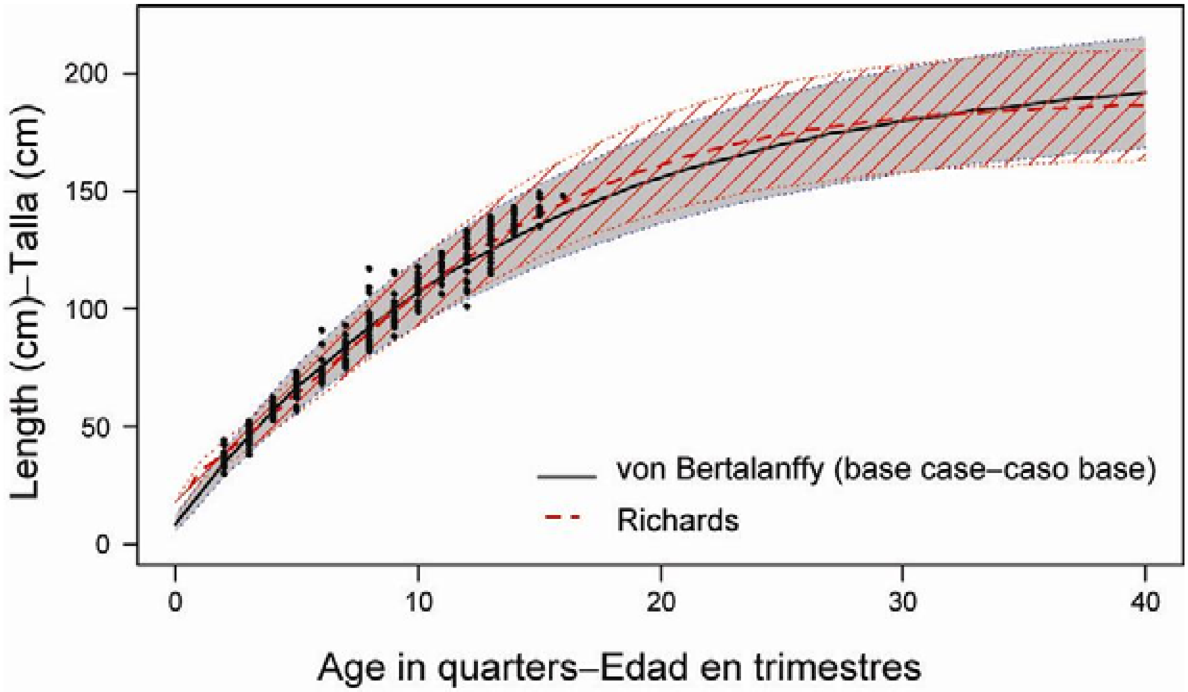

FIGURE B.1. Comparison of the von Bertalanffy (base case) and the Richards growth curves (sensitivity) fitted to age-at-length observations derived from otolith readings (dots). The confidence intervals (±2 standard deviations) of the mean lengths are shown for each growth curve (shaded for the base case and dashed lines for Richards curve)..
FIGURA B.1. Comparación de las curvas de crecimiento de von Bertalanffy (caso base) y de Richards (sensibilidad) ajustadas a las observaciones de edad por talla derivadas de lectura de otolitos (puntos). Se ilustran para cada curva de crecimiento los intervalos de confianza (±2 desviaciones estándar) de las tallas medias (sombreado para el caso base y con líneas de trazos para la curva de Richards).

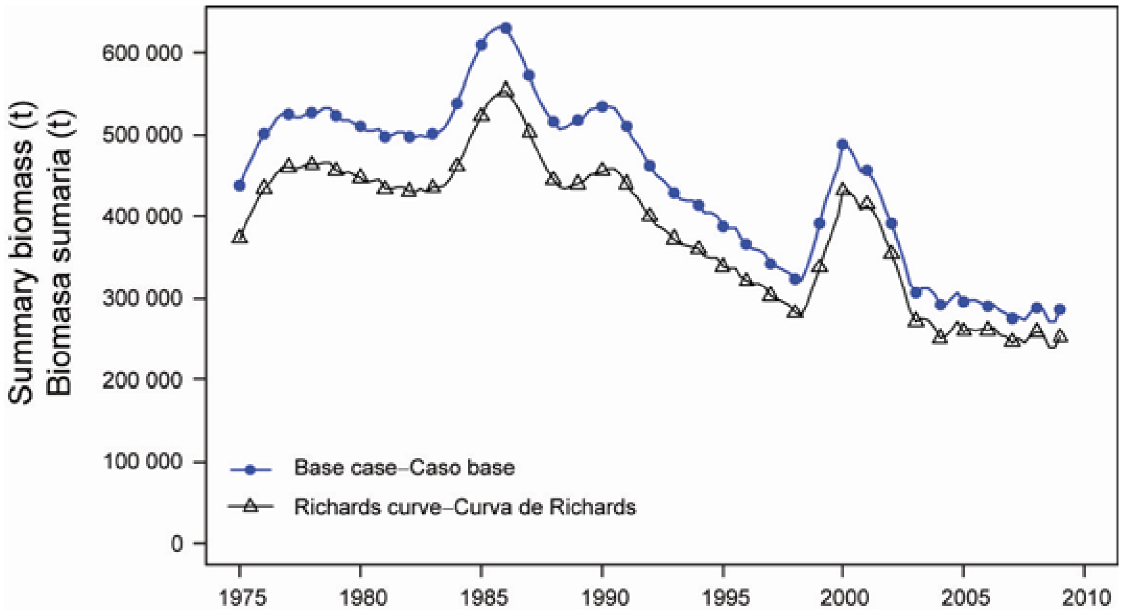

FIGURE B.2. Comparison of estimates of biomass of bigeye tuna from the base case analysis using a von Bertalanffy growth curve with a model which assumes a Richards growth curve. t = metric tons.
FIGURA B.2. Comparación de las estimaciones de biomasa de atún patudo del análisis del caso base con un modelo en el cual se usaron los datos de CPUE de la pesquería de palangre del sur (Pesquería 9) solamente. t = toneladas métricas.

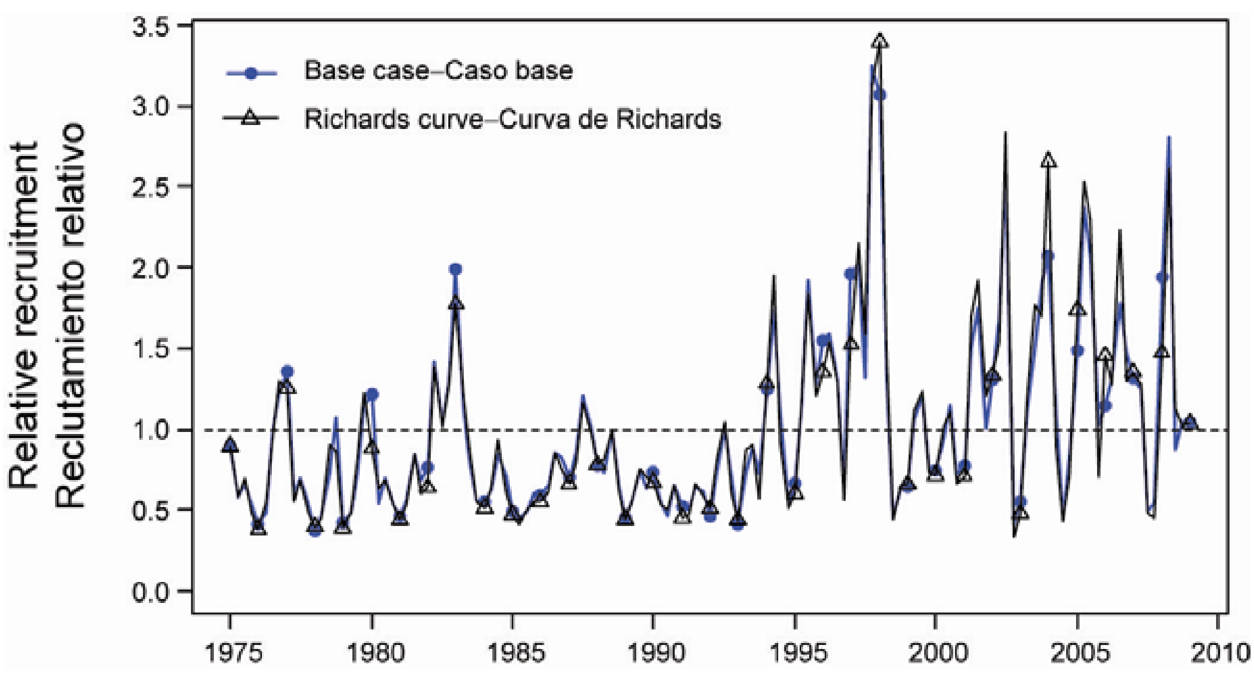

FIGURE B.3. Comparison of estimates of relative recruitment for bigeye tuna from the base case analysis using a von Bertalanffy growth curve with a model which assumes a Richards growth curve.
FIGURA B.3. Comparación de las estimaciones de reclutamiento de atún patudo del análisis del caso base con un modelo en el cual se usaron los datos de CPUE de la pesquería de palangre del sur (Pesquería 9) solamente.

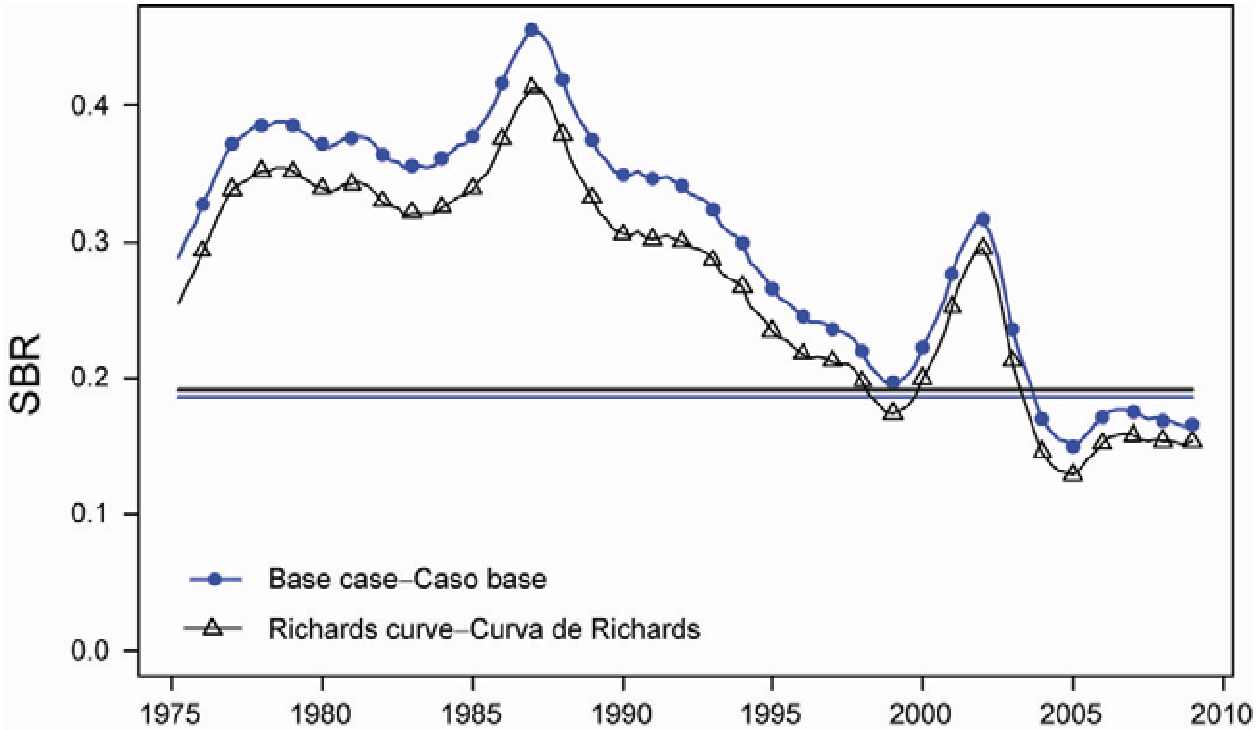

FIGURE B.4. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the base case analysis using a von Bertalanffy growth curve with a model which assumes a Richards growth curve.. The horizontal lines represent the SBRs associated with MSY under the two scenarios.

FIGURA B.4. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún patudo del análisis del caso base con un modelo en el cual se usaron los datos de CPUE de la pesquería de palangre del sur (Pesquería 9) solamente. Las líneas horizontales representan los SBR asociados con el RMS en los dos escenarios.

APPENDIX C: SENSITIVITY ANALYSIS TO EXTENDING THE ASSUMED WESTERN LIMIT OF THE BIGEYE STOCK DISTRIBUTION FROM 150°W TO 170°E

ANEXO C: ANÁLISIS DE SENSIBILIDAD A LA EXTENSIÓN DEL LÍMITE OCCIDENTAL SUPUESTO DE LA DISTRIBUCIÓN DE LA POBLACIÓN DE PATUDO DE 150ºO A 170ºE

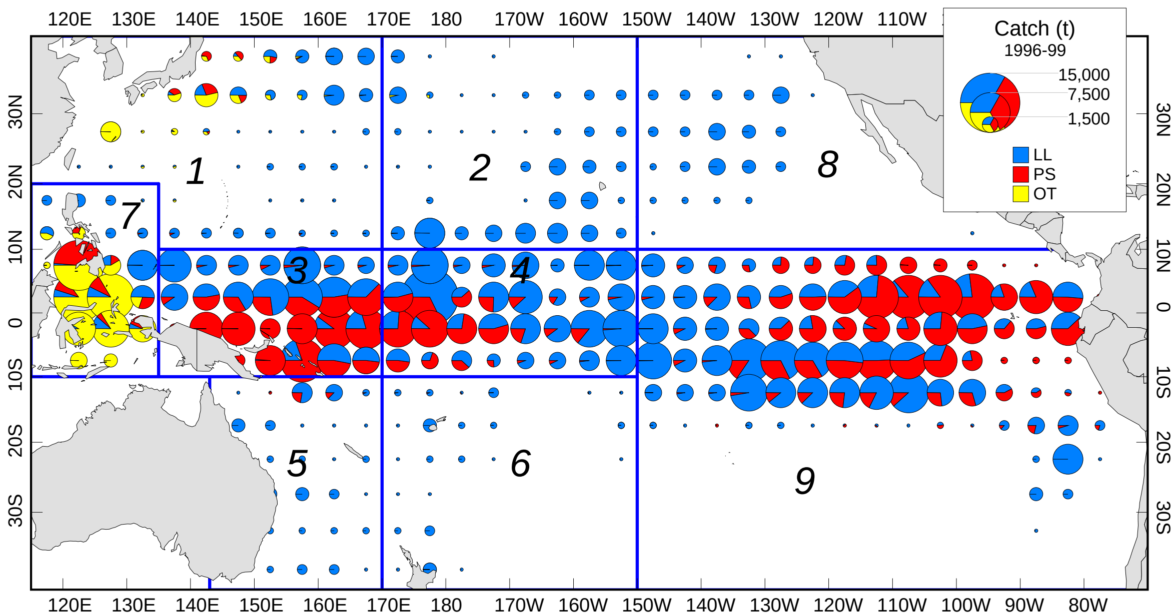

FIGURE C.1. The nine-region spatial structure model previously adopted in the Pacific-wide bigeye stock assessment model (Hampton and Maunder 2006), with total catch by gear type, 1996-1999. The sensitivity analysis added catch taken from regions 2, 4, and 6 to the current EPO (regions 8 and 9) bigeye assessment.

FIGURA C.1. El modelo de estructura especial de nueve regiones adoptado previamente en el modelo de evaluación de la población de patudo del Pacífico entero (Hampton y Maunder 2006), con captura total por tipo de arte, 1996-1999. Los análisis de sensibilidad añadieron la captura obtenida de las regiones 2, 4, y 6 a la evaluación actual del patudo del OPO (regiones 8 y 9).

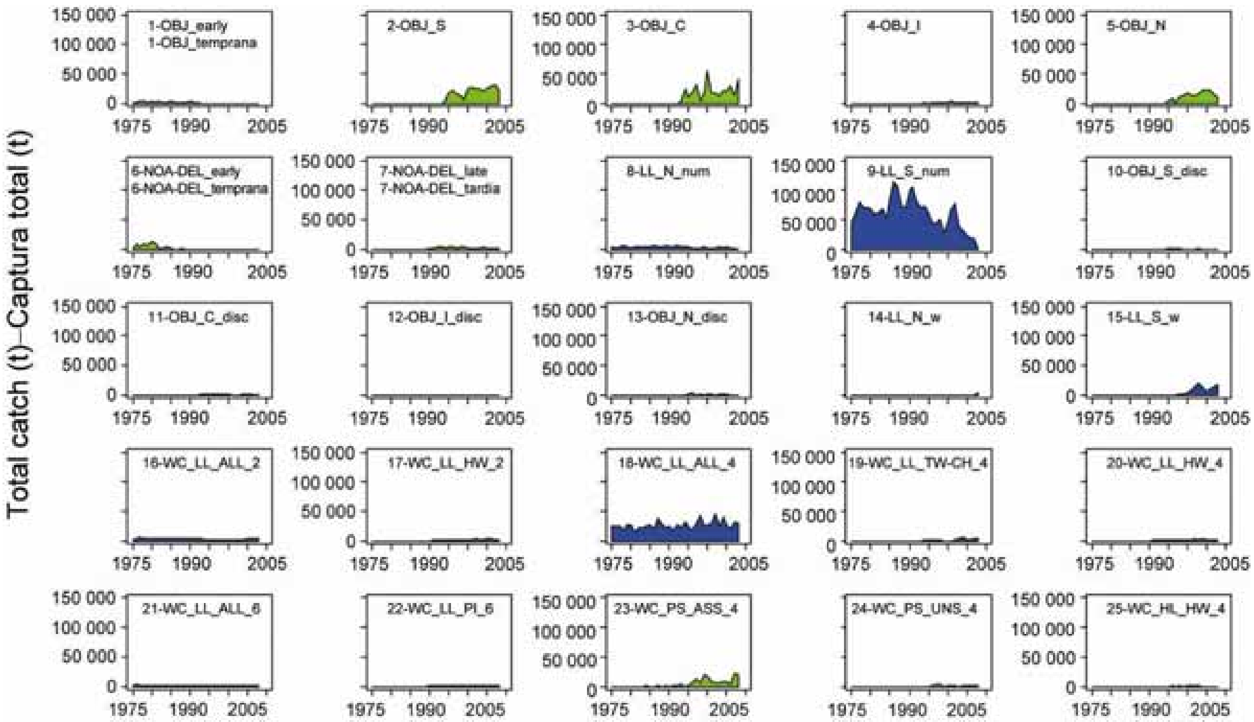

FIGURE C.2. Annual catches of bigeye tuna taken by the fisheries defined in the sensitivity analysis to extending the assumed western limit of the bigeye stock distribution from 150°W to 170°E. The fisheries are defined in Table C.1 in this appendix.

FIGURA C.2. Capturas anuales de atún patudo logradas por las pesquerías definidas en el análisis de sensibilidad a la extensión del límite occidental supuesto de la distribución de la población de patudo de 150ºO a 170ºE. En la Tabla C.1 del presente anexo se definen las pesquerías.

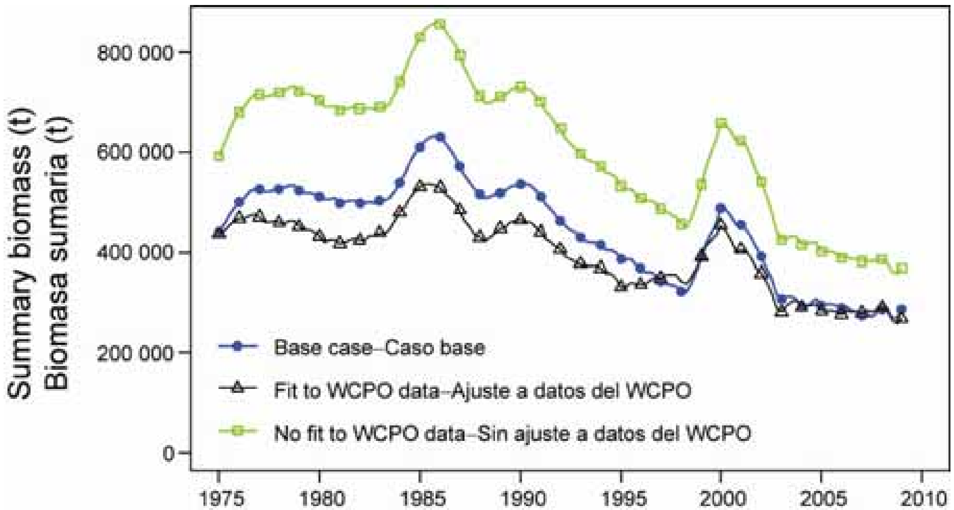

FIGURE C.3. Comparison of estimates of biomass of bigeye from the base case analysis with the two sensitivity analyses in which extending the assumed western limit of the bigeye stock distribution from 150°W to 170°E was: 1) fitted to the WCPO CPUE and size composition data; 2) not fitted to WCPO CPUE and size composition data, but catch was removed from the population by sharing selectivities with similar EPO fisheries. t = metric tons.

FIGURA C.3 Comparación de las estimaciones de la biomasa de patudo del análisis de caso base con los dos análisis de sensibilidad en los que la extensión el límite occidental supuesto de la distribución de la población de patudo de 150°O a 170°E fue: 1) ajustada a los datos de CPUE y composición de tallas del Pacífico occidental y central (WCPO); 2) no ajustada a dichos datos de CPUE, pero con la captura eliminada de la población compartiendo selectividades con pesquerías similares del OPO. t = toneladas métricas.

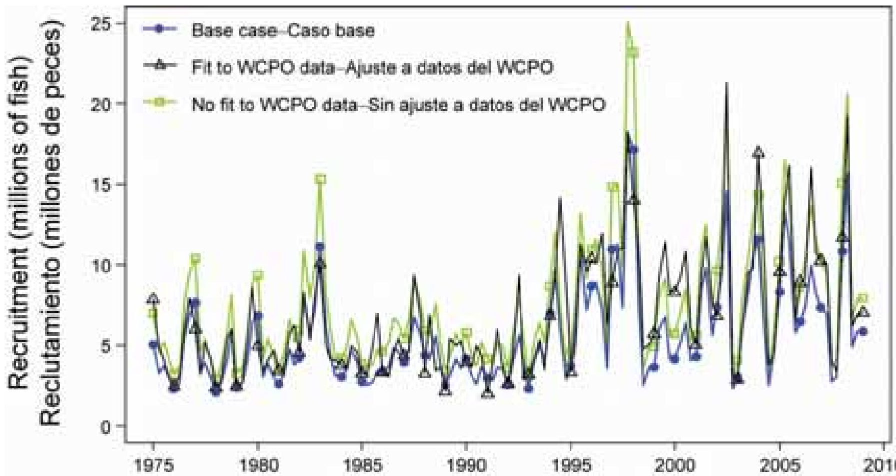

FIGURE C.4a. Comparison of estimates of recruitment (millions of fish) for bigeye tuna from the base case analysis with the two sensitivity analyses in which extending the assumed western limit of the bigeye stock distribution from 150°W to 170°E was: 1) fitted to the WCPO CPUE and size composition data; 2) not fitted to WCPO CPUE and size composition data, and catch removed from the population by sharing selectivities with similar EPO fisheries.

FIGURA C.4a. Comparación de estimaciones del reclutamiento (millones de peces) de atún patudo del análisis de caso base con los dos análisis de sensibilidad en los que la extensión del límite occidental supuesto de la distribución del patudo de 150ºO a 170ºE fue: 1) ajustada a los datos de CPUE y composición de tallas del WCPO; 2) no ajustada a dichos datos, pero con la captura eliminada de la población compartiendo selectividades con pesquerías similares del OPO.

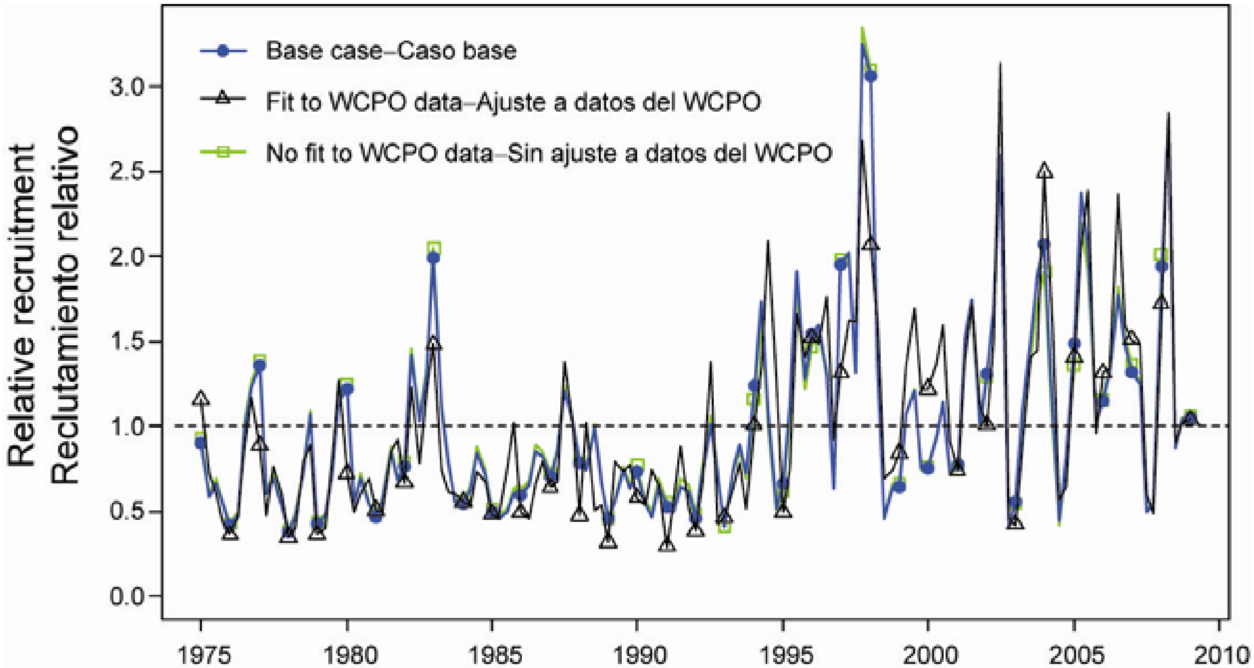

FIGURE C.4b. Comparison of estimates of relative recruitment for bigeye tuna from the base case analysis with the two sensitivity analyses in which extending the assumed western limit of the bigeye stock distribution from 150°W to 170°E was: 1) fitted to the WCPO CPUE and size composition data; 2) not fitted to WCPO CPUE and size composition data, and catch removed from population by sharing selectivities with similar EPO fisheries.

FIGURA C.4b. Comparación de las estimaciones del reclutamiento relativo de atún patudo del análisis de caso base con los dos análisis de sensibilidad en los que la extensión del límite occidental supuesto de la distribución del patudo de 150ºO a 170ºE fue: 1) ajustada a los datos de CPUE y composición de tallas del WCPO; 2) no ajustada a dichos datos, pero con la captura eliminada de la población compartiendo selectividades con pesquerías similares del OPO.

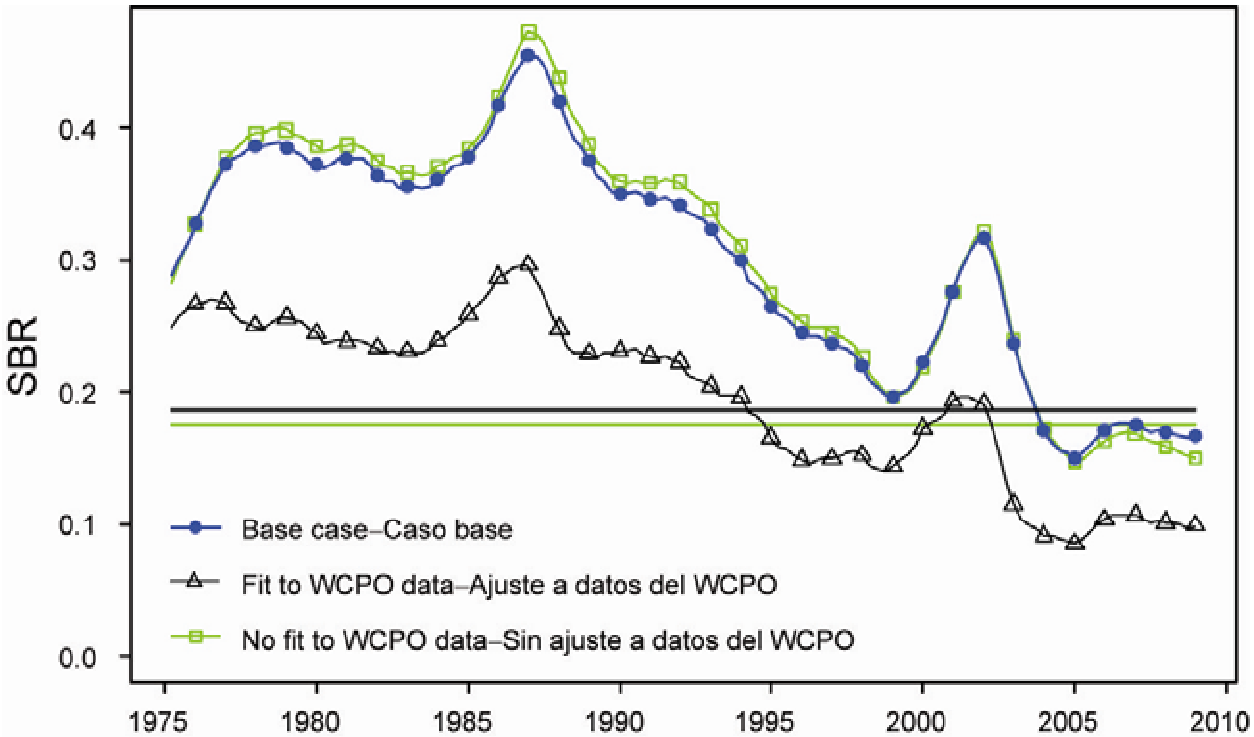

FIGURE C.5. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the base case analysis with the two sensitivity runs in which extending the assumed western limit of the bigeye stock distribution from 150°W to 170°E was: 1) fitted to WCPO CPUE and size composition data; 2) not fitted to WCPO CPUE and size composition data, and catch removed from population by sharing selectivities with similar EPO fisheries.

FIGURA C.5. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún patudo del análisis de caso base con los dos análisis de sensibilidad en los que la extensión del límite occidental supuesto de la distribución del patudo de 150ºO a 170ºE fue: 1) ajustada a los datos de CPUE y composición de tallas del WCPO; 2) no ajustada a dichos datos, pero con la captura eliminada de la población compartiendo selectividades con pesquerías similares del OPO.

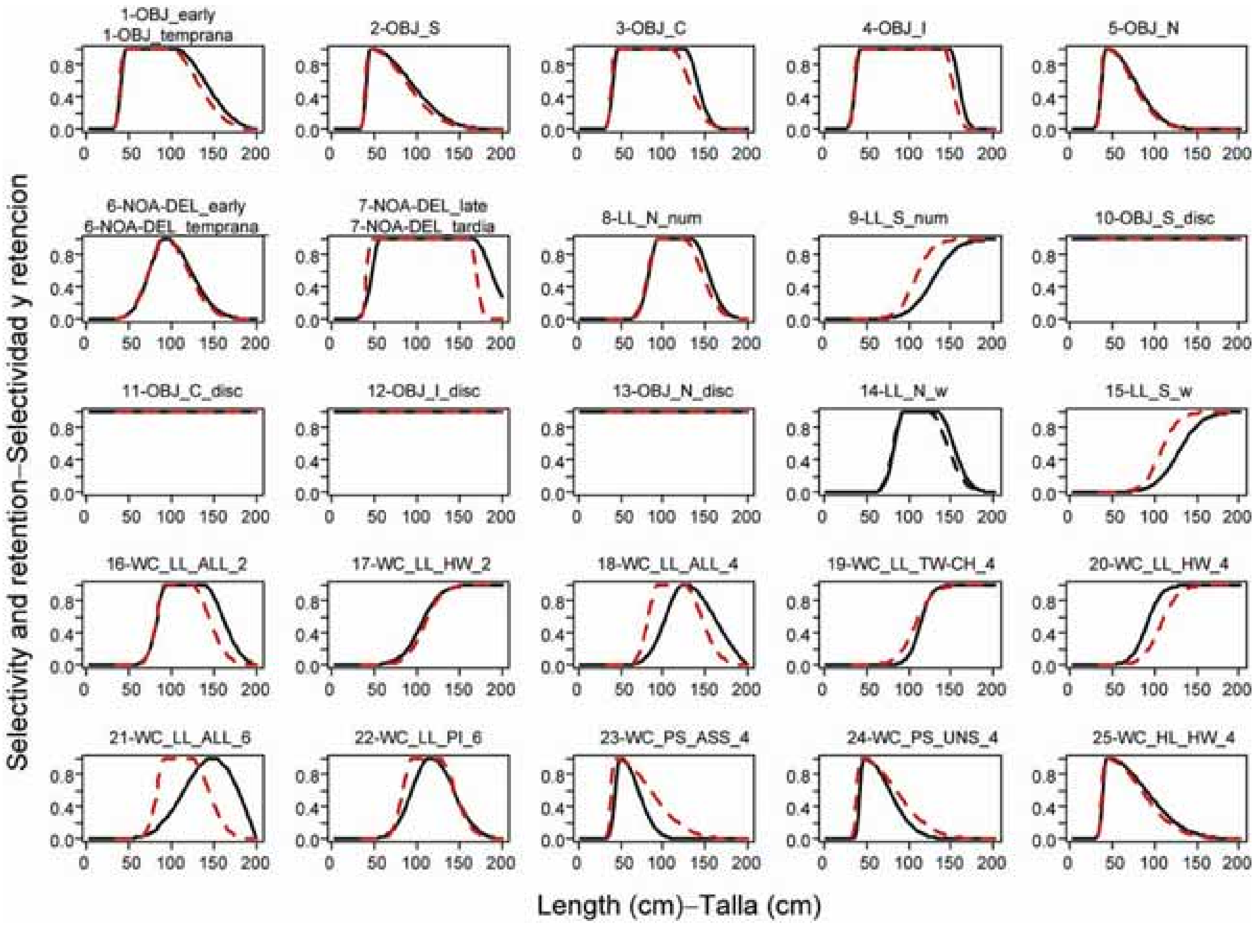

FIGURE C.6. Size selectivity curves for the two sensitivity analyses in which the assumed western limit of the bigeye stock distribution was extended from 150°W to 170°E. Solid lines = fitted to the WCPO CPUE and size composition data; dashed lines = not fitted to WCPO CPUE and size composition data, catch removed from population by sharing selectivities with similar EPO fisheries.

FIGURA C.6. Curvas de selectividad de tamaño de los dos análisis de sensibilidad en los que el límite occidental supuesto de la distribución del patudo fue extendido de 150ºO a 170ºE. Líneas sólidas = con ajuste a los datos de CPUE y composición de tallas del WCPO; líneas de trazos = sin ajuste a dichos datos, y captura sustraída de la población compartiendo selectividades con pesquerías similares del OPO.

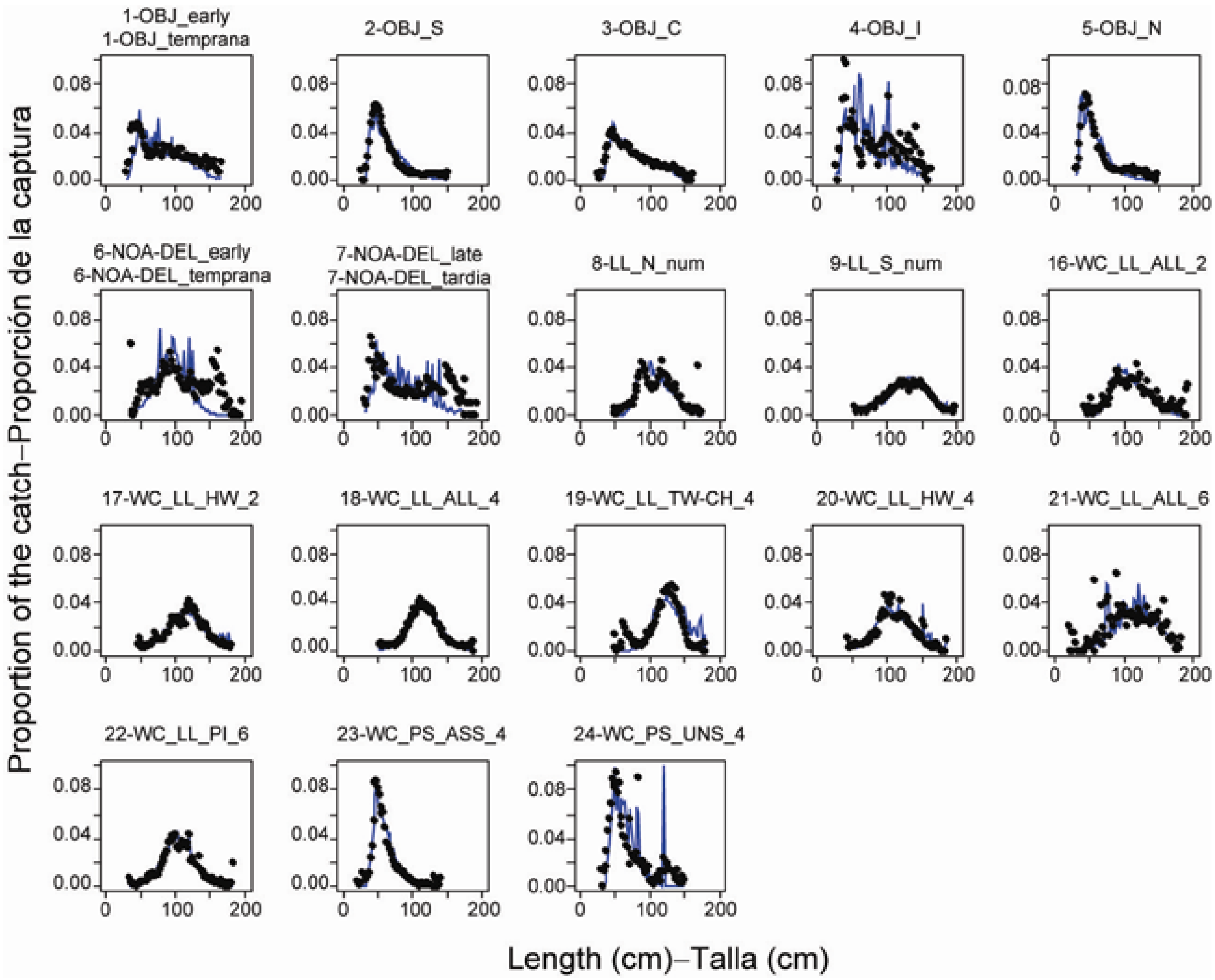

FIGURE C.7a. Model fit to average size compositions for the first of two sensitivity analyses in which the assumed western limit of the bigeye stock distribution was extended from 150°W to 170°E. This model was fitted to the WCPO CPUE and size composition data.

FIGURA C.7a. Ajuste del modelo a la composición de tamaños media del primero de dos análisis de sensibilidad en los que el límite occidental supuesto de la distribución del patudo fue extendido de 150ºO a 170ºE. Este modelo fue ajustado a los datos de CPUE y composición de tamaños del WCPO.

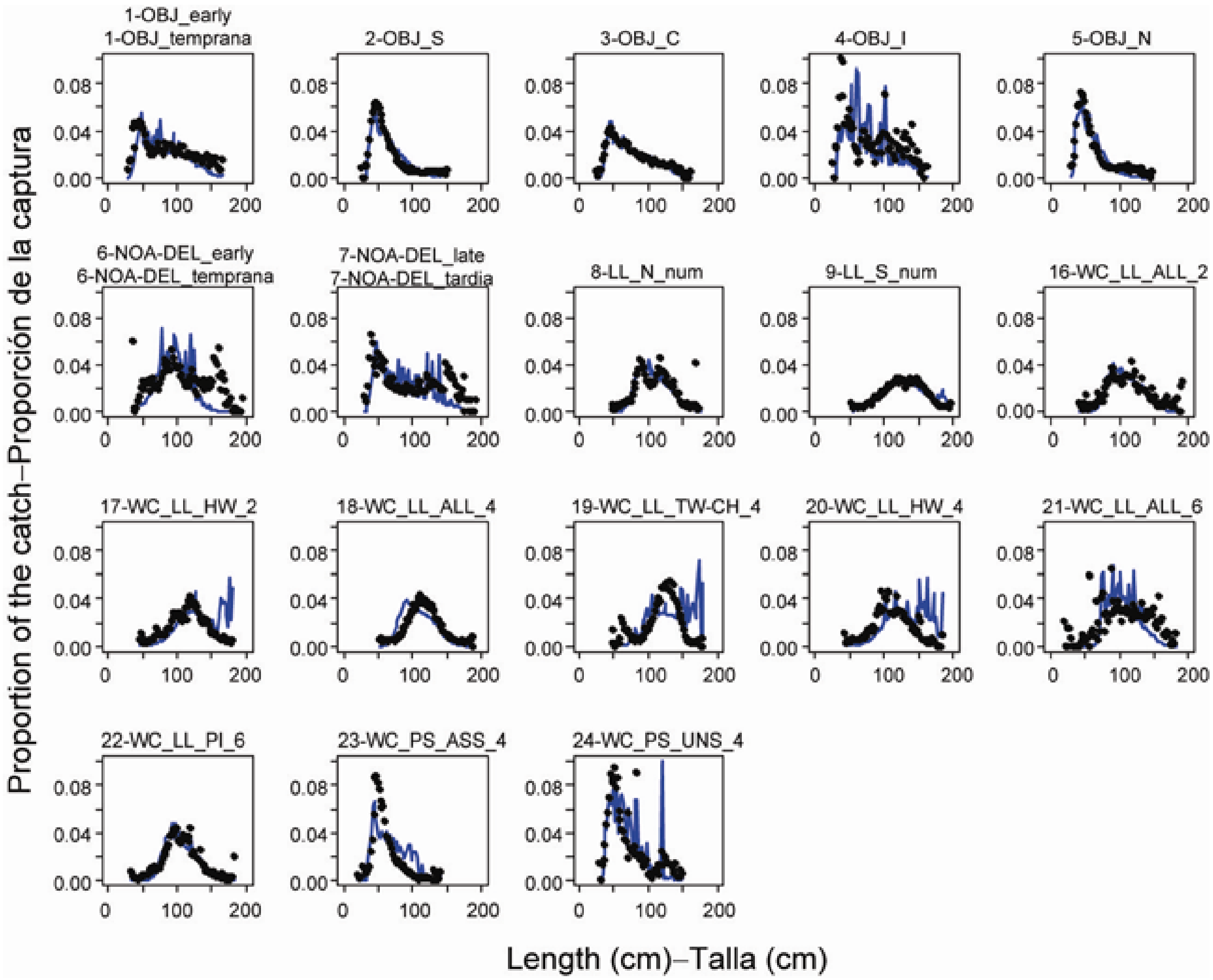

FIGURE C.7b. Model fit to average size compositions for the second of two sensitivity analyses in which the assumed western limit of the bigeye stock distribution was extended from 150°W to 170°E. This model was not fitted to WCPO CPUE and size composition data, and catch was removed from the population by sharing selectivities with similar EPO fisheries.

FIGURA C.7b. Ajuste del modelo a la composición de tamaños media de la segunda de dos análisis de sensibilidad en las que el límite occidental supuesto de la distribución del patudo fue extendido de 150ºO a 170ºE. Este modelo no fue ajustado a los datos de CPUE y composición de tamaños del WCPO, y la captura fue eliminada compartiendo selectividades con pesquerías similares del OPO.

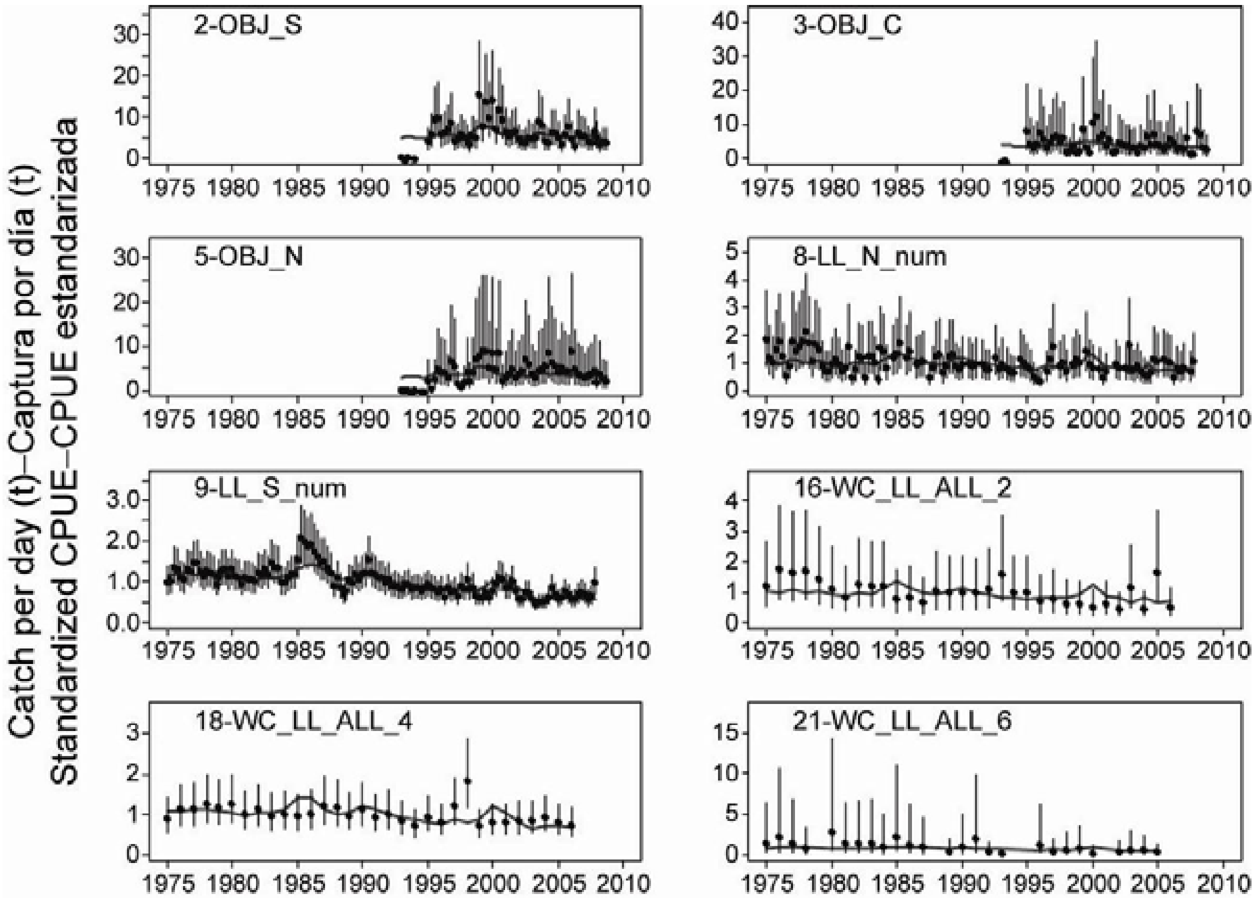

FIGURE C.8a. Model fit to CPUE for the first of two sensitivity analyses in which the assumed western limit of the bigeye stock distribution was extended from 150°W to 170°E. This model was fitted to the WCPO CPUE and size composition data.

FIGURA C.8a. Ajuste del modelo a la CPUE de la primera de dos análisis de sensibilidad en las que el límite occidental supuesto de la distribución del patudo fue extendido de 150ºO a 170ºE. Este modelo fue ajustado a los datos de CPUE y composición de tamaños del WCPO.

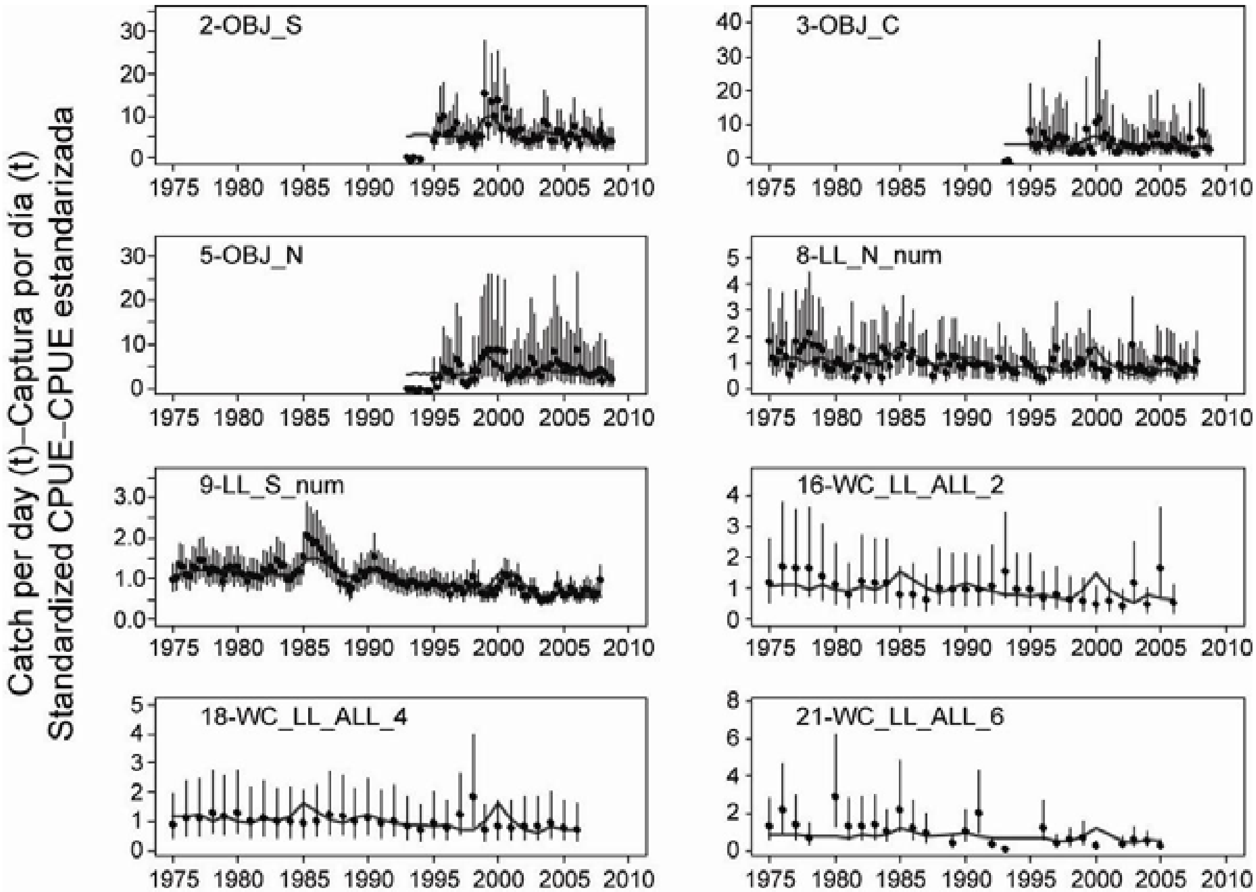

FIGURE C.8b. Model fit to CPUE for the second of two sensitivity analyses in which the assumed western limit of the bigeye stock distribution was extended from 150°W to 170°E. This model was not fitted to WCPO CPUE and size composition data, and the catch was removed from population by sharing selectivities with similar EPO fisheries.

FIGURA C.8b. Ajuste del modelo a la CPUE de la segunda de dos análisis de sensibilidad en las que el límite occidental supuesto de la distribución del patudo fue extendido de 150ºO a 170ºE. Este modelo no fue ajustado a los datos de CPUE y composición de tamaños del WCPO, y la captura fue eliminada compartiendo selectividades con pesquerías similares del OPO.

TABLE C.1. Definitions of the WCPO fisheries used in the sensitivity analysis to extending the assumed western limit of the bigeye stock distribution from 150°W to 170°E. The WCPO fisheries were defined in the model in accordance with Hampton and Maunder (2006), in addition to the 15 EPO fisheries assumed in the base case model (see Table 2.1). The geographical regions are shown in Figure C.1.

TABLA C.1. Definiciones de las pesquerías del Océano Pacífico occidental y central (WCPO) usadas en el análisis de sensibilidad a la extensión del límite occidental de la distribución de la población del patudo de 150°O a 170°E. Se definieron las pesquerías del WCPO en el modelo conforme a Hampton y Maunder (2006), además de las 15 pesquerías del EPO supuestas en el modelo del caso base (ver Tabla 2.1). En la Figura C.1 se ilustran las regiones geográficas.

Fishery	Code	Flag	Gear	Region
16	16-WC_LL_ALL_2	Japan, Korea, Chinese Taipei	Longline	2
17	17-WC_LL_HW_2	United States (Hawaii)	Longline	2
18	18-WC_LL_ALL_4	Japan, Korea	Longline	4
19	19-WC_LL_TW-CH_4	Chinese Taipei, China	Longline	4
20	20-WC_LL_HW_4	United States (Hawaii)	Longline	4
21	21-WC_LL_ALL_6	Japan, Korea, Chinese Taipei	Longline	6
22	22-WC_LL_PI_6	Pacific Island countries/territories	Longline	6
23	23-WC_PS_ASS_4	All	Purse seine: floating-object/FAD sets	4
24	24-WC_PS_UNS_4	All	Purse seine: unassociated sets	4
25	25-WC_HL_HW_4	United States (Hawaii)	Handline	4

Pesquería	Código	Bandera	Arte	Región
16	16-WC_LL_ALL_2	Japón, Corea, Taipei Chino	Palangre	2
17	17-WC_LL_HW_2	Estados Unidos (Hawai)	Palangre	2
18	18-WC_LL_ALL_4	Japón, Corea	Palangre	4
19	19-WC_LL_TW-CH_4	Chino Taipei, China	Palangre	4
20	20-WC_LL_HW_4	Estados Unidos (Hawai)	Palangre	4
21	21-WC_LL_ALL_6	Japón, Corea, Taipei Chino	Palangre	6
22	22-WC_LL_PI_6	Países/territorios isleños del Pacífico	Palangre	6
23	23-WC_PS_ASS_4	Todas	Cerco: lances sobre objetos flotantes/plantados	4
24	24-WC_PS_UNS_4	Todas	Cerco: lances no asociados	4
25	25-WC_HL_HW_4	Estados Unidos (Hawai)	Línea de mano	4

APPENDIX D: 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. This appendix was prepared in response to requests received during the second meeting of the Scientific Working Group.

ANEXO D: 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. Fue preparado en respuesta a solicitudes expresadas durante la segunda reunión del Grupo de Trabajo Científico.

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

	Age (quarters_ - Edad (trimestres)									
	1-4	**5-8**	**9-12**	**13-16**	**17-20**	**21-24**	**25-28**	**29-32**	**33-36**	**37-40**
1975	0.01	0.03	0.09	0.12	0.13	0.12	0.12	0.12	0.12	0.12
1976	0.01	0.05	0.12	0.15	0.15	0.15	0.14	0.14	0.14	0.14
1977	0.01	0.05	0.14	0.19	0.20	0.20	0.20	0.20	0.20	0.20
1978	0.01	0.07	0.16	0.20	0.19	0.19	0.18	0.18	0.18	0.18
1979	0.01	0.05	0.14	0.19	0.19	0.18	0.18	0.18	0.18	0.18
1980	0.01	0.09	0.17	0.20	0.19	0.18	0.18	0.18	0.18	0.18
1981	0.01	0.06	0.14	0.17	0.17	0.17	0.17	0.16	0.16	0.16
1982	0.01	0.04	0.12	0.17	0.17	0.17	0.16	0.16	0.16	0.16
1983	0.01	0.04	0.13	0.18	0.19	0.19	0.19	0.19	0.19	0.18
1984	0.01	0.04	0.11	0.14	0.14	0.14	0.14	0.14	0.14	0.14
1985	0.01	0.03	0.11	0.16	0.17	0.17	0.17	0.17	0.17	0.17
1986	0.00	0.04	0.15	0.23	0.24	0.24	0.24	0.24	0.24	0.24
1987	0.00	0.03	0.15	0.24	0.26	0.26	0.26	0.26	0.26	0.26
1988	0.00	0.03	0.13	0.19	0.20	0.20	0.20	0.20	0.20	0.20
1989	0.00	0.03	0.13	0.19	0.20	0.20	0.20	0.19	0.19	0.19
1990	0.01	0.04	0.16	0.25	0.27	0.27	0.26	0.26	0.26	0.26
1991	0.01	0.05	0.18	0.28	0.30	0.30	0.30	0.30	0.30	0.29
1992	0.01	0.05	0.17	0.25	0.26	0.26	0.25	0.25	0.25	0.25
1993	0.07	0.06	0.17	0.24	0.25	0.24	0.24	0.23	0.23	0.23
1994	0.23	0.19	0.29	0.32	0.29	0.27	0.26	0.26	0.26	0.26
1995	0.51	0.28	0.27	0.28	0.26	0.24	0.24	0.23	0.23	0.23
1996	0.74	0.43	0.32	0.27	0.23	0.21	0.20	0.19	0.19	0.19
1997	0.44	0.40	0.38	0.32	0.25	0.22	0.21	0.20	0.20	0.20
1998	0.24	0.24	0.25	0.28	0.28	0.27	0.26	0.26	0.25	0.25
1999	0.20	0.19	0.18	0.17	0.15	0.13	0.13	0.12	0.12	0.12
2000	0.44	0.49	0.35	0.26	0.19	0.17	0.16	0.15	0.15	0.15
2001	0.46	0.51	0.35	0.30	0.26	0.24	0.24	0.23	0.23	0.23
2002	0.45	0.57	0.48	0.46	0.42	0.40	0.39	0.38	0.38	0.38
2003	0.46	0.45	0.39	0.40	0.37	0.36	0.35	0.34	0.34	0.34
2004	0.43	0.51	0.39	0.35	0.31	0.29	0.28	0.28	0.27	0.27
2005	0.57	0.60	0.38	0.28	0.22	0.19	0.18	0.17	0.17	0.17
2006	0.55	0.70	0.46	0.33	0.24	0.20	0.19	0.18	0.18	0.18
2007	0.43	0.55	0.35	0.27	0.22	0.20	0.19	0.18	0.18	0.18
2008	0.48	0.61	0.44	0.29	0.18	0.13	0.12	0.11	0.11	0.10

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