INTER-AMERICAN TROPICAL TUNA COMMISSION

9TH STOCK ASSESSMENT REVIEW MEETING

LA JOLLA, CALIFORNIA (USA)
12-16 MAY 2008

DOCUMENT SARM-9-06b

STATUS OF BIGEYE TUNA IN THE EASTERN PACIFIC OCEAN

Alexandre Aires-da-Silva and Mark N. Maunder

CONTENTS

1. EXECUTIVE SUMMARY

This report presents the current stock assessment of bigeye tuna (*Thunnus obesus*) in the eastern Pacific Ocean (EPO). As in the last assessment, this assessment was conducted using Stock Synthesis II (SS2; Methot 2005). The assessment reported here is based on the assumption that there is a single stock of bigeye in the EPO, and that there is no exchange of fish between the EPO and the western and central Pacific Ocean.

The stock assessment requires a substantial amount of information. Data on retained catch, discards, catch per unit of effort (CPUE), used as indices of abundance, 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 2007 and revised data for 2003-2006. For the longline fisheries, catch has been updated to include new data for 2007. Two additional years of new CPUE data (2005-2006) are available for the longline fisheries. Updated (2002-2004) and new (2004-2006) length-frequency data are available for the Japanese longline fishery.

The base case stock assessment model assumes that there is no relationship between stock and recruitment (*i.e.*, the steepness of the stock-recruitment relationship equals 1), and includes the CPUE time series for the floating-object and the longline fisheries. A single time-block is assumed for the size-selectivities of the different fisheries. Updated natural mortality (*M*) schedules are used for both sexes.

Analyses were carried out to assess the sensitivity of results to: 1) a stock–recruitment relationship; 2) use of the southern longline CPUE data only; 3) using two time blocks for the size selectivities of the floating-object fisheries, separated by the implementation in 2001 of IATTC Resolution C-00-08, which prohibited discards of tunas in the EPO.

There have been important changes in the amount of fishing mortality caused by the fisheries that catch bigeye tuna in the EPO. On average, since 1993 the fishing mortality of bigeye less than about 15 quarters old has increased substantially, and that of fish more than about 15 quarters old has increased 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 1995-1998, followed by a period of below-average recruitment in 1999-2000. The recruitments have been above average since 2000, and were particularly large in 2005. The most recent recruitment is very uncertain, due to the fact that recently-recruited bigeye are represented in only a few length-frequency samples. The extended period of relatively large recruitments in 1995-1998 coincided with the expansion of the fisheries that catch bigeye in association with floating objects.

The biomass of 3+-quarter-old bigeye increased during 1983-1984, and reached its peak level of about 626 thousand metric tons (t) in 1986, after which it decreased to an historic low of 270 thousand t at the beginning of 2007. 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 increased slightly in recent years.

The estimates of recruitment and biomass are only moderately sensitive to the steepness of the stock-recruitment relationship. Specifically, the estimates of biomass are greater than in the base case assessment, but the trends are similar. The recruitment time series is similar to that of the base case assessment.

When only the CPUE for the southern longline fishery was used, the estimates of biomass are greater than in the base case, but the trends are similar. The recruitment time series is very similar to that of the base case assessment. The recruitment estimates, however, are slightly different in 2007, for which CPUE data for the southern longline fishery are not available.

When two time blocks were applied to the size selectivity of the floating object fisheries, the estimated biomasses and recruitment estimates were very similar to those obtained for the base case assessment.

At the beginning of January 2008, 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 10% less than the level corresponding to the maximum sustainable yield (MSY).

Recent catches are estimated to have been about the MSY level. 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 82% of the current (2005-2007) 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 2008, 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}.

Recent spikes in recruitment are predicted to result in increased levels of SBR and 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.

The effects of IATTC Resolution C-04-09, adopted in 2004, and C-06-02, adopted in 2006, are estimated to be insufficient to allow the stock to remain at levels that would support the MSY.

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

2. DATA

Catch, effort, and size-composition data for January 1975 through December 2007 were used to conduct the stock assessment of bigeye tuna, *Thunnus obesus*, in the eastern Pacific Ocean (EPO). The data for 2007, which are preliminary, include records that had been entered into the IATTC databases as of mid-March 2008. 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.

In previous assessments, two longline fisheries with catch data in numbers were assumed (Fisheries 8 and 9). However, the catch data reported by the longline fisheries are a mixture of catch in numbers and weight records. Since SS2 has the flexibility of including catch data in either numbers or weight, two additional longline fisheries that report catch in weight were defined (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 (discards plus retained catch) 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 2.2.3). 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 2000-2007 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. Watters and Maunder (2001) provide a brief description of the method that is used to estimate surface fishing effort.

New or updated catch data for the longline fisheries (Fisheries 8–9 and 14-15) are available for Chinese Taipei (2004-2006) and Japan (2003-2006). Catch data for 2007 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 from the EPO during each year of the 1975-2007 period are shown in Figure 2.2. There has been substantial annual variation in the catches of bigeye by all fisheries operating in the EPO (Figure 2.2). Prior to 1996, the longline fleet (Fisheries 8-9 and 14-15) removed more bigeye (in weight) from the EPO than did the surface fleet (Fisheries 1-7 and 10-13) (Figure 2.2). Since 1996, however, the catches by the surface fleet have mostly been greater than those by the longline fleet (Figure 2.2). 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 discards as proportions of the retained 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), the proportions of the catches discarded have been low for the last seven years 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 weak year classes after 1997. However, there have been large recruitments since 1997 (Figure 4.5). It is possible that regulations prohibiting discarding of tuna 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 2007. New or updated catch and effort data are available for the Japanese longline fisheries (2003-2006). Trends in the amount of fishing effort exerted by the 15 fisheries defined for the stock assessment of bigeye tuna in the EPO are shown in Figure 2.4. Fishing effort for surface gears is in days of fishing, and that for longliners (Fisheries 8-9 and 14-15) is in standardized hooks.

The CPUE for the purse-seine fisheries 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 (1975-2006) 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 nominal 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 those 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. In addition, the first two years of the purse-seine fisheries were excluded because these fisheries were still expanding. Observations with few effort data were also excluded.

2.4. Size composition data

New length-frequency data for 2007 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 are available (2002-2004). 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-i, 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 2.6b-e, 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 2.6f, Fishery 6). Since 1990, more small and large (>125 cm long) bigeye have been captured in unassociated schools (Figure 2.6g, 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 2.6h). In the area south of 15ºN (Fishery 9), longliners catch substantial numbers of both medium-sized and large bigeye (Figure 2.6i). 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.

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 (Figure 3.1). 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. This growth curve is also used to convert the other biological parameters to age from length and for the estimation of natural mortality.

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.

The length at age used in the assessment model is based on the von Bertalanffy growth curve. The parameters of the growth curve were estimated by obtaining the best correspondence of length at age used by Maunder and Hoyle (2007).

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. A sensitivity analysis that estimated mean length and variation of length at age by integrating age-length data from otolith readings (Schaefer and Fuller 2006) in the assessment model was conducted.

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). The previous stock assessment assumes constant natural mortality (M = 0.1) for fish 0-4 quarters old (Aires-da-Silva and Maunder 2007). New features have been implemented in SS2 which provide more flexibility in the treatment of natural mortality. As a result, a higher natural mortality estimate (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.

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).

SS2 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.

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 fecundity and proportion mature at length into ages (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 SS2 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).

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), zonal-velocity anomalies (velocity anomalies in the east-west direction) at 240 m depth and in an area from 8°N to 15°S and 100° to 150°W were used as the candidate environmental variable for affecting recruitment. The zonal-velocity anomalies were estimated from the hindcast results of a general circulation model obtained at http://ingrid.ldeo.columbia.edu/. 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.

In previous assessments (Watters and Maunder 2001, 2002; Maunder and Harley 2002) it was assumed that oceanographic conditions might influence the efficiency of the fisheries that catch bigeye associated with floating objects (Fisheries 1-5). 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, and no environmental influences on catchability have been considered in this assessment.

4. STOCK ASSESSMENT

The SS2 method was first used to assess the status of bigeye tuna in the EPO by Aires-da-Silva and Maunder (2007). 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. recruitment in every quarter from the first quarter of 1975 through the fourth quarter of 2007 (includes estimation of virgin recruitment and temporal recruitment anomalies);
2. catchability coefficients for the five CPUE time series that are used as indices of abundance;
3. 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);
4. 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. mean length at age (Section 3.1.1., Figure 3.1);
6. 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 harvest (exploitation) rates, by gear, for 2005-2007. The sensitivity of estimates of key management quantities to including the last year (2007) in the 3-year average harvest rate estimate was tested. For this purpose, a 2-year (2005-2006) average harvest 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 three 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 (a single time-block).
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 indices of abundance. The base case assessment included the CPUE time series for Fisheries 2, 3, and 5 (purse-seine sets on floating objects) and 8 and 9 (longline fisheries). A sensitivity analysis of the assessment results to the use of only the standardized CPUE for Fishery 9 was conducted. Standardized CPUE for Fishery 8 was not included, due to the seasonal nature of this fishery.
4. Sensitivity to assuming two time blocks for the size selectivities of the floating-object Fisheries 2-5. A requirement that purse-seine vessels retain all catches of tuna, originally introduced in IATTC Resolution C-00-08, has been in force since 2001 This could have resulted in changes in the selectivity of the retained catches of these fisheries, particularly for smaller fish, which might not have been observed in the size samples taken before the Resolution. Accordingly, two selectivity time blocks were considered: pre-Resolution (1975-2000) and post-Resolution (2001-present). The selectivity patterns of the discard Fisheries (10-13) remained unchanged in this analysis.

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 on bigeye tuna in the EPO. On average, the fishing mortality on 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 on bigeye tuna 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

Previous assessments found that abundance of bigeye tuna being recruited to the fisheries in the EPO appeared to be related to zonal-velocity anomalies at 240 m during the time that these fish are assumed to have hatched (Watters and Maunder 2002). 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. 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). Therefore, no environmental index was included in the analysis.

Over the range of estimated spawning biomasses shown in Figure 4.7, the abundance of bigeye recruits appears to be unrelated to the spawning biomass of adult females at the time of hatching (Figure 4.4). Previous assessments of bigeye in the EPO (*e.g.* Watters and Maunder 2001, 2002) also failed to show a relationship between adult biomass and recruitment over the estimated range of spawning biomasses. The base case estimate of steepness is fixed at 1, which 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 B that assumes that recruitment is moderately related to stock size (steepness = 0.75).

The time series of estimated recruitment of bigeye is shown in Figure 4.5, and the total recruitment estimated to occur during each year is presented in 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 since 2001, and were particularly large in 2005 and 2006. The recent recruitment estimates are very uncertain, due to the fact that recently-recruited bigeye are represented in only a few length-frequency data sets. The extended period of relatively large recruitments in 1994-1998 coincided with the expansion of the fisheries that catch bigeye in association with floating objects.

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 626,000 t in 1986, after which it decreased to an historic low of about 270,000 t at the beginning of 2007.

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 increased slightly in recent years.

There is uncertainty in the estimated biomasses of spawners. The average CV of the spawning biomass estimates is 0.15.

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) as is the recent slight increase in biomass.

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 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 4.11i). The solid and open 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. This overestimation is centered around 80 cm prior to 1988 and then increases to 180 cm, indicating a change in selectivity. A sensitivity analysis was conducted in the previous assessment 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 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 and 5 (CV = 0.79), followed by Fishery 2 (CV = 0.42). 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 (2007), two years (2007 and 2006), three years (2007, 2006, 2005) and four years (2007, 2006, 2005, 2004) of data (Figure 4.12). The retrospective analyses show an increase in biomass over 2004, 2005, 2006, and 2007 whereas the base case shows a nearly stable trend over the same period. 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). Although the trends in the biomasses are the same, in general, the retrospective analysis also 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 the southern longline CPUE data only (Appendix B), and using two time blocks for selectivity of the floating-object fisheries (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 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 estimated stock-recruitment relationship is presented in Figure A.4.

When only the CPUE for the southern longline fishery was used, the estimated biomass was generally greater. However, the estimated biomass trends for the sensitivity analysis and the base case model are very similar (Figure B.1). The recruitment estimates are also very similar for both models (Figure B.2); however, they are slightly different for the most recent quarters in 2007, for which CPUE data for the southern longline fishery are not available. The model fit to the CPUE time series of Fishery 9 is shown in Figure B.4.

Two time blocks were considered for the size selectivities of floating-object Fisheries 2-5; specifically, the periods before (1975-2000) and after (2001-present) Resolution C-00-08, which prohibited discards of small tunas. Minor differences in the size-selectivity curves of these fisheries were obtained (Figure C.4), but the estimated biomasses and recruitment estimates were very similar to those obtained for the base case model.

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 4.14 and 4.15, respectively) estimated by the current and the previous stock assessment model (Aires-da-Silva and Maunder 2007) are very similar in absolute terms. The starting biomasses, however, are slightly lower for the current stock assessment. The recruitments estimated by the current assessment are slightly greater than the estimates from the previous assessment (Figure 4.16a). As expected, because of the increase in natural mortality, recruitments are higher in the base case when compared to the previous assessment. However, the relative recruitments are very similar (Figure 4.16b).

There is a slightly greater absolute difference between the estimates of the spawning biomass ratios (SBRs) from the current and the previous assessments (Aires-da-Silva and Maunder 2007), particularly during the starting years of the model (1975-1980). The trends in the SBRs, however, are very similar.

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 1995-1998, followed by a period of below-average recruitment in 1999-2000. The recruitments have been above average since 2001, and were particularly large in 2005 and 2006. The most recent recruitment is very uncertain, due to the fact that recently-recruited bigeye are represented in only a few length-frequency samples. The extended period of relatively large recruitments in 1995-1998 coincided with the expansion of the fisheries that catch bigeye in association with floating objects.

The biomass of 3+-quarter-old bigeye increased during 1983-1984, and reached its peak level of 625,649 t in 1986, after which it decreased to an historic low of 269,266 t at the beginning of 2007. 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 increased in recent years (2005-2007).

The estimates of 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 only the CPUE for the southern longline fishery is used, the estimates of biomass are greater than those estimated in the base case, but the trends are similar. The recruitment time series is very similar to the base case. The recruitment estimates, however, are slightly different in 2007, for which CPUE data for the southern longline fishery are not available.

When two time blocks were applied to the size selectivity of the floating-object fisheries, the estimates of biomass and recruitment were very similar to those obtained with 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).

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 to be taken 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 (1975-2007) 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 2008, the spawning biomass of bigeye tuna in the EPO was near the historical low level (Figure 5.1). At that time the SBR was about 0.17, 10% less than the level corresponding to the MSY.

At the beginning of 1975, the SBR was about 0.26 (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 0.47. 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 0.33 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 4.15). However, the estimated SBR levels are lower than that estimated in the previous assessment (Aires-da-Silva and Maunder 2007), particularly in the early years of the study period (1975-1980).

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. 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. 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 2005 and 2007. Therefore, while these MSY-based results are currently presented as point estimates, there are uncertainties in the results. While analyses to present uncertainty in the base case estimates were not undertaken as in a previous assessment

(Maunder and Harley 2002), additional analyses were conducted to present the uncertainty in these quantities in relation to the periods assumed to represent catchability and fishing mortality.

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 82% 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 30% less. If bigeye were caught only by the longline fishery the MSY would about 89% 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 1975-1995 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 and spawning biomass relative to the MSY reference points. Overall, the reference points have not been exceeded until recent years. The two 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 0.30, compared to 0.19 for the base case assessment (Table 5.1). The sensitivity analysis for steepness estimates an F multiplier considerably less than that for the base case assessment (0.57). All analyses estimate the current SBR to be less than SBR_{MSY}.

The management quantities are only moderately sensitive 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 82% of the current (2005-2007) 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 2008, 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 surface fleet might simultaneously affect the stock of bigeye tuna in the EPO and the catches of bigeye by the various fisheries. Several 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.

A method based on the normal approximation to the likelihood profile has been applied (Maunder *et al*. 2006). Unfortunately, the appropriate methods are not often applicable to models as large and computationally intense as the bigeye stock assessment model. Therefore, we have used a normal approximation to the likelihood profile that allows for the inclusion of both parameter uncertainty and uncertainty about future recruitment. This method is implemented by extending the assessment model an additional five years with exploitation rates equal to the average for 2005 and 2007. No catch or length-frequency data are included for these years. The recruitments for the five years are estimated as in the assessment model, with a lognormal penalty with a standard deviation of 0.6.

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 (harvest rates) on the stock biomass and catch.

The analyses carried out were:

1. Quarterly harvest rates for each year in the future were set equal to the average harvest rates from 2005 to 2007, to simulate the reduced effort due to the conservation measures of IATTC Resolution C-04-09.
2. An additional analysis was carried out that estimates the population status if the resolution was not implemented. For 2004-2007, purse-seine catch in the third quarter was increased by 86% and the catch in the southern longline fishery was increased by 39% in all quarters. For 2008-2012, the purse-seine harvest rate was increased by 13% for all quarters and the harvest rate in the southern longline fishery was increased by 39% in all quarters.

6.2. Simulation results

The simulations were used to predict future levels of the SBR, total biomass, the total catch taken by the primary surface fisheries that would presumably continue to operate in the EPO (Fisheries 2-5 and 7), and the total 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 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 harvest rates

Projections were undertaken, assuming that harvest rates would remain at the average 2005-2007 levels (including the effort and catch restrictions in IATTC Resolutions C-04-09 and C-06-02).

SBR is estimated to have been increasing slightly in recent years (Figure 5.1). This increase is attributed to two spikes in recent recruitment. If recent levels of effort and catchability continue, the SBR is predicted to increase above the level that would support MSY during 2009-2010, and then to decline during 2011-2013 to a level slightly below to that which would support MSY (Figure 6.1a). The spawning biomass is estimated to increase slightly from 2005-2007, but it will probably decline in the future (Figure 6.2).

Purse-seine catches are predicted to decline during the projection period (Figure 6.3, left panels). Longline catches are predicted to increase moderately in 2008, but start declining by 2009 under current effort (Figure 6.3, right panels). The catches would decline slightly further 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. No management restrictions

IATTC Resolutions C-04-09 and C-06-02 call for restrictions on purse-seine effort and longline catches during 2004-2007: a 6-week closure during the third *or* fourth quarter of the year for purse-seine fisheries, and longline catches not to exceed 2001 levels. To assess the utility of these management actions, we projected the population forward 5 years, assuming that these conservation measures are not implemented in the future. Projected catches would be less if the resolution had not been adopted (Figure 6.3, lower panels).

Comparison of the SBR predicted with and without the restrictions from the resolution show some difference (Figure 6.4). Without the restrictions, SBR would increase only slightly and then decline to lower levels.

The reductions in fishing mortality that could occur as result of the continuation of IATTC Resolution C-06-02 are insufficient to allow the population to maintain above levels corresponding to the MSY in the long term, although an increase above the MSY level is expected for a few years, due to recent high recruitment.

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 increased levels of SBR and longline catches for the next few years. 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.

The effects of IATTC Resolutions C-04-09 and C-06-02 are estimated to be insufficient to allow the stock to remain at levels that would support MSY.

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

7. FUTURE DIRECTIONS

7.1. Collection of new and updated information

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

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

1. Use a more flexible growth curve (*e.g.* the Richards growth curve) or input a vector of length-at-age so that the growth curve better represents that used in previous assessments using A-SCALA.
2. Make it easier to run projections with fixed harvest rates.
3. Re-evaluate the definitions of fisheries.
4. Determine appropriate weighting of the different data sets.
5. Include available tagging data in the assessment.

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

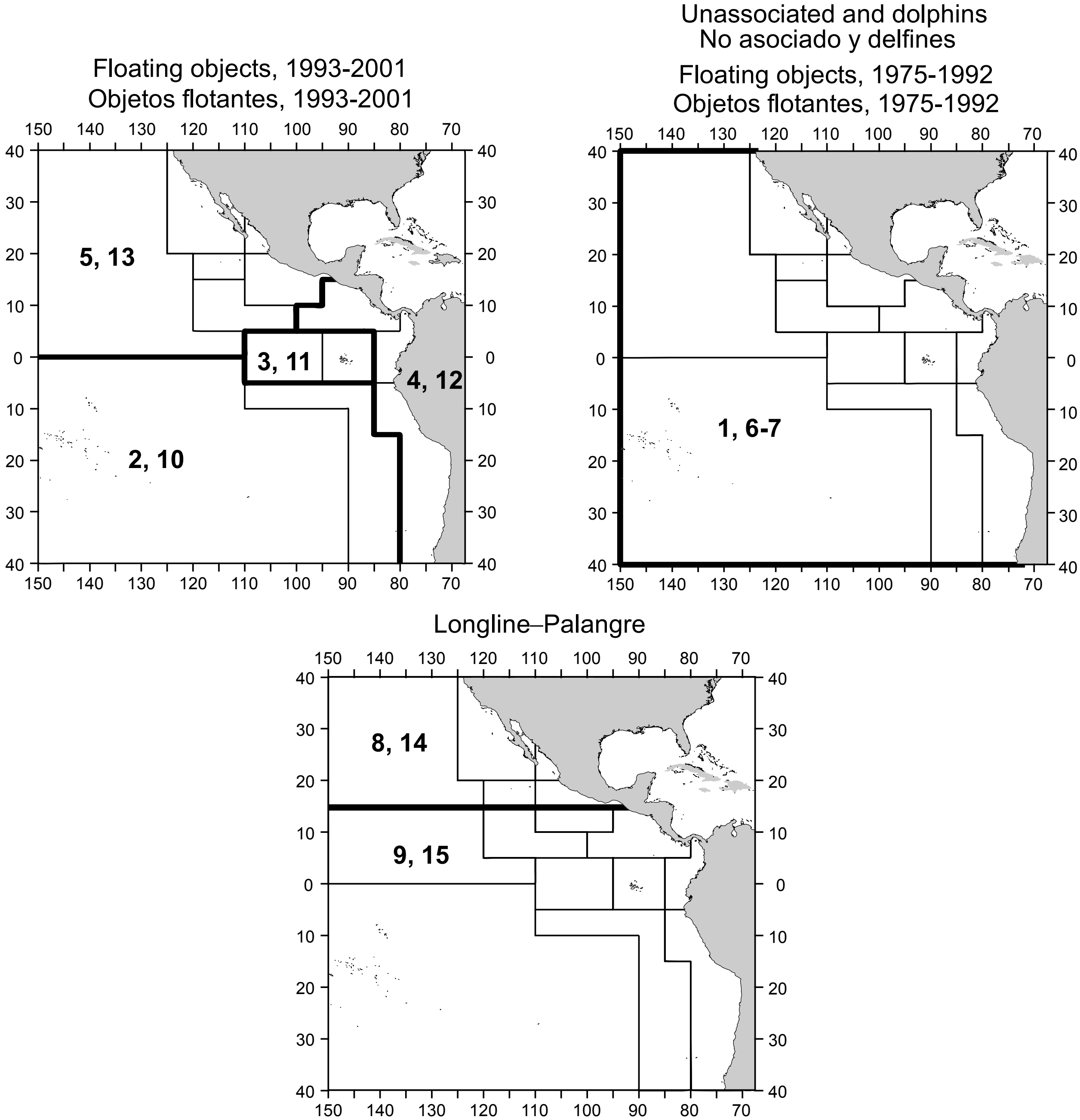

FIGURE 2.1. Spatial extents of the fisheries defined for the stock assessment of bigeye tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the bold numbers the fisheries to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

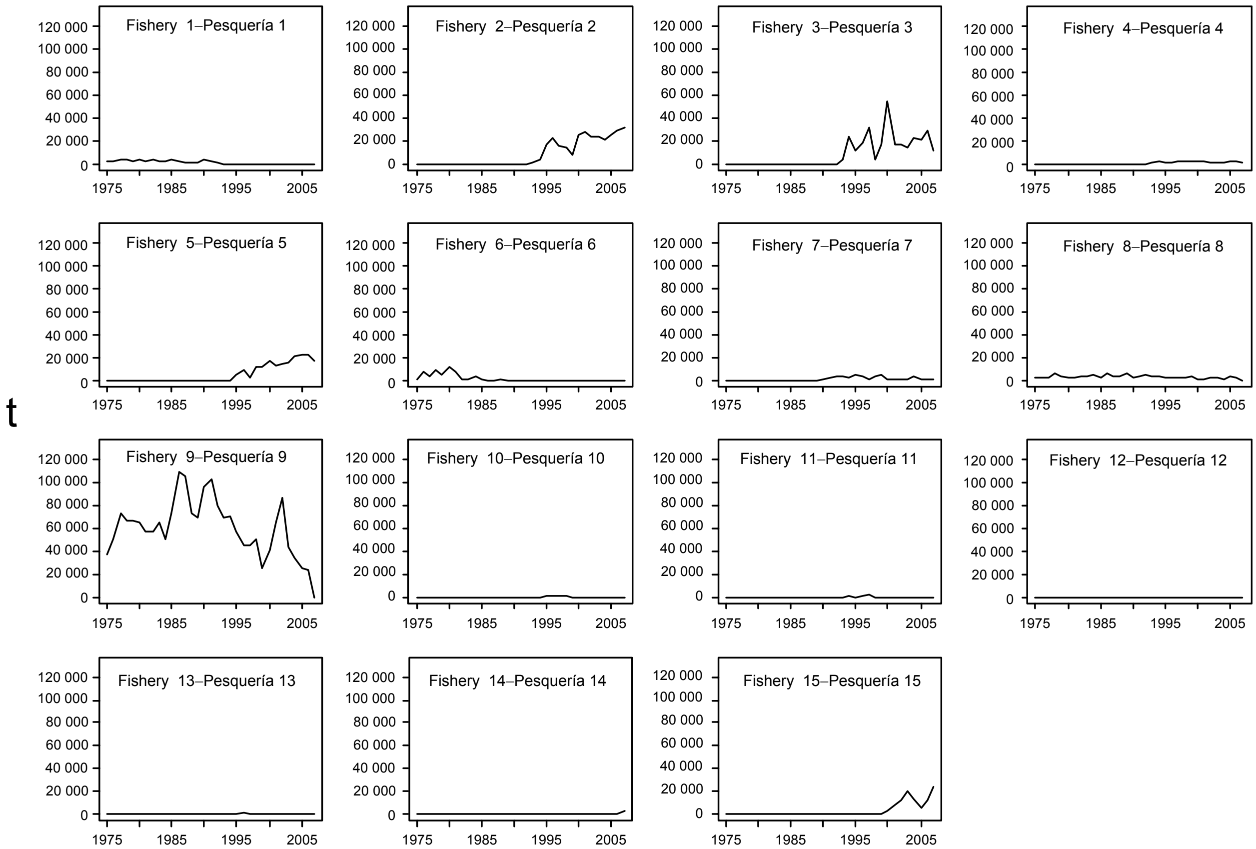

FIGURE 2.2. Annual catches of bigeye tuna taken by the fisheries defined for the stock assessment of that species in the EPO (Table 2.1). Although all the catches are displayed as weights, the stock assessment model uses catches in numbers of fish for Fisheries 8 and 9. Catches in weight for Fisheries 8 and 9 were estimated by multiplying the catches in numbers of fish by estimates of the average weights. 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. t = toneladas métricas.

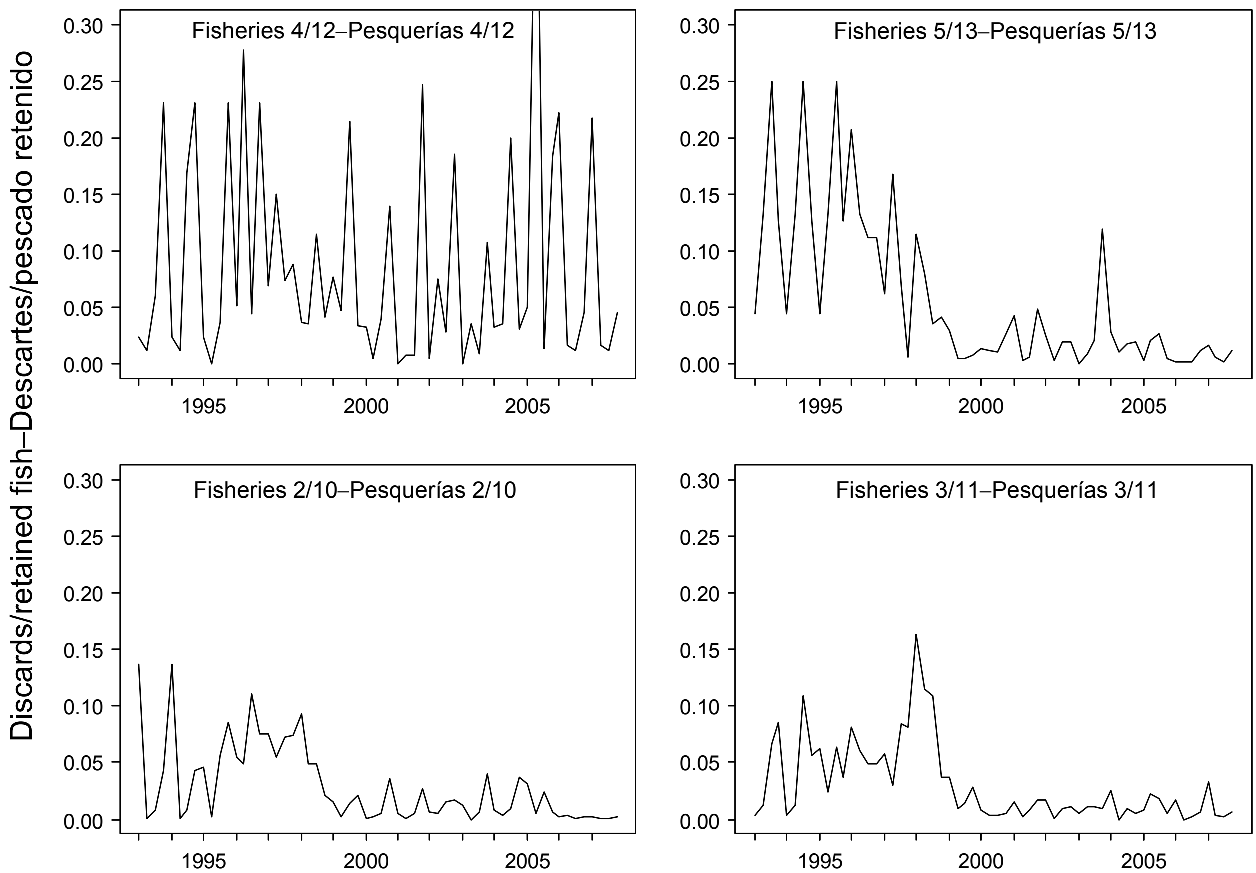

FIGURE 2.3. Weights of discarded bigeye tuna as proportions of the retained quarterly catches for the four floating-object fisheries. Fisheries 2, 3, 4, and 5 are the "real" fisheries, and Fisheries 10, 11, 12, and 13 are the corresponding discard fisheries.

FIGURA 2.3. Pesos de atún patudo descartado como proporción de las capturas trimestrales retenidas de las cuatro pesquerías sobre objetos flotantes. Las pesquerías 2, 3, 4, y 5 son las pesquerías "reales", y las Pesquerías 10, 11, 12, y 13 las pesquerías de descarte correspondientes.

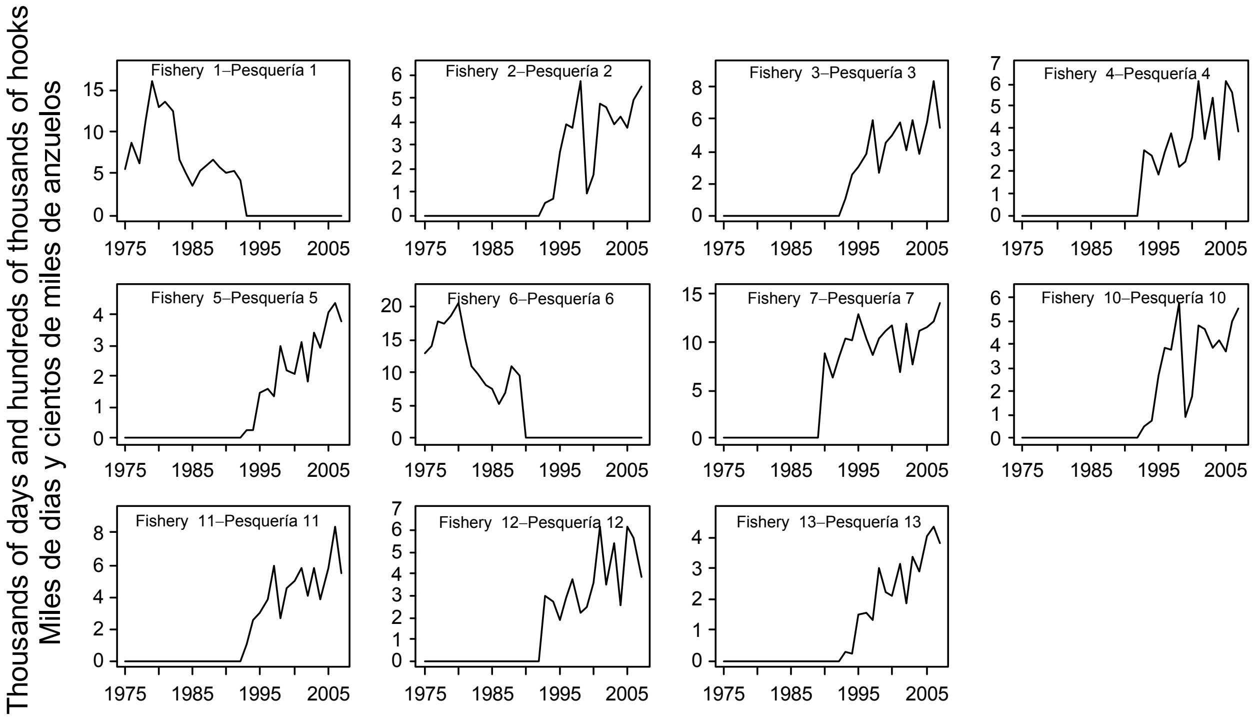

FIGURE 2.4. Annual fishing effort exerted by the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). The effort for Fisheries 1-7 and 10-13 is in days fished, and that for Fisheries 8-9, and 13-15 in standardized numbers of hooks. Note that the vertical scales of the panels are different.

FIGURA 2.4. Esfuerzo de pesca anual ejercido por 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 1-7 y 10-13 en días de pesca, y el de las Pesquerías 8, 9, y 13-15 en número estandardizado de anzuelos. Nótese que las escalas verticales de los recuadros son diferentes.

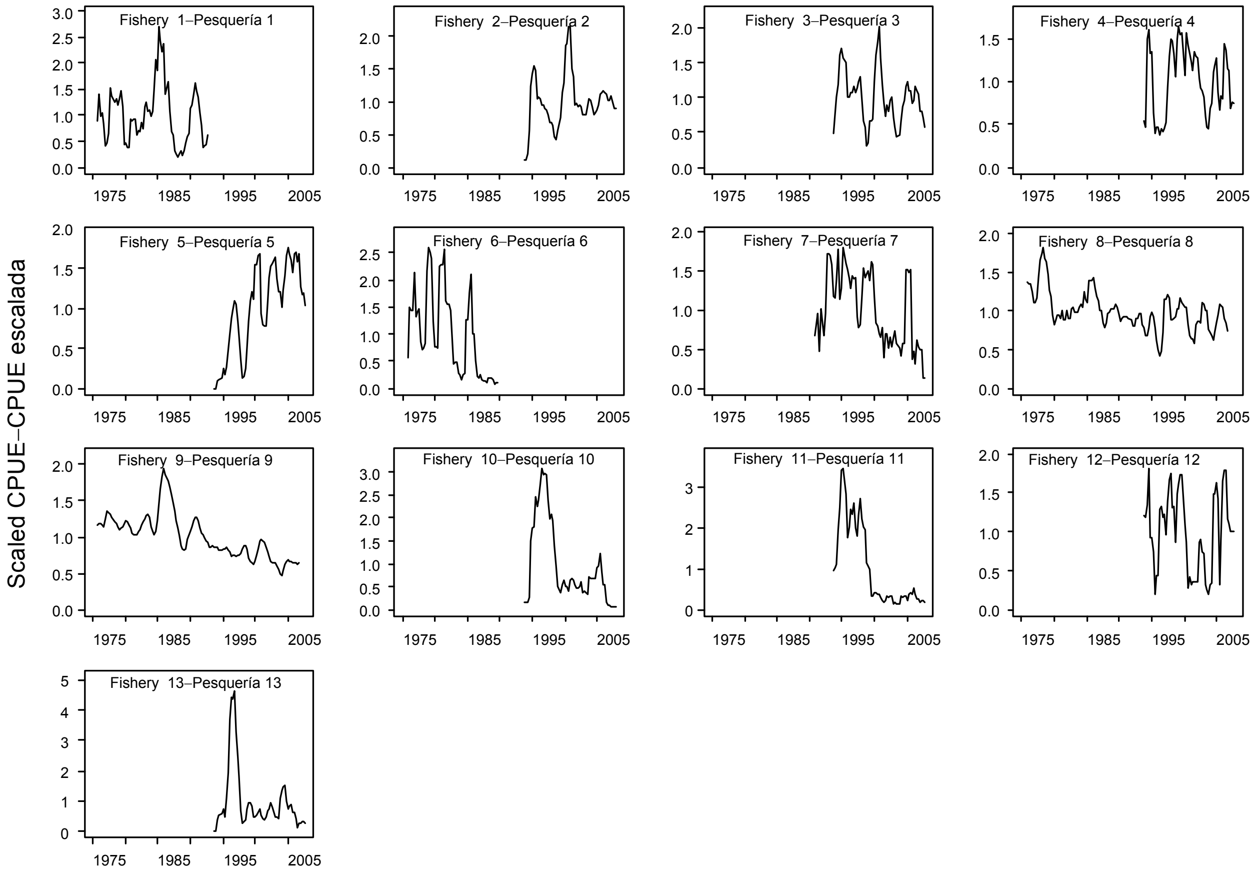

FIGURE 2.5. Four-quarterly running average CPUEs of the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). The CPUEs for Fisheries 1-7 and 10-13 are in kilograms per day fished, and those for Fisheries 8 and 9 in numbers of fish caught per standardized number of hooks. The data are adjusted so that the mean of each time series is equal to 1.0. Note that the vertical scales of the panels are different.

FIGURA 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 1-7 y 10-13 en kilogramos por día de pesca, y las de las Pesquerías 8 y 9 en número de peces capturados por número estandarizado de anzuelos. Se ajustaron los datos para que el promedio de cada serie de tiempo equivalga a 1,0. Nótese que las escalas verticales de los recuadros son diferentes.

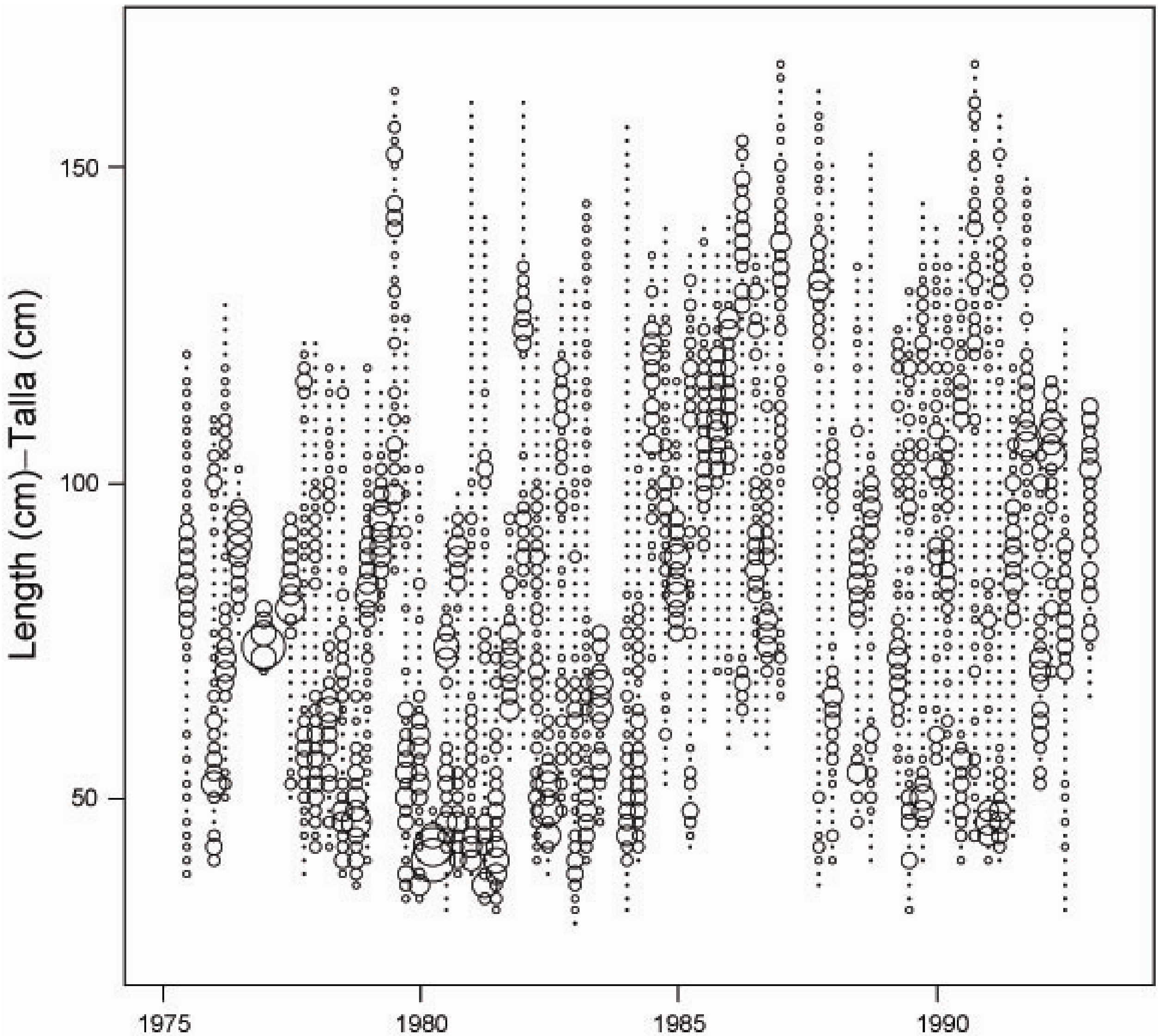

FIGURE 2.6a. Size compositions of the catches of bigeye tuna taken by Fishery 1, by quarter. The sizes of the circles are proportional to the catches.
FIGURA 2.6a. Composición por talla de las capturas de patudo de la Pesquería 1, por trimestre. El tamaño de los círculos es proporcional a la captura.

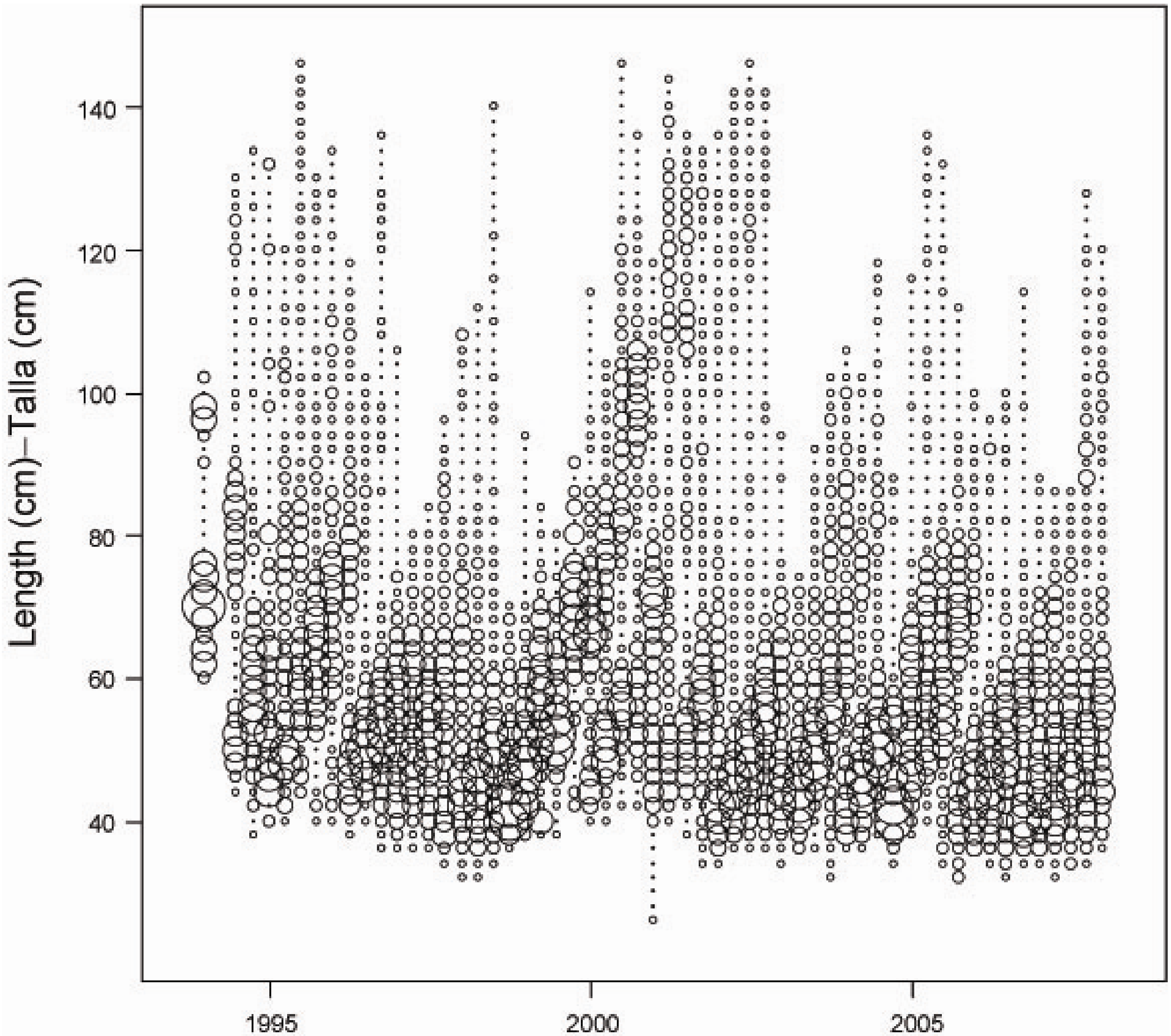

FIGURE 2.6b. Size compositions of the catches of bigeye tuna taken by Fishery 2, by quarter. The sizes of the circles are proportional to the catches.

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.

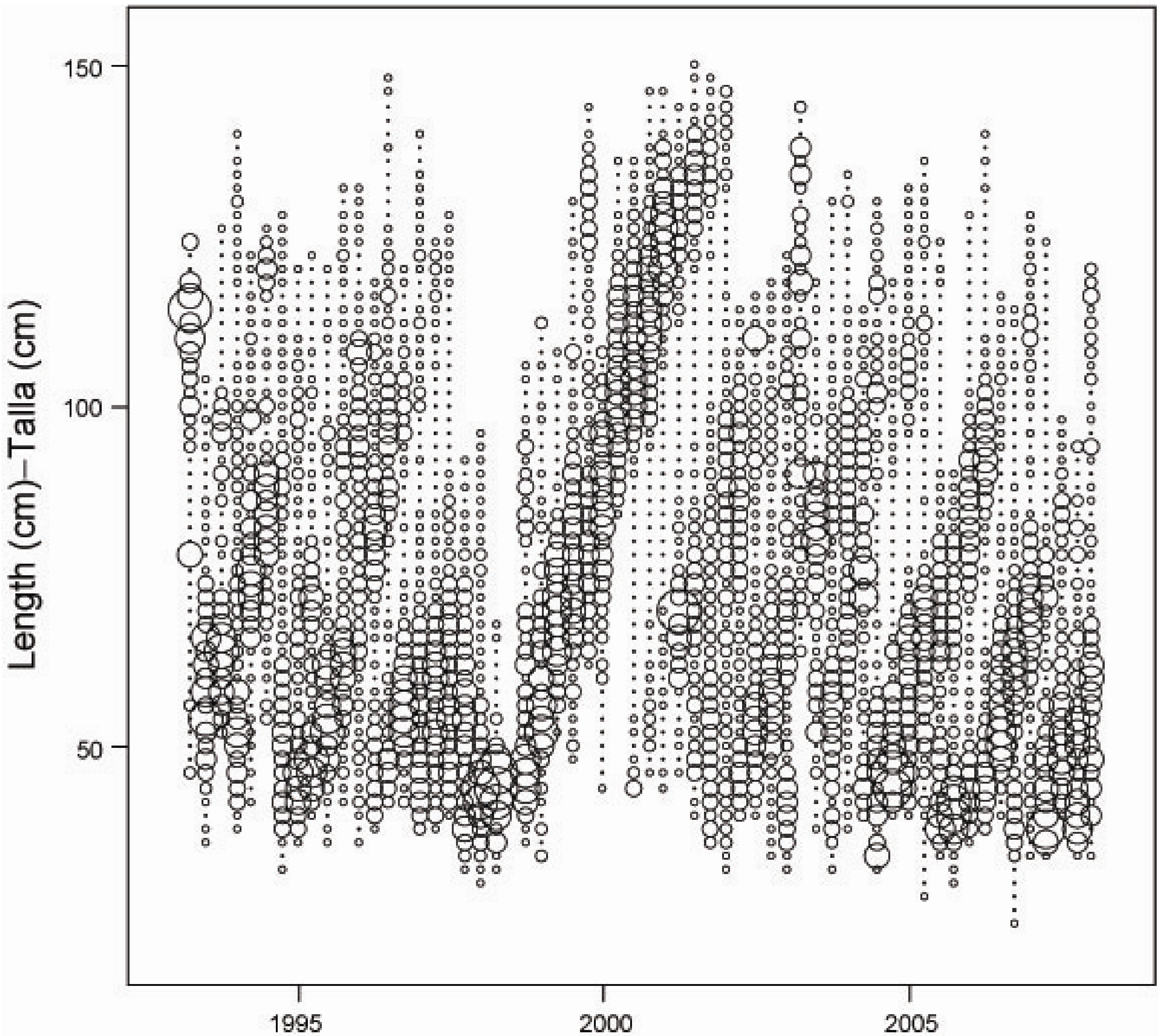

FIGURE 2.6c. Size compositions of the catches of bigeye tuna taken by Fishery 3, by quarter. The sizes of the circles are proportional to the catches.

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.

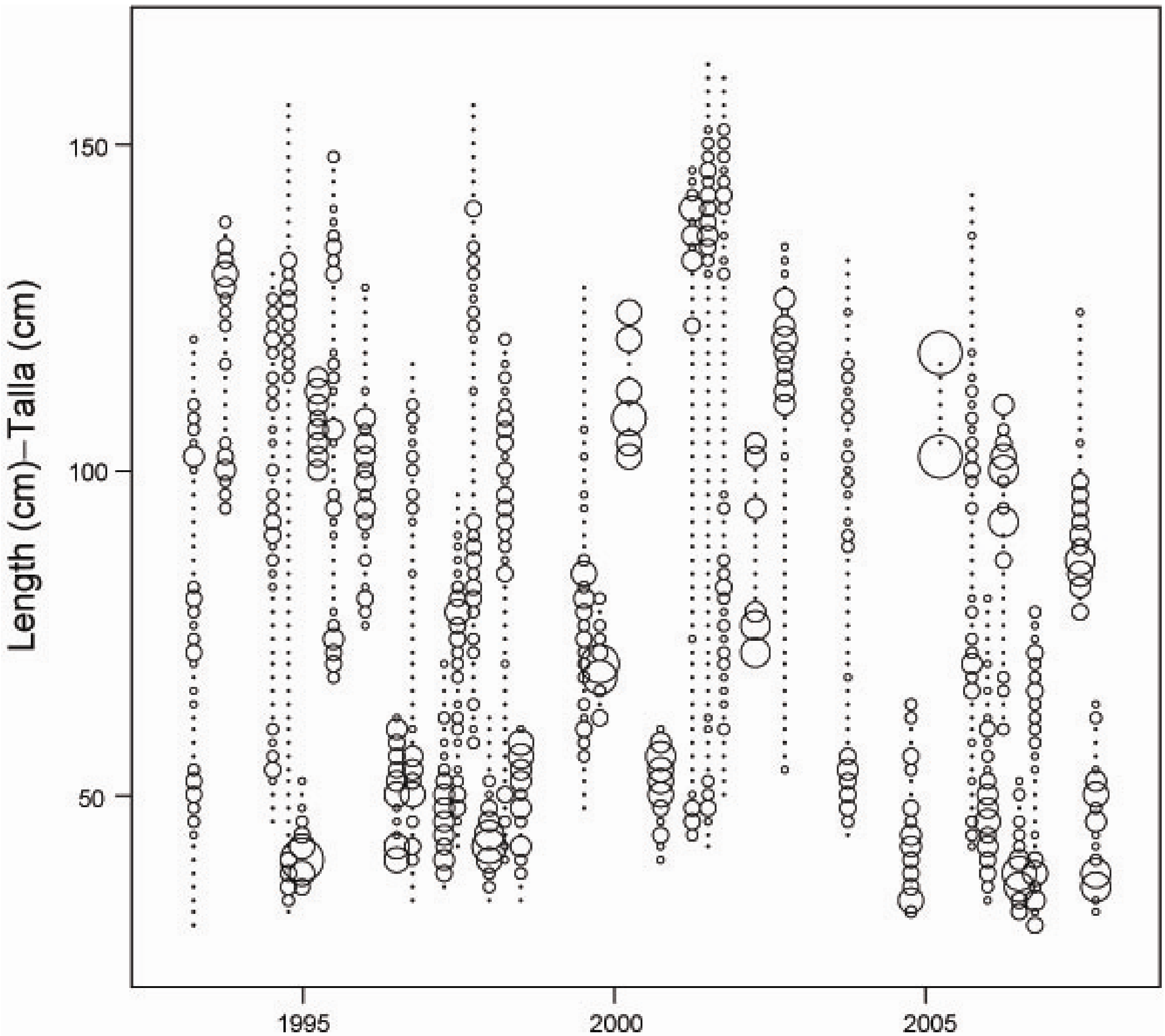

FIGURE 2.6d. Size compositions of the catches of bigeye tuna taken by Fishery 4, by quarter. The sizes of the circles are proportional to the catches.

FIGURA 2.6d. Composición por talla de las capturas de patudo de la Pesquería 4, por trimestre. El tamaño de los círculos es proporcional a la captura.

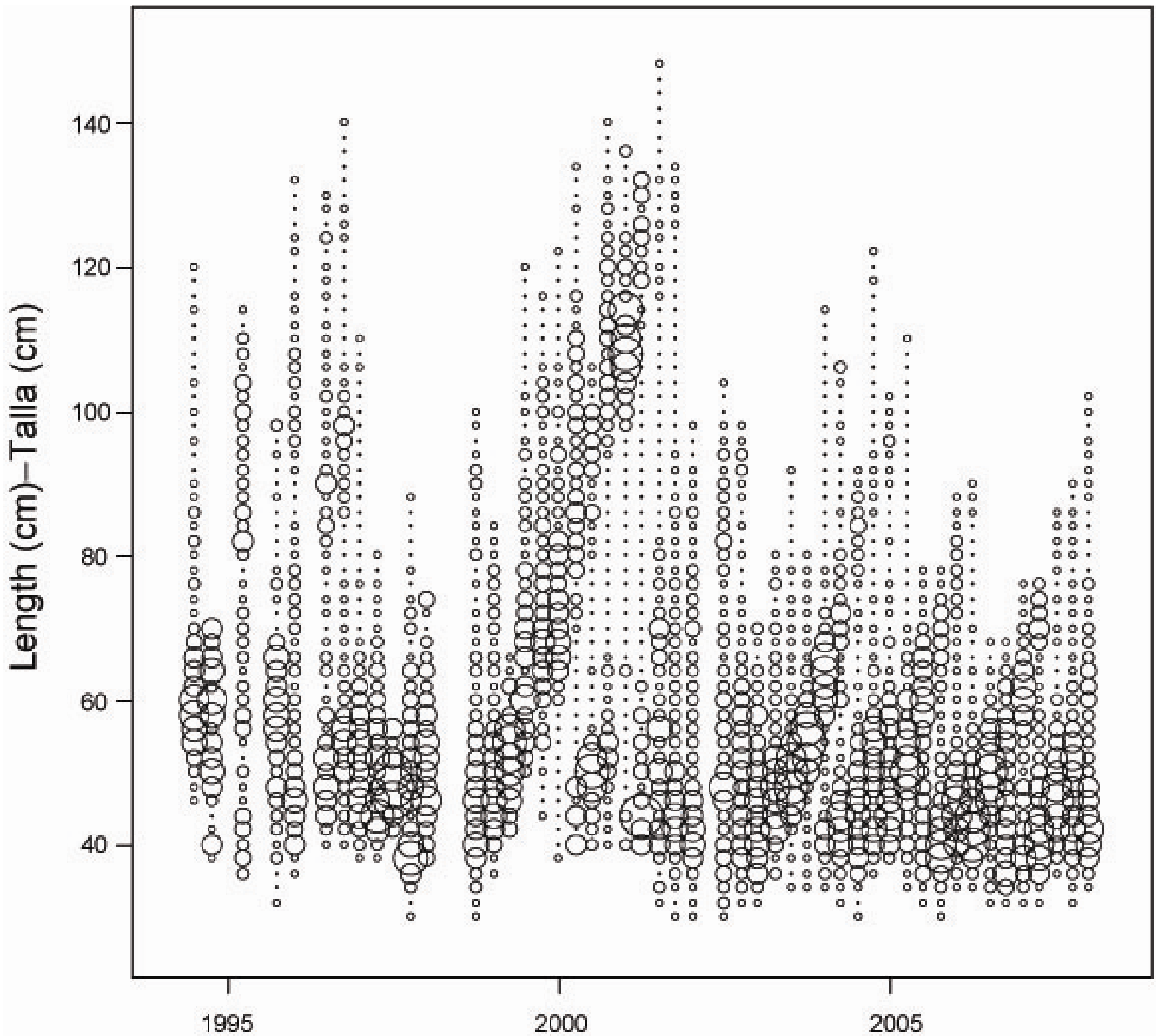

FIGURE 2.6e. Size compositions of the catches of bigeye tuna taken by Fishery 5, by quarter. The sizes of the circles are proportional to the catches.
FIGURA 2.6e. Composición por talla de las capturas de patudo de la Pesquería 5, por trimestre. El tamaño de los círculos es proporcional a la captura.

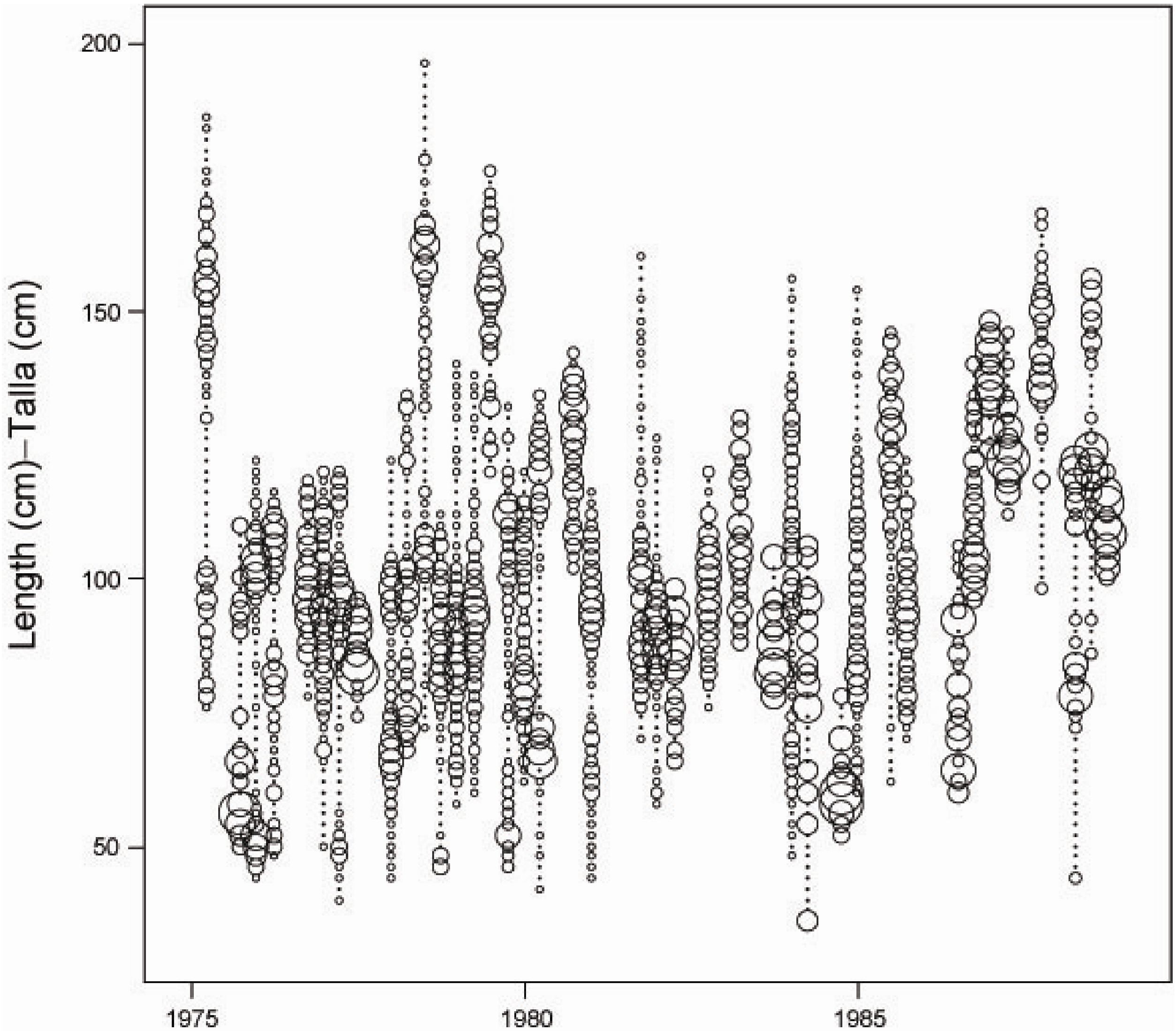

FIGURE 2.6f. Size compositions of the catches of bigeye tuna taken by Fishery 6, by quarter. The sizes of the circles are proportional to the catches.
FIGURA 2.6f. Composición por talla de las capturas de patudo de la Pesquería 6, por trimestre. El tamaño de los círculos es proporcional a la captura.

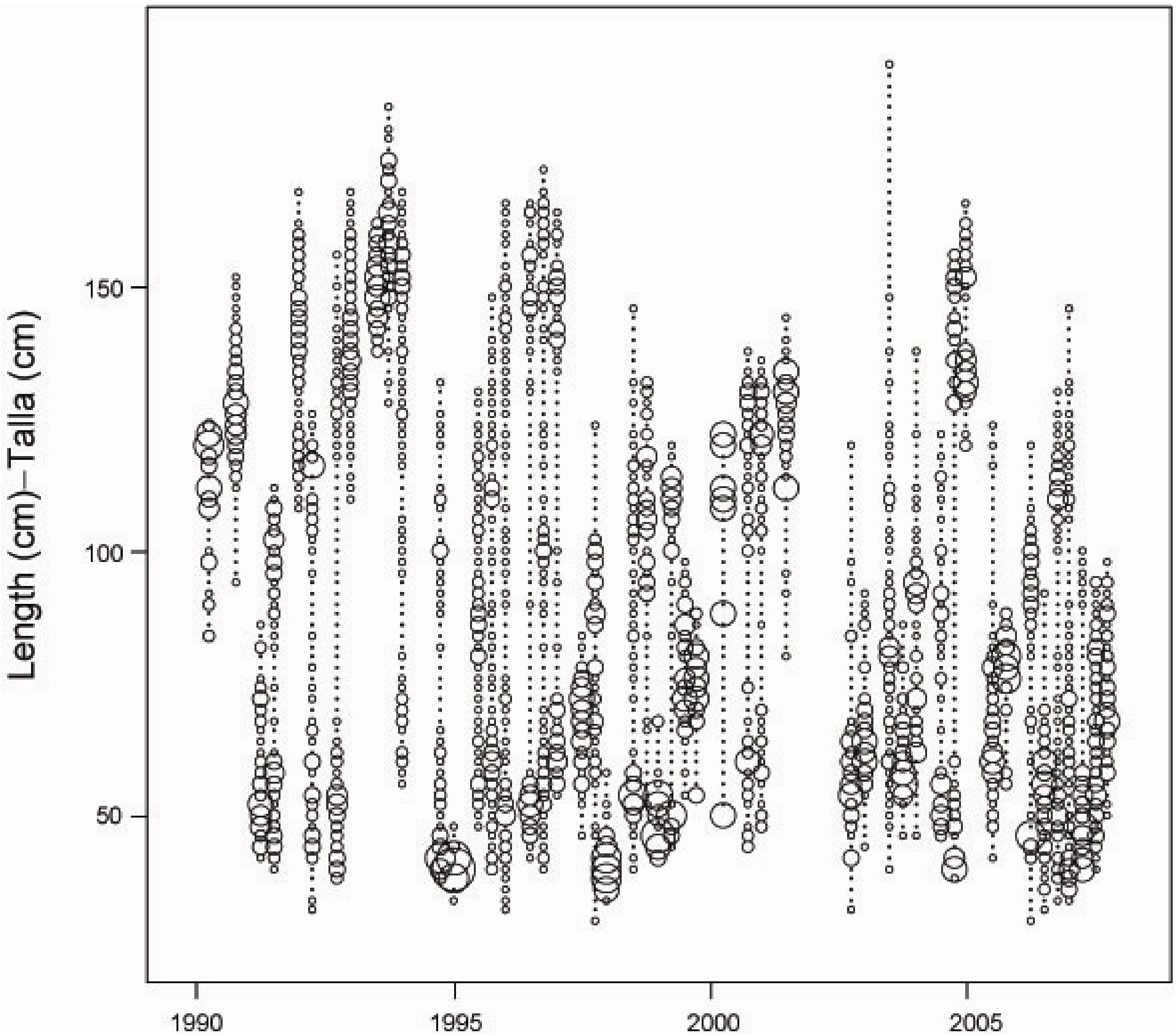

FIGURE 2.6g. Size compositions of the catches of bigeye tuna taken by Fishery 7, by quarter. The sizes of the circles are proportional to the catches.

FIGURA 2.6g. Composición por talla de las capturas de patudo de la Pesquería 7, por trimestre. El tamaño de los círculos es proporcional a la captura.

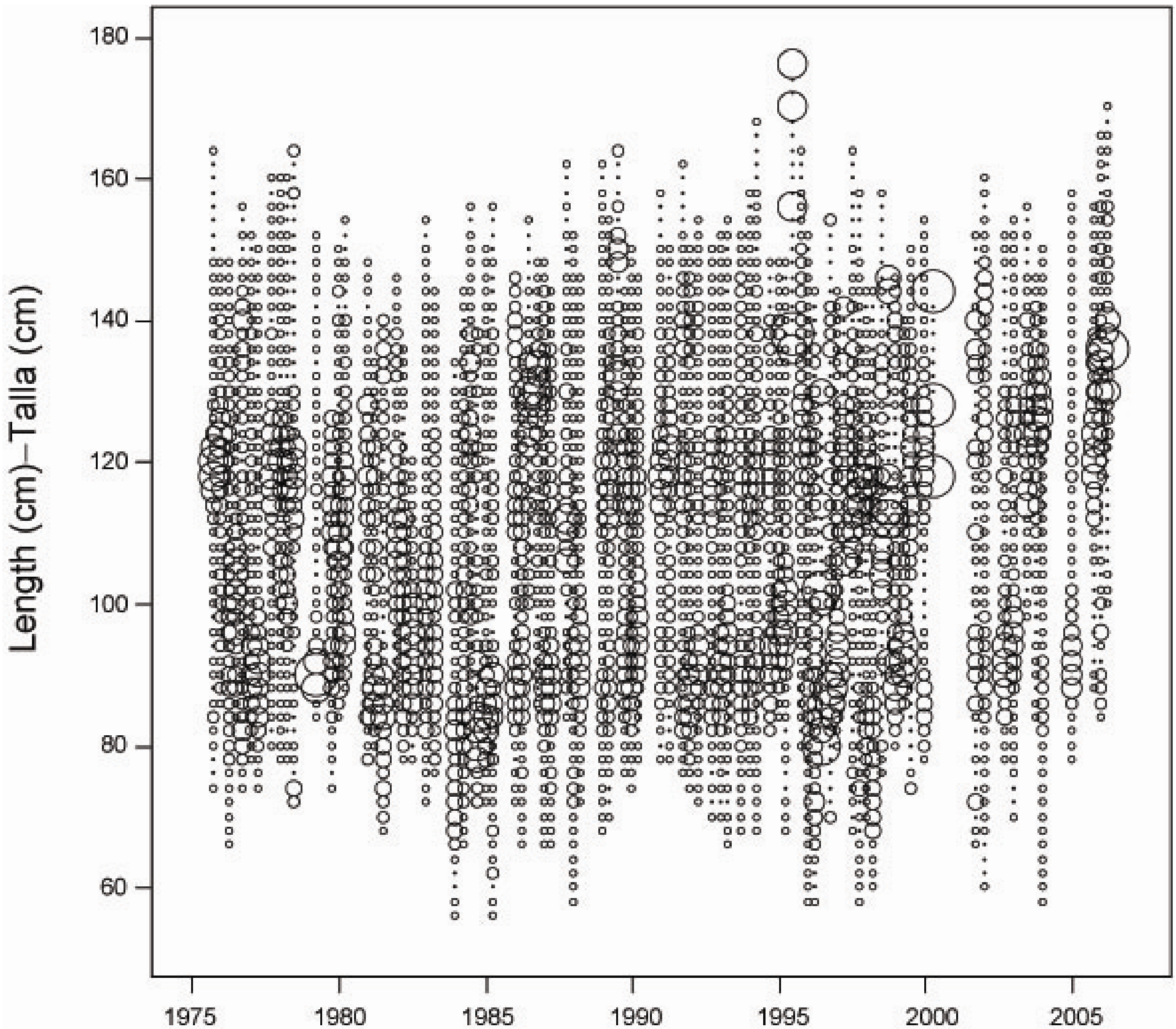

FIGURE 2.6h. Size compositions of the catches of bigeye tuna taken by Fishery 8, by quarter. The sizes of the circles are proportional to the catches.
FIGURA 2.6h. Composición por talla de las capturas de patudo de la Pesquería 8, por trimestre. El tamaño de los círculos es proporcional a la captura.

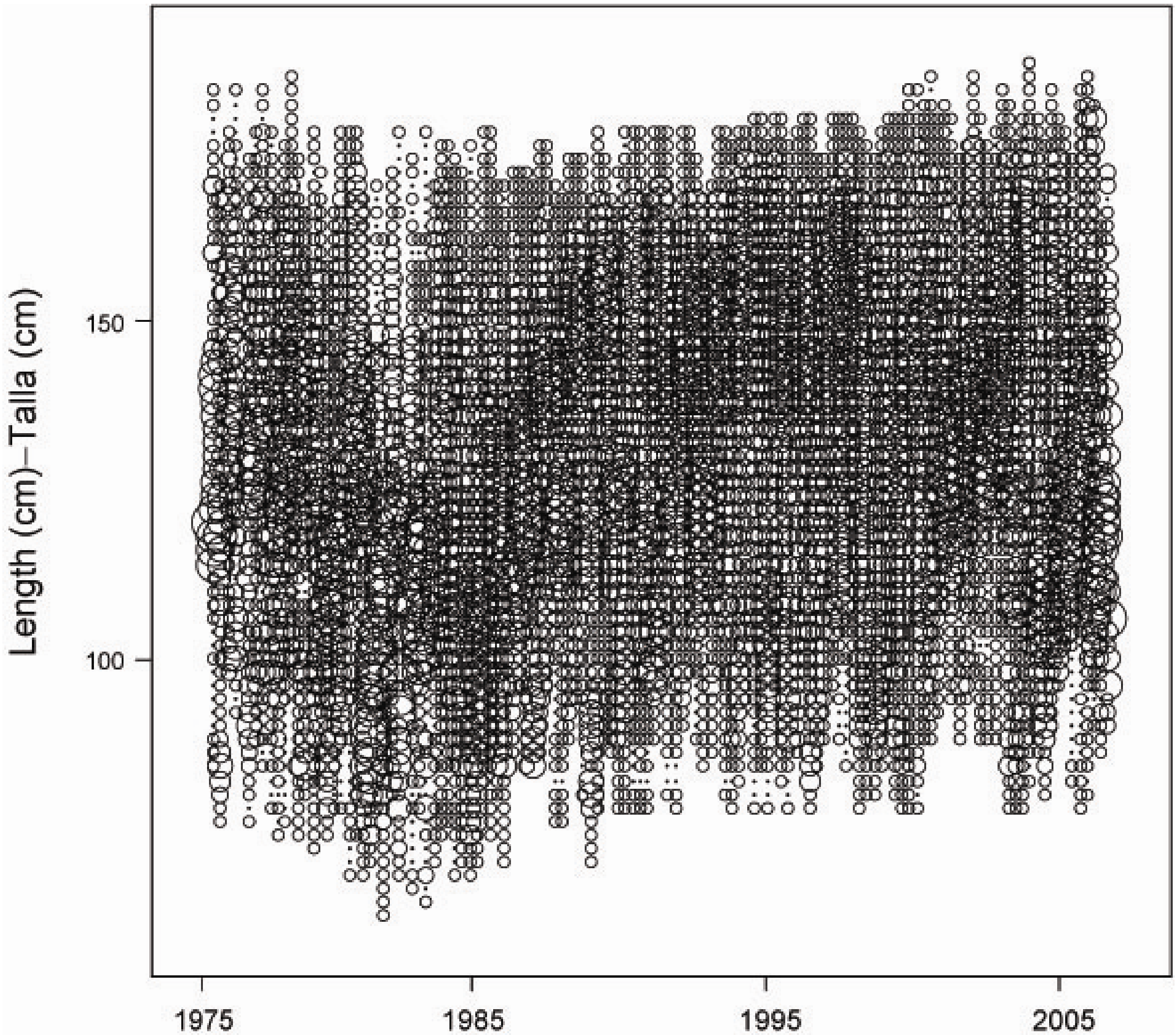

FIGURE 2.6i. Size compositions of the catches of bigeye tuna taken by Fishery 9, by quarter. The sizes of the circles are proportional to the catches.
FIGURA 2.6i. Composición por talla de las capturas de patudo de la Pesquería 9, por trimestre. El tamaño de los círculos es proporcional a la captura.

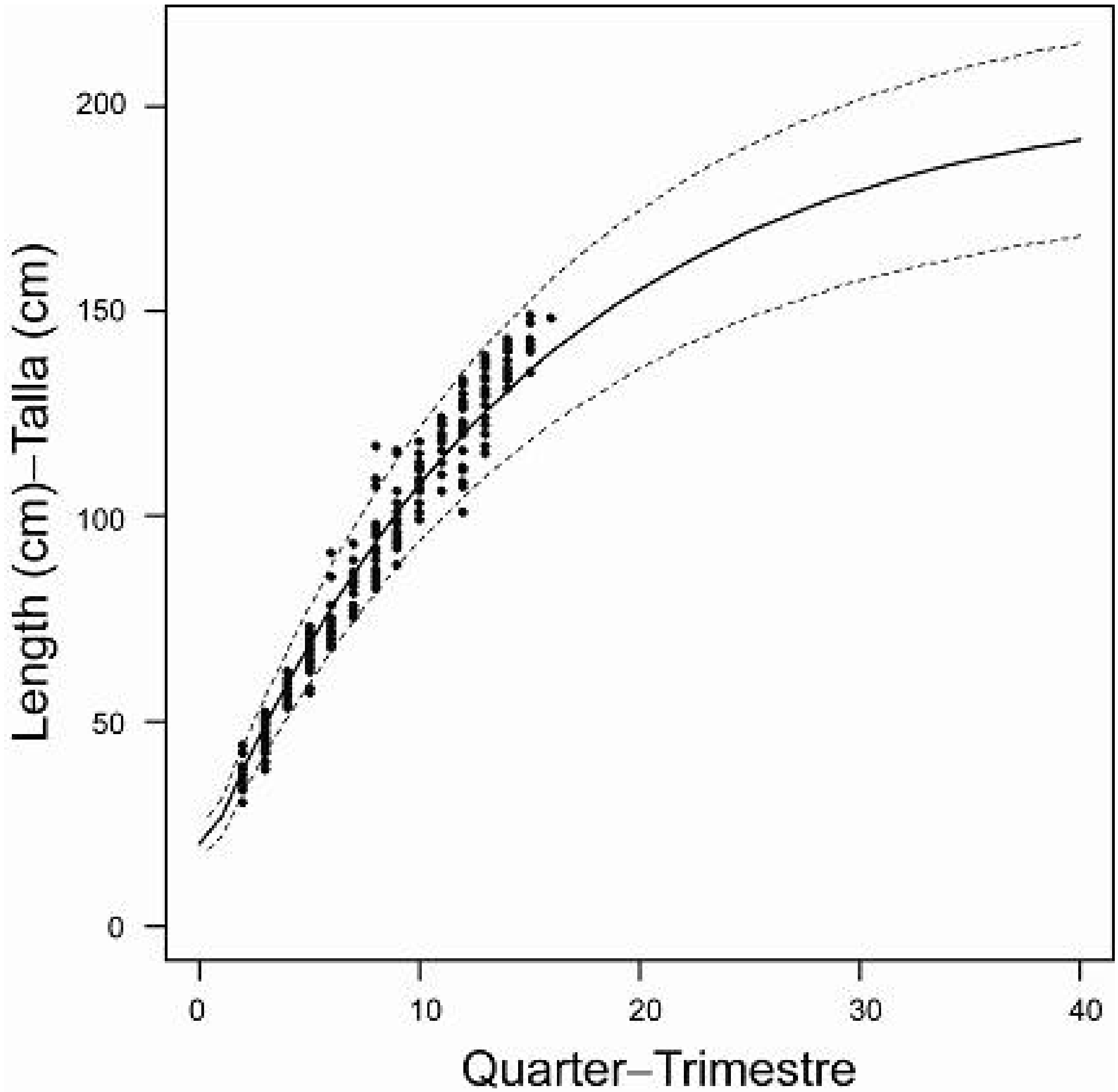

FIGURE 3.1. Estimated average lengths at age for bigeye tuna in the EPO. The dots represent the otolith age-length data from Schaefer and Fuller (2006). The dashed lines indicate the confidence intervals (±2 standard deviations) of the mean lengths at age.
FIGURA 3.1. Talla a edad media estimada del atún patudo en el OPO. Los puntos representan los datos de otolitos de talla a edad de Schaefer y Fuller (2006). Las líneas de trazos indican los intervalos de confianza (±2 desviaciones estándar) de la talla media a edad.

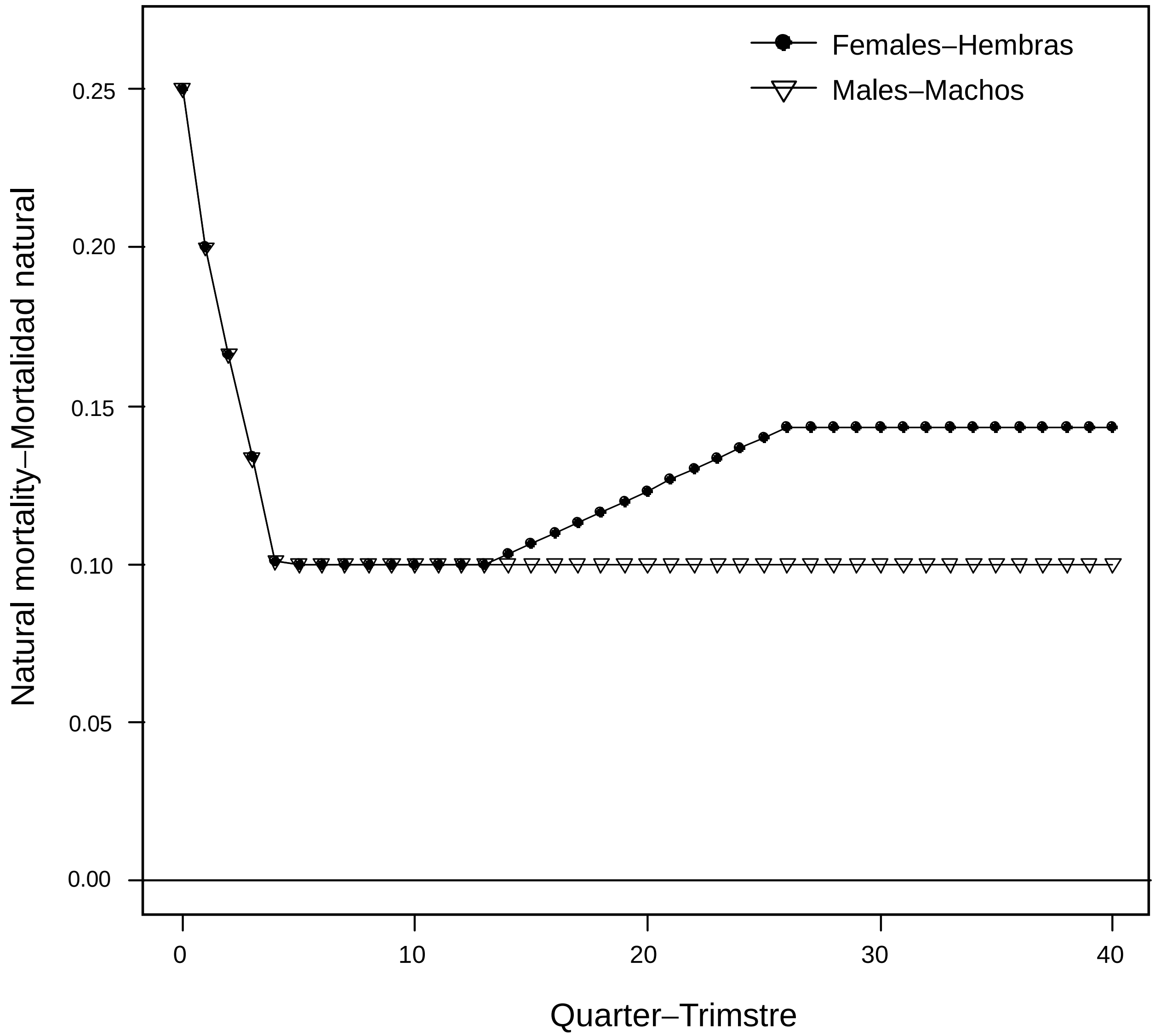

FIGURE 3.2. Quarterly natural mortality (*M*) rates used for the base case assessment of bigeye tuna in the EPO.

FIGURA 3.2. Tasas trimestrales de mortalidad natural (*M*) usadas en la evaluación del caso base del atún patudo en el OPO.

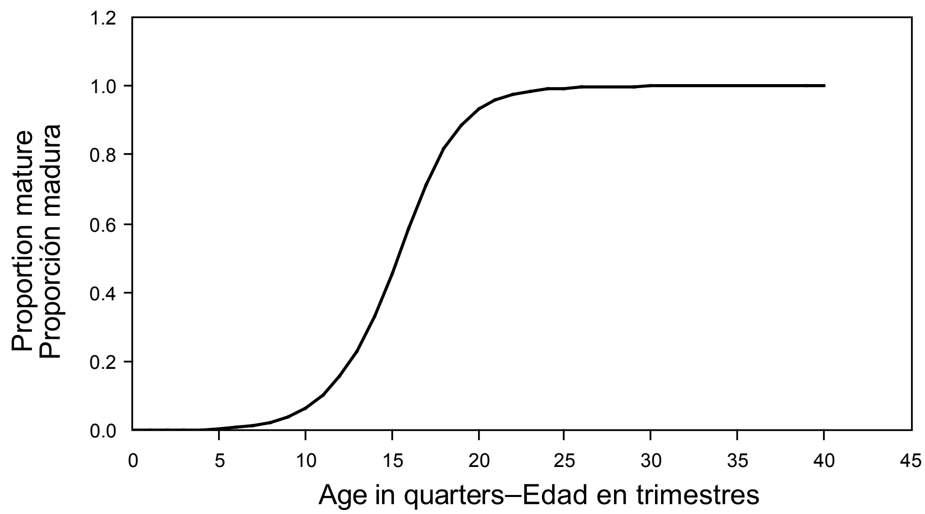

FIGURE 3.3. Age-specific index of fecundity of bigeye tuna as assumed in the base case model and in the estimation of natural mortality.
FIGURA 3.3. Índice de fecundidad por edad de atún patudo supuesto en el modelo del caso base y en la estimación de la mortalidad natural.

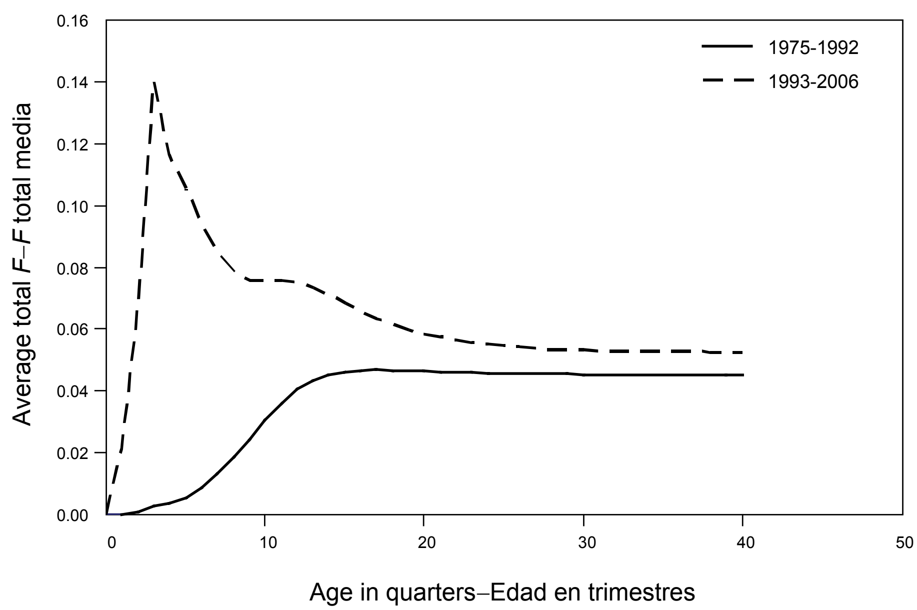

FIGURE 4.1. Average quarterly fishing mortality (approximated by exploitation rate) at age of bigeye tuna, by all gears, in the EPO. The curves for 1975-1992 and 1993-2007 display the averages for the periods prior to and since the expansion of the floating-object fisheries, respectively.
FIGURA 4.1. 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.

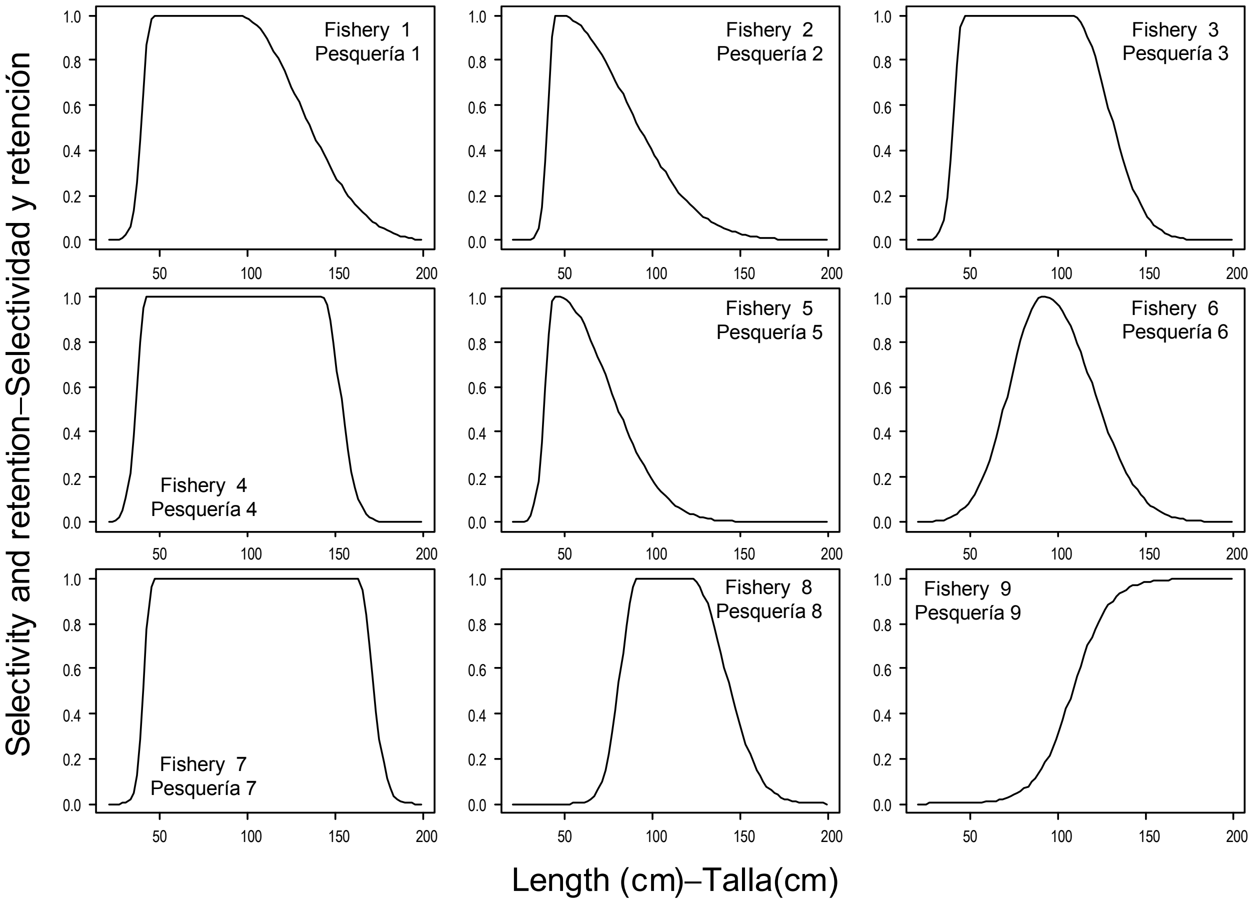

FIGURE 4.2. Size selectivity curves for Fisheries 1-9, estimated with SS2. Fish are assumed to be fully selected for the discard Fisheries 10-13. The selectivity curves for Fisheries 14 and 15 are the same as Fisheries 8 and 9, respectively.

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.

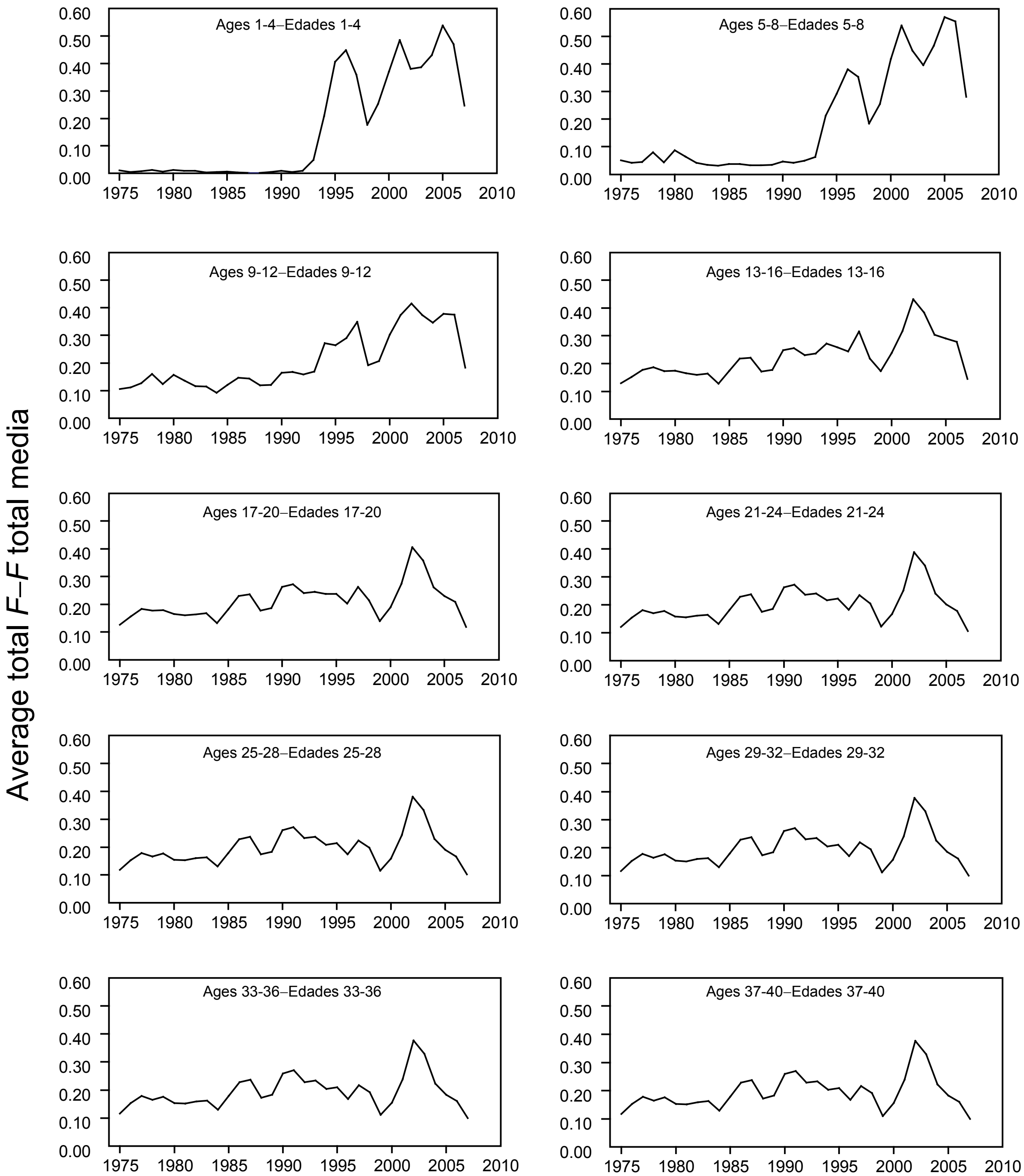

FIGURE 4.3. Average annual fishing mortality, by all gears, of bigeye tuna recruited to the fisheries of the EPO. Each panel illustrates an average of four annual fishing mortality vectors that affected the fish within the range of ages indicated in the title of each panel. For example, the trend illustrated in the upper-left 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 todos los 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 izquierdo es un promedio de las mortalidades por pesca que afectaron a los peces de entre 1-4 trimestres de edad.

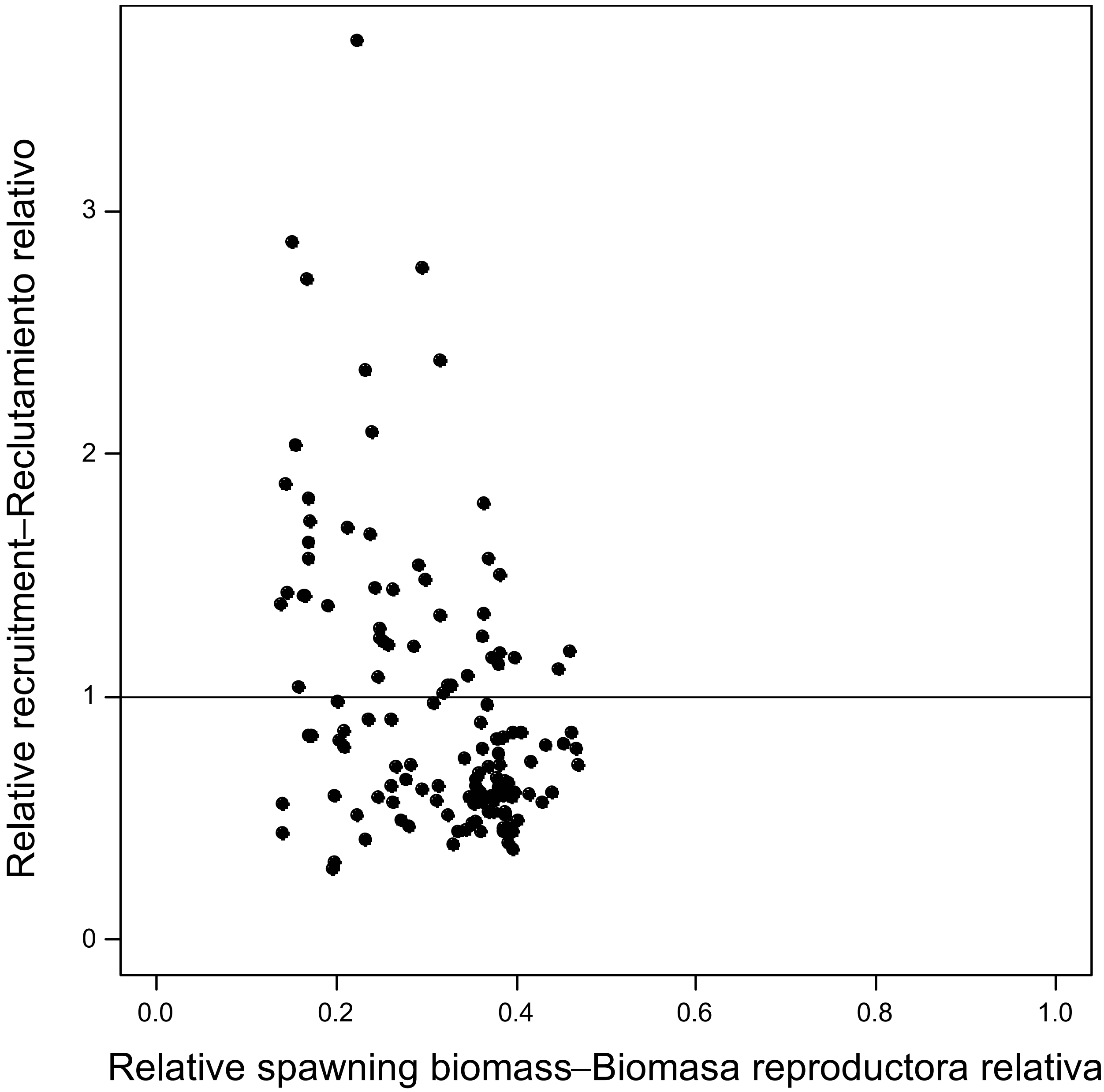

FIGURE 4.4. Estimated relationship between the recruitment of bigeye tuna and spawning biomass. The recruitment is scaled so that the estimate of virgin recruitment is equal to 1.0. Likewise, the spawning biomass is scaled so that the estimate of virgin spawning biomass is equal to 1.0. The horizontal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

FIGURA 4.4. 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.

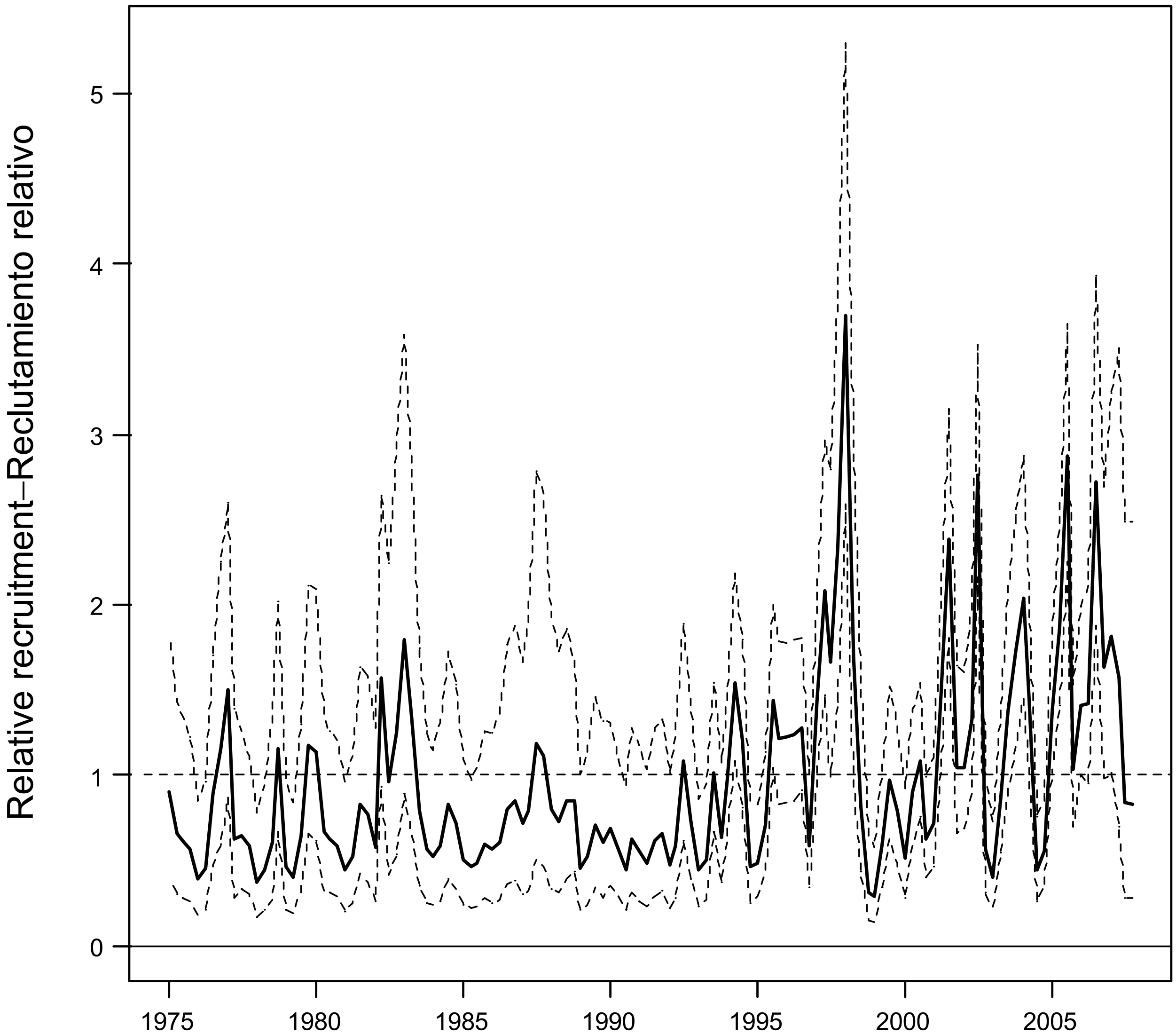

FIGURE 4.5. Estimated recruitment of bigeye tuna to the fisheries of the EPO. The estimates are scaled so that the estimate of virgin recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the thin dashed lines the confidence intervals (±2 standard 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. 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.

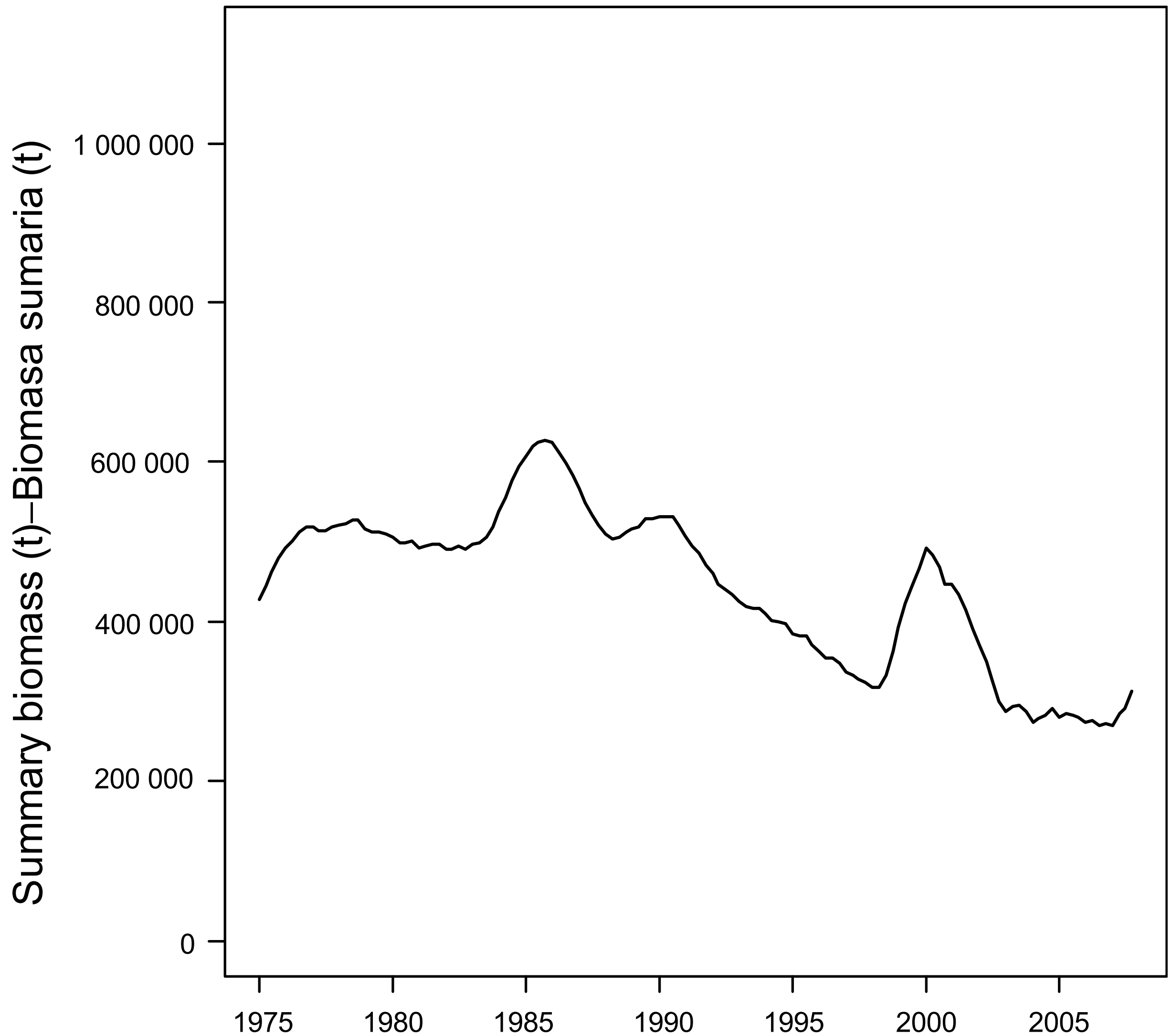

FIGURE 4.6. Maximum likelihood estimates of the biomass of bigeye tuna 3+ quarters old in the EPO (summary biomass). Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year. t = metric tons.

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.

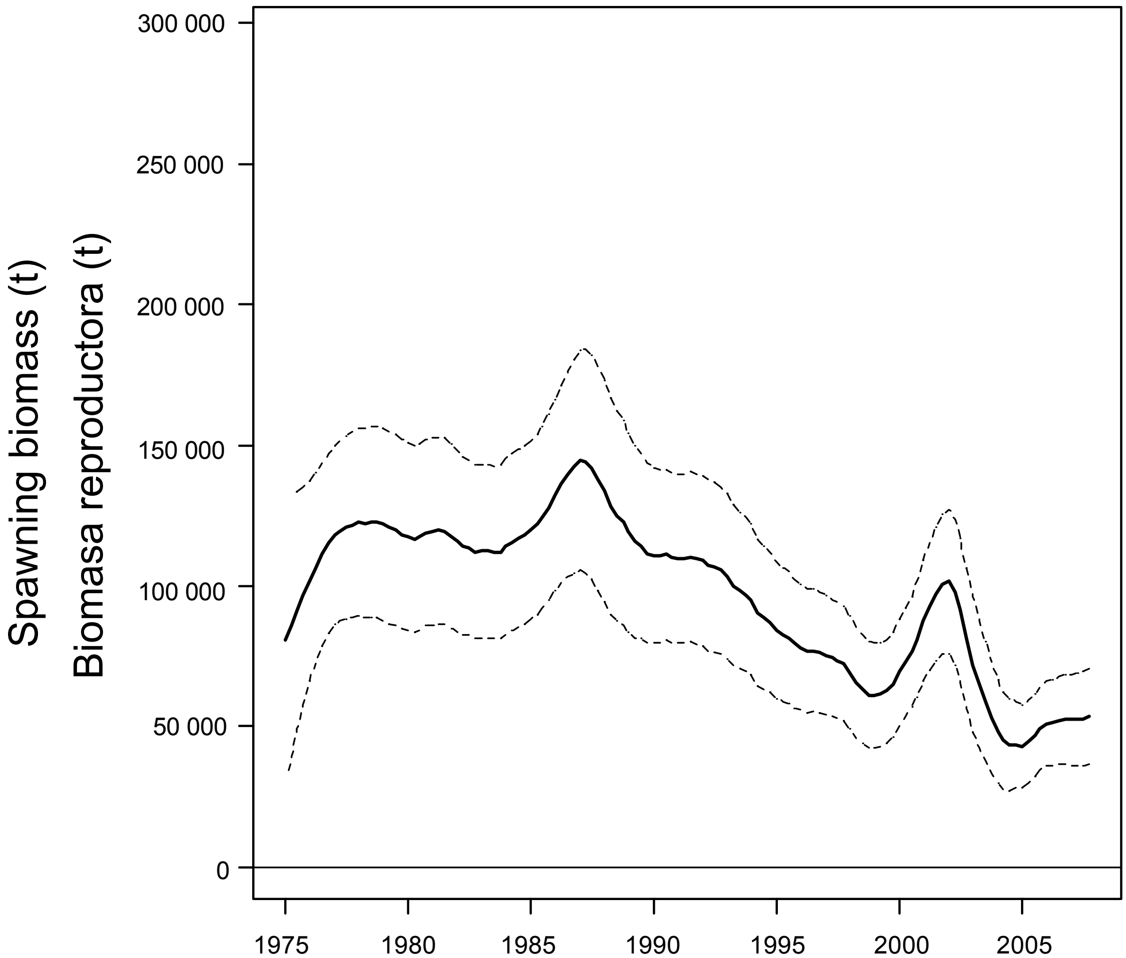

FIGURE 4.7. Maximum likelihood estimates of the spawning biomass (see Section 4.1.3) of bigeye tuna in the EPO. The bold line illustrates the maximum likelihood estimates of the biomasses, and the thin dashed lines the confidence intervals (±2 standard deviations) around those estimates. Since the assessment 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 gruesa ilustra las estimaciones de verosimilitud máxima de la biomasa, y las líneas delgadas 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.

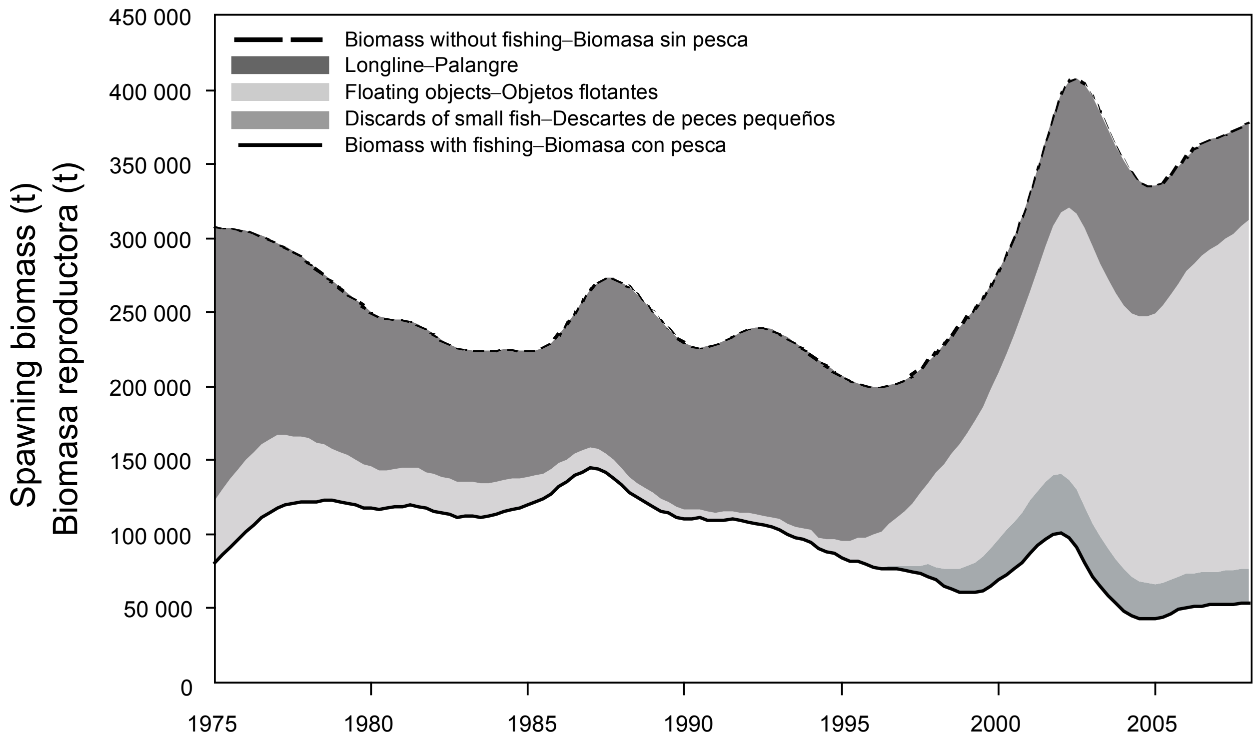

FIGURE 4.8. Trajectory of the spawning biomass of a simulated population of bigeye tuna that was not exploited (top line) and that predicted by the stock assessment model (bottom line). The shaded areas between the two lines show the portions of the impact attributed to each fishing method. t = metric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

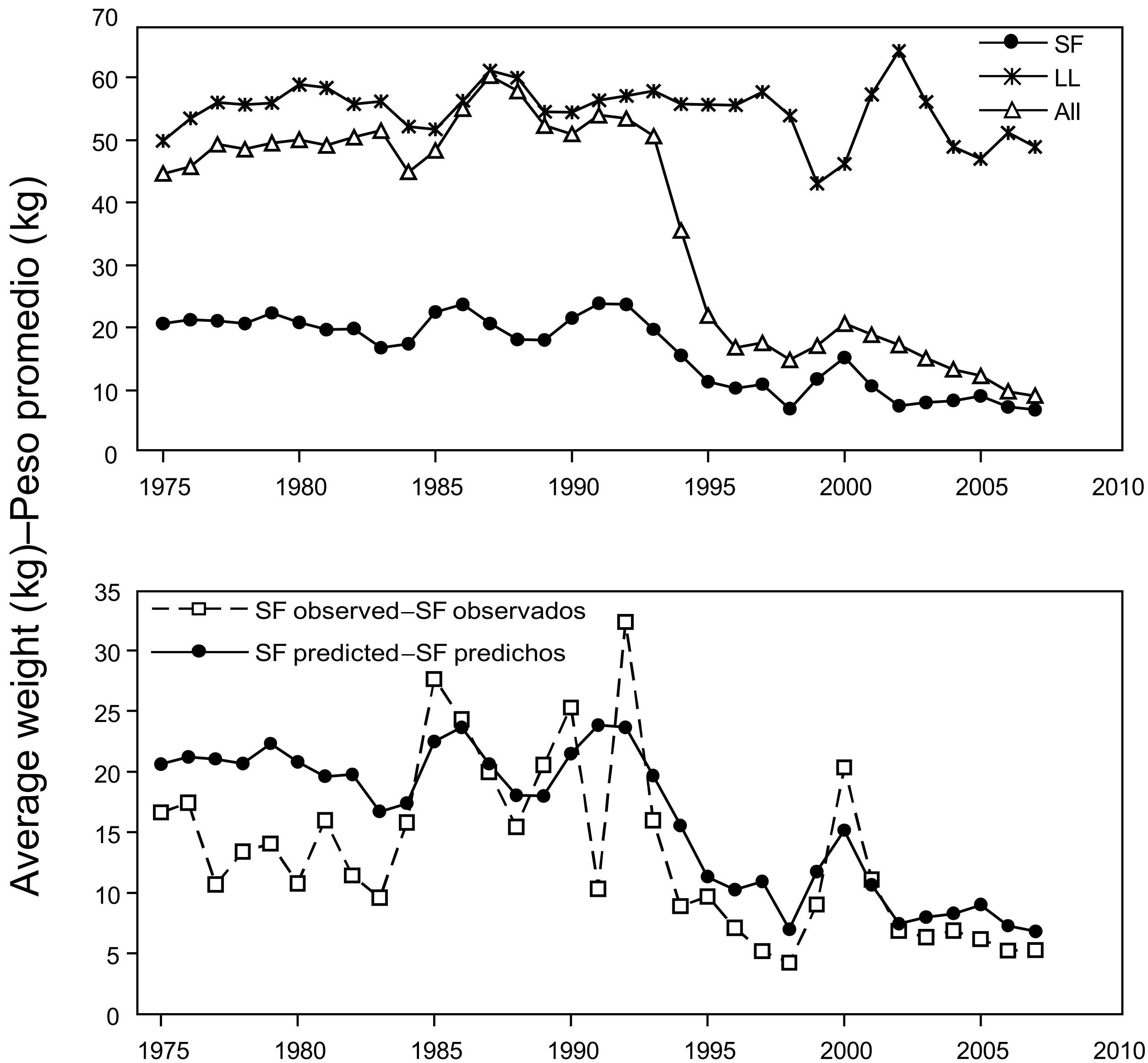

FIGURE 4.9. Average weights of bigeye tuna caught in the EPO, 1975-2007, by the surface fisheries (SF, Fisheries 1-7), longline fisheries (LL, Fisheries 8-9 and 14-15), and all fisheries combined (All). Upper panel: predicted average weights; lower panel: predicted and observed average weights for the surface fisheries.

FIGURA 4.9. Peso medio estimado de atún patudo capturado en el OPO, 1975-2007,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.

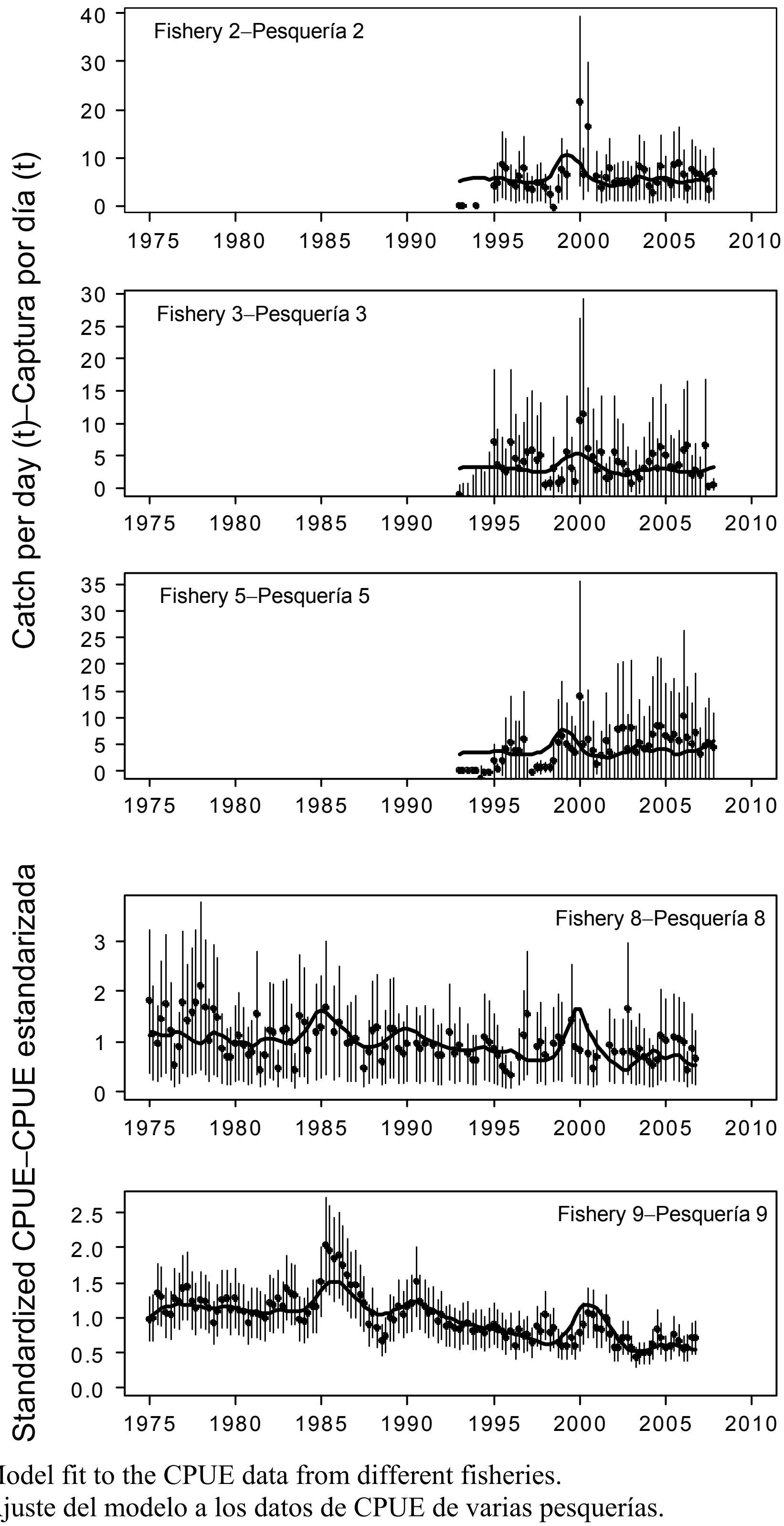

FIGURE 4.10. Model fit to the CPUE data from different fisheries.
FIGURA 4.10. Ajuste del modelo a los datos de CPUE de varias pesquerías.

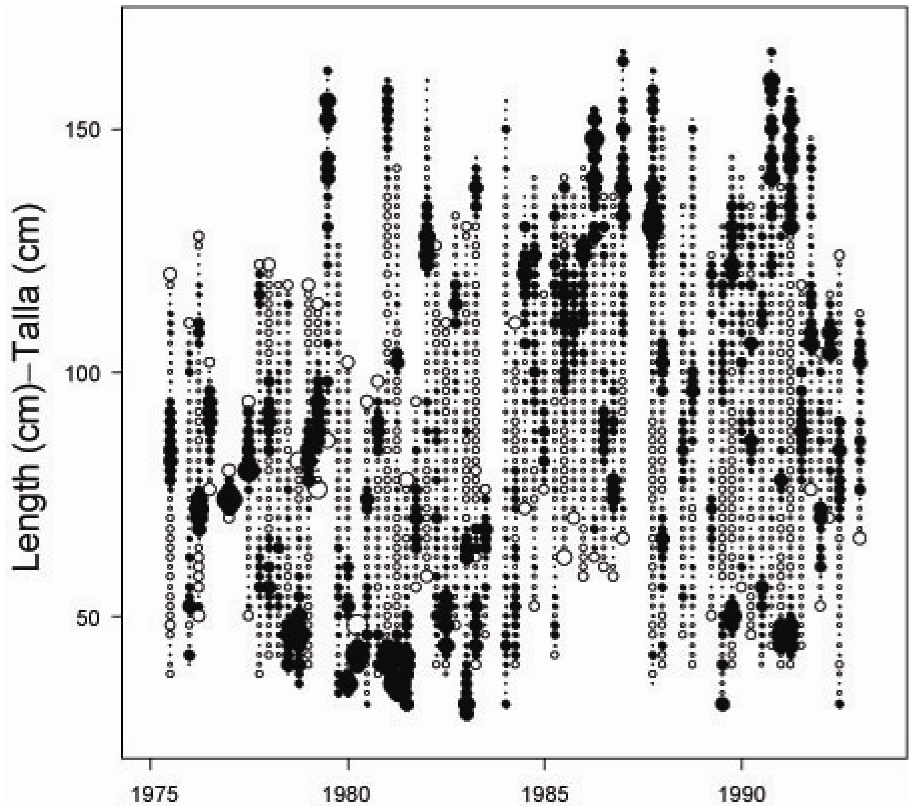

FIGURE 4.11a. Pearson residual plots for the model fits to the length composition data for Fishery 1. The open and solid circles represent observations that are higher and lower, respectively, than the model predictions. The sizes of the circles are proportional to the absolute values of the residuals.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

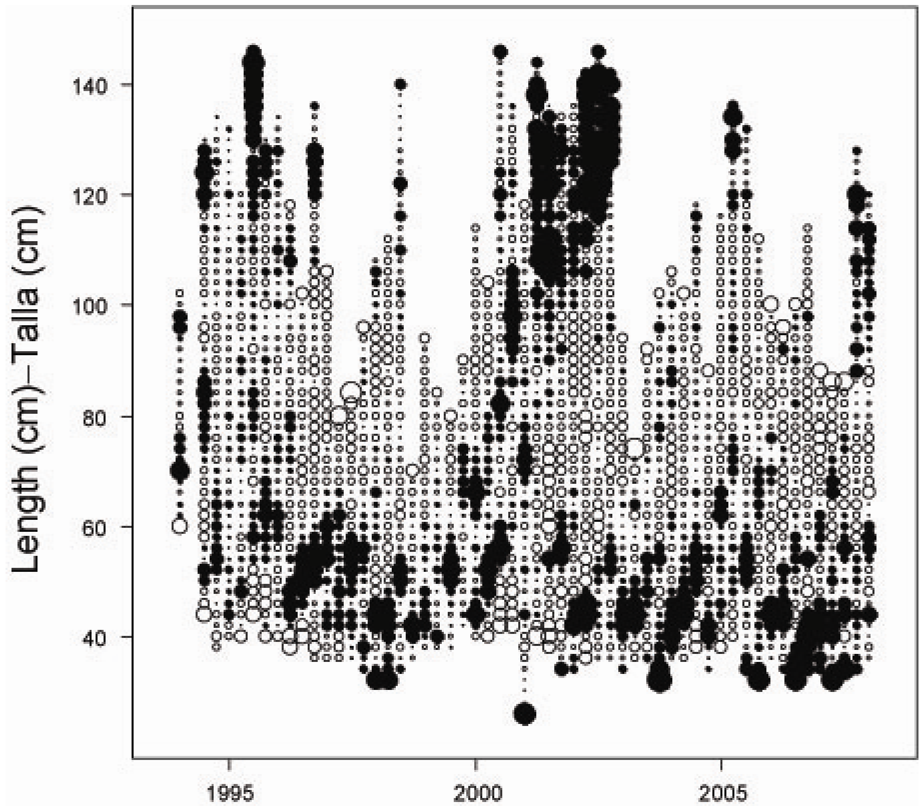

FIGURE 4.11b. Pearson residual plots for the model fits to the length composition data for Fishery 2. The open and solid circles represent observations that are higher and lower, respectively, than the model predictions. The sizes of the circles are proportional to the absolute values of the residuals.

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.

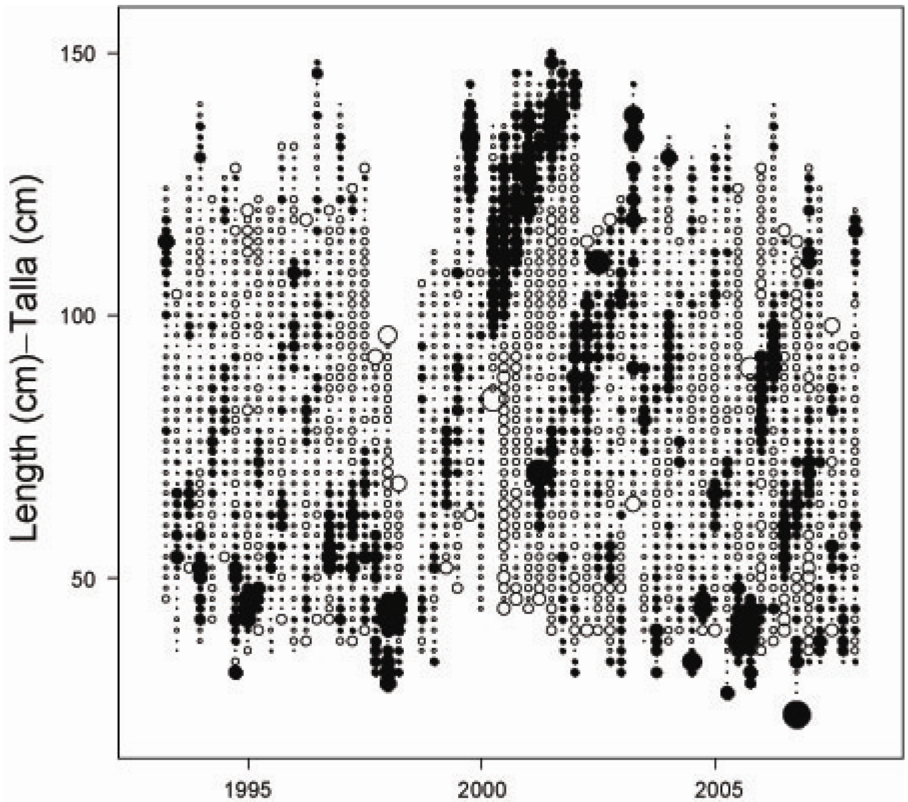

FIGURE 4.11c. Pearson residual plots for the model fits to the length composition data for Fishery 3. The open and solid circles represent observations that are higher and lower, respectively, than the model predictions. The sizes of the circles are proportional to the absolute values of the residuals.

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.

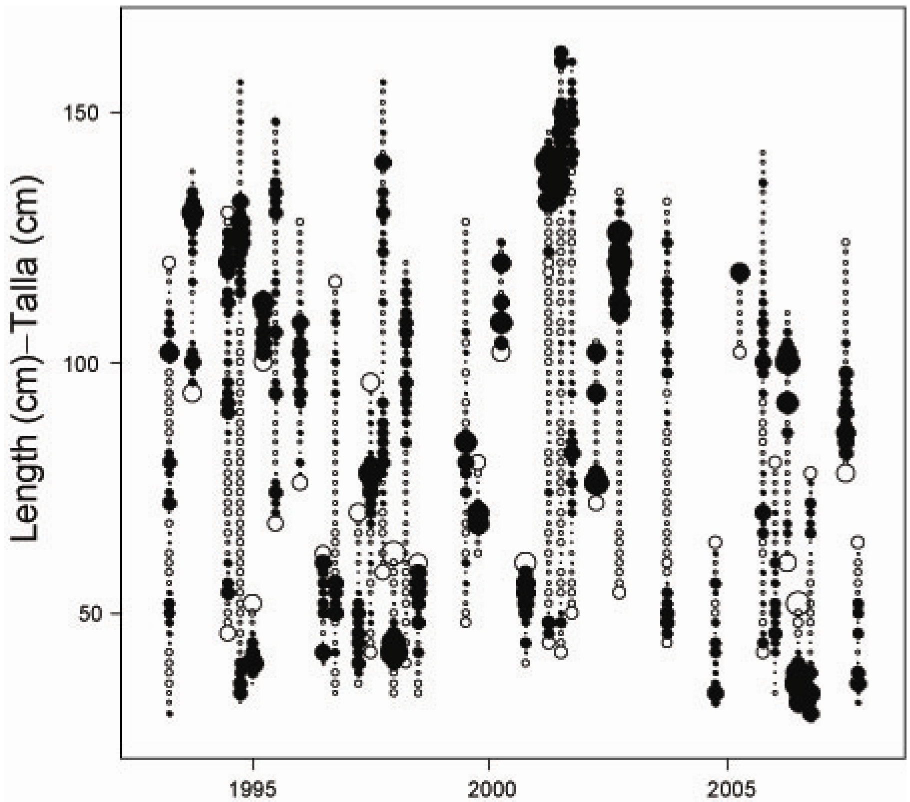

FIGURE 4.11d Pearson residual plots for the model fits to the length composition data for Fishery 4. The open and solid circles represent observations that are higher and lower, respectively, than the model predictions. The sizes of the circles are proportional to the absolute values of the residuals.

FIGURA 4.11d. Gráficas de residuales de Pearson para los ajustes del modelo a los datos de composición por talla de la Pesquería 4. 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.

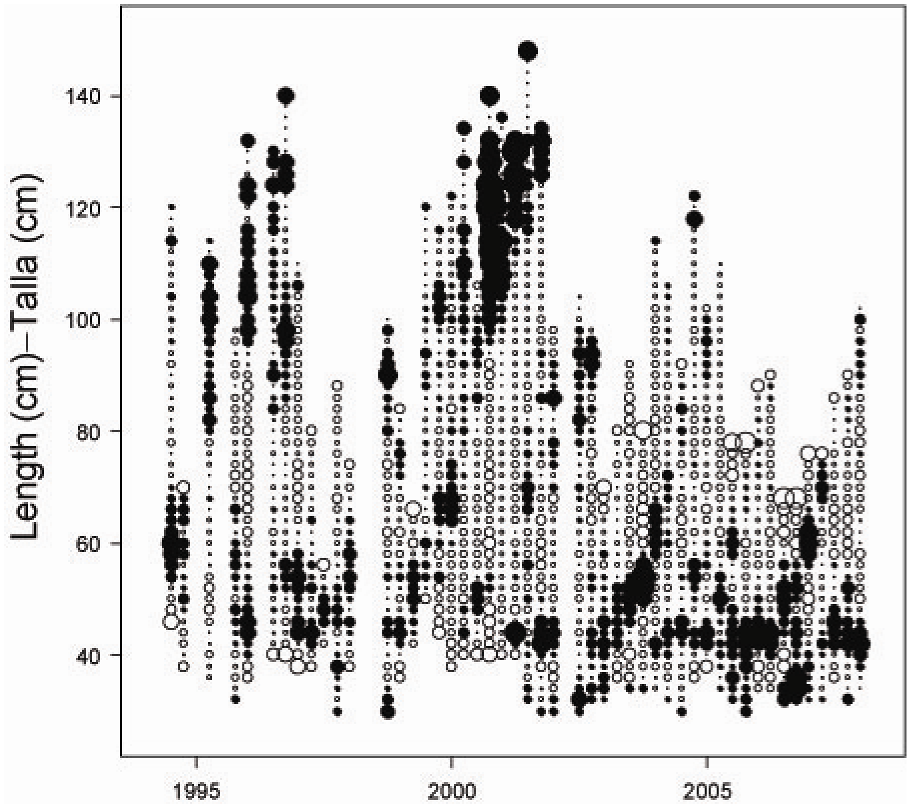

FIGURE 4.11e. Pearson residual plots for the model fits to the length composition data for Fishery 5. The open and solid circles represent observations that are higher and lower, respectively, than the model predictions. The sizes of the circles are proportional to the absolute values of the residuals.

FIGURA 4.11e. Gráficas de residuales de Pearson para los ajustes del modelo a los datos de composición por talla de la Pesquería 5. 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.

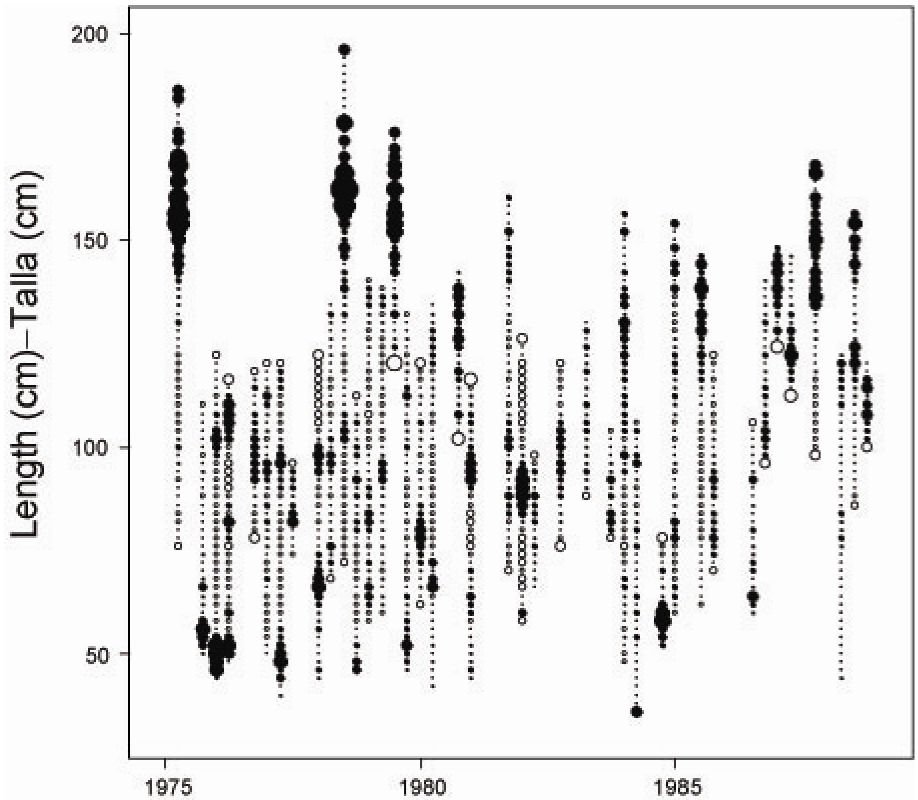

FIGURE 4.11f. Pearson residual plots for the model fits to the length composition data for Fishery 6. The open and solid circles represent observations that are higher and lower, respectively, than the model predictions. The sizes of the circles are proportional to the absolute values of the residuals.

FIGURA 4.11f. Gráficas de residuales de Pearson para los ajustes del modelo a los datos de composición por talla de la Pesquería 6. 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.

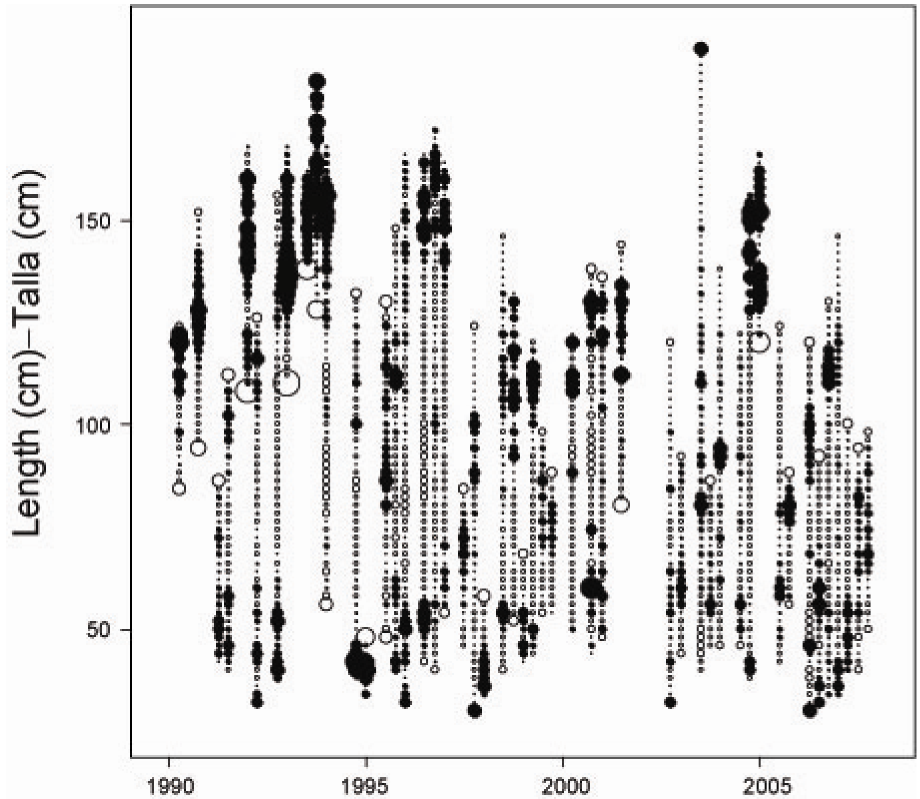

FIGURE 4.11g. Pearson residual plots for the model fits to the length composition data for Fishery 7. The open and solid circles represent observations that are higher and lower, respectively, than the model predictions. The sizes of the circles are proportional to the absolute values of the residuals.

FIGURA 4.11g. Gráficas de residuales de Pearson para los ajustes del modelo a los datos de composición por talla de la Pesquería 7. 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.

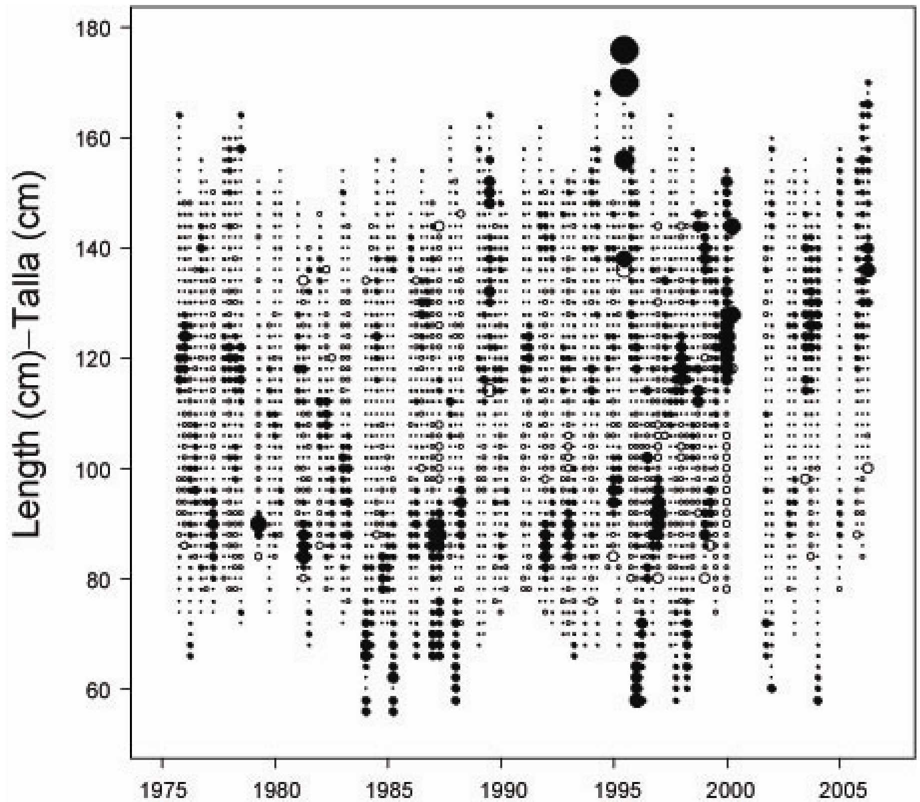

FIGURE 4.11h. Pearson residual plots for the model fits to the length composition data for Fishery 8. The open and solid circles represent observations that are higher and lower, respectively, than the model predictions. The sizes of the circles are proportional to the absolute values of the residuals.

FIGURA 4.11h. Gráficas de residuales de Pearson para los ajustes del modelo a los datos de composición por talla de la Pesquería 8. 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.

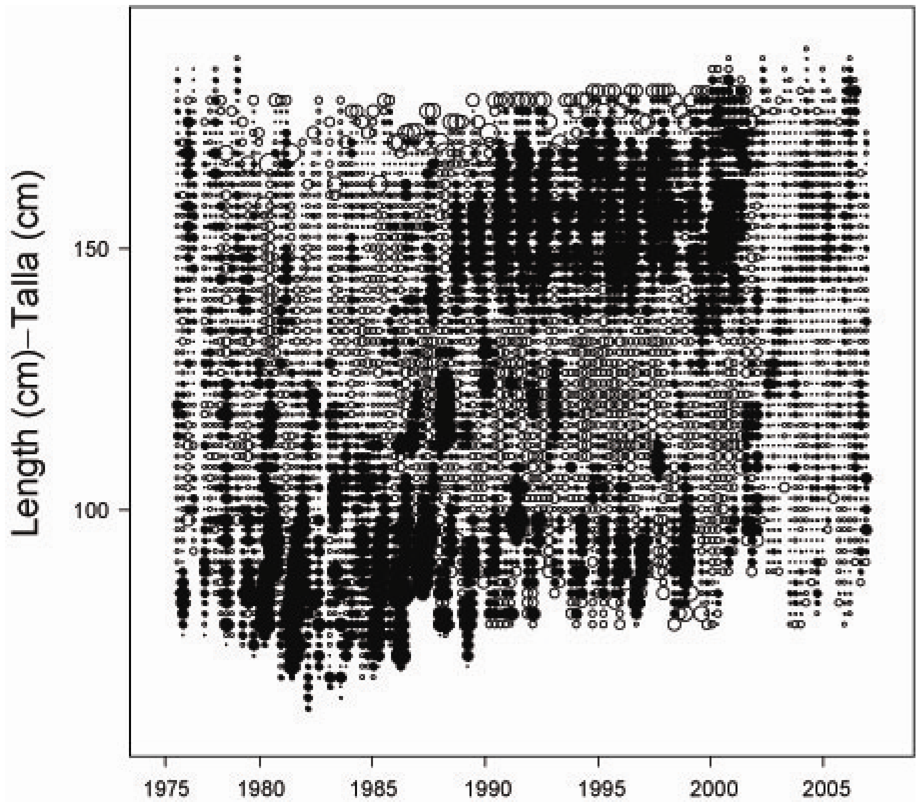

FIGURE 4.11i. Pearson residual plots for the model fits to the length composition data for Fishery 9. The open and solid circles represent observations that are higher and lower, respectively, than the model predictions. The sizes of the circles are proportional to the absolute values of the residuals.
FIGURA 4.11i. Gráficas de residuales de Pearson para los ajustes del modelo a los datos de composición por talla de la Pesquería 9. 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.

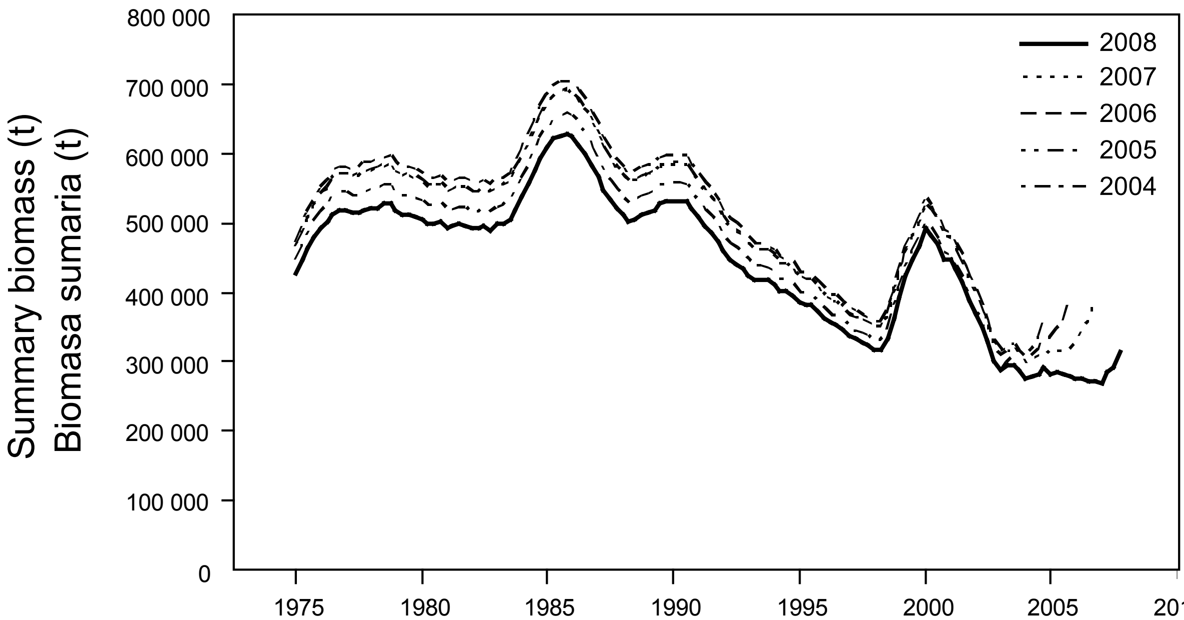

FIGURE 4.12. Retrospective comparisons of estimates of the summary biomass (fish of age 3 quarters and older) of bigeye tuna in the EPO. The estimates from the base case model are compared with the estimates obtained when the most recent year (2007), two years (2007 and 2006), three years (2007, 2006 and 2005) or four years (2007, 2006, 2005 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. Se comparan las estimaciones del modelo del caso base con aquéllas obtenidas cuando se excluyeron los datos del año más reciente (2007), a de los dos años (2007 y 2006), tres años (2007, 2006, y 2005), o cuatro años (2007, 2006, 2005 y 2004) más recientes. t = toneladas métricas.

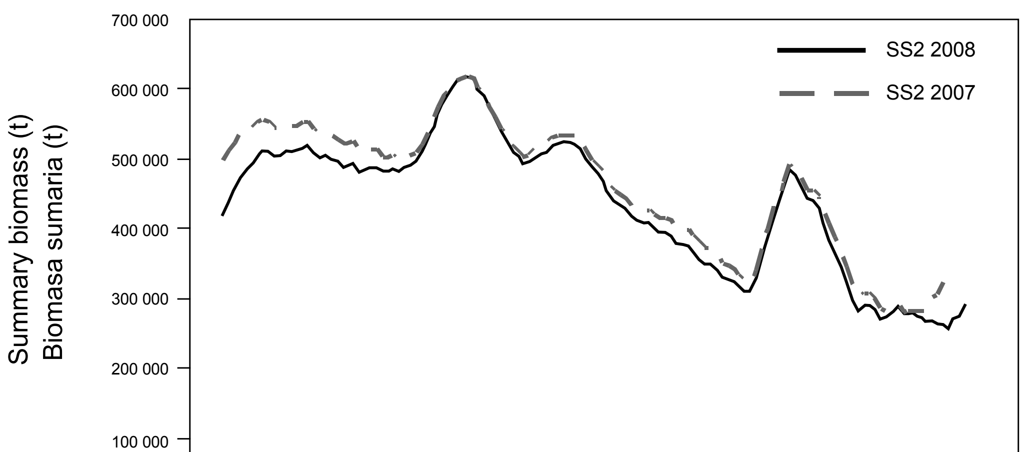

FIGURE 4.13. Comparison of estimates of the summary biomass (fish of age 3 quarters and older) of bigeye tuna from the most recent assessment (2007) and the current assessment, both using SS2. t = metric tons.

FIGURA 4.13. Comparación de las estimaciones de la biomasa sumaria (peces de 3 trimestres y más de edad) de atún patudo de la evaluación más reciente (2007) y la evaluación actual, ambas con SS2. t = toneladas métricas.

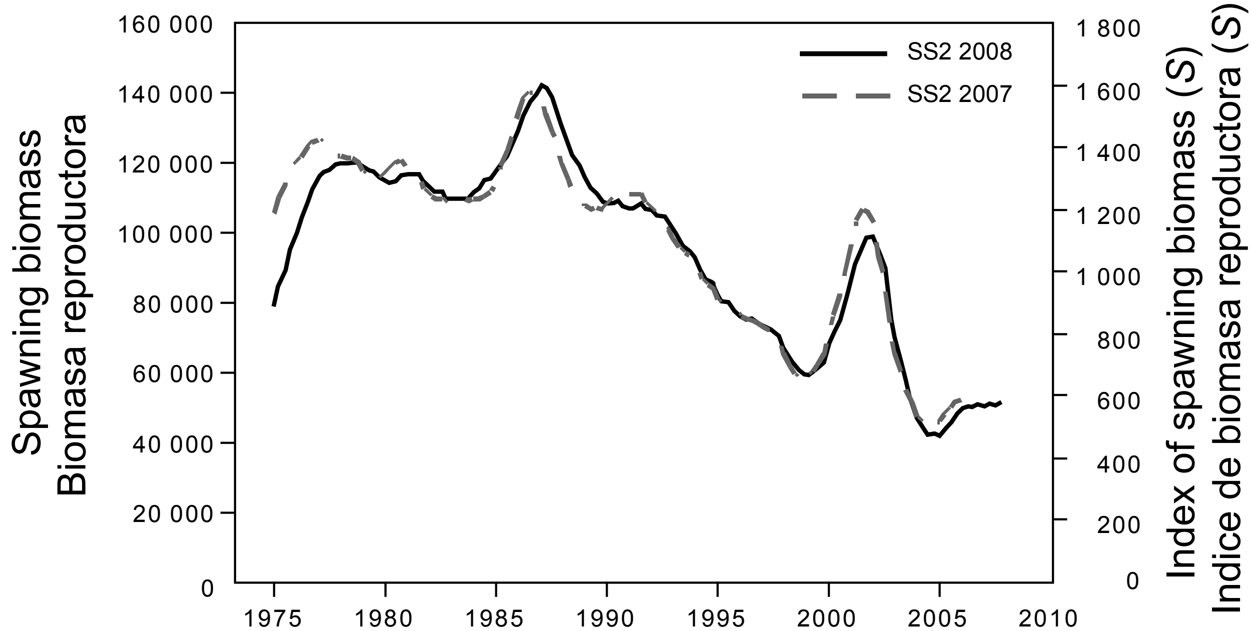

FIGURE 4.14. Comparison of estimates of the index of spawning biomass for bigeye tuna in the EPO from the most recent assessment (2007) and the current assessment (SS2), both using SS2.
FIGURA 4.14. Comparación del índice de biomasa reproductora estimada del atún patudo en el OPO de la evaluación más reciente (2007) y la evaluación actual, ambas con SS2.

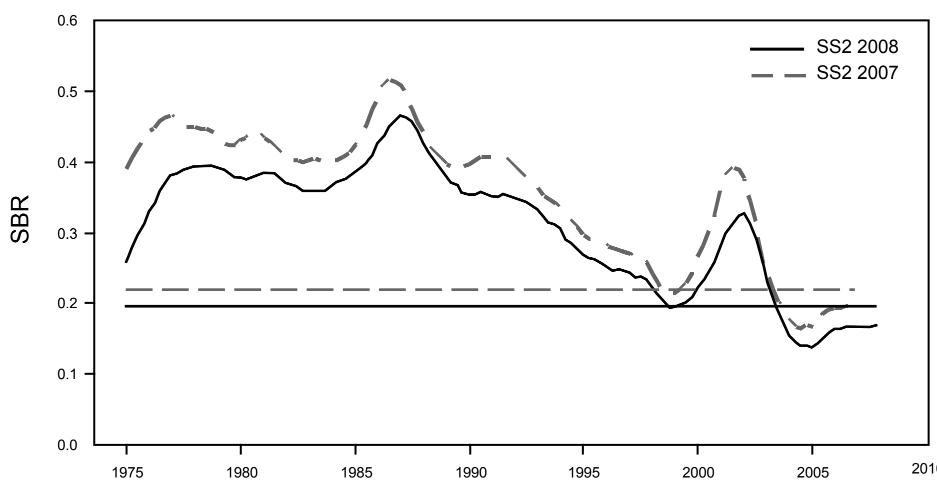

FIGURE 4.15. Comparison of estimated spawning biomass ratios (SBRs) for bigeye tuna in the EPO from the most recent assessment (2007) and the current assessment, both using SS2. The horizontal line (at about 0.22) indicates the SBR at MSY.
FIGURA 4.15. Comparación del cociente de biomasa reproductora (SBR) del atún patudo en el OPO de la evaluación más reciente (2007) y la evaluación actual, ambas con SS2. La línea horizontal (en aproximadamente 0,22) indica el SBR en RMS.

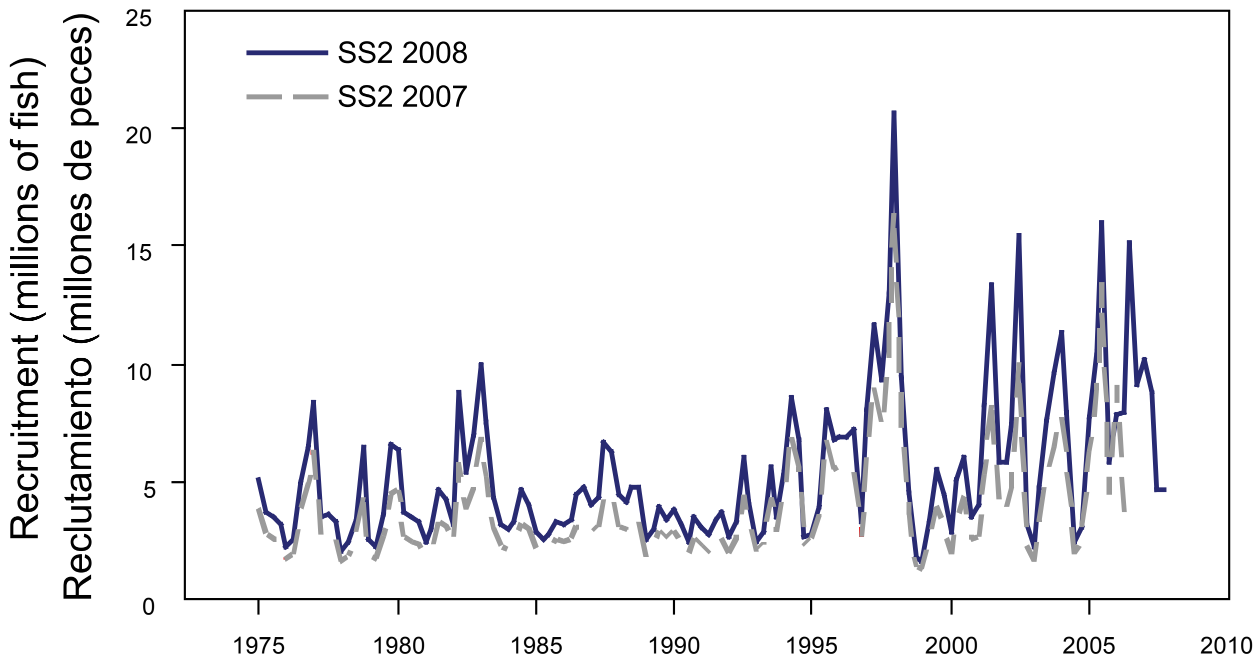

FIGURE 4.16a. Comparison of estimated recruitment of bigeye tuna in the EPO from the most recent assessment (2007) and the current assessment (SS2), both using SS2.
FIGURA 4.16. Comparación del reclutamiento estimado del atún patudo en el OPO de la evaluación más reciente (2007) y la evaluación actual (SS2), ambas con SS2.

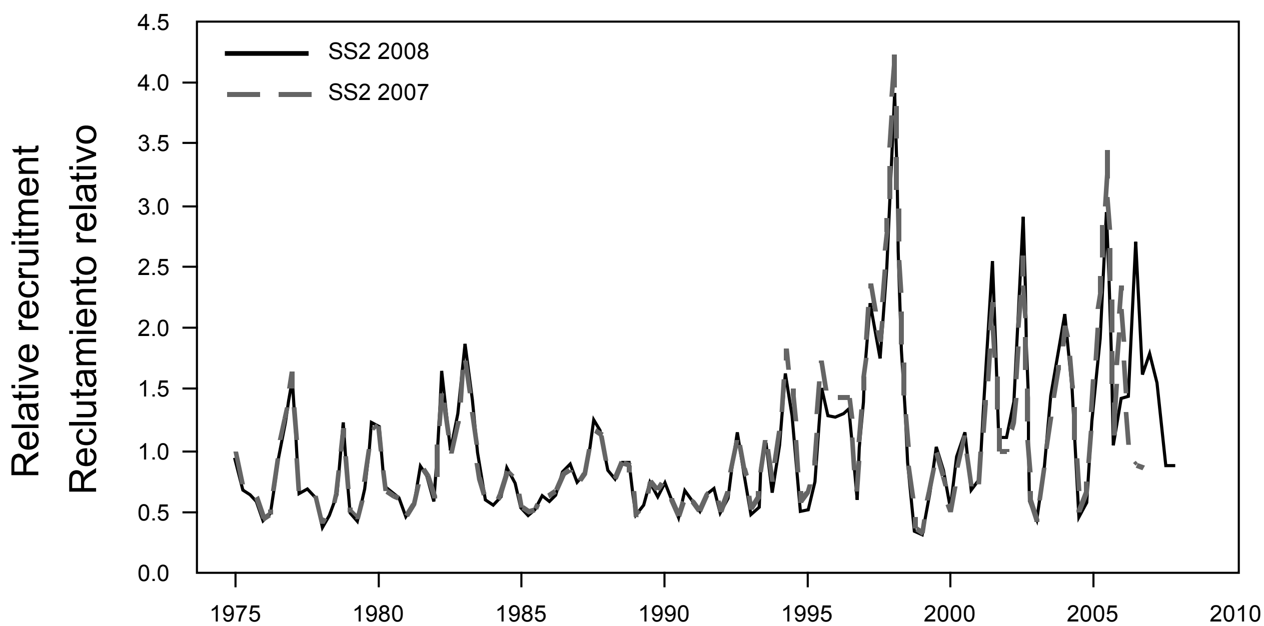

FIGURE 4.16b. Comparison of estimated relative recruitment of bigeye tuna in the EPO from the most recent assessment (2007) and the current assessment (SS2), both using SS2.
FIGURA 4.16b. Comparación del reclutamiento relativo estimado del atún patudo en el OPO de la evaluación más reciente (2007) y la evaluación actual (SS2), ambas con SS2.

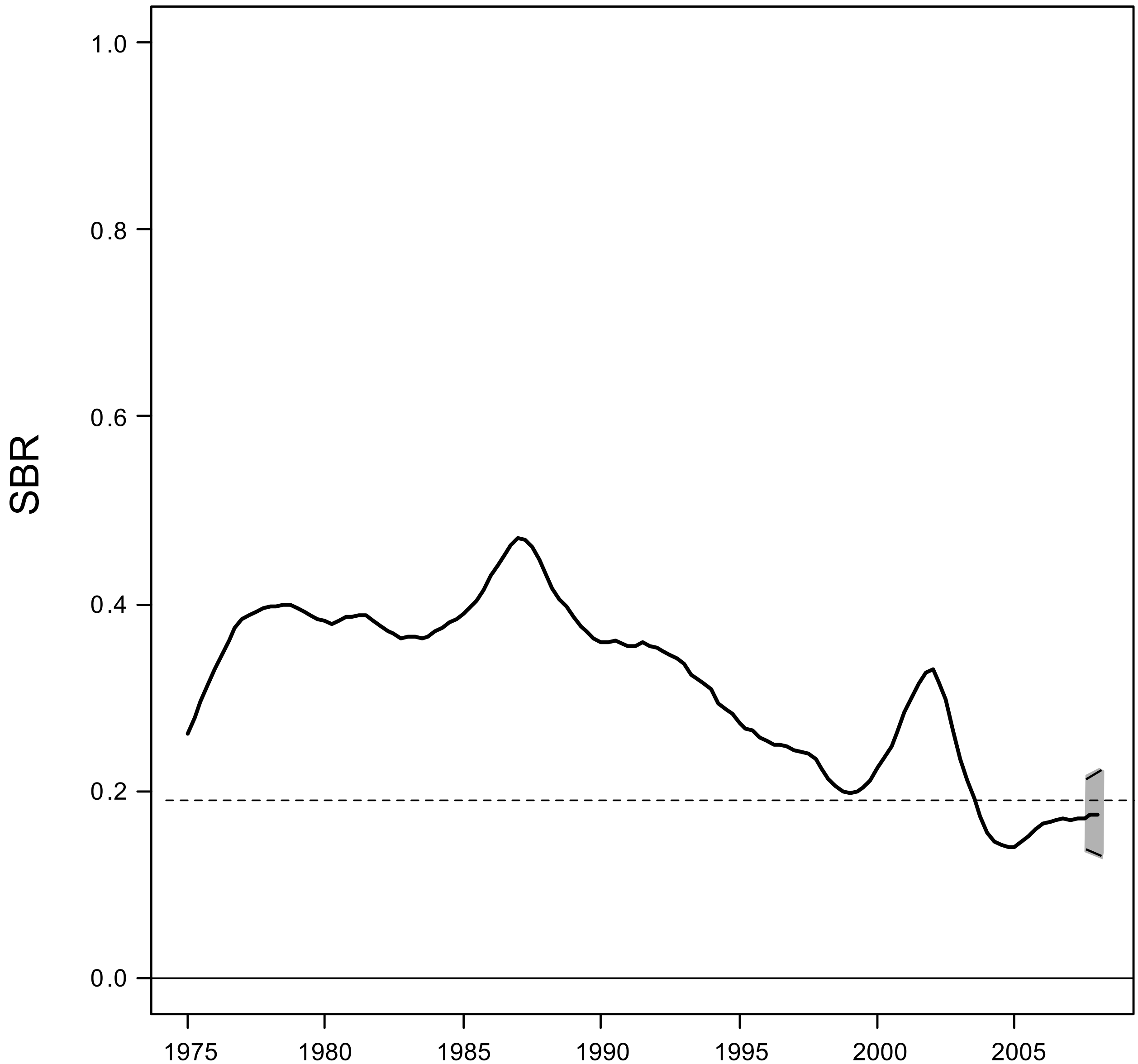

FIGURE 5.1. Estimated spawning biomass ratios (SBRs) for bigeye tuna in the EPO. The dashed horizontal line (at about 0.19) identifies the SBR at MSY. The curve illustrates the maximum likelihood estimates, and the dots at the end of the time series represents the confidence intervals (±2 standard deviations) 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 0,22) identifica el SBR en RMS. La curva ilustra las estimaciones de verosimilitud máxima, y los puntos al fin de la serie de tiempo representan los intervalos de confianza (±2 desviaciones estándar) alrededor de esas estimaciones.

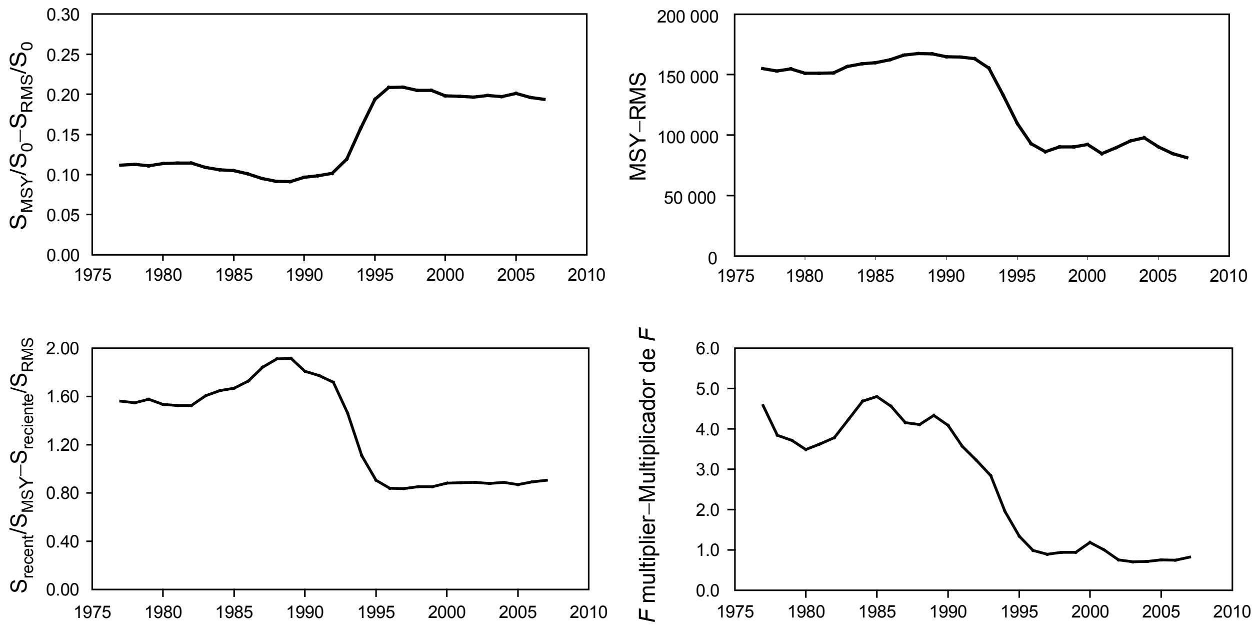

FIGURE 5.2. Estimates of MSY-related quantities calculated using the average age-specific fishing mortality for each year. (S_{recent} is the spawning biomass at the beginning of 2006.)
FIGURA 5.2. Estimaciones de cantidades relacionadas con el RMS calculadas usando la mortalidad por pesca por edad para cada año. ($S_{reciente}$ es la biomasa reproductora al principio de 2006.)

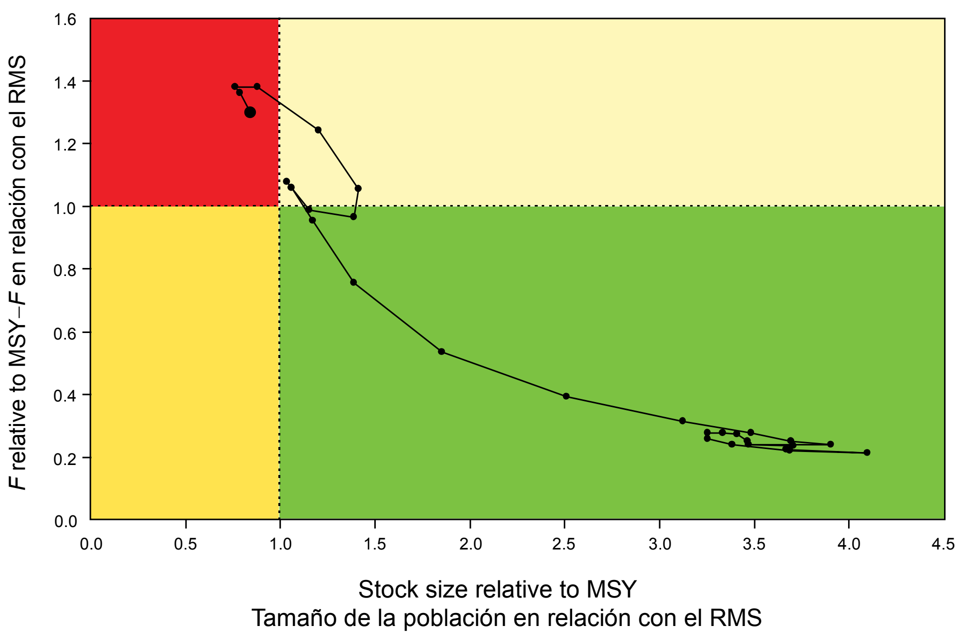

FIGURE 5.3. Phase plot of the time series of estimates of stock size and fishing mortality relative to their MSY reference points. Each dot is based on the average exploitation rate over three years; the large dot indicates the most recent estimate.
FIGURA 5.3. Gráfica de fase de la serie de tiempo de las estimaciones del tamaño de la población y la mortalidad por pesca en relación con sus puntos de referencia de RMS. Cada punto representa un promedio móvil de tres años. Cada punto se basa en la tasa de explotación media de tres años; el punto grande indica la estimación más reciente.

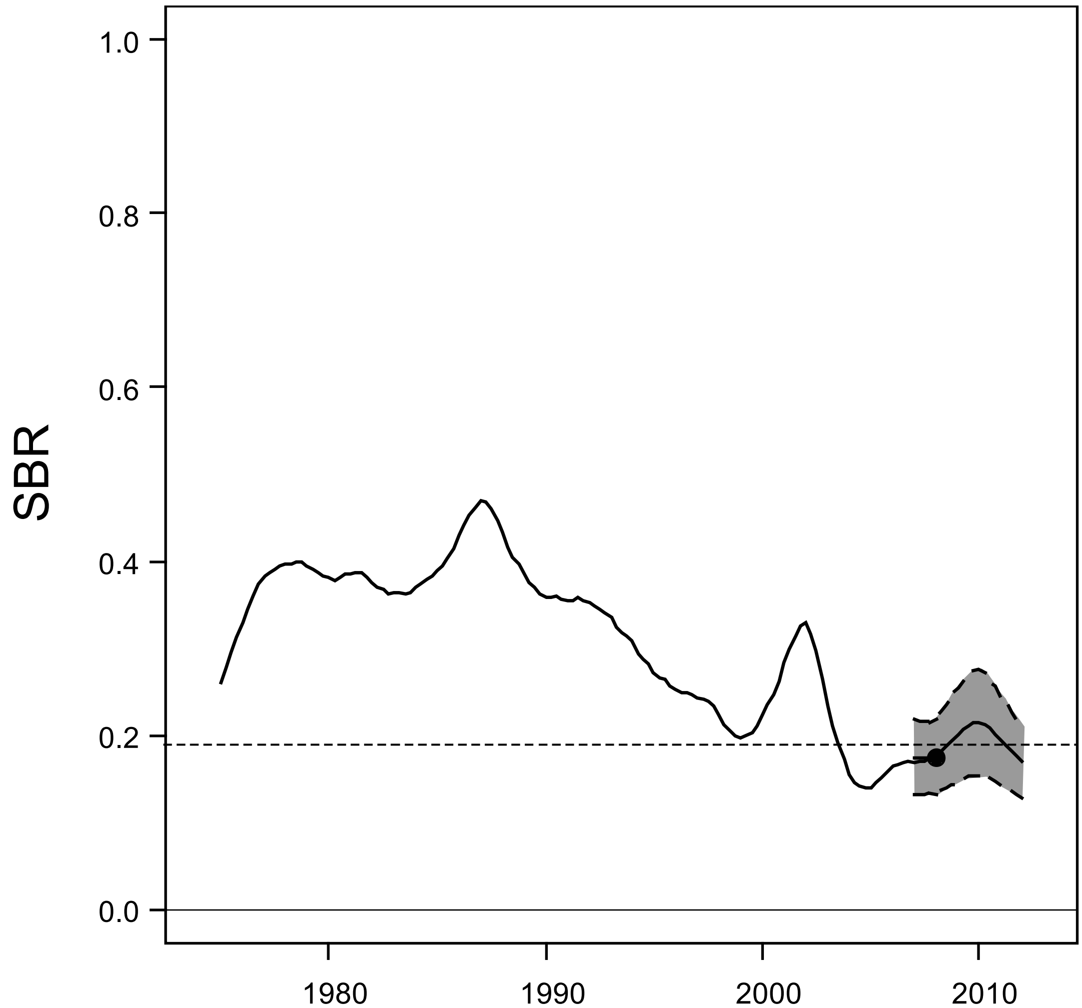

FIGURE 6.1a. Spawning biomass ratios (SBRs) of bigeye tuna in the EPO. The dashed horizontal line (at about 0.22) identifies the SBR at MSY. The solid curve illustrates the maximum likelihood estimates, and the estimates after 2006 (the large dot) indicate the SBR predicted to occur if fishing mortality rates continue at the average of that observed in 2004 and 2005. 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. La línea de trazos horizontal (en aproximadamente 0.22) identifica el SBR en RMS. La curva sólida ilustra las estimaciones de verosimilitud máxima, y las estimaciones a partir de 2006 (el punto grande) señalan el SBR predicho si las tasas de mortalidad por pesca continúa en el promedio observado en 2004 y 2005. Las líneas de trazos representan los intervalos de confianza de 95% alrededor de esas estimaciones.

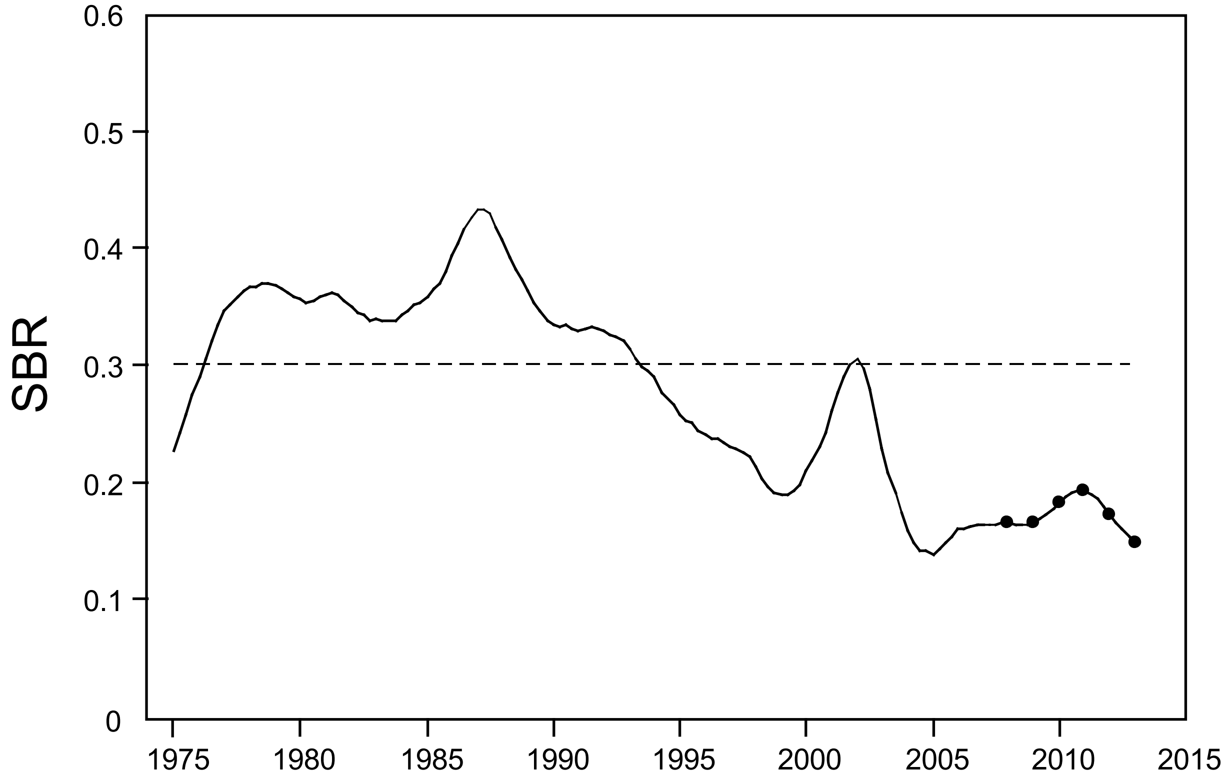

FIGURE 6.1b. Spawning biomass ratios (SBRs) of bigeye tuna in the EPO from the stock-recruitment sensitivity analysis. The dashed horizontal line (at about 0.31) identifies the SBR at MSY.
FIGURA 6.1b. Cocientes de biomasa reproductora (SBR) para el atún patudo en el OPO del análisis de sensibilidad de población-reclutamiento. La línea de trazos horizontal (en aproximadamente 0,31) identifica el SBR en RMS.

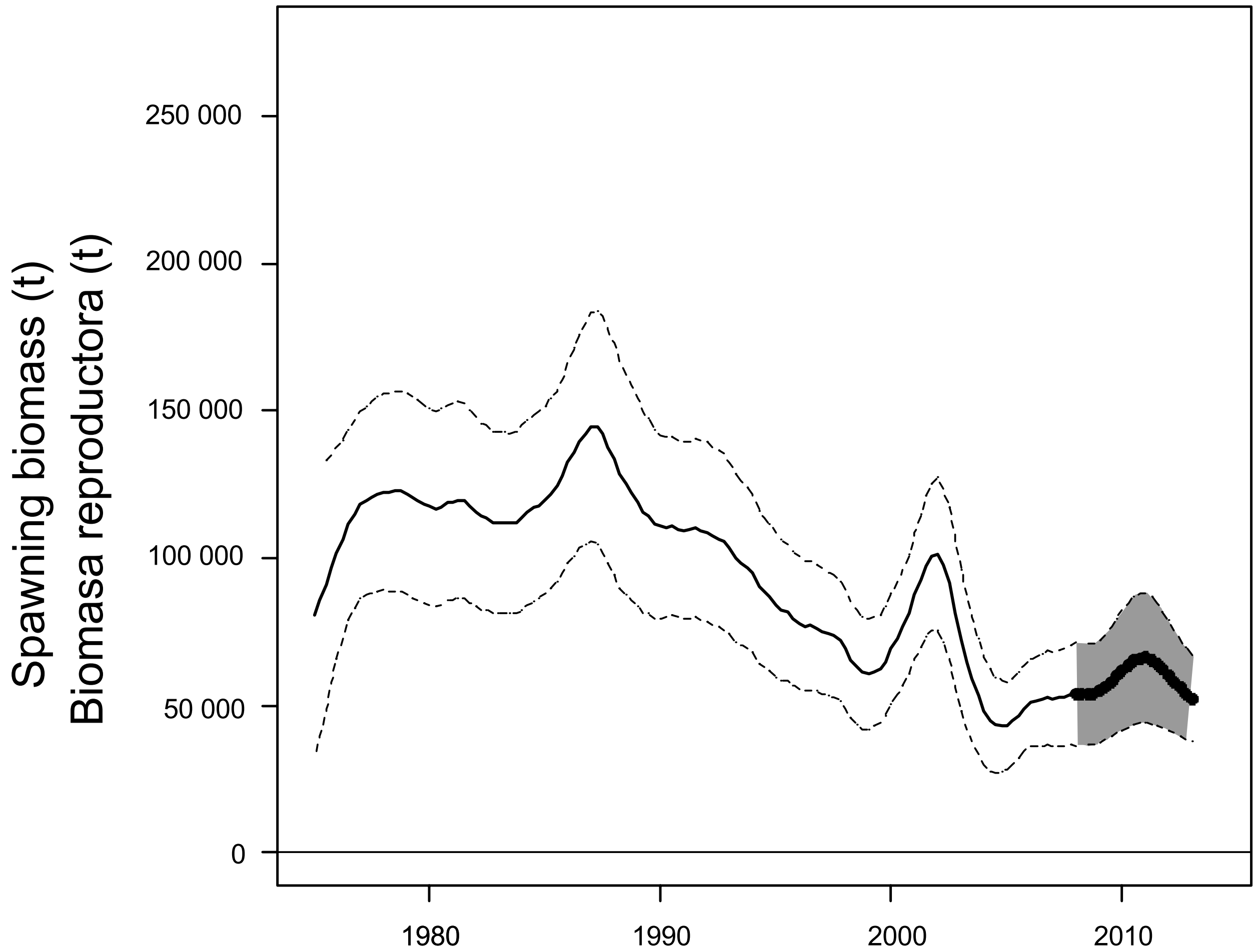

FIGURE 6.2. Spawning biomass of bigeye tuna, including projections for 2006-2010 with average fishing mortality rates for 2004-2005. These calculations include parameter estimation uncertainty and uncertainty about future recruitment. The areas between the dashed curves indicate the 95-percent confidence intervals, and the large dot indicates the estimate for the first quarter of 2007. t = metric tons.
FIGURE 6.2. Biomasa reproductora de atún patudo, incluyendo proyecciones para 2006-2010 con las tasas de mortalidad por pesca media de 2004-2005. Los cálculos incluyen incertidumbre en la estimación de los parámetros y sobre el reclutamiento futuro. Las zonas entre las curvas de trazos señalan los intervalos de confianza de 95%, y el punto grande indica la estimación correspondiente al primer trimestre de 2007. t = toneladas métricas.

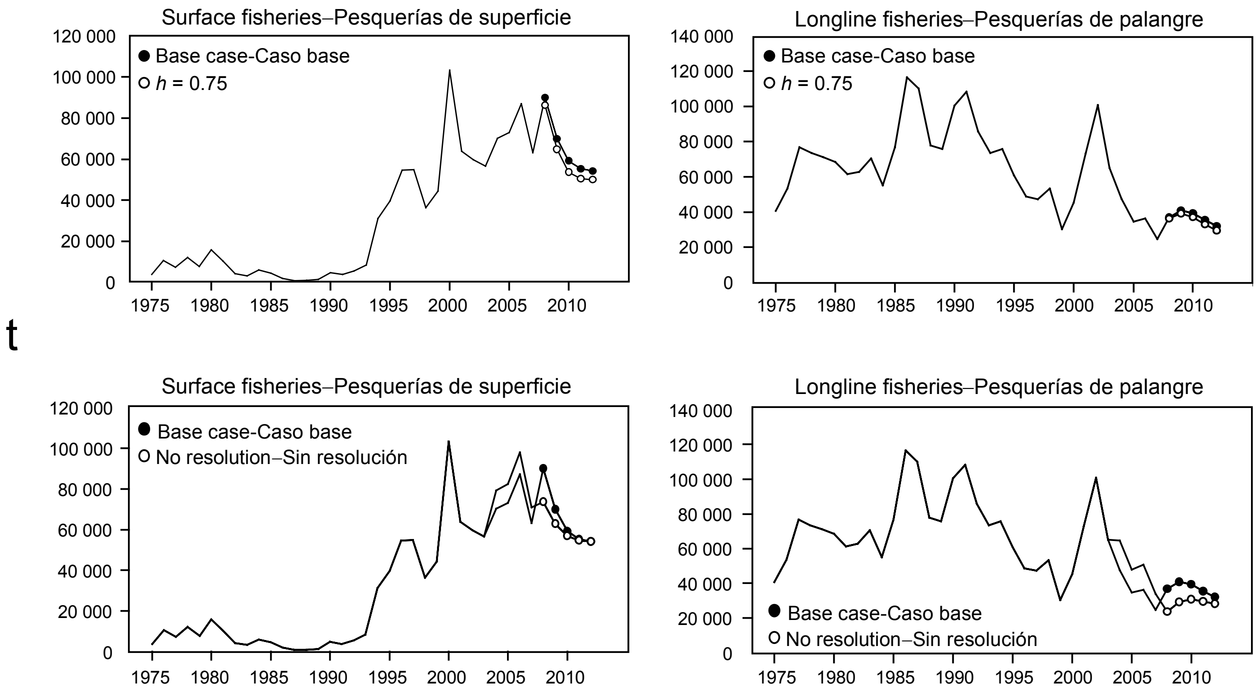

FIGURE 6.3. Predicted quarterly catches of bigeye tuna for the purse-seine and pole-and-line (left panels) and longline (right panels) fisheries, based on fishing mortality rates for 2004 and 2005. Predicted catches are compared between the base case and the analysis in which a stock-recruitment relationship was used (upper panels), and the analysis assuming that IATTC Resolution C-04-09 was not implemented (lower panels). t = metric tons.

FIGURA 6.3. Capturas trimestrales predichas de atún patudo en las pesquerías de cerco y caña (recuadros izquierdos) y palangreras (recuadros derechos), basadas en las tasas de mortalidad por pesca de 2004 y 2005. Se comparan las capturas predichas entre el caso base y el análisis en el que se usó una relación población-reclutamiento (recuadros superiores), y el análisis que supuso que la Resolución C-04-09 de la CIAT no fue aplicada (recuadros inferiores)**.** t = toneladas métricas.

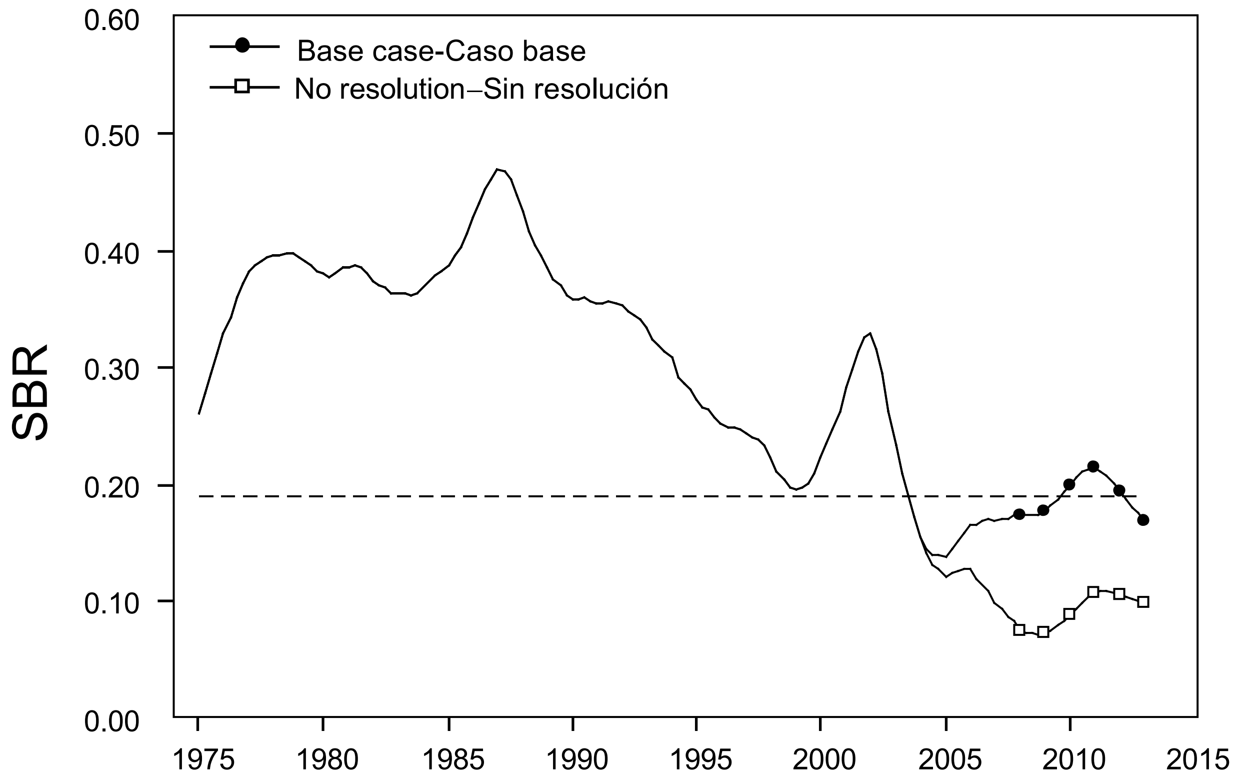

FIGURE 6.4. Predicted spawning biomass ratio (SBR) from the base case model and without restriction from IATTC Resolution C-04-09.

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 2.2.2.

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 2.2.2 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	1993-2007	11-12	retained catch + discards from inefficiencies in fishing process–captura retenida + descartes de ineficacias en el proceso de pesca
3	PS	OBJ	1993-2007	7, 9	
4	PS	OBJ	1993-2007	5-6, 13	
5	PS	OBJ	1993-2007	1-4, 8, 10	
6	PS LP	NOA DEL	1980-1989	1-13	retained catch only–captura retenida solamente
7	PS LP	NOA DEL	1990-2007	1-13	retained catch + discards from inefficiencies in fishing process–captura retenida + descartes de ineficacias en el proceso de pesca
8	LL		1975-2007	N of–de 15°N	retained catch only (in numbers)–captura retenida solamente (en número)
9	LL		1975-2007	S of–de 15°N	retained catch only (in numbers) –captura retenida solamente (en número)
10	PS	OBJ	1993-2007	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	1993-2007	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	1993-2007	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	1993-2007	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		1975-2007	N of–de 15°N	retained catch only (in weight) –captura retenida solamente (en peso)
15	LL		1975-2007	S of–de 15°N	retained catch only (in weight) –captura retenida solamente (en peso)

TABLE 3.1. Age-specific fecundity indices used to define the spawning biomass.
TABLA 3.1. Indices de fecundidad por edad 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 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), biomasa sumaria (peces de 3 trimestres de edad o más), biomasa reproductora (toneladas métricas), y cociente de biomasa reproductora (SBR) de atún patudo en el OPO.

	Total recruitment	**Summary biomass**	**Spawning biomass**	**SBR**
	Reclutamiento total	**Biomasa sumaria**	**Biomasa reproductora**	**SBR**
1975	15,338	427,658	80,521	0.26
1976	16,163	493,735	101,649	0.33
1977	18,740	517,906	118,106	0.38
1978	14,362	520,505	122,406	0.40
1979	15,025	516,832	121,751	0.40
1980	16,852	504,587	117,604	0.38
1981	14,318	492,050	118,996	0.39
1982	24,314	490,930	115,565	0.38
1983	25,029	497,205	112,265	0.36
1984	14,825	538,212	113,814	0.37
1985	11,486	607,408	119,768	0.39
1986	15,734	625,649	132,436	0.43
1987	21,241	566,617	144,627	0.47
1988	18,052	316,600	68,973	0.22
1989	12,819	515,483	119,009	0.39
1990	12,987	532,348	110,604	0.36
1991	12,899	508,176	109,307	0.35
1992	16,114	459,742	108,763	0.35
1993	14,524	425,610	103,356	0.34
1994	23,386	410,968	95,086	0.31
1995	21,536	383,839	84,041	0.27
1996	24,167	362,174	78,039	0.25
1997	42,093	336,192	75,197	0.24
1998	36,458	316,600	68,973	0.22
1999	14,792	392,346	60,771	0.20
2000	17,451	491,649	69,165	0.22
2001	31,451	446,712	87,335	0.28
2002	31,842	369,524	101,459	0.33
2003	24,346	287,106	71,941	0.23
2004	24,944	274,856	48,030	0.16
2005	39,998	281,335	42,747	0.14
2006	40,093	274,956	50,988	0.17
2007	28,242	269,266	52,205	0.17
2008		330,719	53,831	0.17

TABLE 4.2. Estimates of the average sizes of bigeye tuna. The ages are quarters after hatching.
TABLA 4.2. Estimaciones del tamaño medio del atún patudo. 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	26.61	0.51	21	158.52	89.67
2	38.25	1.46	22	161.52	94.69
3	49.12	3.01	23	164.33	99.54
4	59.29	5.18	24	166.96	104.22
5	68.79	7.97	25	169.41	108.71
6	77.67	11.33	26	171.70	113.00
7	85.97	15.21	27	173.84	117.09
8	93.72	19.54	28	175.85	120.96
9	100.97	24.25	29	177.72	124.61
10	107.74	29.27	30	179.47	128.03
11	114.07	34.53	31	181.10	131.22
12	119.99	39.99	32	182.63	134.17
13	125.51	45.57	33	184.06	136.89
14	130.68	51.22	34	185.39	139.40
15	135.51	56.90	35	186.64	141.69
16	140.02	62.57	36	187.80	143.78
17	144.24	68.19	37	188.89	145.68
18	148.18	73.74	38	189.91	147.41
19	151.86	79.18	39	190.86	148.97
20	155.30	84.49	40	191.75	150.40

TABLE 4.3. Likelihood components obtained for the base case and sensitivity analyses. OBJ: fishery on floating objects.
TABLA 4.3. Componentes de verosimilitud obtenidos para la análisis del caso base y de sensibilidad. OBJ: pesquería sobre objetos flotantes.

Data		**Base case**	**h = 0.75**	**CPUE Fishery 9**	**Time blocks (OBJ)**
Datos		**Caso base**	**h = 0.75**	**CPUE Pesquería 9**	**Bloques de tiempo (OBJ)**
CPUE					
Fishery Pesquería	2	-17.83	-17.32	103.47	-18.1856
	3	13.78	13.77	112.26	13.614
	5	12.93	13.42	105.79	14.2527
	8	-44.92	-44.80	237.11	-45.4316
	9	-165.95	-166.86	-151.11	-166.918
Size composition Composición por talla					
Fishery Pesquería	1	171.03	170.85	170.87	171.044
	2	260.51	261.00	250.31	259.993
	3	298.24	298.19	289.48	297.602
	4	67.87	67.74	66.92	67.2198
	5	169.72	170.17	164.04	161.977
	6	144.66	144.91	144.17	144.66
	7	133.18	131.97	131.24	133.677
	8	126.10	125.89	126.21	125.937
	9	313.39	317.37	316.47	312.761
Age at length Edad a talla		-	-	-	-
Recruitment Reclutamiento		-21.93	-17.53	-19.52	-22.0554
Total		**1460.77**	**1468.78**	**2047.71**	**1450.1469**

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 2005-2007. B_{recent} and B_{MSY} are defined as the biomass of fish 3+ quarters old at the beginning of 2006 and at MSY, respectively, and S_{recent} and S_{MSY} are defined as indices of spawning biomass (therefore, they are not in metric tons). C_{recent} is the estimated total catch in 2006. OBJ: fishery on floating objects.

TABLA 5.1. Estimaciones del RMS y sus cantidades asociadas de 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 2005-2007. Se definen B_{recent} y B_{RMS} como la biomasa de peces de 3+ trimestres de edad al principio de 2006 y en RMS, respectivamente, y S_{recent} y S_{RMS} como los índices de la biomasa reproductora (por lo tanto, no se expresan en toneladas métricas). C_{recent} es la captura total estimada en 2006. OBJ: pesquería sobre objetos flotantes.

	Base case	**h = 0.75**	**CPUE Fishery 9**	**Time blocks (OBJ)**
	Caso base	**h = 0.75**	**CPUE Pesquería 9**	**Bloques de tiempo (OBJ)**
MSY—RMS	81,350	78,150	85,005	79,654
B_{MSY}—B_{RMS}	287,912	500,357	303,515	287,613
S_{MSY}—S_{RMS}	59,626	118,154	63,318	59,963
B_{MSY}/B_0—B_{RMS}/B_0	0.26	0.34	0.25	0.26
S_{MSY}/S_0—S_{RMS}/B_0	0.19	0.30	0.19	0.20
C_{recent}/MSY—C_{recent}/RMS	1.08	1.12	1.03	1.18
B_{recent}/B_{MSY}—B_{recent}/B_{RMS}	1.15	0.74	1.23	1.12
S_{recent}/S_{MSY}—S_{recent}/S_{RMS}	0.90	0.56	0.90	0.89
F multiplier—Multiplicador de *F*	0.82	0.57	0.85	0.81

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 2005-2007. A sensitivity of the management quantities estimates to using the average fishing mortality rates for the period 2005-2006, 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**	**2005-2006**
	Caso base	**Cerco solamente**	**Palangre solamente**	**2005-2006**
MSY—RMS	81,350	57,503	168,419	80,934
B_{MSY}—B_{RMS}	287,912	223,293	300,043	287,750
S_{MSY}—S_{RMS}	59,626	50,080	26,604	59,685
B_{MSY}/B_0—B_{RMS}/B_0	0.26	0.20	0.27	0.26
S_{MSY}/S_0—S_{RMS}/B_0	0.19	0.16	0.09	0.19
C_{recent}/MSY—C_{recent}/RMS	1.08	1.53	0.52	1.08
B_{recent}/B_{MSY}—B_{recent}/B_{RMS}	1.15	1.48	1.10	1.15
S_{recent}/S_{MSY}—S_{recent}/S_{RMS}	0.90	1.07	2.02	0.90
F multiplier—Multiplicador de F	0.82	1.24	5.56	0.74

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

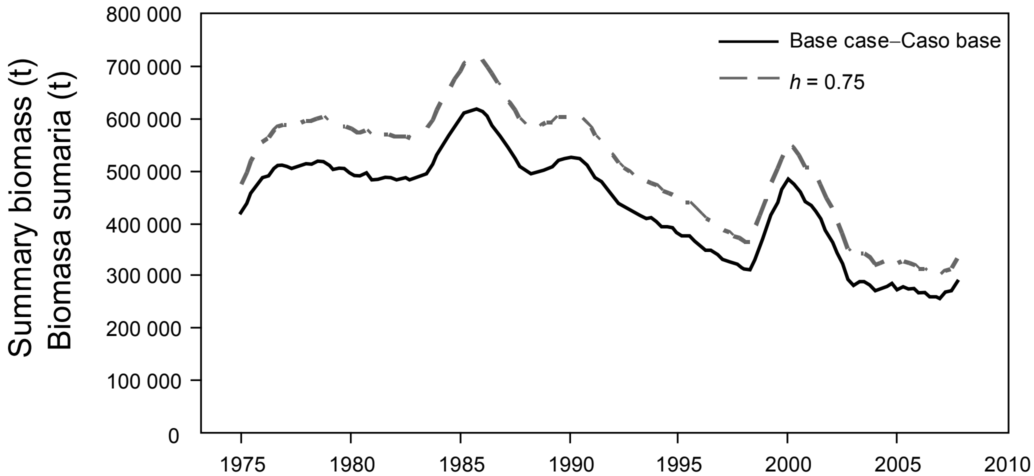

FIGURE A.1. Comparison of estimates of biomass of bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). t = metric tons.
FIGURA A.1. Comparación de las estimaciones de la biomasa de atún patudo del análisis sin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

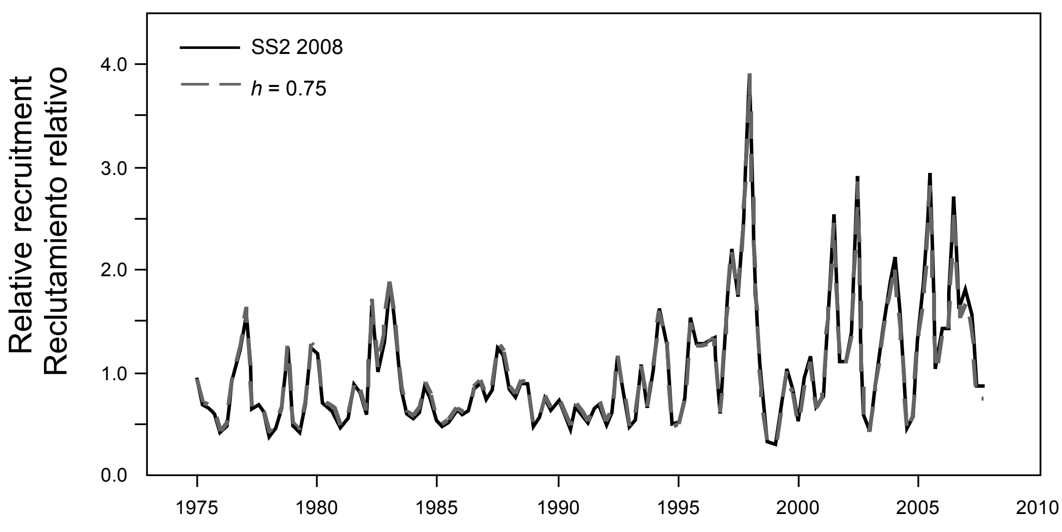

FIGURE A.2. Comparison of estimates of relative recruitment for bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).
FIGURA A.2. Comparación de las estimaciones de reclutamiento relativo de atún patudo del análisis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

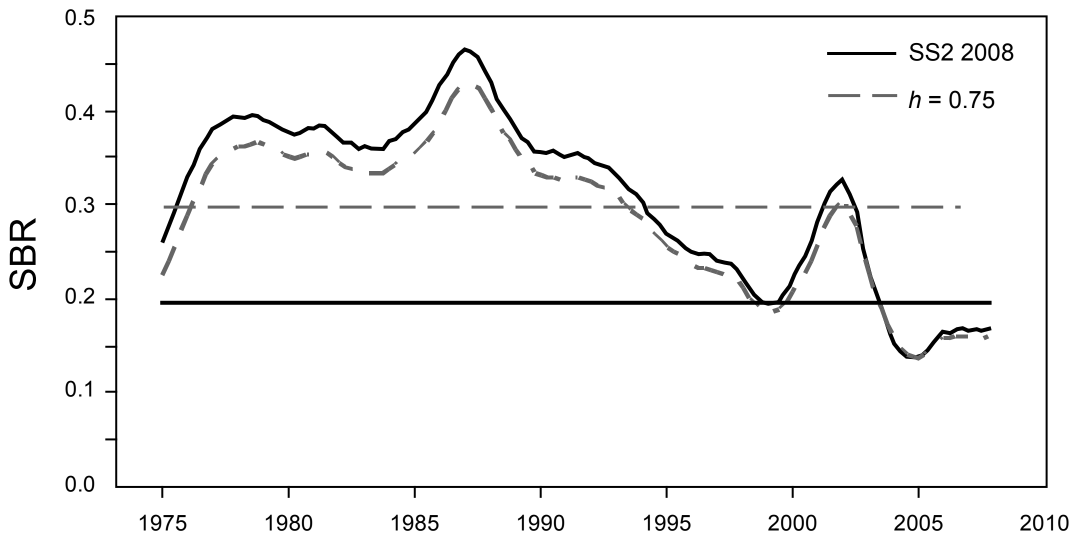

FIGURE A.3. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). The horizontal lines represent the SBRs associated with MSY under the two scenarios.

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.

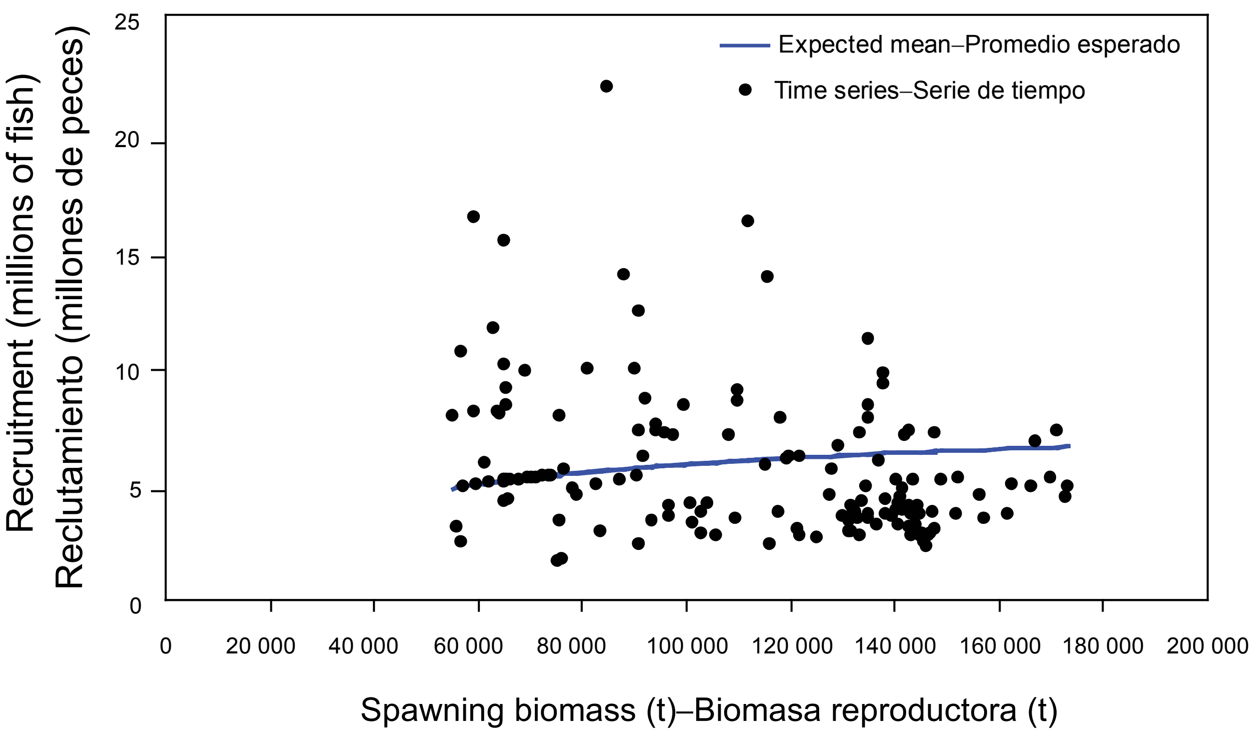

FIGURE A.4. Recruitment of bigeye tuna plotted against spawning biomass when the analysis has a stock-recruitment relationship (steepness = 0.75).

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 USING CPUE DATA FOR SOUTHERN LONGLINE FISHERY ONLY
ANEXO B: ANÁLISIS DE SENSIBILIDAD USANDO DATOS DE CPUE DE LA PESQUERÍA DE PALANGRE DEL SUR SOLAMENTE

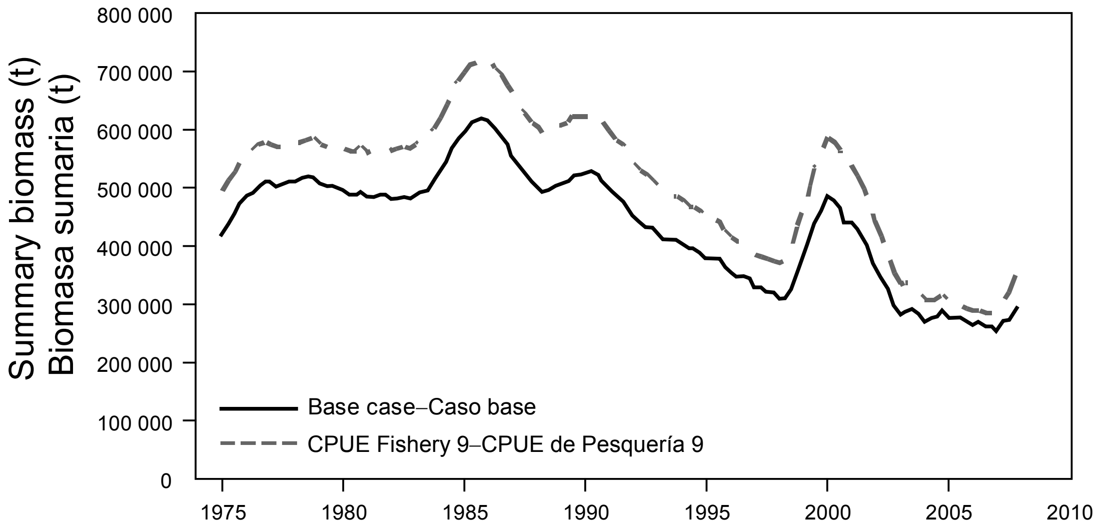

FIGURE B.1. Comparison of estimates of biomass of bigeye tuna from the base case analysis with a model in which only the CPUE data for the southern longline fishery (Fishery 9) were used. t = metric tons.
FIGURA B.1. Comparación de las estimaciones de biomasa de atún patudo del análisis del caso base con un modelo en el cual se usaron los datos de CPUE de la pesquería de palangre del sur (Pesquería 9) solamente. t = tonelades métricas.

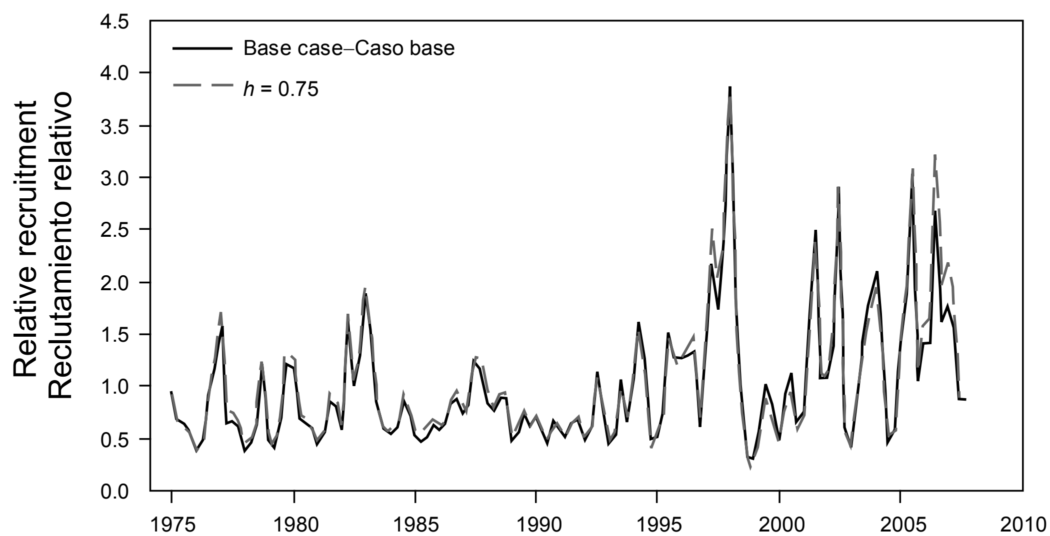

FIGURE B.2. Comparison of estimates of recruitment for bigeye tuna from the base case analysis with a model in which only the CPUE data for the southern longline fishery (Fishery 9) were used.
FIGURA B.2. Comparación de las estimaciones de reclutamiento de atún patudo del análisis del caso base con un modelo en el cual se usaron los datos de CPUE de la pesquería de palangre del sur (Pesquería 9) solamente.

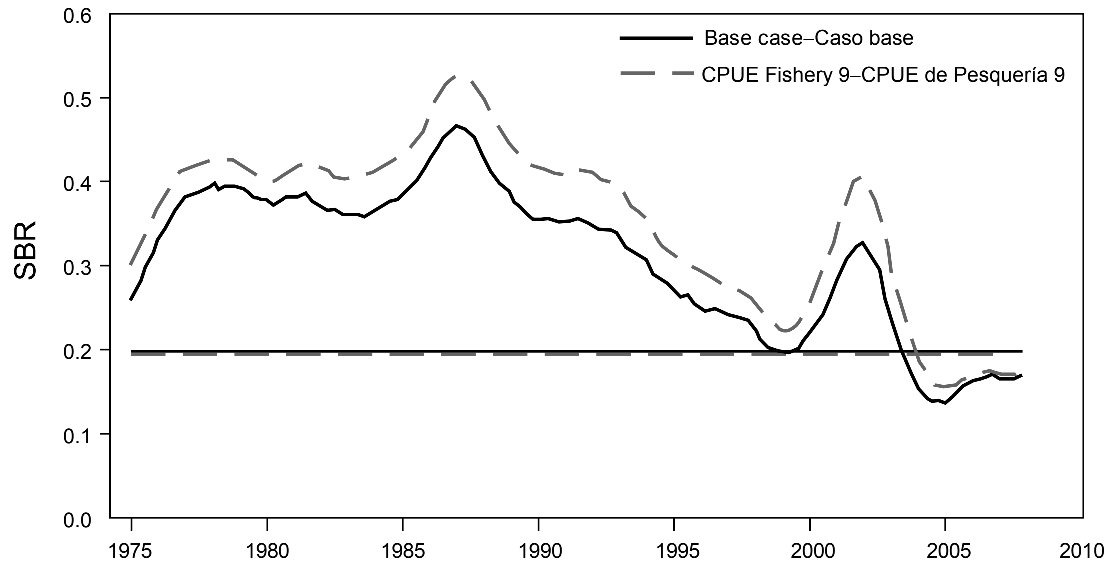

FIGURE B.3. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the base case analysis with a model in which only the CPUE data for the southern longline fishery (Fishery 9) were used. The horizontal lines represent the SBRs associated with MSY under the two scenarios.
FIGURA B.3. 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.

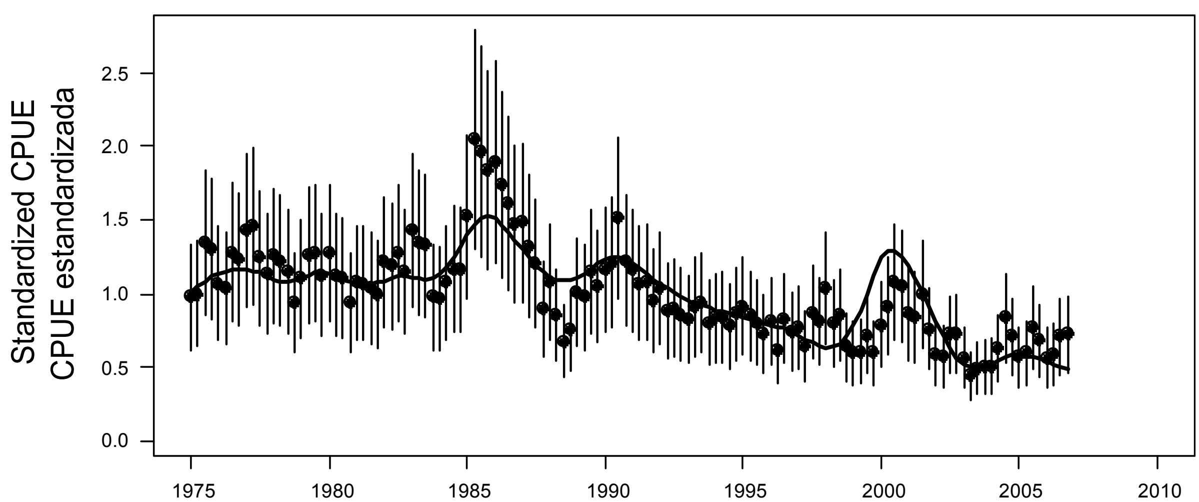

FIGURE B.4. Model fit to the CPUE data for the southern longline fishery (Fishery 9). The vertical lines are the approximate 95% confidence intervals.
FIGURA B.4. Ajuste del modelo a los datos de CPUE de la pesquería de palangre del sur (Pesquería 9). Las líneas verticales representan los intervalos de confianza aproximados de 95%

APPENDIX C: SENSITIVITY ANALYSIS TO ASSUMING TWO TIME BLOCKS FOR THE SELECTIVITIES OF THE FLOATING-OBJECT FISHERIES
ANEXO C: ANÁLISIS DE SENSIBILIDAD AL SUPUESTO DE DOS BLOQUES DE TIEMPO PARA LA SELECTIVIDAD DE LAS PESQUERÍAS SOBRE OBJETOS FLOTANTES

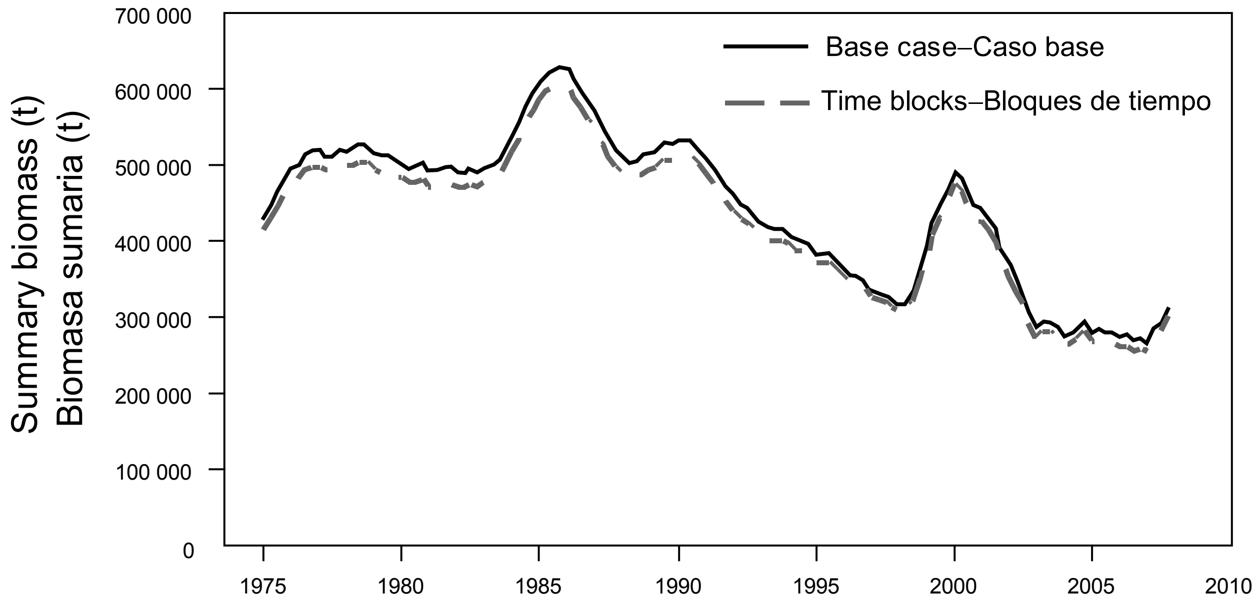

FIGURE C.1. Comparison of estimates of biomass of bigeye tuna from the base case analysis with a model in which two time blocks for the floating-object fisheries were used. t = metric tons.
FIGURA C.1. Comparación de estimaciones de la biomasa de patudo del análisis de caso base con un modelo en el cual se usaron dos bloques de tiempo para las pesquerías sobre objetos flotantes. t = toneladas métricas.

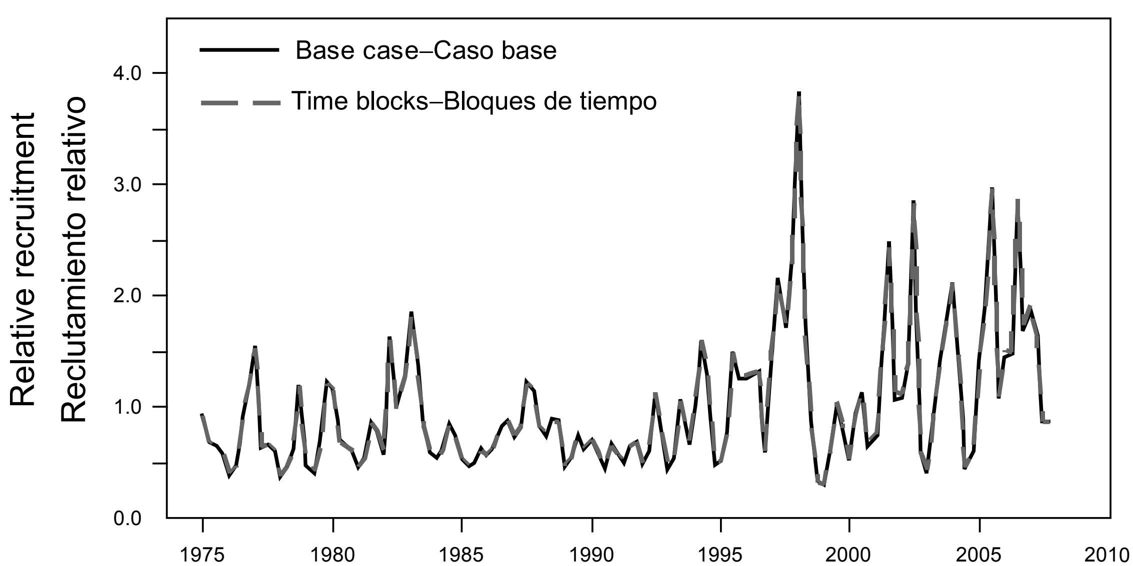

FIGURE C.2. Comparison of estimates of recruitment for bigeye tuna from the base case analysis with a model in which two time blocks for the floating-object fisheries were used.
FIGURA C.2. Comparación de estimaciones del reclutamiento de patudo del análisis de caso base con un modelo en el cual se usaron dos bloques de tiempo para las pesquerías sobre objetos flotantes.

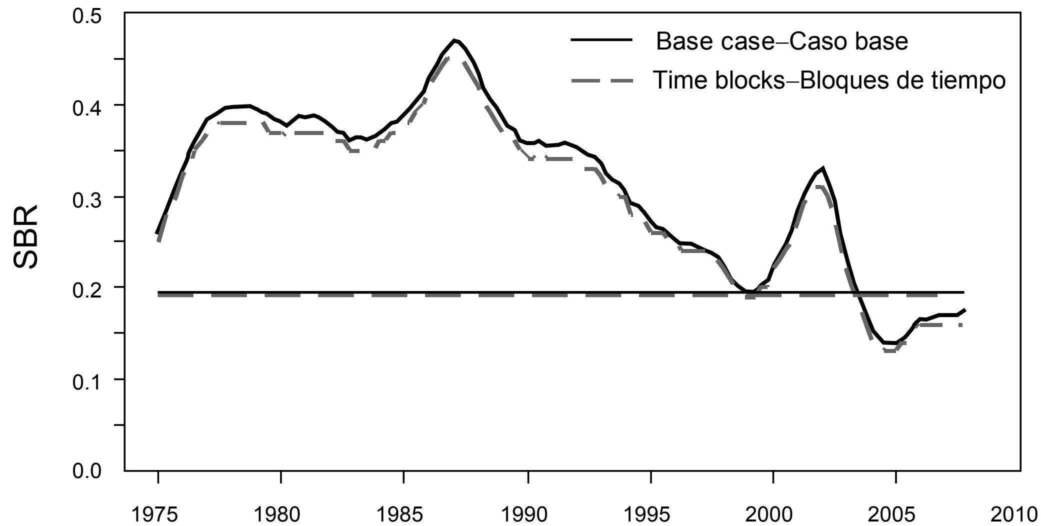

FIGURE C.3. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the base case analysis with a model in which two time blocks for the floating-object fisheries were used. The horizontal lines represent the SBRs associated with MSY under the two scenarios.

FIGURA C.3. Comparación de estimaciones del cociente de biomasa reproductora (SBR) de patudo del análisis de caso base con un modelo en el cual se usaron dos bloques de tiempo para las pesquerías sobre objetos flotantes. Las líneas horizontales representan los SBR asociados con el RMS para los dos escenarios.

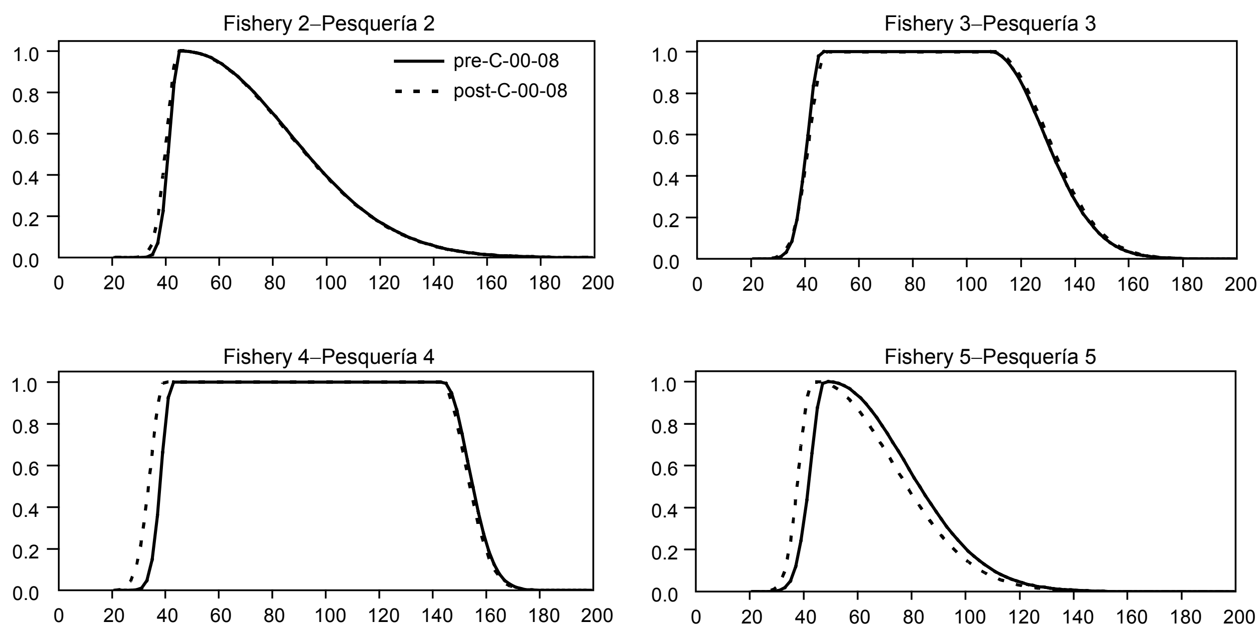

FIGURE C.4. Size selectivity curves for the floating object fisheries (Fisheries 2-5) for two periods: 1) pre-Resolution C-00-08 (1975-2000), and post-Resolution C-00-08 (2001-present).

FIGURA C.4. Curvas de selectividad de tamaño de las pesquerías sobre objetos flotantes (Pesquerías 2-5) durante dos períodos: 1) antes de la Resolución C-00-08 (1975-2000), y después de la misma (2001-presente).

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 tuna in the EPO for the base case assessment.
TABLA D.1. Tasas medias de mortalidad anual por pesca de atún patudo en el OPO para la evaluación del caso base.

Year	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	0.08	0.12	0.12	0.12	0.11	0.11	0.11	0.11
1976	0.01	0.05	0.11	0.14	0.14	0.14	0.13	0.13	0.13	0.13
1977	0.01	0.05	0.13	0.18	0.19	0.18	0.18	0.18	0.18	0.18
1978	0.01	0.07	0.15	0.18	0.18	0.17	0.17	0.17	0.17	0.17
1979	0.01	0.05	0.13	0.17	0.17	0.17	0.17	0.17	0.17	0.17
1980	0.01	0.08	0.16	0.18	0.18	0.17	0.17	0.17	0.17	0.17
1981	0.01	0.06	0.13	0.16	0.16	0.16	0.15	0.15	0.15	0.15
1982	0.01	0.04	0.11	0.16	0.16	0.16	0.15	0.15	0.15	0.15
1983	0.01	0.04	0.12	0.17	0.18	0.17	0.17	0.17	0.17	0.17
1984	0.01	0.04	0.10	0.13	0.13	0.13	0.13	0.13	0.13	0.13
1985	0.01	0.03	0.11	0.15	0.16	0.16	0.16	0.16	0.16	0.16
1986	0.00	0.04	0.14	0.21	0.23	0.22	0.22	0.22	0.22	0.22
1987	0.00	0.03	0.15	0.22	0.24	0.24	0.24	0.24	0.24	0.24
1988	0.00	0.03	0.12	0.18	0.19	0.19	0.19	0.19	0.19	0.19
1989	0.00	0.03	0.12	0.18	0.19	0.18	0.18	0.18	0.18	0.18
1990	0.01	0.04	0.15	0.23	0.24	0.24	0.24	0.24	0.24	0.24
1991	0.01	0.05	0.17	0.26	0.27	0.27	0.27	0.27	0.27	0.27
1992	0.01	0.05	0.16	0.23	0.24	0.24	0.23	0.23	0.23	0.23
1993	0.05	0.06	0.16	0.22	0.23	0.22	0.22	0.22	0.22	0.21
1994	0.17	0.18	0.27	0.29	0.26	0.25	0.24	0.24	0.24	0.24
1995	0.34	0.26	0.25	0.25	0.24	0.22	0.21	0.21	0.21	0.21
1996	0.47	0.39	0.29	0.25	0.21	0.19	0.18	0.18	0.18	0.18
1997	0.38	0.36	0.35	0.29	0.23	0.20	0.19	0.19	0.19	0.18
1998	0.21	0.21	0.23	0.26	0.26	0.25	0.24	0.24	0.24	0.24
1999	0.17	0.17	0.16	0.16	0.14	0.12	0.12	0.11	0.11	0.11
2000	0.41	0.45	0.32	0.23	0.17	0.15	0.14	0.14	0.13	0.13
2001	0.46	0.50	0.34	0.28	0.24	0.22	0.22	0.21	0.21	0.21
2002	0.42	0.51	0.45	0.44	0.41	0.38	0.38	0.37	0.37	0.37
2003	0.38	0.39	0.37	0.39	0.36	0.35	0.34	0.34	0.34	0.34
2004	0.41	0.45	0.35	0.33	0.30	0.28	0.27	0.26	0.26	0.26
2005	0.51	0.52	0.34	0.26	0.20	0.18	0.17	0.16	0.16	0.16
2006	0.50	0.59	0.41	0.32	0.24	0.21	0.20	0.19	0.19	0.19
2007	0.33	0.39	0.25	0.20	0.16	0.14	0.13	0.13	0.13	0.13

REFERENCES

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Hoyle, S.D. and Maunder M.N. (2006) Standardisation of yellowfin and bigeye CPUE data from Japanese longliners, 1975-2004. IATTC Working Group on Stock Assessments, 6th Meeting, SAR-7-07. http://www.iattc.org/PDFFiles2/SAR-7-07-LL-CPUE-standardization.pdf

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Methot, R. D. 2005. Technical description of the Stock Synthesis II assessment program. NOAA Fisheries.

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

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

Reed, W.J. 1980. Age-specific harvesting in a nonlinear population model. Biometrics 36: 579-593.

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

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

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

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

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

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

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

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

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

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

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