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STATUS OF BIGEYE TUNA IN THE EASTERN PACIFIC OCEAN IN 2003 AND OUTLOOK FOR 2004

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CONTENTS

1. EXECUTIVE SUMMARY

This report presents the most current stock assessment of bigeye tuna (*Thunnus obesus*) in the eastern Pacific Ocean (EPO). A-SCALA, an age-structured, catch-at-length analysis, was used to conduct this assessment. Previous assessments of bigeye in the EPO were also conducted using the A-SCALA method. The current version of A-SCALA is similar to that used for the most recent assessment.

A mid-year technical meeting on reference points was held in La Jolla, California, USA, on October 27-29, 2003. The outcome from this meeting was (1) a set of general recommendations on the use of reference points and research, (2) specific recommendations for the IATTC stock assessments. Several of the recommendations have been included in this assessment.

The stock assessment requires a substantial amount of information. Data on retained catch, discards, fishing effort, and the size compositions of the catches from several different fisheries have been analyzed. Several assumptions regarding processes such as growth, recruitment, movement, natural mortality, fishing mortality, and stock structure have also been made. The assessment for 2003 differs in several from the previous assessment carried out for 2002:

1. Revised inputs for maturity, fecundity, age-specific proportions of females in the population, and age-specific natural mortality vectors, based on updated data.
2. Catch and length-frequency data for the surface fisheries have been updated to include new data for 2003.

3. Effort data for the surface fisheries have been updated to include new data for 2003 and revised data for 1975 to 2002.
4. Catch data for the Japanese longline fisheries have been updated for 1999 to 2001 and new data added for 2002.
5. Catch data for the longline fisheries of Chinese Taipei have been updated for 1975 to 1999 and new data added for 2000 and 2001.
6. Catch data for the longline fisheries of the Peoples Republic of China have been included for 2001 and 2002.
7. Catch data for the longline fisheries of South Korea have been updated for 1987 to 1997 and new data added for 1998 to 2002.
8. Longline effort data based on neural-network standardization of catch per unit of effort have been updated to include data for 2001.
9. Longline catch-at-length data for 1975-2001 were updated and new data added for 2002 .
10. Future projections are based on a new method that allows the inclusion of parameter uncertainty in the calculation of confidence intervals for future quantities.

The following sensitivity analyses were carried out to assess sensitivity to model assumptions and data and are described in this report:

1. Sensitivity to the steepness of the stock-recruitment relationship. The base case included an assumption that recruitment was independent of stock size, and a Beverton-Holt (1957) stock-recruitment relationship with steepness of 0.75 was used for the sensitivity analysis.
2. Sensitivity to estimates of purse-seine catches. In the base case, estimates of purse-seine catches were based on species composition estimates for 2000–2003 and scaled estimates back to 1993. For sensitivity we compared these to cannery and unloading estimates of bigeye catches in the purse-seine fisheries, as used by Maunder and Harley (2002).
3. Sensitivity to assumed rates of natural mortality for bigeye younger than ten quarters old. Quarterly rates of natural mortality were increased for individuals less than ten quarters old.

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 for bigeye less than about 20 quarters old has increased substantially since 1993, and that on fish more than about 24 quarters old has increased slightly. The increase in average fishing mortality on the younger fish was caused by the expansion of the fisheries that catch bigeye in association with floating objects. The base case assessment suggests that 1) the use of FADs has substantially increased the catchability of bigeye by fisheries that catch tunas associated with floating objects, and 2) that bigeye are substantially more catchable when they are associated with floating objects in offshore areas.

Recruitment of bigeye tuna to the fisheries in the EPO is variable, and the mechanisms that explain variation in recruitment have not been identified. Nevertheless, the abundance of bigeye tuna being recruited to the fisheries in the EPO appears to be related to zonal-velocity anomalies at 240 m during the time that these fish are assumed to have hatched. 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 two important features in the estimated time series of bigeye recruitment. First, greater-than-average recruitments occurred in 1977, 1979, 1982-1983, 1992, 1994, 1995-1997, and during the second quarters of 2001 and 2002. The lower confidence bounds of these estimates were greater than the estimate of virgin recruitment only for 1994, 1997, and the recruitment in 2001 and 2002. Second, aside from these two recruitment pulses in 2001 and 2002, recruitment has been much less than average from the second quarter of 1998 to the end of 2003, and the upper confidence bounds of many of these recruitment estimates are below the virgin recruitment. Evidence for these low recruitments comes from the decreased CPUEs achieved by some of the floating-object fisheries, discard records collected by observers, length-frequency data, and poor environmental conditions for recruitment. The extended sequence of low recruitments is important because, in concert with high levels of fishing mortality, they are likely to produce a sequence of years in which the spawning biomass ratio (the ratio of spawning biomass to that for the unfished stock; SBR) will be considerably below the level that would support the average maximum sustainable yield (AMSY).

The biomass of 1+-year-old bigeye increased during 1980-1984, and reached its peak level of about 586,000 t in 1986. After reaching this peak, the biomass of 1+-year-olds decreased to an historic low of about 156,000 t at the start of 2004. Spawning biomass has generally followed a trend similar to that for the biomass of 1+-year-olds, but lagged by 1-2 years. There is uncertainty in the estimated biomasses of both 1+-year-old bigeye and spawners. Nevertheless, it is apparent that fishing has reduced the total biomass of bigeye present in the EPO. Both are predicted to be at their lowest levels by the end of 2004. There has been an accelerated decline in biomass since the small peak in 2000. Analysis of the impacts attributed to each fishery indicates that the initial decline can be attributed to longline fishing by the most recent declines are mainly attributed to purse-seine fishing.

The estimates of recruitment and biomass were not sensitive to the range of alternative parameterizations of the assessment model considered or to the alternative data source included in the assessment. However, in the current assessment, a narrower range of alternative analyses were considered.

At the beginning of January 2004, the spawning biomass of bigeye tuna in the EPO was declining from a recent high level. At that time the SBR was about 0.14, about 32% less than the level that would be expected to produce the AMSY, with lower and upper confidence limits (± 2 standard deviations) of about 0.07 and 0.21. The estimate of the upper confidence bound is only slightly greater than the estimate of SBR_{AMSY} (0.20), suggesting that, at the start of January 2004, the spawning biomass of bigeye in the EPO was less than the level that is required to produce the AMSY. The dramatic change from being above the SBR_{AMSY} level to below it has been predicted by the past three assessments.

Estimates of the average SBR projected to occur during 2004-2014 indicate that the SBR is likely to reach an historic low level in 2007-2008, and remain below the level required to produce the AMSY for many years unless fishing mortality is greatly reduced or recruitment is greater than average levels for a number of years. This decline is likely to occur because of the recent weak cohorts and the high estimated levels of fishing mortality.

The average weight of fish in the catch of all fisheries combined has been below the critical weight (about 49.8 kg) since 1993, suggesting that the recent age-specific pattern of fishing mortality is not satisfactory from a yield-per-recruit perspective. The average weight of purse-seine-caught fish is currently about 10 kg, while the average weight of longline fish is about 60 kg.

Recent catches are estimated to have been about 26% above the AMSY level. If fishing mortality is proportional to fishing effort, and the current patterns of age-specific selectivity are maintained, the level of fishing effort that is estimated to produce AMSY is about 62% of the current level of effort. Decreasing the effort to 62% of its present level would increase the long-term average yield by 8% and would increase the spawning potential of the stock by about 156%. The AMSY 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 individuals close to the critical size.

All analyses considered suggest that at the start of 2004 the spawning biomass was below the level that would be present if the stock were producing the AMSY. AMSY and the fishing mortality (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 the level that will produce the AMSY.

Presently the purse-seine fishery on floating objects has the greatest impact on the bigeye tuna stock. Restrictions that apply only to a single fishery (*e.g.* longline or purse-seine), particularly restrictions on longline fisheries, are predicted to be insufficient to allow the stock to rebuild to levels that will support the AMSY. Large (50%) reductions in effort (on bigeye tuna) from the purse-seine fishery will allow the stock to rebuild towards the AMSY level, but restrictions on both longline and purse-seine fisheries are necessary to rebuild the stock to the AMSY level in ten years. Simulations suggest that the restrictions inmposed by the 2003 Resolution on the Conservation of Tuna in the EPO will not be sufficient to rebuild the stock.

Projections indicate that, if fishing mortality rates continue at their recent (2002 and 2003) levels, longline catches and SBR will decrease to extremely low levels. As the base case does not include a stock-recruitment relationship, recruitment will not decline, so purse-seine catches are predicted to decline only slightly from recent levels.

2. DATA

Catch, effort, and size-composition data for January 1975 through December 2003 were used to conduct the stock assessment of bigeye tuna, *Thunnus obesus*, in the eastern Pacific Ocean (EPO). The data for 2003, which are preliminary, include records that had been entered into the IATTC databases as of March, 2004. All data are summarized and analyzed on a quarterly basis.

2.1. Definitions of the fisheries

Thirteen 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 (sets on floating objects, unassociated schools, and dolphins), time period, and IATTC length-frequency sampling area or latitude. The bigeye fisheries are defined in Table 2.1; these definitions were used in previous assessments of bigeye in the EPO (Watters and Maunder 2001, 2002; Maunder and Harley 2002; Harley and Maunder 2004). 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 mix 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 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.

2.2. Catch and effort data

The catch and effort data in the IATTC databases are stratified according to the fishery definitions presented in Table 2.1.

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 for this report has been changed to be consistent with the standard terminology used in other IATTC reports. The standard usage of landings is catch landed in a given year, even if it was not caught in that year. Previously, landings referred to retained catch taken in a given year. This catch will now be termed retained catch. Throughout the document the term “catch” will be used to reflect both total catch (discards plus retained catch) and retained catch, and the reader is referred to the context to determine the appropriate definition.

All three 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 2.2.3).

Updated and new catch and effort data for the surface fisheries (Fisheries 1-7 and 10-13) have been incorporated into the current assessment. As in the assessment of Harley and Maunder (2004), the species composition method (Tomlinson 2002) was used to estimate catches of the surface fisheries. Comparisons of catch estimates from different sources have not yet provided specific details on the most appropriate method to scale historical estimates of catches that were based on unloading and cannery data. This analysis is complex as the cannery and unloading data are collected at the trip level while the species composition samples are collected at the well level and only represent a small subset of the data. Differences in catch estimates could be due to the proportion of small tunas in the catch and/or differing efforts to distinguish the tuna species at the cannery, or even biases introduced in the species composition algorithm in determining the species composition in strata where no species composition samples are available. In this assessment we calculated fishery-specific scaling factors for 2000-2003 and applied these to the cannery and unloading estimates for 1993-1999. We present a sensitivity analysis in which we use the cannery unloading estimates of surface fishery landings in Appendix C. It is important to note that the assumed effort does not change. Watters and Maunder (2001) provide a brief description of the method that is used to estimate surface fishing effort.

Updates and new catch and effort data for the longline fisheries (Fisheries 8 and 9) have also been incorporated into the current assessment. New catch data is available for Japan (2002), Chinese Taipei (2000 and 2001), Peoples Republic of China (2001 and 2002), and Korea (1998 to 2002), and updated data was received for Japan (1999 to 2001), Chinese Taipei (1975 to 1999), and Korea (1987 to 1997). The IATTC staff is working to include landings for several smaller and new longline fleets into the database for inclusion in future assessments.

As in the previous assessments of bigeye of the EPO (Watters and Maunder 2001, 2002), the amount of longlining effort was estimated by dividing standardized estimates of the catch per unit of effort (CPUE) from the Japanese longline fleet into the total longline landings. In previous assessments (Watters and Maunder 2001, 2002, Maunder and Harley 2002), estimates of standardized CPUE were obtained with regression trees (Watters and Deriso 2000) or by the habitat-based method (Hinton and Nakano 1996, Bigelow *et al.* (2003)). As with the assessment of Harley and Maunder (2004), standardized CPUEs for 1975–2001 were estimated using the neural network described by Maunder and Hinton (submitted).

2.2.1. Catch

Trends in the catches of bigeye tuna taken from the EPO during each quarter from January 1975 through December 2003 are illustrated in Figure 2.2. There has been substantial annual and quarterly variation in the catches of bigeye made by all fisheries operating in the EPO (Figure 2.2). Prior to 1996, the longline fleet (Fisheries 8 and 9) 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 January 1, 1975, and substantial amounts of bigeye were already being removed from the EPO by that time.

For this assessment, the longline landings data are available through 2002. In the assessment, the estimated longline landings in 2003 are a function of the longline effort in 2002, the estimated abundance in 2003, and the estimated selectivities and catchabilities for the longline fisheries (Fisheries 8 and 9).

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

2.2.2. Effort

Trends in the amount of fishing effort exerted by the 13 fisheries defined for the stock assessment of bigeye tuna in the EPO are illustrated in Figure 2.3. Fishing effort for surface gears (Fisheries 1-7 and 10-13) is in days fishing, and that for longliners (Fisheries 8 and 9) is in standardized hooks. There has been substantial variation in the amount of fishing effort exerted by all of the fisheries that catch bigeye from the EPO. Nevertheless, there have been two important trends in fishing effort. First, since about 1993, there has been a substantial increase in the effort directed at tunas associated with floating objects. Second, the amount of longlining effort expended in the EPO, which is directed primarily at bigeye, has declined substantially since about 1991, but has increased again since 2000.

Compared to 2002, the total amount of fishing effort expended by Fisheries 2 and 7 decreased during 2003. As percentages of the effort expended in 2002, these decreases were, respectively, about 8%, and 4%. Effort for these fisheries had increased in 2002 from 2001 levels. The total amount of fishing effort expended by Fisheries 3 (50%), 4 (46%) and 5 (49%) increased from 2002 to 2003. These results indicate that the floating-object fishery in the southern offshore area (Fishery 2) stopped expanding during 2003, as was the case during 2000 to 2002. Increases for Fisheries 3, 4, and 5 are greater than declines observed in 2002. It should be noted, however, that the spatial expansion and contraction of effort in the fisheries that catch bigeye in association with floating objects vary greatly among years (Watters 1999).

For the longline fisheries, standardized CPUE was available to estimate effective effort for each quarter from 1975 to 2001. For 2002, standardized CPUE for each quarter was predicted from nominal CPUE that was available for 1975 to 2002. Fishing effort was calculated by dividing the observed catches by the standardized CPUE. Effort for 2001 and 2002 is much greater than that estimated by Harley and Maunder (2004). This occurred because of this assessment includes catch data for the recently expanding longline fisheries for Chinese Taipei and the Peoples Republic of China. No catch or effort data were available for the longline fishery operations in 2003. It was assumed that quarterly effort in 2003 was the same as that estimated for 2002.

It is assumed that the fishing effort in Fisheries 10-13 is equal to that in Fisheries 2-5 (Figure 2.3) because the catches taken by Fisheries 10-13 are derived from those taken by Fisheries 2-5 (Section 2.2.3).

The large quarter-to-quarter variations in fishing effort illustrated in Figure 2.3 are partly a result of how fisheries have been defined for the purposes of stock assessment. Fishing vessels often tend to fish in different locations at different times of year, and, if these locations are widely separated, this behavior can cause fishing effort in any single fishery to be more variable.

2.2.3. 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 both cases, 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. New discard data for 2003 are included in the analysis.

Estimates of discards resulting from inefficiencies in the fishing process are added to the catches made by purse-seine vessels (Table 2.1). No observer data are available to estimate discards 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/landings) is equal to the discard rate for the same quarter in the previous year or, if not available, the year before that.

Discards that result from the process of sorting the catch are treated as separate fisheries (Fisheries 10-13), and the catches taken by these fisheries are assumed to be composed only of fish that are 2-4 quarters old (see Figure 4.5). Watters and Maunder (2001) provide a short 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 presented in Figure 2.4. For the largest floating-object fisheries (2,3,and 5), the proportion of the catch discarded has been low for the last five years compared to that 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 estimated in recent years. It is also possible that regulations regarding discarding of tuna have also played a role.

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

2.3. Size composition data

New length-frequency data are available for the surface fisheries for 2003. New longline length-frequency data from the Japanese fleet are available for 2002 and data for previous years have been updated. No size composition data is available from other longline fleets.

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 two previous assessments (Watters and Maunder 2001, 2002). The fisheries that catch bigeye associated with floating objects typically catch small (<75 cm long) and medium-sized (75 to 125 cm long) bigeye (Figure 4.2, Fisheries 1-5). Prior to 1993, the catch of small bigeye was roughly equal to that of medium bigeye (Figure 4.2, Fishery 1). Since 1993, however, small bigeye have dominated the catches of fisheries that catch bigeye in association with floating objects (Figure 4.2, Fisheries 2-5). Prior to 1990, mostly medium-sized bigeye were captured from unassociated schools (Figure 4.2, Fishery 6). Since 1990, more small- and large-sized (>125 cm long) bigeye have been captured in unassociated schools (Figure 4.2, 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, longliners catch mostly medium-sized bigeye, and the average size composition has two distinct peaks (Figure 4.2, Fishery 8). In the southern area, longliners catch substantial numbers of both medium-sized and large bigeye, and the size composition has a single mode (Figure 4.2, Fishery 9).

During any given quarter, the size-composition data collected from a fishery will not necessarily be similar to the average conditions illustrated in Figure 4.2. The data presented in Figure 4.3 illustrate this point. The most recent (2003) size compositions for the fisheries that catch bigeye in association with floating objects contain more medium sized bigeye than observed in samples from 2002. This observation is consistent with the higher proportion of small fish observed in the 2002 samples.

3. ASSUMPTIONS AND PARAMETERS

3.1. Biological and demographic information

3.1.1. Growth

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

(Fisheries 10-13) when they are 30 cm long and two quarters old.

In a previous bigeye assessment (Watters and Maunder 2002), the A-SCALA method was used to compare the statistical performance of different assumptions about growth. An assessment in which the growth increments were fixed and set equal to those from the von Bertalanffy curve estimated by Suda and Kume (1967) was compared to an assessment in which the growth increments were estimated as free parameters. In the former assessment, the fixed growth increments were generated from a von Bertalanffy curve with $L_\infty = 214.8$ cm, $k = 0.2066$, the length at recruitment to the discard fisheries = 30 cm, and the age at recruitment to the fishery = 2 quarters. The previous analysis showed that fixing growth was statistically preferable to estimating growth. However, in this assessment we have chosen to estimate growth using the von Bertalanffy growth curve of Suda and Kume (1967) as a strong prior only for the older age-classes (12 to 40 quarters old). This is because the EPO yellowfin tuna assessment (Maunder 2002) and tuna assessments in the western and central Pacific Ocean (Hampton and Fournier 2001a, b; Lehodey *et al*. 1999) suggest that tuna growth does not follow a von Bertalanffy growth curve for the younger ages. The prior is used for the older ages because there is usually insufficient information in the length-frequency data to estimate mean lengths for the older ages. Previous assessments of bigeye tuna in the EPO (Watters and Maunder 2001) produced estimates of variation of length at age that were unrealistically high. Therefore, we use the variation at age estimated from the otolith data collected in the western and central Pacific Ocean. Estimates of variation of length at age from the MULTIFAN-CL Pacific-wide bigeye tuna assessment were consistent with otolith data collected in the western and central Pacific Ocean (Hampton and Fournier 2001b). The amount of variation at age is also consistent with estimates from dorsal spine data (Sun *et al*. 2001) and estimates for yellowfin in the EPO (Maunder 2002).

For sensitivity to the base case assessment, we estimated the linear model between mean length at age and variance in length at age. The estimated growth curve and variation were similar to the base case so the results are not presented here.

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. 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).

A-SCALA allows a Beverton-Holt (1957) stock-recruitment relationship to be specified. The Beverton-Holt curve is parameterized so that the relationship between spawning biomass and recruitment is determined by estimating the average recruitment produced by an unexploited population (virgin recruitment), a parameter called steepness, and the initial age structure of the population. 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 cause recruitment to be extremely variable. Thus, to estimate steepness it is often necessary to specify how this parameter might be distributed statistically. (This is known as specifying a prior distribution.)

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, steepness 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, it is further assumed that recruitment should not be less than 25% of its average level and not greater than four times its average level more often than about 1% of the time. These constraints imply that, on a quarterly time step, such extremely small or large recruitments should not occur more than about once every 25 years.

Reproductive inputs were revised for the assessment of Harley and Maunder (2004) based on preliminary results from biological studies undertaken by IATTC staff. Subsequently, further samples have been analyzed, including samples provided by Dr. N. Miyabe, and these inputs have been further revised. Fifty percent of females are assumed to be mature at 4.5 years of age (18 quarters), compared to 5 years assumed by Harley and Maunder (2004) (Figure 3.2). Revised estimates of the age-specific proportion of females are almost identical to the preliminary estimates used by Harley and Maunder (2004) and are based on a mixture of recent and historical (Kume and Joseph 1966) samples (Figure 3.3 and Table 3.1). These estimates are similar to those from samples from the Japanese longline fleet for the EPO (Dr. N. Miyabe, *pers. comm.*) The fecundity index at age is assumed to be equal to the mean weight at age estimated by inserting mean lengths from the growth curve provided by Suda and Kume (1967) into the weight-length relationship provided by Nakamura and Uchiyama (1966) (see Section 3.1.1). The age-specific proportions of female bigeye and fecundity indices used in the current assessment are provided in Table 3.1.

Assumptions regarding biological parameters may change again in the future as research continues.

3.1.3. Movement

The current assessment does not consider movement explicitly. Rather, it is assumed that bigeye move around the EPO at rates that are rapid enough to ensure that the population is randomly mixed at the start of each quarter of the year. The IATTC staff is currently studying the movement of bigeye within the EPO, using data recently collected from conventional and archival tags, and these studies may eventually provide information that is useful for stock assessment.

3.1.4. Natural mortality

Age-specific vectors of natural mortality (*M*) used in the previous assessment of bigeye tuna (Watters and Maunder 2001, 2002, Maunder and Harley 2002) were based on fitting to age-specific proportions of females, maturity-at-age, and natural mortality estimates of Hampton (2000). As the first two of these quantities have again been revised in this assessment, new age-specific vectors of natural mortality were estimated outside of the assessment model (Harley and Maunder, unpublished analysis). These new estimates are slightly lower than previous estimates, and increase at lesser ages due to the slightly earlier maturity assumed. 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 that would produce AMSY (Watters and Maunder 2001) remains. Two sensitivity analyses were undertaken to assess sensitivity to natural mortality. The first, which is not presented, was based on the values assumed by Harley and Maunder (2004). For the second, natural mortality for bigeye younger than 10 quarters was increased. This analysis is described in Appendix D.

3.1.5. Stock structure

There are not enough data available to determine whether there are one or several stocks of bigeye tuna in the Pacific Ocean. 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 movement between these areas. The IATTC staff is currently collaborating with scientists of the SPC, Oceanic Fisheries Programme, and of the National Research Institute of Far Seas Fisheries of Japan to conduct a Pacific-wide assessment of bigeye. 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 A-SCALA method. Recent analyses (Hampton et al. 2003) that estimate movement rates within the Pacific Ocean, estimated very similar biomass trends 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. To incorporate such a possibility, an environmental variable is integrated into the stock assessment model, and it is determined whether this variable explains a significant amount of the variation in the estimates of recruitment. For the assessment of Harley and Maunder (2004), a modification was made to A-SCALA to allow for missing values in the environmental index thought to be related to recruitment. This allowed us to start the population model in 1975, five years before the start of the time series for the environmental index. As in previous assessments (Watters and Maunder 2001, 2002, Maunder and Harley 2002), zonal-velocity anomalies (velocity anomalies in the east-west direction) at 240 m depth and in an area from 8°N-15°S and 100°-150°W are used as the candidate environmental variable for affecting recruitment. The zonal-velocity anomalies were calculated as the quarterly averages of anomalies from the long-term (January 1980-December 2002) monthly climatology. These data were included in the stock assessment model after they had been offset by two quarters because it was assumed that recruitment of bigeye in any quarter of the year might be dependent on environmental conditions in the quarter during which the fish were hatched. The zonal-velocity anomalies were estimated from the hind cast results of a general circulation model obtained at http://ingrid.ldeo.columbia.edu.

In previous assessments (Watters and Maunder 2001, 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 only for Fishery 3. It was found that including this effect did not greatly improve the results and as the current model cannot accommodate missing values for environmental indices thought to be related to catchability, no environmental influences on catchability have been considered in this assessment.

4. STOCK ASSESSMENT

The A-SCALA method (Maunder and Watters 2003) is currently used to assess the status of the bigeye tuna stock in the EPO. This method was also used to conduct the previous three assessments of bigeye (Watters and Maunder 2001, 2002, Maunder and Harley 2002). A general description of the A-SCALA method is included in the previously-cited assessment documents, and technical details are provided by Maunder and Watters (2003) with more recent developments described in Maunder and Harley (2003) and Harley and Maunder (2003). The assessment model is fitted to the observed data (catches and size compositions) by finding a set of population dynamics and fishing parameters that maximize a constrained likelihood, given the amount of fishing effort expended by each fishery. Many of the constraints imposed on this likelihood are identified as assumptions in Section 3, but the following list identifies other important constraints that are used to fit the assessment model.

1. Bigeye tuna are recruited to the discard fisheries (Fisheries 10-13) two quarters after hatching, and these discard fisheries catch only fish of the first few age classes.
2. Bigeye tuna are recruited to the discard fisheries before they are recruited to the other fisheries of the EPO.
3. If a fishery can catch fish of a particular age, it should be able to catch fish that are somewhat younger and older (*i.e.* selectivity curves should be relatively smooth).
4. As bigeye tuna age, they become more vulnerable to longlining in the area south of 15°N, and the oldest fish are the most vulnerable to this gear (*i.e.* the selectivity curve for Fishery 9 is monotonically increasing).
5. There are random events that can cause the relationship between fishing effort and fishing

mortality to change from quarter to quarter.

6. The data for fisheries that catch bigeye tuna from unassociated schools (Fisheries 6 and 7) and fisheries whose catch is composed of the discards from sorting (Fisheries 10-13) provide relatively little information about biomass levels. This constraint is based on the fact that these fisheries do not direct their effort at bigeye.
7. It is extremely difficult for fishermen to catch more than about 60% of the fish from any one cohort during a single quarter of the year.

It is important to note that the assessment model can, in fact, make predictions that do not adhere strictly to Constraints 3-7 nor to those outlined in Section 3. The constraints are designed so that they can be violated if the observed data provide good evidence against them.

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 first quarter of 2004 (This includes estimation of virgin recruitment, recruitment anomalies, and an environmental effect.);
2. catchability coefficients for the 13 fisheries that take bigeye from the EPO (This includes estimation of an average catchability for each fishery and random effects.);
3. selectivity curves for 9 of the 13 fisheries (Fisheries 10-13 have an assumed selectivity curve.);
4. a single, average growth increment between ages 2 and 5 quarters and the average quarterly growth increment of fish older than 5 quarters;
5. 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. age-specific natural mortality rates (Figure 3.1);
2. age-specific sex ratios (Table 3.1 and Figure 3.2);
3. age-specific maturity schedule (Section 3.1.2 and Figure 3.2);
4. age-specific fecundity indices (Table 3.1 and Figure 3.2);
5. selectivity curves for the discard fisheries (Figure 4.5, Fisheries 10-13);
6. the steepness of the stock-recruitment relationship;
7. parameters of a linear model relating the standard deviations in length at age to the mean lengths at age.

Weighting factors for the selectivity smoothness penalties were the same values as were assumed for the assessment of Harley and Maunder (2004). These values were determined by cross-validation.

Yield and catchability estimates for AMSY calculations or future projections were based on estimates of quarterly fishing mortality or catchability (mean catchability plus effort deviates) for 2001 and 2002, thus the most recent estimates were not included in these calculations. It was determined by retrospective analysis (Maunder and Harley 2003) that the most recent estimates were uncertaint and should not be considered. Sensitivity of estimates of key management quantities to this assumption was tested.

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

4.1. Indices of abundance

Catches per unit of effort (CPUEs) have been presented in previous assessments of bigeye tuna of the EPO (*e.g.* Watters and Maunder 2001, 2002; Maunder and Harley, 2002). CPUEs are indicators of fishery performance, but trends in CPUE will not always follow trends in biomass or abundance. The CPUEs of the 13 fisheries defined for the assessment of bigeye are illustrated in Figure 4.1, but the trends in this figure should be interpreted with caution. Trends in estimated biomass are discussed in Section 4.2.3. There has been substantial variation in the CPUEs of bigeye tuna by both the surface fleet (Fisheries 1-7) and the longline fleet (Fisheries 8 and 9) (Figure 4.1). Notable trends in CPUE have occurred in the fisheries that catch bigeye in association with floating objects. On average, the CPUEs of these fisheries increased substantially from 1997 through 2000, but have generally decreased since (except for Fishery 4) (Figure 4.1, Fisheries 2-5). Notable trends in CPUE have also occurred for the two longline fisheries. The neural network standardized CPUEs of both longline fisheries decreased markedly between 1985 and 2000 and have experienced a “spike” in CPUE during 2000-2002 that is attributed to strong cohorts passing through the fishery (Figure 4.1, Fisheries 8 and 9.

Comparing the CPUEs of the surface fisheries of 2003 to those of 2002 indicates that performance of these fisheries is quite variable. Aside from Fishery 2 for which CPUE was only down in the second and third quarters, CPUEs from the purse-seine fisheries were down during the first three quarters of 2002 and were up only slightly in quarter 4. These decreases are consistent with the weak recruitment estimated since 1998, and the increase at the end of 2003 is consistent with the single strong recruitment estimated for the second quarter of 2002 (see Section 4.2.2). CPUEs for the discard fisheries (Fisheries 10–13) have generally been low for the last four years, which is consistent with weak recruitment (Section 4.2.2).

4.2. Assessment results

Below we describe the important aspects of the base case assessment (1 below) and the change for each sensitivity analysis:

1. Base case: steepness of the stock-recruitment relationship equals 1 (no relationship between stock and recruitment), species-composition estimates of surface fishery catches scaled back to 1993, neural network-standardized CPUE , and assumed sample sizes for the length-frequency data.
2. Sensitivity to the steepness of the stock-recruitment relationship. The base case included an assumption that recruitment was independent of stock size, and a Beverton-Holt (1957) stock-recruitment relationship with steepness of 0.75 was used for the sensitivity analysis.
3. Sensitivity to estimates of purse-seine catches. In the base case, estimates of purse-seine catches were based on species composition estimates for 2000–2002 and scaled estimates back to 1993. For sensitivity, we compared this to cannery and unloading estimates of bigeye catches in the purse-seine fisheries, as used by Maunder and Harley (2002).
4. Sensitivity to assumed rates of natural mortality for bigeye younger than ten quarters old. Quarterly rates of natural mortality were increased for individuals less than ten quarters old.

Base case results are described in the text, and the sensitivity analyses are described in the text with figures and tables presented in Appendices B-D. We also undertook several sensitivity analyses that are not presented here. We examined models for which the purse-seine CPUE data was downweighted, last years biological inputs were assumed, recruitment variation was estimated, and the environmental data were included as anomalies rather than absolute values. Most of these produced results very similar to those of the base case. We have chosen to restrict our presentation to plausible sensitivity analyses that had an effect on management quantities. A more comprehensive presentation of sensitivity analysis, including investigation of growth estimation, environmental effects on recruitment and catchability, and natural mortality can be found in Watters and Maunder (2002) and Harley and Maunder (2004).

The base case assessment is constrained to fit the time series of catches made by each fishery almost perfectly (this is a feature of the A-SCALA method), and the 13 time series of bigeye catches predicted with the base case model are nearly identical to those plotted in Figure 2.2.

In practice, it is more difficult to predict the size composition than to predict the catch. Predictions of the size compositions of bigeye tuna caught by Fisheries 1-9 are summarized in Figure 4.2. This figure simultaneously illustrates the average observed and predicted size compositions of the catches taken by these nine fisheries. The average size compositions for the fisheries that catch most of the bigeye taken from the EPO are reasonably well described by the base case assessment (Figure 4.2, Fisheries 2, 3, 5, 8, and 9).

Although the base case assessment reasonably describes the average size composition of the catches by each fishery, it is less successful at predicting the size composition of each fishery's catch during any given quarter. In many instances this lack of fit may be due to inadequate data or to variation in the processes that describe the dynamics (*e.g.* variation in growth). The most recent size-composition data for Fisheries 4 and 7 are not informative (Figure 4.3). In other cases, the base case assessment tends to over-smooth, and does not capture modes that move through the size-composition data. Recent length-frequency data for Fisheries 2, 3, and 5 are generally in good agreement in relation to the position and transition modes, and so are well fitted by the model. There is strong agreement in the lack of strong cohorts during 1998 and 2001 and some evidence of moderate-strength cohorts in the second quarters of 2001 and 2002. The fit to these data is governed by complex tradeoffs between estimates of growth, selectivity, recruitment, and agreement among fisheries in the presence and absence of modes.

Of all the constraints used to fit the assessment model (see Sections 3 and 4), those on growth, catchability, and selectivity had the most influence. The penalties are very similar to those of the previous assessment of Harley and Maunder (2004). This following list indicates the major penalties (a large value indicates that the constraint was influential):

Total likelihood = -354466
Likelihood for catch data = 4.5
Likelihood for size-composition data = -354998.2
Constraints and priors on recruitment parameters = 6.0
Constraints and priors on growth parameters = 49.8
Constraints on fishing mortality rates = 0.0
Constraints and priors on catchability parameters = 482.5
Constraints on selectivity parameters = 19.4

The constraints on catchability and selectivity represent the sum of many small constraints on multiple parameters estimated for each fishery.

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.

4.2.1. 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 bigeye less than about 20 quarters old has increased since 1993, and that on fish more than about 24 quarters old has increased slightly since then (Figure 4.4). 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 less than 20–25 quarters old (Figure 4.5), and have expended a relatively large amount of fishing effort since 1993 (Figure 2.3).

Temporal trends in the age-specific amounts of fishing mortality on bigeye tuna are shown in Figure 4.6a. These trends reflect the distribution of fishing effort among the various fisheries that catch bigeye (see Section 2.2.2 and Figure 2.3) and changes in catchability. Changes in catchability are described in the following paragraphs. The trend in fishing mortality rate by time also shows that fishing mortality has increased greatly for young fish and only slightly for older fish since about 1993. Recent estimates indicate a large increase in fishing mortality on young fish, but these estimates should be treated with caution, as they are quite uncertain (Figure 4.6b). An annual summary of the estimates of total fishing mortality is presented in Appendix E (Table E.1).

In the first assessment of bigeye from the EPO using A-SCALA (Watters and Maunder 2001), catchability (q) was considered to be composed of three effects: effects of changes in technology and the behavior of fishermen, effects of the environment, and random effects that temporarily change the relationship between fishing effort and fishing mortality. The base case assessment described in this report and that of the three most recent assessments (Watters and Maunder 2002, Maunder and Harley 2002, Harley and Maunder 2004) does not include the first component, and this assessment does not estimate an environmental effect for any of the fisheries. The random effects on q are retained in the base case assessment, and these effects have dominated the temporal trends in q for all fisheries (Figure 4.7).

For two of the main surface fisheries (Fisheries 2 and 5) there are strong increasing trends in catchability in recent years indicating that the effective effort (capacity) of the fleet is increasing. Catchability for the last time period for Fishery 8 is estimated to be very high. This estimate is extremely uncertain and represents a time period with very low effort and only small catches. Aside for this one outlier, there has been little change in the catchability of bigeye tuna by the longline fleet (Figure 4.7, Fisheries 8 and 9, bold lines). This result is to be expected, given the effort data for these fisheries were standardized before they were incorporated into the stock assessment model (Section 2.2.2).

4.2.2. Recruitment

The abundance of bigeye tuna being recruited to the fisheries in the EPO appears 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, Figure 4.8, upper panel). The mechanism that is responsible for this relationship has not been identified, and correlations between recruitment and environmental indices are often spurious. Given these latter two caveats, the relationship between zonal-velocity and bigeye recruitment should be viewed with some skepticism. Nevertheless, the relationship tends to indicate that bigeye recruitment is increased by strong El Niño events and decreased by strong La Niña events. A sensitivity analysis in which no environmental indices were included gave estimates of recruitment similar to those of the base case model (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 maybe useful for reducing uncertainty in estimates of the strengths of the most recent cohorts for which few size composition samples are available.

Over the range of estimated spawning biomasses shown in Figure 4.11, the abundance of bigeye recruits appears to be unrelated to the spawning potential of adult females at the time of hatching (Figure 4.8). 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. As noted in Section 3.1.2, the absence of an emergent relationship between stock and recruitment does not indicate that such a relationship is nonexistent because stock sizes may not have been sufficiently reduced, we may not have a reliable measure of spawning biomass, or environmental variation may mask the relationship. In this assessment, there have been changes in assumptions regarding biological parameters and these may change again in the future as research continues. 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 are far worse than underestimating it in terms of lost yield and potential for recruitment overfishing (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 estimated time series of bigeye recruitment is shown in Figure 4.9, and the total recruitment estimated to occur during each year is presented in Table 4.2. There are two important features in the estimated time series of bigeye recruitment. First, greater-than-average recruitments occurred in 1977, 1979, 1982-1983, 1992, 1994, 1995-1997, and during the second quarters of 2001 and 2002. The lower confidence bounds of these estimates were greater than the estimate of virgin recruitment only for 1994, 1997, and the recruitment in 2001 and 2002. Second, aside from those two recruitment pulses in 2001 and 2002, recruitment has been much less than average from the second quarter of 1998 to the end of 2003, and the upper confidence bounds of many of these recruitment estimates are below the virgin recruitment The extended period of relatively large recruitments in 1995 to 1998 coincided with the expansion of the fisheries that catch bigeye in association with floating objects.

Evidence for these low recruitments since 1998 comes from the decreased CPUEs of some of the floating-object and discard fisheries (Table 4.1 and Figures 2.4 and 4.1), the length-frequency data (Maunder and Harley 2002, Figure 4.3), and by poor environmental conditions for recruitment. The extended series of low recruitments is important because it is likely to produce a sequence of years in which the spawning biomass ratio (the ratio of the current spawning biomass to that for the unfished stock) will be below the level that would support the average maximum sustainable yield (AMSY) (see Section 5.1).

There is considerable uncertainty in the estimated levels of recruitment, particularly in the early years before fishing on floating objects expanded. The average CV of the recruitment estimates is about 0.36. Most of the uncertainty in recruitment is a result of the fact that the observed data can be fitted equally well by a model with different estimates of the assessment parameters. Also, pre-1993 estimates are particularly uncertain, as the floating-object fisheries, which catch small bigeye, were not operating. Uncertainty in the most recent estimates of recruitment is, however, also caused by the fact that recently-recruited bigeye are represented in only a few length-frequency data sets.

4.2.3. Biomass

Trends in the biomass of 1+-year-old bigeye tuna in the EPO are shown in Figure 4.10, and estimates of the biomass at the start of each year are presented in Table 4.2. The biomass of 1+-year-old bigeye increased during 1980-1984, and reached its peak level of about 586,000 t in 1986. After reaching this peak, the biomass of 1+-year-olds decreased to an historic low of about 156,000 t at the start of 2004.

The trend in spawning biomass is also shown in Figure 4.10 (lower panel), and estimates of the spawning biomass at the start of each year are presented in Table 4.2. The spawning biomass has generally followed a trend similar to that for the biomass of 1+-year-olds, but is lagged by 1-2 years. A summary of the age-specific estimates of the abundance of bigeye in the EPO at the beginning of each calendar year is presented in Appendix E (Figure E.1).

There is uncertainty in the estimated biomasses of both 1+-year-old bigeye and of spawners. The average CV of the biomass estimates of 1+-year-old bigeye is 0.14. The average CV of the spawning biomass estimates is 0.18.

Given the amount of uncertainty in both the estimates of biomass and the estimates of recruitment (Section 4.2.2), it is difficult to determine whether, trends in the biomass of bigeye have been influenced more by variation in fishing mortality or by variation in 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 4.12). Second, the biomass of bigeye can be substantially increased by strong recruitment events. Both peaks in the biomass of 1+-year-old bigeye (1985 and 2000; Figure 4.10) were preceded by peak levels of recruitment (1982-1983 and 1995-1997, respectively; Figure 4.9).

To estimate the impact that different fisheries have had on the depletion of the stock we run simulations where each gear is excluded and the model is run forward as is done in the no-fishing simulation. The results of this analysis are also provided in Figure 4.12. It is clear that the longline fishery had the greatest impact on the stock prior to 1990, but with the decrease in effort from the longline fisheries, and expansion of the floating object fishery, the impact on the population is far greater for the purse-seine fishery than for the longline fishery. The discarding of small bigeye has a small. But detectable impact on the depletion of the stock. Overall the biomass is estimated to be about 15% of that expected had no fishing occurred.

4.2.4. Average weights of fish in the catch

Trends in the average weights of bigeye captured by the fisheries that operate in the EPO are illustrated in Figure 4.13. The fisheries that catch bigeye in association with floating objects (Fisheries 1-5) have taken mostly fish that, on average, weigh less than the critical weight, which indicates that these fisheries do not maximize the yield per recruit (see Section 5.2). During 1999 the average weights of bigeye taken from associations around floating objects increased substantially (Figure 4.13, Fisheries 2-5). During the latter half of 2000, however, the average weight of the fish taken by Fisheries 2, 3, and 5 decreased (Figure 4.13). Fisheries 7 and 8 have captured bigeye that are, on average, 30% less than the critical weight. The average weights of bigeye taken by Fishery 8 increased since 1999 (Figure 4.13). The average weight of bigeye taken by the longline fishery operating south of 15°N (Fishery 9) has always been around the critical weight, which indicates that this fishery tends to maximize the yield per recruit (see Section 5.2). In general the average weight of bigeye taken by the all of the surface fisheries combined (excluding the discard fisheries) increased during 1998 and early 1999, and then decreased (Figure 4.13). The average weight of bigeye taken by both longline fisheries combined appears to have decreased during early 1997, 1998, and 1999, and then increased (Figure 4.13). These two trends, for the combined surface fisheries and the combined longline fisheries, were probably caused by the strong cohorts of 1995–1997 moving through the surface fisheries and into the longline fisheries and the subsequent weak recruitment since 1998 (Figure 4.9).

4.3. Comparisons to external data sources

In the base case assessment, the growth increments are estimated for the younger bigeye. The estimated mean lengths at age are less than those given by Suda and Kume (1967: Table 4.3 and Figure 4.14). The most recent assessment of bigeye tuna in the western and central Pacific Ocean (Hampton 2002) also estimated reduced growth rates for young bigeye, and this is also consistent with reduced growth found in both growth and tagging studies (Lehody *et al.* 1999)

4.4. Diagnostics

A technical meeting on diagnostics was held in October 2002. The outcome from this meeting was 1) a set of diagnostics that should be evaluated regularly, 2) a set of diagnostics that should be evaluated periodically, and 3) a list of specific research questions. Several of the recommendations have been included in this assessment. We present these in three sections; 1) residual plots, 2) parameter correlations, and 3) retrospective analysis.

4.4.1. Residual plots

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

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

The estimated quarterly effort deviations are shown versus time in Figure A.4. These residuals are assumed to be normally distributed (the residual is exponentiated before multiplying by the effort so the distribution is actually lognormal) with a mean of zero and a given standard deviation. A trend in the residuals indicates that the assumption that CPUE is proportional to abundance is violated. The assessment assumes that the Southern longline fishery (Fishery 9) provides the most reasonable information about abundance (standard deviation = 0.2) the floating-object and the Northern longline fisheries have the least information (standard deviation = 0.4), and the discard fisheries have no information (standard deviation = 2). Therefore, a trend is less likely in the southern longline fishery (Fishery 9) than in the other fisheries. The trends in effort deviations are estimates of the trends in catchability (see Section 4.2.1). Figure A.4 shows no overall trend in the southern longline fishery effort deviations, but there are some consecutive residuals that are all above or all below the average. The standard deviation of the residuals is much greater than the 0.2 assumed for this fishery. For the other fisheries, the standard deviations of the residuals are all greater than those assumed, except for the discard fisheries. These results indicate that the assessment gives more weight to the CPUE information than it should (see below and Section 4.5 for additional indication that less weight should be given to the CPUE information and more to the length-frequency data). The effort residuals for the floating-object fisheries show an increasing trend over time. These trends may be related to true trends in catchability.

4.4.2. Parameter correlations

Often quantities, such as recent estimates of recruitment deviates and fishing mortality can be highly correlated. This information indicates a flat solution surface, which implies that alternative states of nature have similar likelihoods. Effort deviates and recruitment deviates in recent years are both uncertain and correlated. To account for this, we have excluded recent effort deviates and fishing mortality estimated for 2003 from yield calculations and projections.

There is negative correlation (around 0.4) between the current estimated effort deviates for each fishery and estimated recruitment deviates lagged to represent cohorts entering each fishery, particularly for the discard fisheries. Earlier effort deviates are positively correlated with these recruitment deviates.

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

4.4.3. Retrospective analysis

Retrospective analysis is 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 to the comparison of recent assessments (Section 4.6) 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.

No retrospective analyses were conducted for this assessment, but the results of previous retrospective analyses are described in Harley and Maunder (2004).

4.5. Sensitivity analysis

Three sensitivity analyses are conducted for the current assessment: sensitivity to the stock–recruitment relationship (Appendix B), sensitivity to the method used to estimate catches in the surface fisheries (Appendix C), sensitivity to assumed levels of natural mortality for bigeye younger than ten quarters. Additional sensitivity analyses were conducted, but are not presented and Watters and Maunder (2002) and Harley and Maunder (2004) presented several sensitivity analyses. Here we describe differences in model fit and model prediction, and delay our discussion of differences in yields and stock status to Section 5.6.

For the analysis with steepness of the Beverton-Holt (1957) stock-recruitment relationship equal to 0.75, the estimates of biomass (Figure A.1) and recruitment (Figure A.2) are essentially the same as for the base case. This probably occurs for two reasons: 1) there is sufficient information in the catch-at-length data for all years, and 2) there is little contrast in spawning biomass, so the stock-recruitment model has little effect. Therefore, the stock-recruitment relationship does not provide additional information to the stock assessment in terms of biomass or recruitment.

When the cannery and unloading estimates of purse-seine catches are used (as by Maunder and Harley, 2002), both biomass (Figure C.1) and recruitment (Figure C.2) are lower. The cannery and unloading estimates of catch are much lower, especially in 2001 and 2002 (Figure C.4).

When higher levels of natural mortality are assumed for bigeye younger than ten quarters the biomass was almost identical to the base case (Figure D.1), but estimates of absolute recruitment were higher (Figure D.2). This latter observation is not surprising as the higher natural mortality requires higher intial recruitment to ensure that sufficient fish are available to be taken.

4.6. Comparison to previous assessments

Despite the large number of changes in important model assumptions and inputs, *e.g.* natural mortality, CPUE, and selectivity penalties, the trends in relative abundance for the last four assessments give a picture very similar to the base case assessment for 2003. Biomass trajectories are very similar (Figure 4.15) and the differences can be attributed to changes in natural mortality and catches.

To make valid comparisons of changes in estimates of spawning biomass, we applied the values of maturity and fecundity assumed in this assessment to the estimated age structure from the previous assessments. This is not completely satisfactory, as the 2001 assessment (Watters and Maunder 2002) assumed a stock-recruitment relationship, assuming different spawning biomass. Patterns are similar, but the differences are increased when compared to the biomass comparison (Figure 4.15). Again, the results for the 2003 assessment are most similar to this assessment.

4.7. 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 20 quarters old has increased substantially since 1993, and that on fish more than about 24 quarters old has increased a little since then. The increase in average fishing mortality on the younger fish was caused by the expansion of the fisheries that catch bigeye in association with floating objects. The base case assessment suggests that 1) the use of FADs has substantially increased the catchability of bigeye by fisheries that catch tunas associated with floating objects, and 2) that bigeye are substantially more catchable when they are associated with floating objects in offshore areas.

Recruitment of bigeye tuna to the fisheries in the EPO is variable, and the mechanisms that explain variation in recruitment have not been identified. Nevertheless, the abundance of bigeye tuna being recruited to the fisheries in the EPO appears to be related to zonal-velocity anomalies at 240 m during the time that these fish are assumed to have hatched. 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 two important features in the estimated time series of bigeye recruitment. First, greater-than-average recruitments occurred in 1977, 1979, 1982-1983, 1992, 1994, 1995-1997, and during the second quarters of 2001 and 2002. The lower confidence bounds of these estimates were greater than the estimate of virgin recruitment only for 1994, 1997, and the recruitment in 2001 and 2002. Second, aside from those two recruitment pulses in 2001 and 2002, recruitment has been much less than average from the second quarter of 1998 to the end of 2003, and the upper confidence bounds of many of these recruitment estimates are below the virgin recruitment. Evidence for these low recruitments comes from the decreased CPUEs achieved by some of the floating-object fisheries, discard records collected by observers, length-frequency data, and poor environmental conditions for recruitment. The extended sequence of low recruitments is important because, in concert with high levels of fishing mortality, they are likely to produce a sequence of years in which the spawning biomass ratio (the ratio of spawning biomass to that for the unfished stock; SBR) will be considerably below the level that would support the average maximum sustainable yield (AMSY).

The biomass of 1+-year-old bigeye increased during 1980-1984, and reached its peak level of about 586,000 t in 1986. After reaching this peak, the biomass of 1+-year-olds decreased to an historic low of about 156,000 t at the start of 2004. Spawning biomass has generally followed a trend similar to that for the biomass of 1+-year-olds, but lagged by 1-2 years. There is uncertainty in the estimated biomasses of both 1+-year-old bigeye and spawners. Nevertheless, it is apparent that fishing has reduced the total biomass of bigeye present in the EPO. Both are predicted to be at their lowest levels by the end of 2004. There has been an accelerated decline in biomass since the small peak in 2000.

The estimates of recruitment and biomass were not sensitive to the range of alternative parameterizations of the assessment model considered or to the alternative data source included in the assessment. However, in the current assessment, a narrower range of alternative analyses were considered.

5. STOCK STATUS

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

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

1. S_{AMSY}, the spawning biomass when the stock is at the AMSY level, as a target reference point,
2. F_{MSY} as a limit reference point,
3. S_{min}, the minimum spawning biomass seen in the model time frame, as a limit reference point.

Maintaining tuna stocks at levels capable of producing the AMSY is the current management objective specified by the IATTC Convention. The S_{min} reference point is based on the observation that the population has recovered from this population size in the past. Unfortunately, for bigeye, this may not be an appropriate reference point, as historic levels have been above the level that would produce AMSY. Development of reference points that are consistent with the precautionary approach to fisheries management will continue.

5.1. Assessment of stock status based on spawning biomass

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

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

where S_t is the spawning biomass at any time (t) during a period of exploitation, and $S_{F=0}$ is the spawning biomass that would be present if there were no fishing for a long period (*i.e.* the equilibrium spawning biomass if $F = 0$). The SBR has a lower bound of zero. If the SBR 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.

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

Estimates of SBR for bigeye tuna in the EPO have been computed from the base case assessment. Estimates of the spawning biomass during the period of harvest are presented in Section 4.2.3. The equilibrium spawning biomass of an unexploited population is estimated to be about 204,000 t, with lower and upper confidence limits (± 2 standard deviations) of about 165,000 t and 243,000 t. The SBR that would be expected if the stock were producing the AMSY ($\mathrm{SBR}_{\mathrm{AMSY}}$) is estimated to be about 0.20.

At the beginning of January 2004, the spawning biomass of bigeye tuna in the EPO was less than that in 1975 and declining rapidly from a recent peak in 2000. At that time the SBR was about 0.14, about 32% less than the level that would be expected to produce the AMSY, with lower and upper confidence limits (± 2 standard deviations) of about 0.07 and 0.21. The estimate of the upper confidence bound is only slightly greater than the estimate of $\mathrm{SBR}_{\mathrm{AMSY}}$ (0.20), suggesting that, at the start of January 2004, the spawning biomass of bigeye in the EPO was less than the level that is required to produce the AMSY. The dramatic change from being above the $\mathrm{SBR}_{\mathrm{AMSY}}$ level to below it has been predicted by the past three assessments (Watters and Maunder 2002, Maunder and Harley 2002, and Harley and Maunder 2004).

A time series of SBR estimates for bigeye tuna in the EPO is shown in Figure 5.1. At the start of 1975, the SBR was about 0.40. This is consistent with the fact that the stock of bigeye in the EPO was being utilized for a long period prior to 1975 and that the spawning biomass is made up of older individuals that may be more quickly removed from an exploited population. The SBR increased during 1983-1987, and by the beginning of the first quarter of 1987 was 0.53. This increase can be attributed to the large cohorts that were recruited during 1982 and 1983 (Figure 4.9) and to the relatively small catches that were taken by the surface fisheries during this 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 0.23 by the first quarter of 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 1985-1995 (Figure 2.2, Fishery 9). In 2000 the SBR increased to about 0.37 by the first quarter of 2002. This increase can be attributed to the relatively high levels of recruitment that are estimated to have occurred during 1997 (Figure 4.9). During the later part of 2002 and through 2003, the SBR decreased rapidly, due to the weak year classes since 1998 and the greater catches from surface fisheries and recent increases in longline catches.

The SBR estimates are reasonably precise; the average CV of these estimates is about 0.14. The relatively narrow confidence intervals (±2 standard deviations) around the SBR estimates suggest that for most quarters during January 1975 to January 1997 the spawning biomass of bigeye in the EPO was greater than the level that would be expected to occur if the population were producing the AMSY (Section 5.3). This level is shown as the dashed line at 0.20 in Figure 5.1.

5.2. Assessment of stock status based on yield per recruit

Yield-per-recruit calculations have also been used in previous assessments of bigeye from the EPO. Watters and Maunder (2001) reviewed the concept of "critical weight," and compared the average weights of bigeye taken by all fisheries combined to the critical weight. This comparison was used to evaluate the performance of the combined fishery relative to an objective of maximizing the yield per recruit. If the average weight in the catch is close to the critical weight, the fishery is considered to be satisfactorily achieving this objective. If the combined fishery is not achieving this objective, the average weight can be brought closer to the critical weight by changing the distribution of fishing effort among fishing methods with different patterns of age-specific selectivity.

Using the natural mortality and growth curves from the base case assessment (Figures 3.1 and 4.13 respectively), the critical weight for bigeye tuna in the EPO is estimated to be about 49.8 kg. The critical age of 17 quarters is about the age at which 50% of females are assumed to be mature.

Figure 5.2 shows that the fishery was catching, on average, bigeye near the critical weight during 1975-1993, but the expansion of the floating-object fishery, which catches bigeye below the critical weight, caused the average weight of bigeye caught since 1993 to be less than the critical weight.

5.3. Assessment of stock status based on AMSY

Maintaining tuna stocks at levels capable of producing the AMSY is the management objective specified by the IATTC Convention. One definition of the AMSY is the maximum long-term yield that can be achieved under average conditions, using the current, age-specific selectivity pattern of all fisheries combined. Watters and Maunder (2001) describe how the AMSY 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 AMSY 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 AMSY-based estimates were computed with the parameter estimates from the base case assessment and estimated fishing mortality patterns averaged over 2001 and 2002. Therefore, while these AMSY-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 2004, the biomass of bigeye tuna in the EPO appears to have been about 43% less than the level that would be expected to produce the AMSY (Table 5.1). However, the recent catches are estimated to have been about 26% above the AMSY level.

If fishing mortality is proportional to fishing effort, and the current patterns of age-specific selectivity (Figure 4.5) are maintained, the level of fishing effort that is estimated to produce AMSY is about 62% of the current level of effort. Decreasing effort by 38% of its present level would increase the long-term average yield by about 8%, and would increase the spawning potential of the stock by about 156% (Figure 5.3). The results of the sensitivity analysis (Section 5.4) give the results of an assessment with a stock-recruitment relationship.

Recent catches may have been greater than the AMSY because large cohorts were recruited to the fishery throughout most of the 1995-1998 period (Figure 4.9) and current fishing mortality levels are not sustainable. The AMSY-based quantities are estimated by assuming that the stock is at equilibrium with fishing, but during 1995-1998 the stock was not at equilibrium. 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. If this is the case, the catches of bigeye taken by the surface fleet will probably decline when the large cohorts recruited during 1995-1998 are no longer vulnerable to these fisheries.

Estimates of the AMSY, and its associated quantities, are sensitive to the age-specific pattern of selectivity that is used in the calculations. The AMSY-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 AMSY 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 fishery (Table 5.3). If only the purse-seine fishery was operating the AMSY would be considerably lower (55,319 t versus 77,747 t for the base case). Interestingly, in this case, current levels of effort are about the level required to produce the AMSY. This suggests that if there was no longline fishery, current levels of purse-seine effort would be optimal. If bigeye were only caught in the longline fishery the AMSY would be almost double that estimated for all gears combined (132,426 t versus 77,747 t for the base case). To achieve this AMSY level longline effort would need to be increased by 350%. This would result in effort near the levels observed in the late 1980s and early 1990s. This suggests that, prior to the expansion of the purse-seine fishery on floating objects, the bigeye stock was probably near a level that would have produced an AMSY of over 100,000 t.

5.4. Lifetime reproductive potential

One common management objective is the conservation of spawning biomass. Conservation of spawning biomass allows an adequate supply of eggs so that future recruitment is not adversely affected. If reduction in catch is required to protect the spawning biomass, it is advantageous to know at which ages to avoid catching fish to maximize the benefit to the spawning biomass. This can be achieved by estimating the lifetime reproductive potential for each age class. If a fish of a given age is not caught it has an expected (average over many fish of the same age) lifetime reproductive potential (*i.e.* the expected number of eggs that a fish will produce over its remaining lifetime). This value is a function of the fecundity of the fish at the different stages of its remaining life and the natural and fishing mortality it is subjected to. The higher the mortality, the less likely the individual is to survive and continue reproducing. Younger individuals may appear to have more time in which to reproduce, and therefore greater lifetime reproductive potential; however, because younger individuals have a greater rate of natural mortality their remaining expected lifespan is less. An older individual, which has survived through the ages for which mortality is high, has a greater expected lifespan, and thus may have a greater lifetime reproductive potential. Mortality rates may be greater at the oldest ages and reduce the expected lifespan of these ages, thus reducing lifetime reproductive potential. Therefore, the age of maximum lifetime reproductive potential may be at an intermediate age. Calculations are made for each quarterly age-class to calculate the lifetime reproductive potential. Because current fishing mortality is included, the calculations are based on marginal changes (*i.e.* the change in egg production if one individual or one unit of weight is removed from the population), and any large changes in catch would produce somewhat different results because of changes in the future fishing mortality rates. In the calculations the average fishing mortality at age over 2001 and 2002 is used. If fishing avoids catching a single individual, the most benefit to the spawning biomass would be achieved by avoiding an individual at age 26 quarters (Figure 5.4, upper panel). These calculations suggests that restricting catch from fisheries that capture old bigeye would provide the most benefit to the spawning biomass. However, this is not a fair comparison because an individual of age 26 quarters is considerably heavier than an individual recruiting to the fishery at age 2 quarters. The calculations were repeated based on avoiding capturing one unit of weight. If fishing avoids catching a single unit of weight, the most benefit to the spawning biomass would be achieved by avoiding catching fish recruiting to the fishery at age 2 quarters (Figure 5.4, lower panel). These calculations suggest that restricting catch from fisheries that capture young bigeye would provide the most benefit to the spawning biomass. The results also suggest that reducing catch by one ton of young bigeye will protect approximately the same amount of spawning biomass as reducing the catch of old bigeye by about two tons.

5.5 MSY$_{ref}$ and SBR$_{ref}$

Section 5.3 discusses how MSY and the SBR at MSY are dependent on the selectivity of the different fisheries and the effort distribution among these fisheries. MSY can be increased or deceased applying more effort to one fishery or another. If the selectivity of the fisheries could be modified at will, there is an optimum yield that can be obtained (Global MSY Beddington and Taylor 1973; Getz 1980; Reed 1980). Maunder (2002b) showed that the optimal yield can be approximated (usually exactly) by applying a full or partial harvest at a single age. Maunder (2002b) termed this harvest MSY$_{ref}$ and suggested that two thirds of MSY$_{ref}$ may be an appropriate limit reference point (*e.g.* effort allocation and selectivity patterns should produce MSY that is at or above $^2\!/_3\, MSY_{ref}$). The two thirds suggestion was based on analyses by other investigators that indicated the best practical selectivity patterns could produce 70-80% of MSY$_{ref}$, that the yellowfin assessment at the time (Maunder and Watters 2002a) estimated that the dolphin fisheries produce about this MSY, and that two-thirds is a convenient fraction.

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

MSY$_{ref}$ is estimated to be 158,277 t and SBR$_{ref}$ is estimated to be 0.09 (Figure 5.5). The low SBR$_{ref}$ is a function of the lack of inclusion of a stock-recruitment relationship in the base case model. This is also consistent with the critical age (17 quarters) being about the age at which 50% of the females are assumed to be mature. MSY at the current effort allocation is only 49% of MSY$_{ref}$. If the fishery were exploited assuming the same selectivity patterns as the longline fisheries (Fisheries 8 and 9) MSY would be 84% of MSY$_{ref}$. More research is needed to determine if reference points based on MSY$_{ref}$ and SBR$_{ref}$ are appropriate. MSY$_{ref}$ assuming a stock-recruitment relationship is compared in Section 5.6.

5.6. 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. The base case used average fishing mortality for 2000 and 2001.

Including a stock-recruitment model with a steepness of 0.75, the SBR required if the population was producing AMSY is estimated to be at 0.30, compared to 0.20 for the base case (Table 5.1). This value does not change much for any of the other sensitivity analyses. The sensitivity analysis for steepness estimates a F multiplier considerably less than the base case (0.38), while others are greater, even the greatest F-multiplier of 0.80 (associated with the use of cannery purse-seine catch estimates) suggests that significant reductions in effort are required.

The F multiplier is much more sensitive than other management quantities to the periods for fishing mortality assumed in the calculations (Table 5.2). Assuming recent (2002 and 2003) fishing mortality estimates gives a lower F multiplier (0.50), and using the 2000 and 2001 estimated fishing mortalities gives a F multiplier of 0.87. This is because levels of fishing mortality have been estimated to be increasing over time.

If a moderate stock-recruitment relationship exists, and bigeye are only caught by the purse-seine fishery, effort for this fishery should be reduced by 40% to allow the stock to produce the AMSY (Table 5.3). If bigeye are only caught by the longline fishery, effort for this fishery should be increased by 50% to allow the stock to produce the AMSY (Table 5.3).

5.7. Summary of stock status

At the beginning of January 2004, the spawning biomass of bigeye tuna in the EPO was declining from a recent high level (Figure 5.1). At that time the SBR was about 0.14, about 32% less than the level that would be expected to produce the AMSY, with lower and upper confidence limits (± 2 standard deviations) of about 0.07 and 0.21. The estimate of the upper confidence bound is only slightly greater than the estimate of SBR_{AMSY} (0.20), suggesting that, at the start of January 2004, the spawning biomass of bigeye in the EPO was less than the level that is required to produce the AMSY. The dramatic change from being above the SBR_{AMSY} level to below it has been predicted by the past three assessments.

The relatively narrow confidence intervals (±2 standard deviations) around the SBR estimates suggest that for most quarters during January 1975 to January 1997 the spawning biomass of bigeye in the EPO was probably greater than the level that would be expected to occur if the population were producing the AMSY. This level is shown as the dashed line at 0.20 in Figure 5.1.

Recent catches are estimated to have been about 26% above the AMSY 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 that is estimated to produce AMSY is about 62% of the current level of effort. Decreasing the effort to 62% of its present level would increase the long-term average yield by 8% and would increase the spawning potential of the stock by about 156%. The AMSY 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 close to the critical size.

All analyses considered suggest that at the start of 2004 the spawning biomass was below the level that would be present if the stock were producing the AMSY (Tables 5.1 and 5.2). AMSY and the fishing mortality (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 the level that will produce the AMSY.

6. SIMULATED EFFECTS OF FUTURE FISHING OPERATIONS

A simulation study was conducted to gain further understanding as to how, in the future, hypothetical changes in the amount of fishing effort exerted by the surface fleet might simultaneously affect the stock of yellowfin tuna in the EPO and the catches of 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 new method based on the normal approximation to the likelihood profile has been applied. The previously-used method (Maunder and Watters 2001) does not take parameter uncertainty into consideration. It considers only uncertainty about future recruitment. A substantial part of the total uncertainty in predicting future events is caused by uncertainty in the estimates of the model parameters and current status. This uncertainty should be considered in any forward projections. Unfortunately, the appropriate methods are often not applicable to models as large and computationally intense as the 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 5 years with effort data equal to the effort for 2003, by quarter scaled by the effort weighted average catchability for 2001 and 2002. No catch or length-frequency data are included for these years,. The recruitments for the ten years are estimated as in the assessment model with a lognormal penalty with a standard deviation of 0.6. Normal approximations to the likelihood profile are generated for SBR, surface catch, and longline catch. We also use the Maunder and Watters (2001) method to compare alternative effort scenarios to the base case assumptions.

6.1. Assumptions about fishing operations

6.1.1. Fishing effort

Several future projection studies were carried out to investigate the influence of different levels of fishing effort on the stock biomass and catch. All methods assumed that catchability is equal to the average catchability, by quarter, in 2001 and 2002. The average was weighted by the effort to ensure that extreme values of catchability from years where effort was restricted due to management did not overly influence the catchability used in the future projections.

The scenarios investigated were:

a. Effort for each year in the future equal to the effort in 2003 by quarter;
b. The same as (a) except that effort for the third quarter was reduced by 50% (a six week closure) for all surface fisheries except pole and line[1];
c. Effort was reduced by 25 or 50% across all four quarters for all purse-seine fisheries.
d. The same as (c) except the effort reductions were for longline fisheries.
e. Simultaneous reductions of 25 or 50% for both purse-seine and longline fisheries.

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 and 9). There is probably more uncertainty in the future levels of these outcome variables than suggested by the results presented in Figures 6.1-6.7. The amount of uncertainty is probably underestimated because the simulations were conducted under the assumption that the parameters estimated by and used in the stock assessment model accurately describe the dynamics of the system. As mentioned in Section 4, this assumption is not likely to be fulfilled.

6.2.1 Current effort levels

Projections were undertaken assuming that effort would remain at 2003 levels. As this was the year where conservation measures likely had the least impact on fishing effort (S J Harley unpublished analysis), this scenario can be compared to the predictions from the alternative management scenarios described in 6.1.1.

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[1] The 2003 Resolution on Conservation of tuna closes the purse-seine fishery from 1 August 2004 until 11 September 2004.

Figure 5.1 showed that SBR is estimated to have been declining rapidly in recent years. This decline is attributed to both poor recruitment and excessive levels of fishing mortality. If recent levels of effort and catchability continue, SBR is predicted to decline further until about 2008 and remain at a very low level (0.04) (Figure 6.1). This trend is also estimated for total biomass (Figure 6.2).

Purse-seine catches are predicted to decline by about 30% during the projection period (Figure 6.3, top panel). This is because fishing mortality levels are too high and result in suboptimal yields. The catches would decline further is a stock-recruitment relationship was included due to reductions in the levels of recruitment that contribute to purse-seine catches.

Longline catches are predicted to decline to very low levels under current effort (Figure 6.3, bottom panel). This is because few fish are predicted to make it through the purse-seine fishery, so the biomass of fish vulnerable to longline gears will be very low. These low longline catches have important implications for the predicted benefits of further reductions in longline effort on the rate of rebuilding of the population. This will be discussed in 6.2.3.

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 ability of fishers to catch bigeye increases at low abundance, catches will, in the short term, be larger than those predicted here. Also, if longline vessels chose to target smaller bigeye, their catches will also increase in the short term.

6.2.2. 2003 Resolution on the Conservation of tuna in the EPO

The 2003 Resolution on the Conservation of Tuna in the EPO imposes restrictions on purse-seine effort and longline catches for 2004. For purse-seine fisheries, a six week closure during the third quarter of the year is imposed and longline catches are not to exceed 2001 levels. To assess the utility of these management actions we projected the population forward ten years assuming that the conservation measures would be implemented each year.

Comparison of the predicted SBR with no closure and that predicted with the restrictions from the resolution show very little difference. With the restrictions SBR still declines to very low levels (0.06) and shows no sign of recovering to AMSY levels (Figure 6.4). In this simulation longline catches did not reach close to 2001 levels, so the longline part of the 2003 Resolution was not invoked. This is because 2003 effort levels are insufficient to obtain 2001 catches due to the large reduction in biomass vulnerable to longline gears. We did not perform an analysis where longline effort increased to obtain these catches, but such an analysis would show even greater reductions in SBR.

Clearly the reductions in fishing mortality that could occur as result of the 2003 Resolution are insufficient to allow the population to rebuild to levels that would allow it to support the AMSY. This is supported by the *F* multiplier estimates that suggest that effort reductions of 40% (or larger is a stock-recruitment relationship exists) are necessary (Table 5.1).

6.2.3 Alternative effort restrictions

A number of alternative scenarios were considered to determine what levels of effort restrictions could allow the population to rebuild toward the level that would support the AMSY in a reasonable time frame. This analysis does not include any assumptions about how these effort reductions would occur and a number of management actions are possible, *e.g.* time/area closures, catch limits, restrictions on fishing operations. Effective effort, in terms of bigeye tuna, could be reduced in several ways. For example, if purse-seine vessels could change their fishing practices in such a way that bigeye catches were reduced by 50%, the effort reductions could be achieved without time/area restrictions.

We compared scenarios where longline and purse-seine effort was reduced by 25 or 50%, both separately and together. This provided insights into the interactions of the two gears.

Reductions in longline effort by 25 and 50% are predicted to have negligible impacts on SBR (Figure 6.5 and Table 6.1) and purse-seine catches (Figure 6.6) while reducing longline catches by about 20% (Figure

6.7). The minor impacts of longline reductions can be attributed to the low catches predicted for them (Figure 6.3). Reductions in purse-seine effort by 25 and 50% are predicted to have a greater impact on SBR than the longline reductions. This is consistent with the observation that the purse-seine fishery currently has the greatest impact on the stock (Figure 4.12). SBR is predicted to increase to 0.12 if purse-seine effort is reduced by 50% (Figure 6.5 and Table 6.1). This reduction is associated with an increase in both purse-seine and longline catches (Figures 6.6 and 6.7 and Table 6.1) as fishing mortality is moving closer to AMSY levels.

When effort for both fleets is reduced by 25% the effects are still negligible indicating that greater reductions are necessary to rebuild the stock (Figure 6.5 and Table 6.1). Reducing both fleets by 50% gives much greater benefits that reducing each fishery separately (Figure 6.5). SBR is predicted to move close to the AMSY level by 2014 if overall effort is reduced by 50% (Figure 6.5). Purse-seine catches are higher if effort for both fleets is reduced, but longline catches are higher if only purse-seine effort is reduced (Figures 6.6 and 6.7 and Table 6.1).

6.3 Summary of the simulation results

The poor recruitment since 1998 and high levels of fishing mortality are predicted to result in very low levels of SBR and longline catches for the next few years. Under current effort levels, SBR is predicted to decline to very low levels and remain there. Thus, the population is unlikely to rebuild unless fishing mortality levels are greatly reduced or recruitment is above average for a number of consecutive years.

The impacts of the 2003 Resolution on the conservation of tuna are estimated to be small and insufficient to allow the stock to rebuild. Also, longline catches are not predicted to reach 2001 levels under 2003 effort due to large reductions predicted in vulnerable biomass.

Restrictions on longline effort alone are predicted to be less effective than restrictions on purse-seine effort alone, with simultaneous restrictions of both gears predicted to have the most benefit. Reductions of effort of around 50% are likely to be necessary to allow the population to rebuild within ten years to levels that would support the AMSY. These reductions in effective effort on bigeye tuna could be achieved in a number of ways in addition to time/area closures that have been used in recent years to restrict fishing mortality.

These simulations are based on the assumption that selectivity and catchability patterns will not change in the future. Changes in targeting practices or increasing vulnerability 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 data for 2003 and new data collected during 2004 and 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, we will attempt to obtain data for recently developed and growing fisheries.

The collection and analysis of data from otoliths of bigeye caught in the EPO, which is currently in progress, will help determine mean length at age and variation in length at age.

7.2. Refinements to the assessment model and methods

The IATTC staff intends to continue to develop the A-SCALA method and further refine the stock assessment of bigeye tuna in the EPO. In particular, the staff plans to extend the model so that information obtained on mixing rates and fishing mortality from the tagging studies that the IATTC staff has conducted can be incorporated into the A-SCALA analyses. The staff also intends to reinvestigate indices of bigeye abundance from the CPUEs of purse-seiners fishing in the EPO. If this work is successful, the results will, as far as possible, be integrated into future stock assessments.

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

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

Collaboration with SPC on the Pacific-wide bigeye model will continue.

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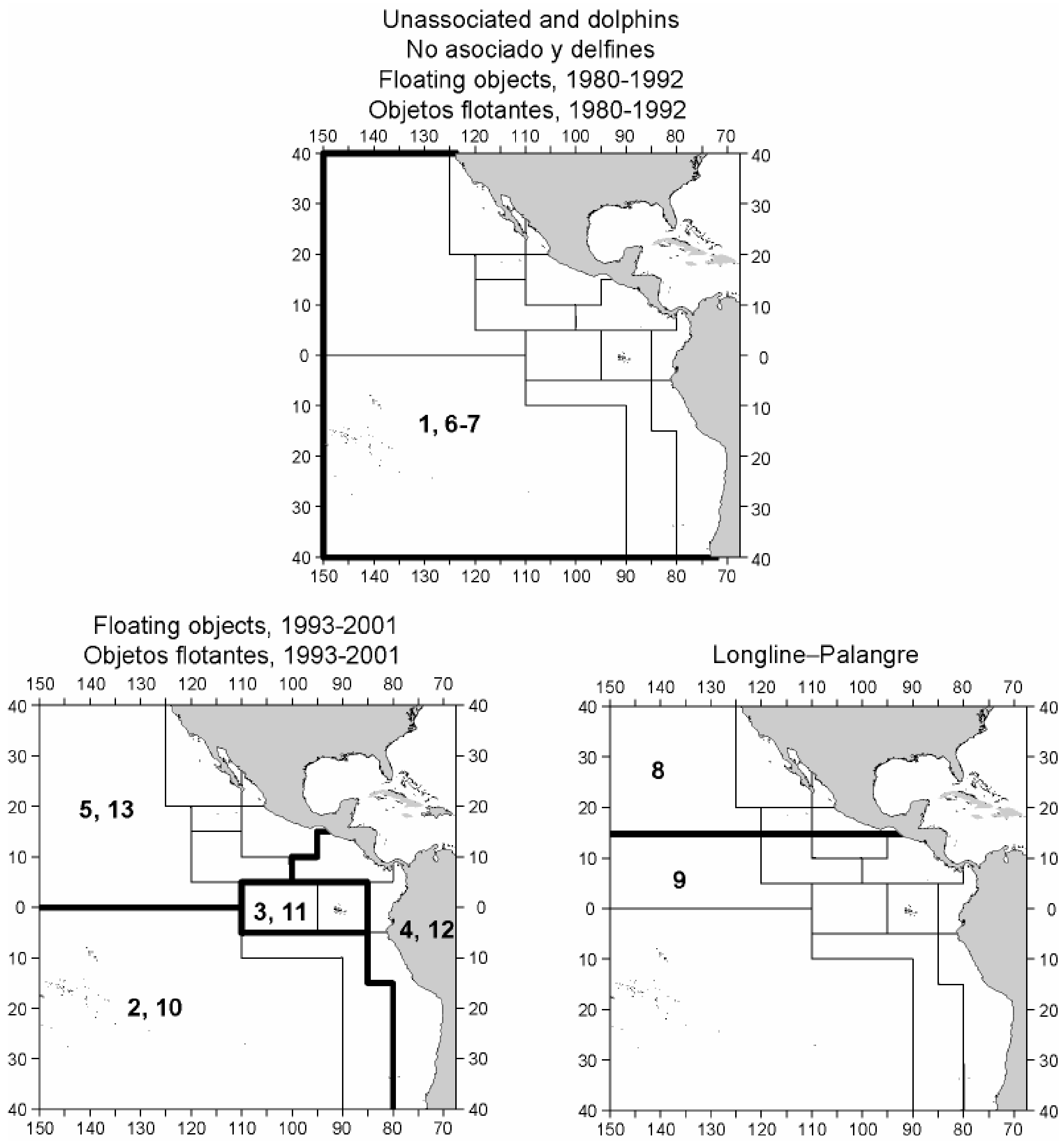

FIGURE 2.1. Spatial extents of the fisheries defined for the stock assessment of bigeye tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the heavy lines the boundaries of each fishery defined for the stock assessment, and the bold numbers the fisheries to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

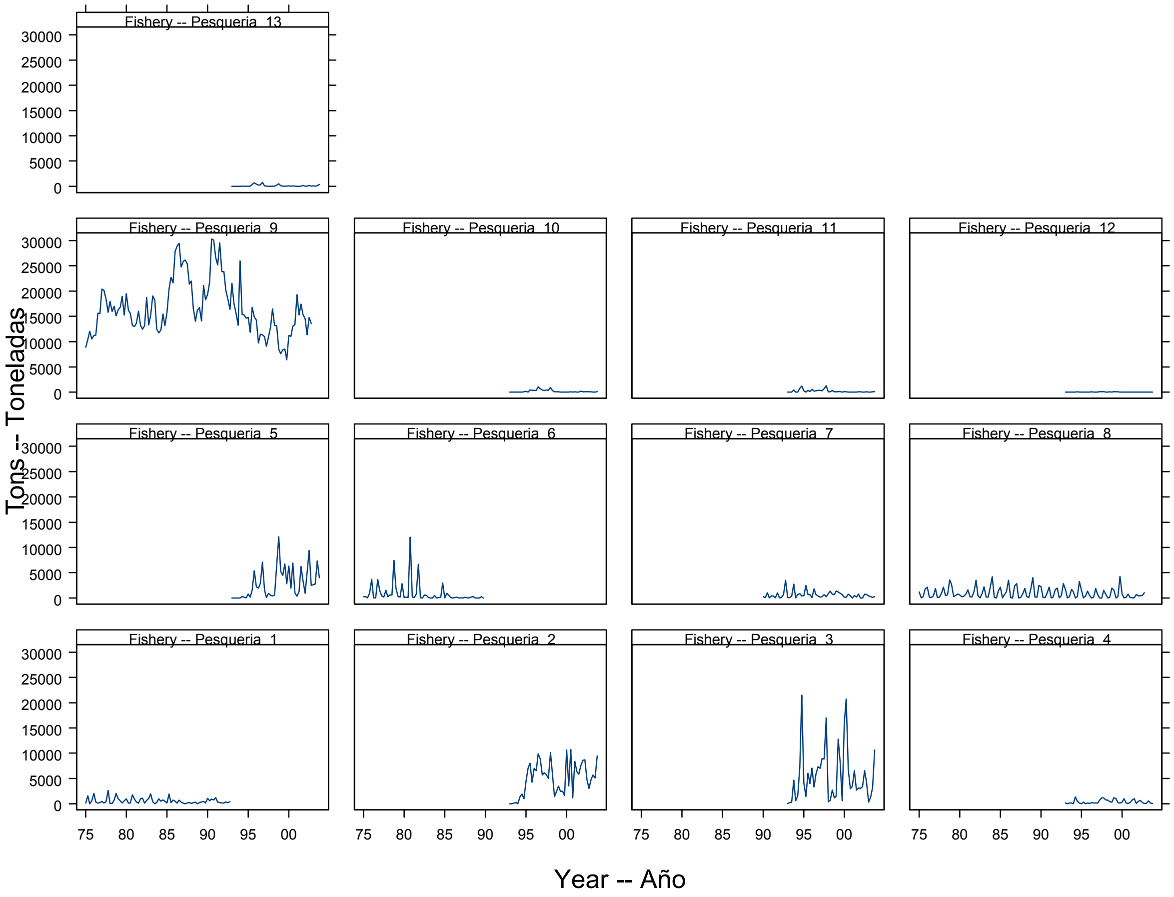

FIGURE 2.2. Catches taken by the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). Since the data were analyzed on a quarterly basis, there are four observations of catch for each year. Although all the catches are displayed as weights, the stock assessment model uses catch in numbers of fish for Fisheries 8 and 9. Catches in weight for Fisheries 8 and 9 are estimated by multiplying the catches in numbers of fish by estimates of the average weights.

FIGURA 2.2. Capturas realizadas por las pesquerías definidas para la evaluación de la población de atún patudo en el OPO (Tabla 2.1). Ya que los datos fueron analizados por trimestre, hay cuatro observaciones de captura para cada año. 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.

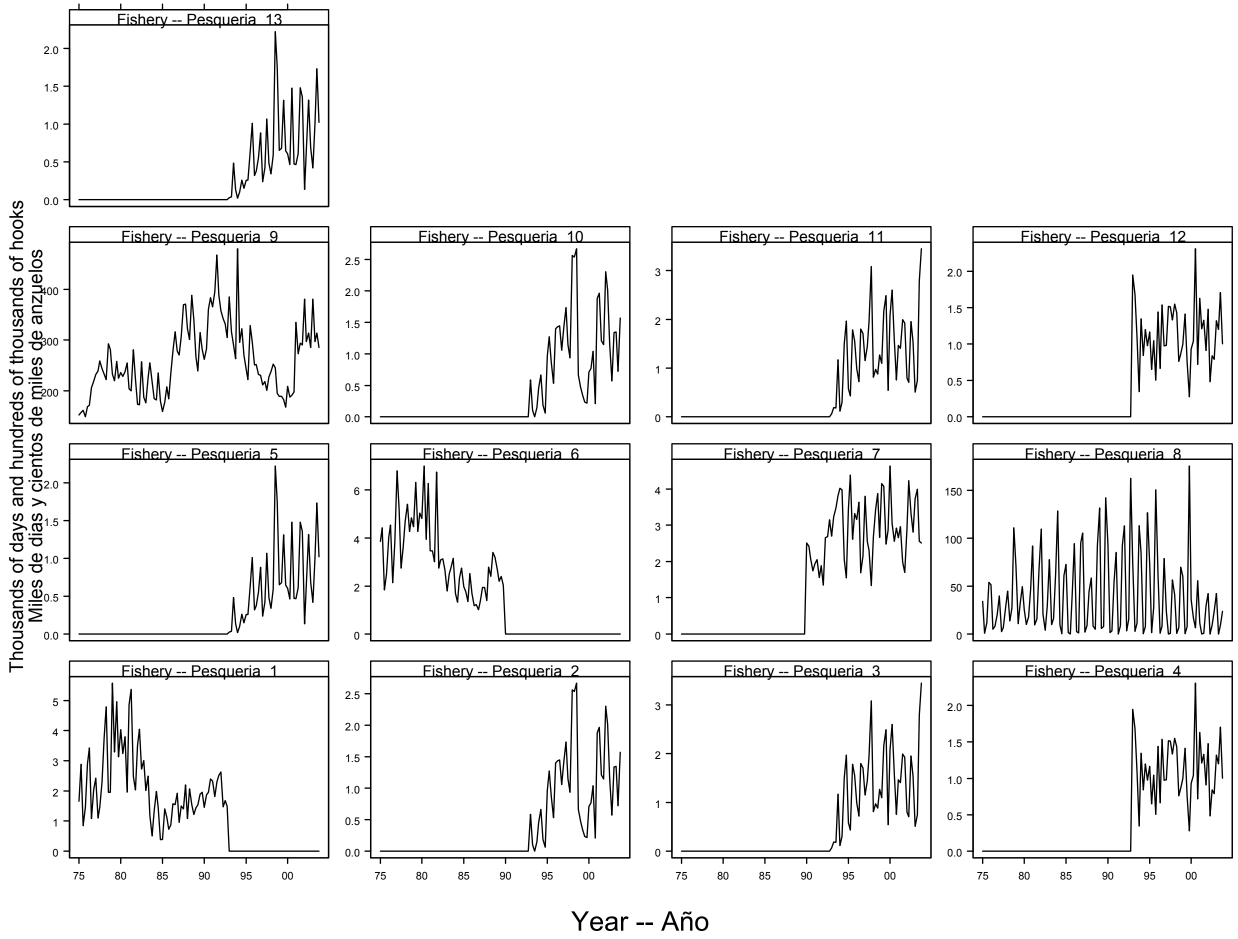

FIGURE 2.3. Fishing effort exerted by the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of effort for each year. The effort for Fisheries 1-7 and 10-13 is in days fished, and that for Fisheries 8 and 9 is in standardized numbers of hooks. Note that the vertical scales of the panels are different.

FIGURA 2.3. Esfuerzo de pesca ejercido por las pesquerías definidas para la evaluación de la población de atún patudo en el OPO (Tabla 2.1). Ya que se analizaron los datos por trimestre, hay cuatro observaciones de esfuerzo para cada año. Se expresa el esfuerzo de las Pesquerías 1-7 y 10-13 en días de pesca, y el de las Pesquerías 8 y 9 en número estandardizado de anzuelos. Nótese que las escalas verticales de los recuadros son diferentes.

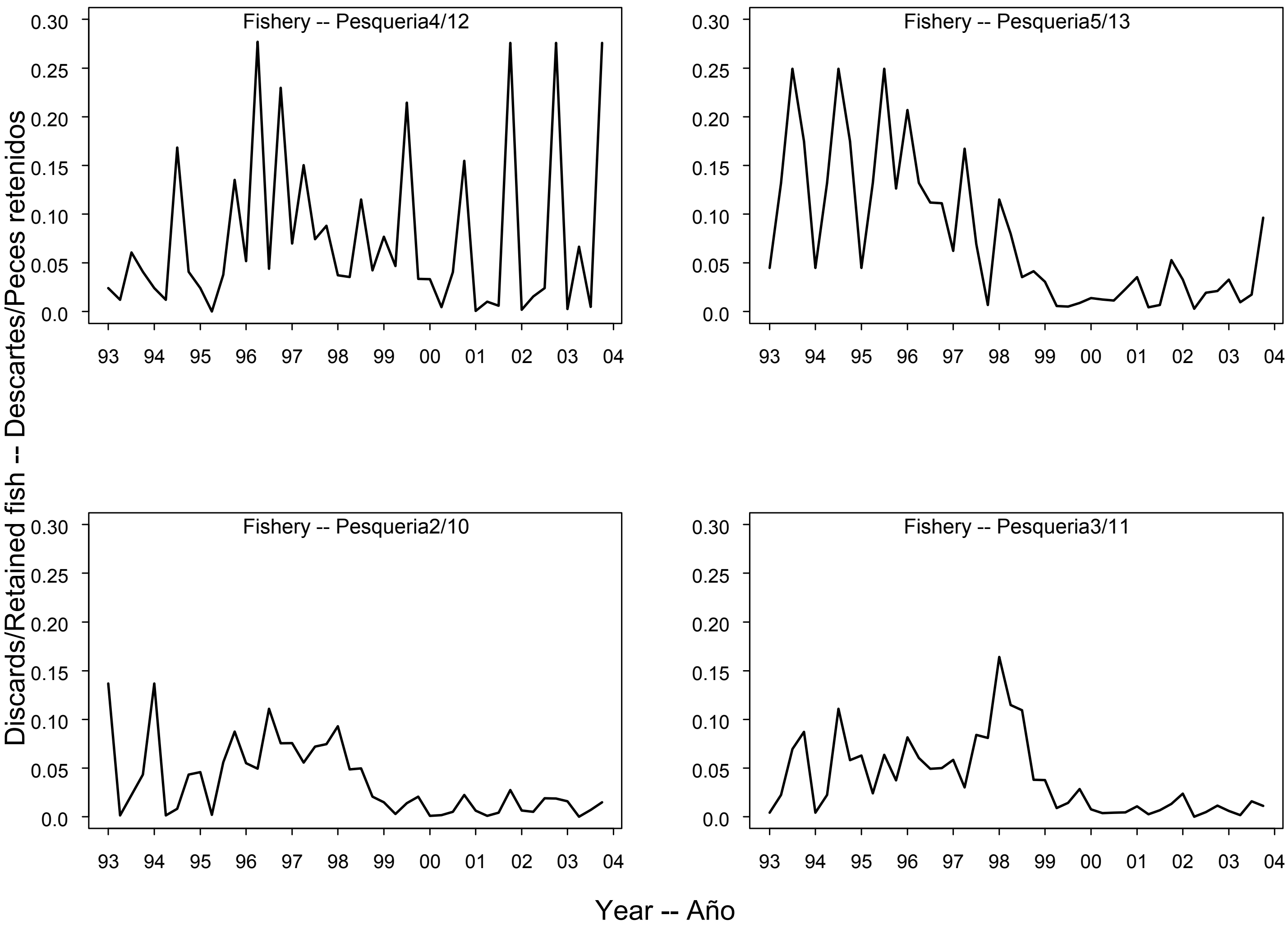

FIGURE 2.4. Weights of discarded bigeye tuna as proportions of the retained quarterly catches for the four floating-object fisheries. Fisheries 2, 3, 4, and 5 are the "real" fisheries, and Fisheries 10, 11, 12, and 13 are the corresponding discard fisheries.

FIGURA 2.4. Peso de atún patudo descartado como proporción de las capturas retenidas trimestrales 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 son las pesquerías de descarte correspondientes.

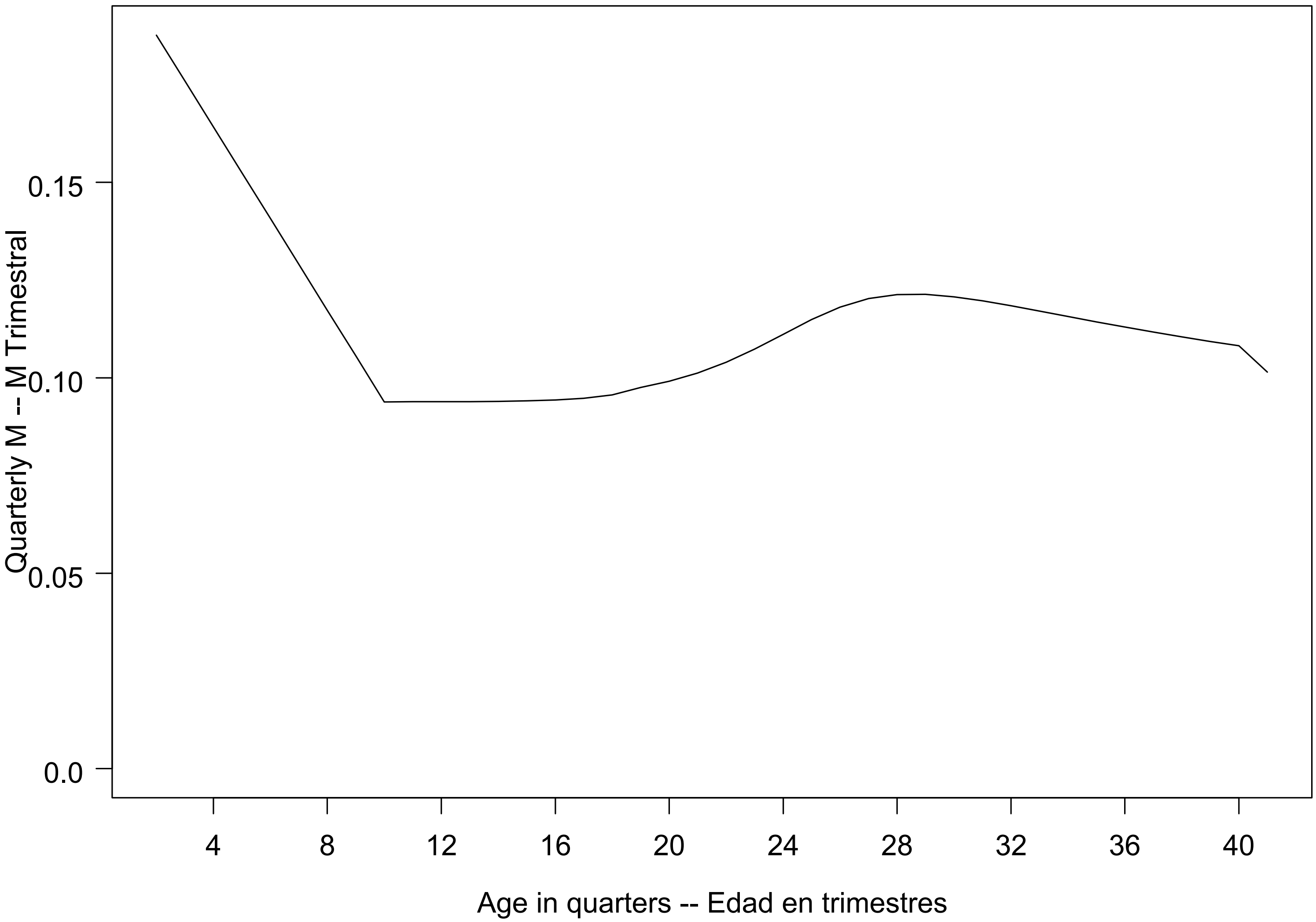

FIGURE 3.1. Quarterly natural mortality (*M*) rates used for the base case assessment of bigeye tuna in the EPO.
FIGURA 3.1. Tasas de mortalidad natural (*M*) trimestral usadas para la evaluación del caso base de atún patudo en el OPO.

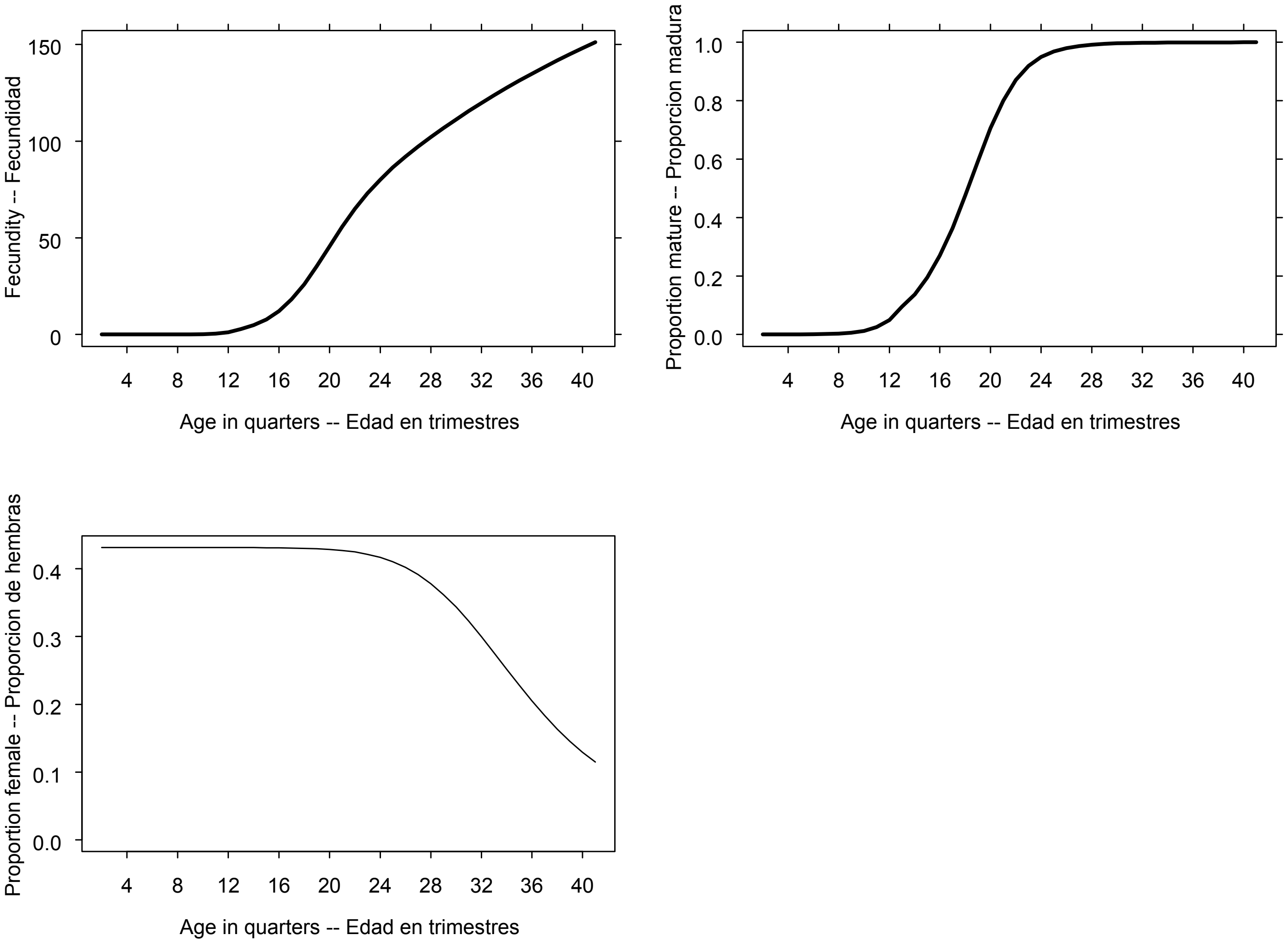

FIGURE 3.2. Age-specific fecundity of bigeye tuna (top left panel), age-specific proportion of females that are mature (top right panel), and age-specific proportion of females in the population (bottom panel), as assumed in the base case model and in estimation of natural mortality.
FIGURA 3.2. Fecundidad de atún patudo por edad (recuadro superior), proporción de hembras maduras por edad (recuadro medio), y proporción de hembras en la población por edad (recuadro inferior), supuestas en el modelo de caso basa y en la estimación de mortalidad natural.

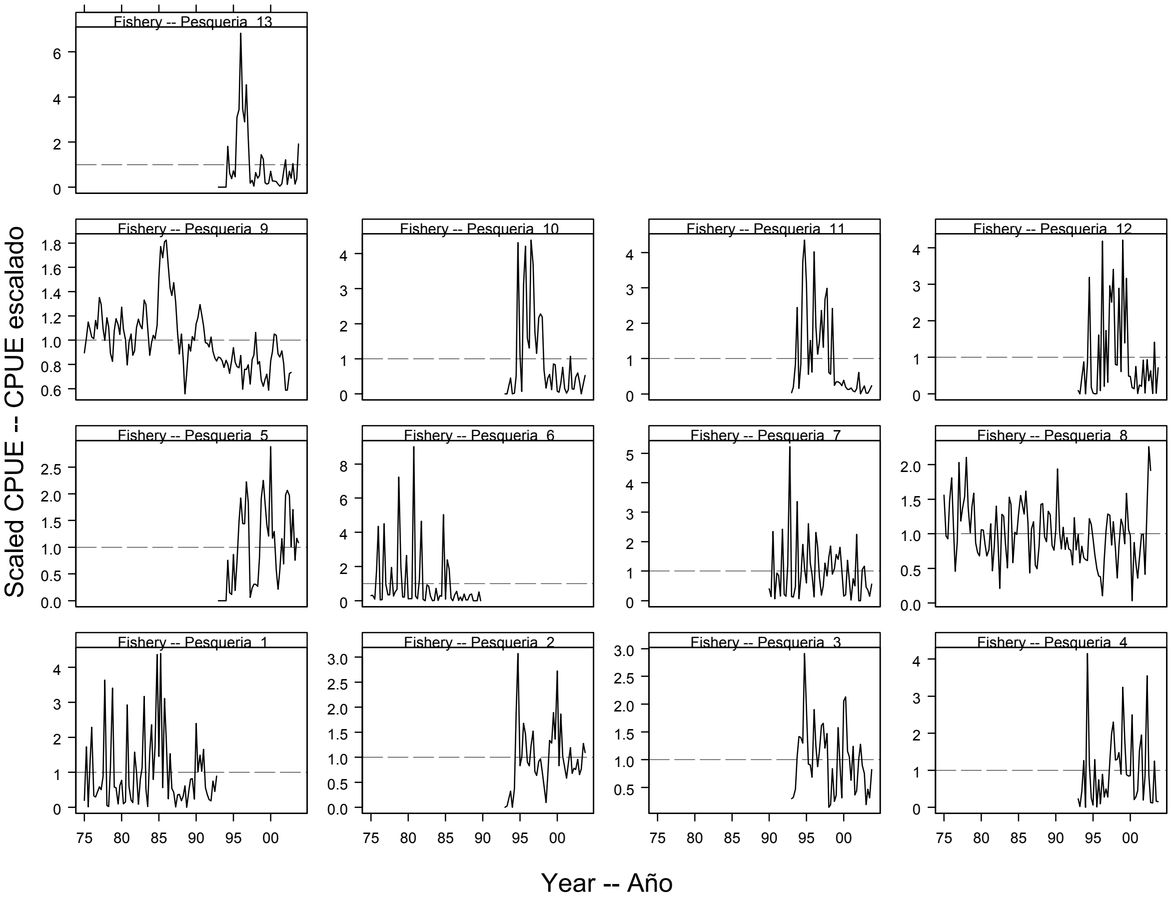

FIGURE 4.1. CPUEs of the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of CPUE for each year. The CPUEs for Fisheries 1-7 and 10-13 are in kilograms per day fished, and those for Fisheries 8 and 9 are 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 4.1. CPUE logradas por las pesquerías definidas para la evaluación de la población de atún patudo en el OPO (Tabla 2.1). Ya que se resumieron los datos por trimestre, hay cuatro observaciones de CPUE para cada año. Se expresan las CPUE de las Pesquerías 1-7 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.

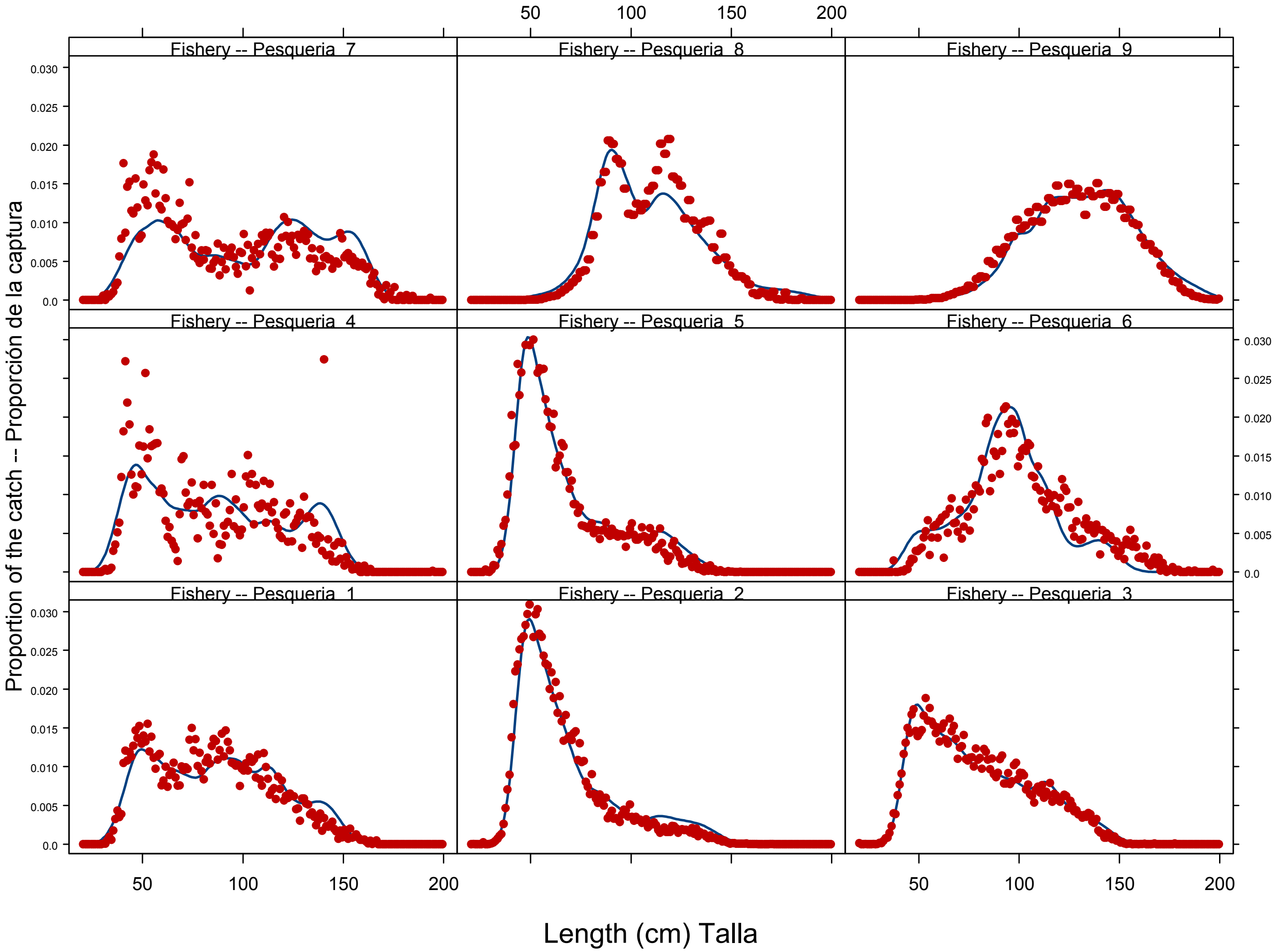

FIGURE 4.2. Average observed (dots) and predicted (curves) size compositions of the catches taken by the fisheries defined for the stock assessment of bigeye tuna in the EPO.

FIGURA 4.2. Composición media por tamaño observada (puntos) y predicha (curvas) de las capturas realizadas por las pesquerías definidas para la evaluación de la población de atún patudo en el OPO.

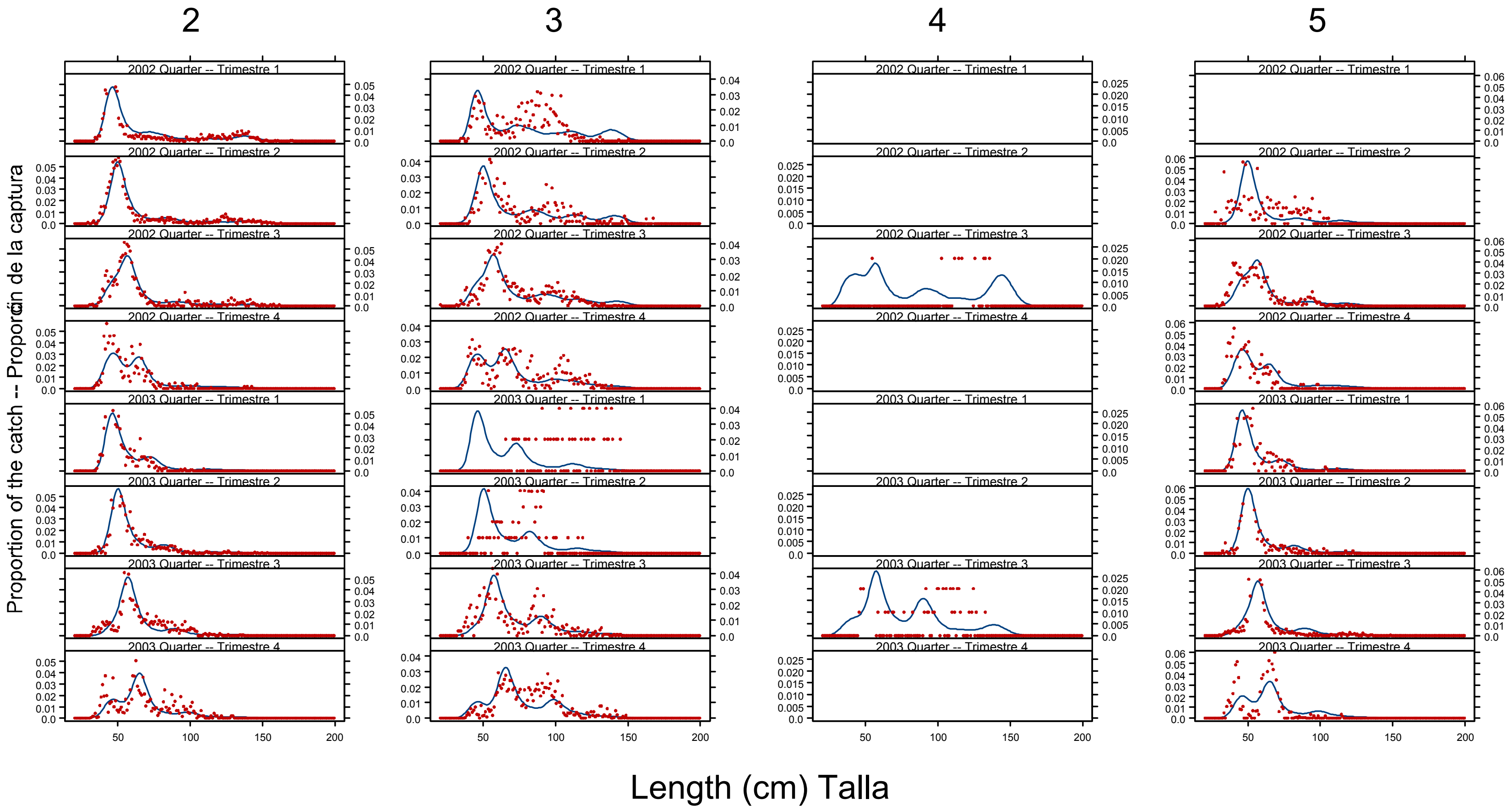

FIGURE 4.3. Recent size compositions of the catches of bigeye tuna taken by Fisheries 2-5. The dots are observations, and the curves are predictions from the base case assessment.

FIGURA 4.3. Composiciones por tamaño recientes de las capturas de atún patudo de las pesquerías que operan en el OPO. Los puntos son observaciones y las curvas son las predicciones de la evaluación del caso base.

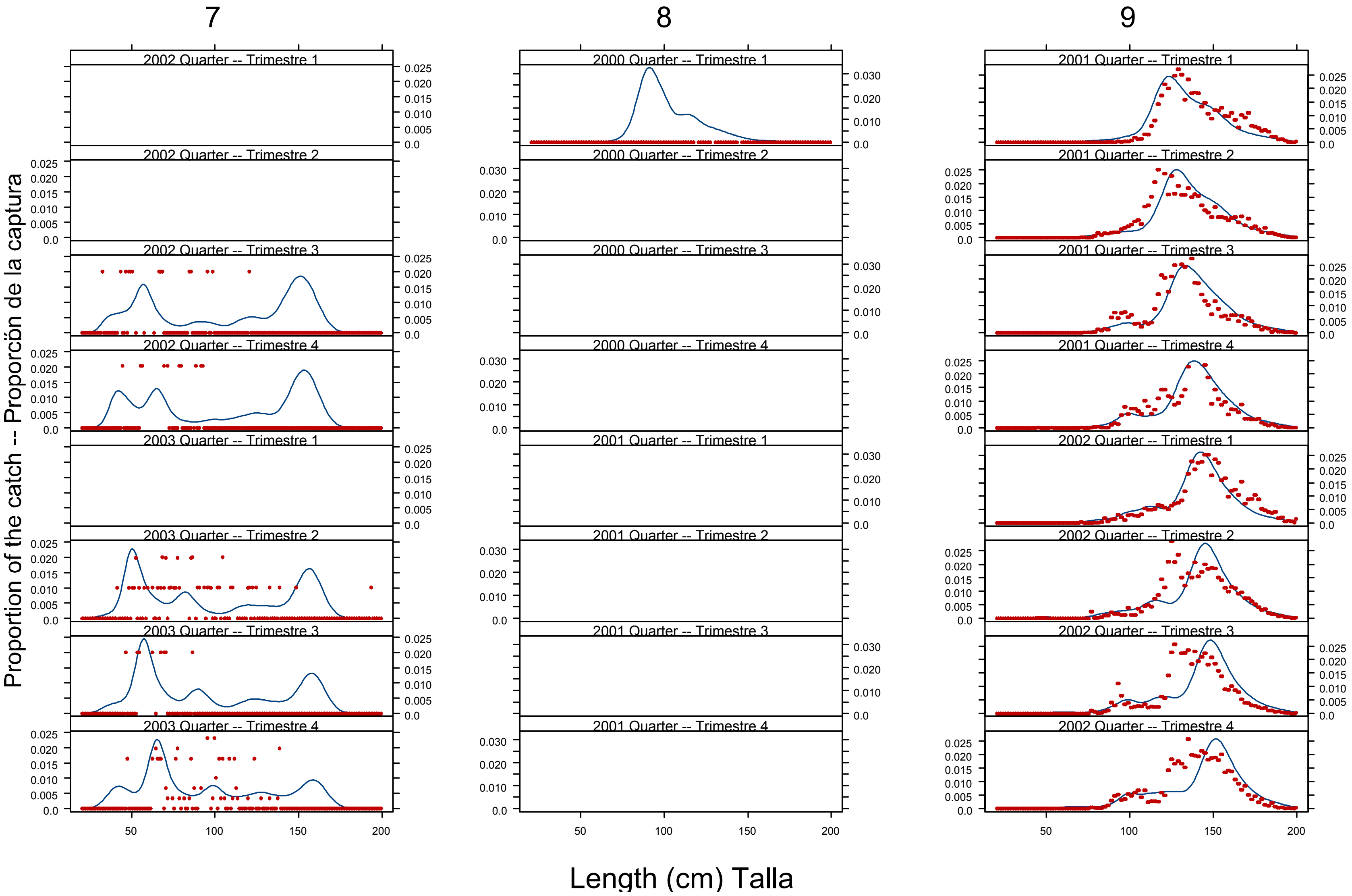

FIGURE 4.3. (continued)
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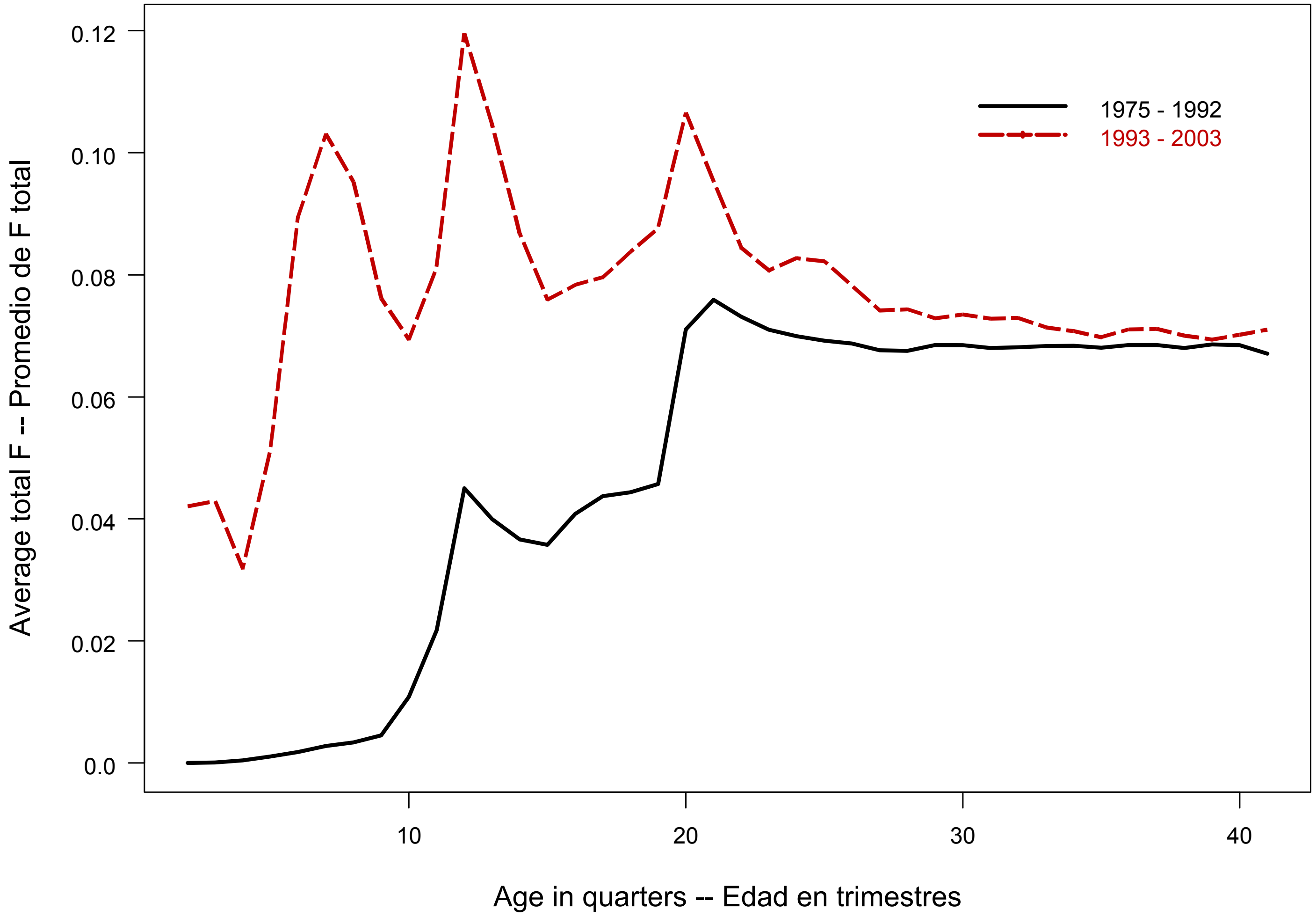

FIGURE 4.4. Average total quarterly fishing mortality at age on bigeye tuna in the EPO. The curve for 1975-1992 displays averages for the period prior to the expansion of the floating-object fisheries, and that for 1993-2003 displays averages for the period since this expansion.

FIGURA 4.4. Mortalidad por pesca trimestral total media a edad de atún patudo en el OPO. La curva de 1975-1992 indica los promedios para el período previo a la expansión de la pesquería sobre objetos flotantes, y la curva de 1993-2003 los promedios para el período desde dicha expansión.

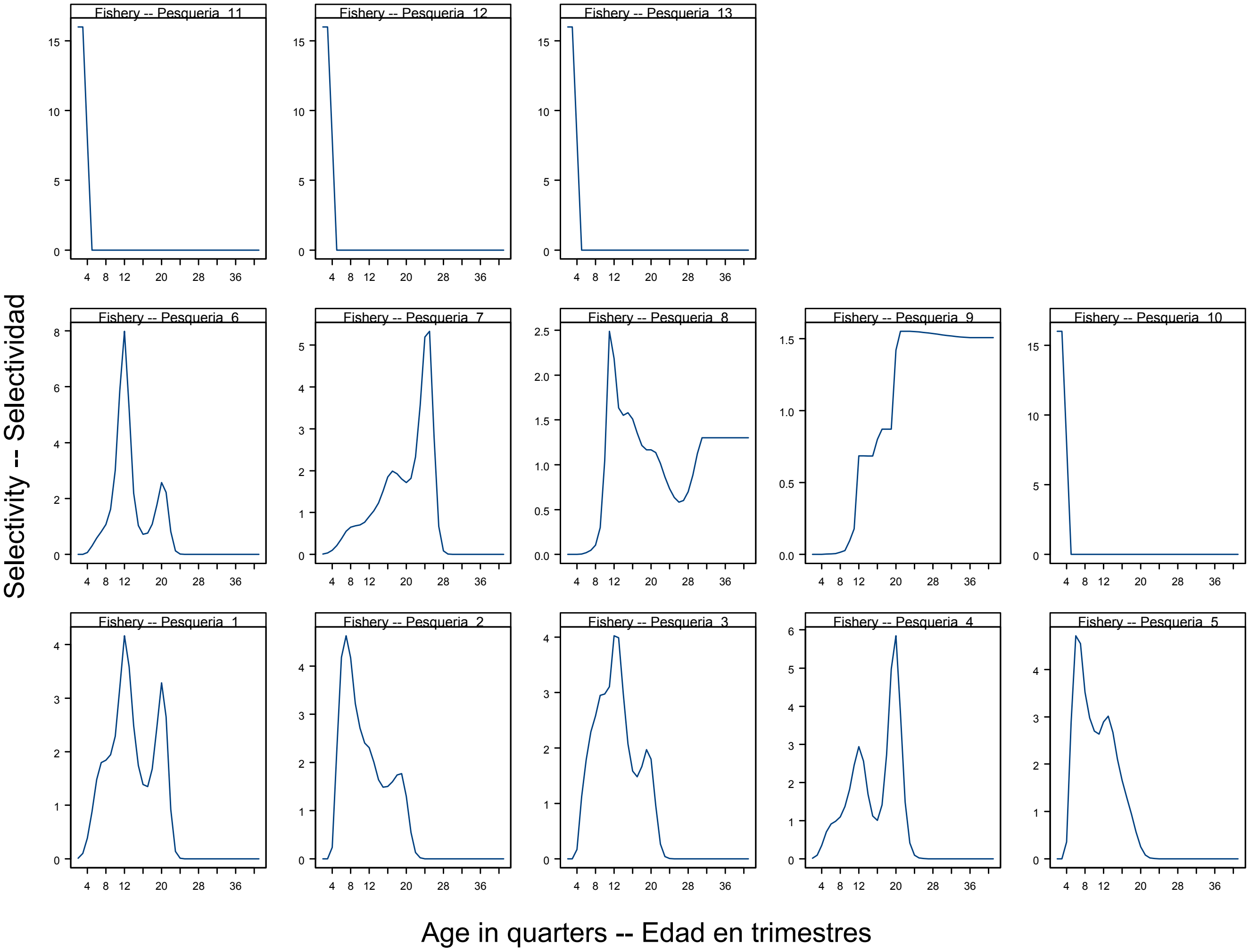

FIGURE 4.5. Selectivity curves for the 13 fisheries that take bigeye tuna in the EPO. The selectivity curves for Fisheries 1 through 9 were estimated with the A-SCALA method, and those for Fisheries 10-13 are based on assumptions.

FIGURA 4.5. Curvas de selectividad para las 13 pesquerías que capturan atún patudo en el OPO. Se estimaron las curvas de selectividad de las Pesquerías 1 a 9 con el método A-SCALA; las de las Pesquerías 10-13 se basan en supuestos.

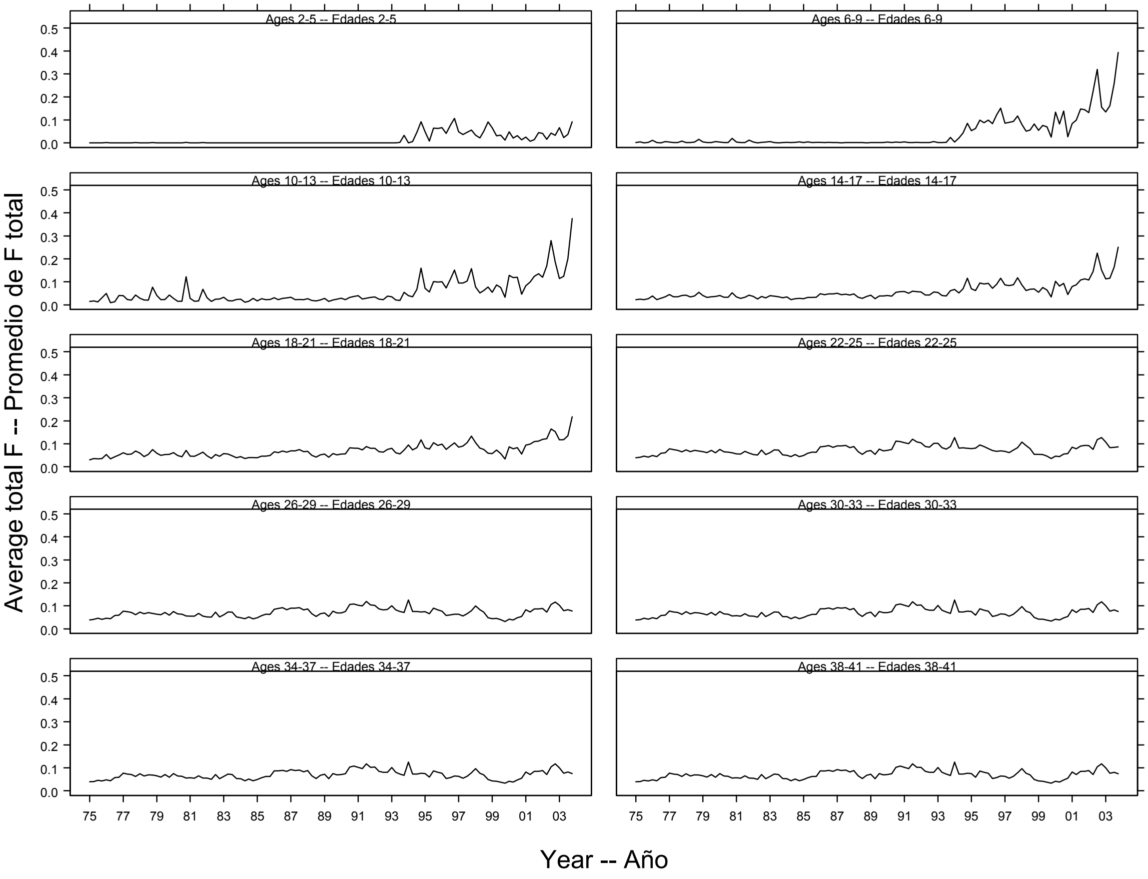

FIGURE 4.6a. Time series of average total quarterly fishing mortality on bigeye tuna that have been recruited to the fisheries of the EPO. Each panel illustrates an average of four quarterly fishing mortality vectors that affected the fish that were within the range of ages indicated in the title of each panel. For example, the trend illustrated in the upper-left panel is an average of the fishing mortalities that affected fish that were 2-5 quarters old.

FIGURA 4.6a. Series de tiempo de la mortalidad por pesca trimestral total media de atún patudo reclutado a las pesquerías del OPO. Cada recuadro ilustra un promedio de cuatro vectores trimestrales de mortalidad por pesca que afectaron los peces de la edad indicada en el título de cada recuadro. Por ejemplo, la tendencia ilustrada en el recuadro superior izquierdo es un promedio de las mortalidades por pesca que afectaron peces de entre 2 y 5 trimestres de edad.

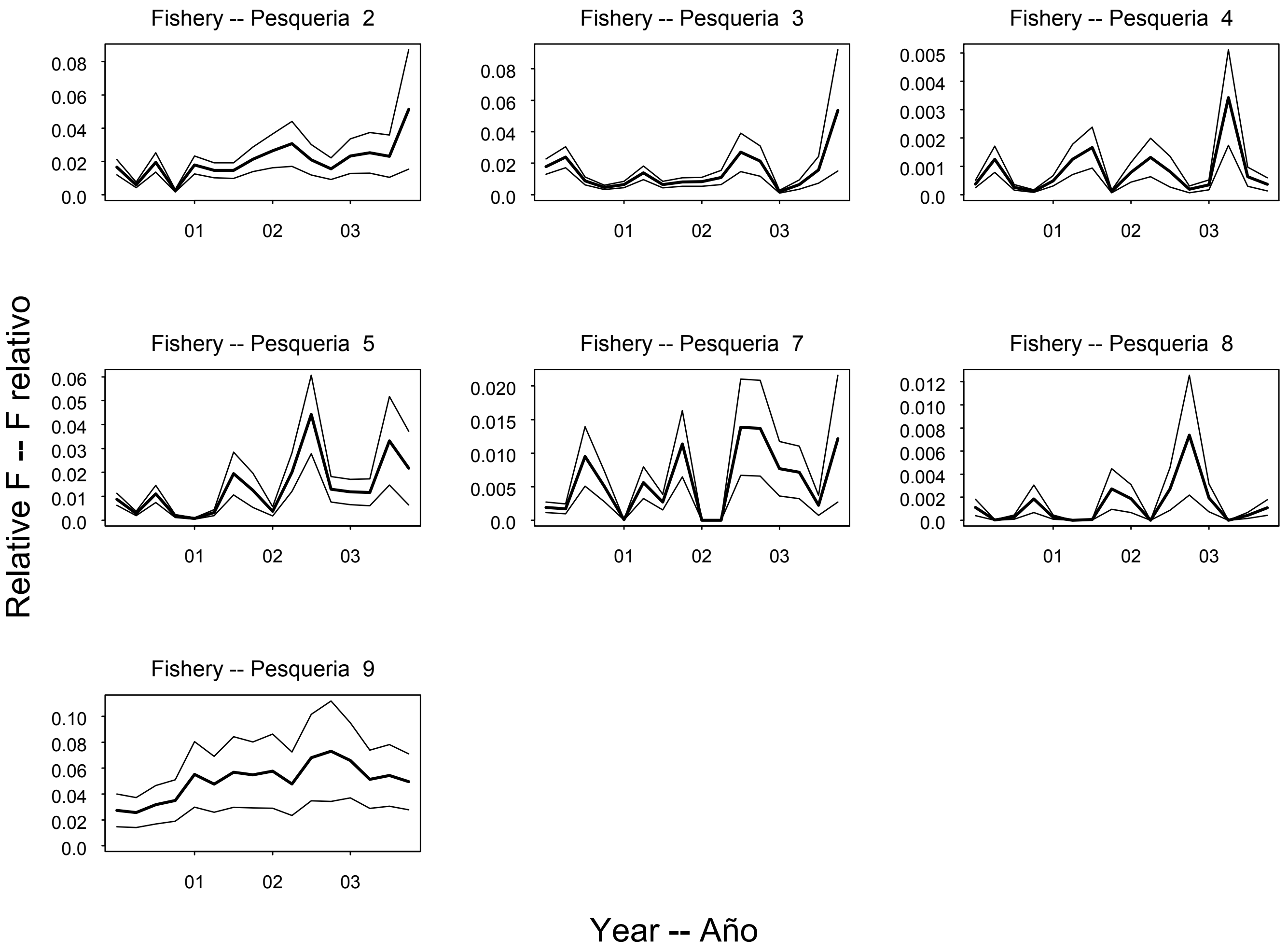

FIGURE 4.6b. Gear- and year-specific fishing mortality scalars (heavy lines) for bigeye tuna for the most recent 16 quarters for fisheries currently operating in the EPO. The upper and lower 95% confidence intervals are indicated by thin lines.

FIGURA 4.6b. Escaladores de mortalidad por pesca de atún patudo por arte y por año (líneas gruesas) correspondientes a los 16 trimestres más recientes para pesquerías que operan actualmente en el OPO. Las líneas delgadas indican los intervalos de confianza de 95% superiores e inferiores.

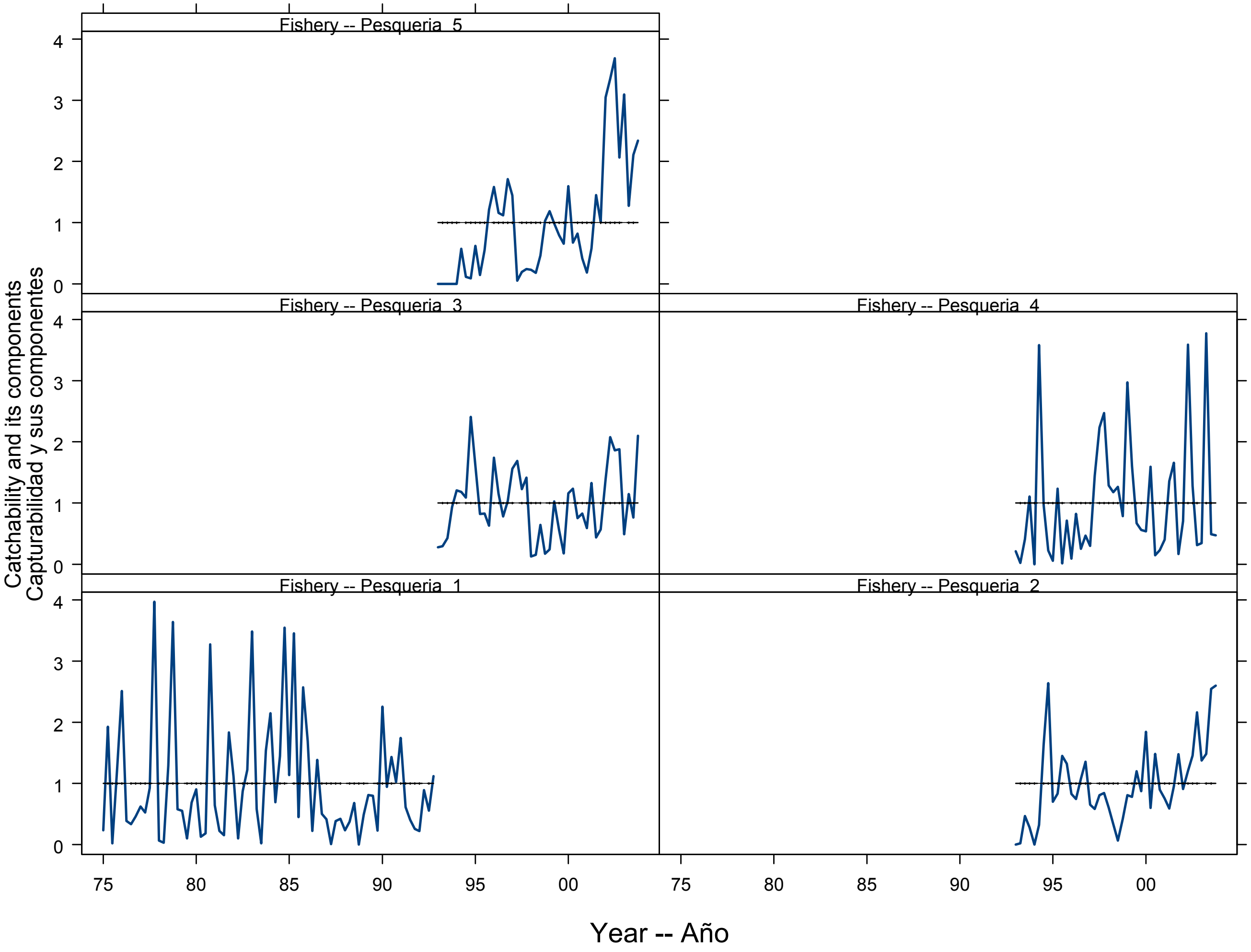

FIGURE 4.7. Trends in catchability (*q*) for the 13 fisheries that take bigeye tuna in the EPO. The estimates are scaled to the first estimate of *q* for each fishery (dashed line). The heavy lines include random effects, and illustrate the overall trends in catchability.

FIGURA 4.7. Tendencias en capturabilidad (*q*) para las 13 pesquerías que capturan atún patudo en el OPO. Se escalan las estimaciones a la primera estimación de *q* para cada pesquería (línea de trazos). Las líneas gruesas incluyen efectos aleatorios e ilustran las tendencias generales en capturabilidad.

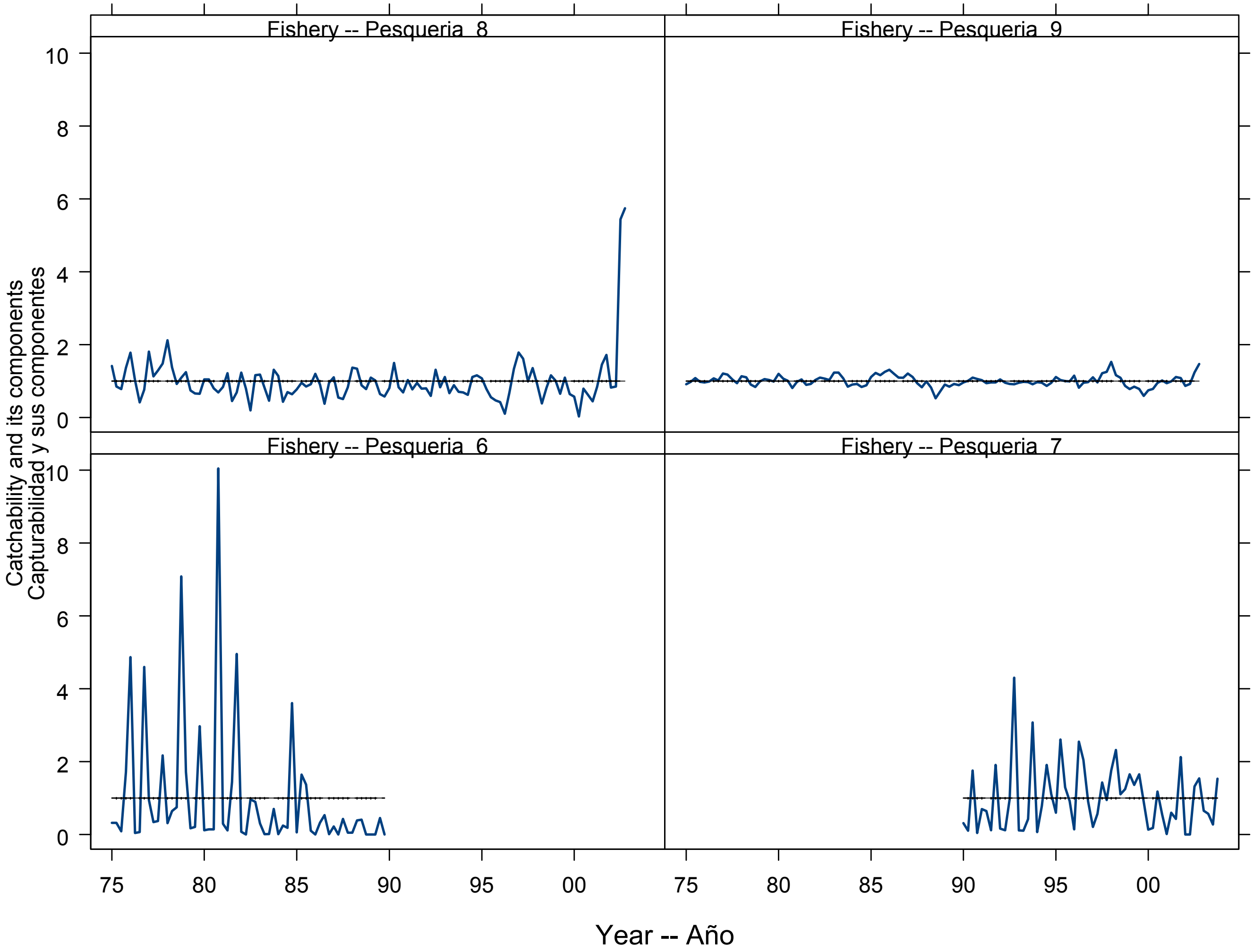

FIGURE 4.7. (continued)
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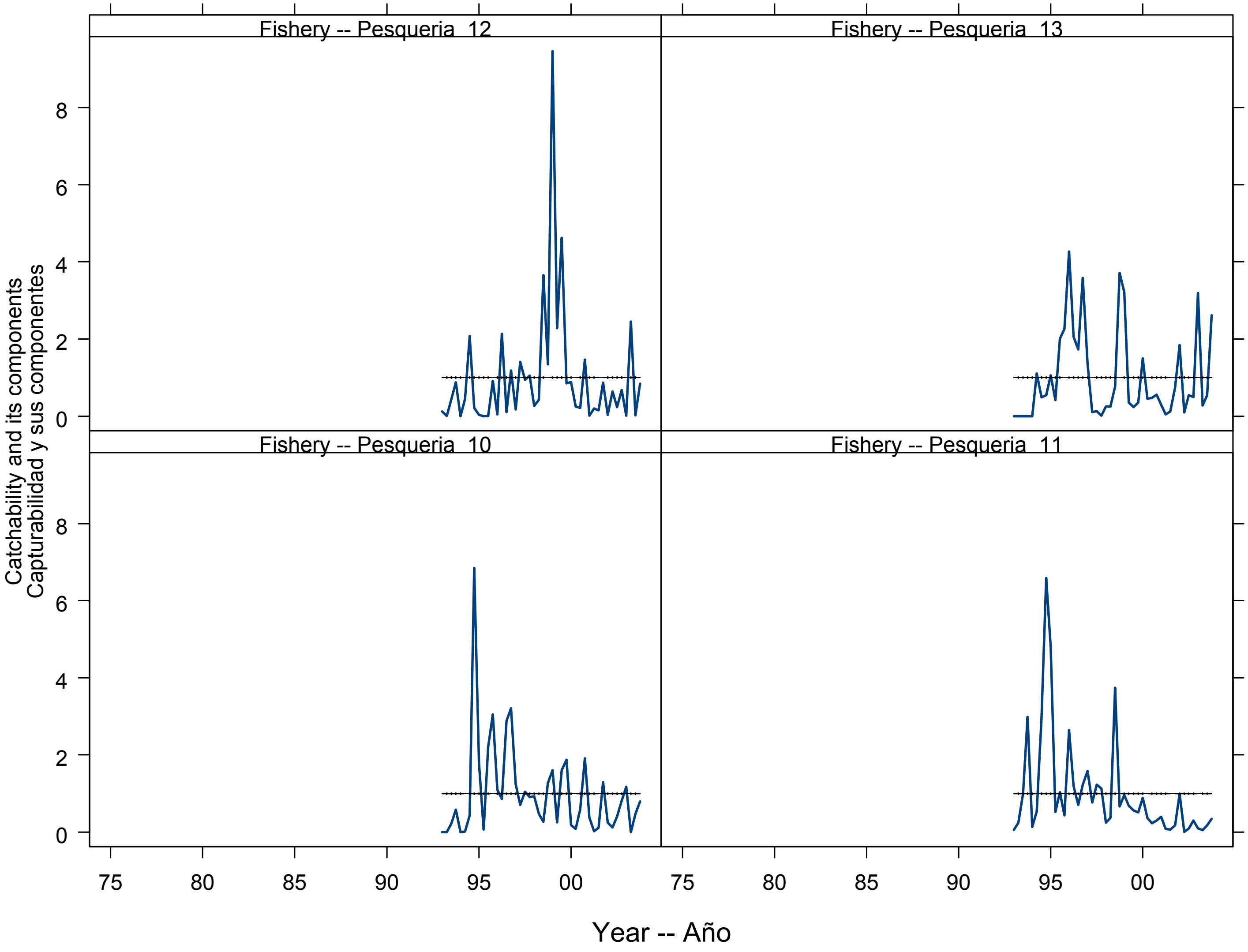

FIGURE 4.7. (continued)
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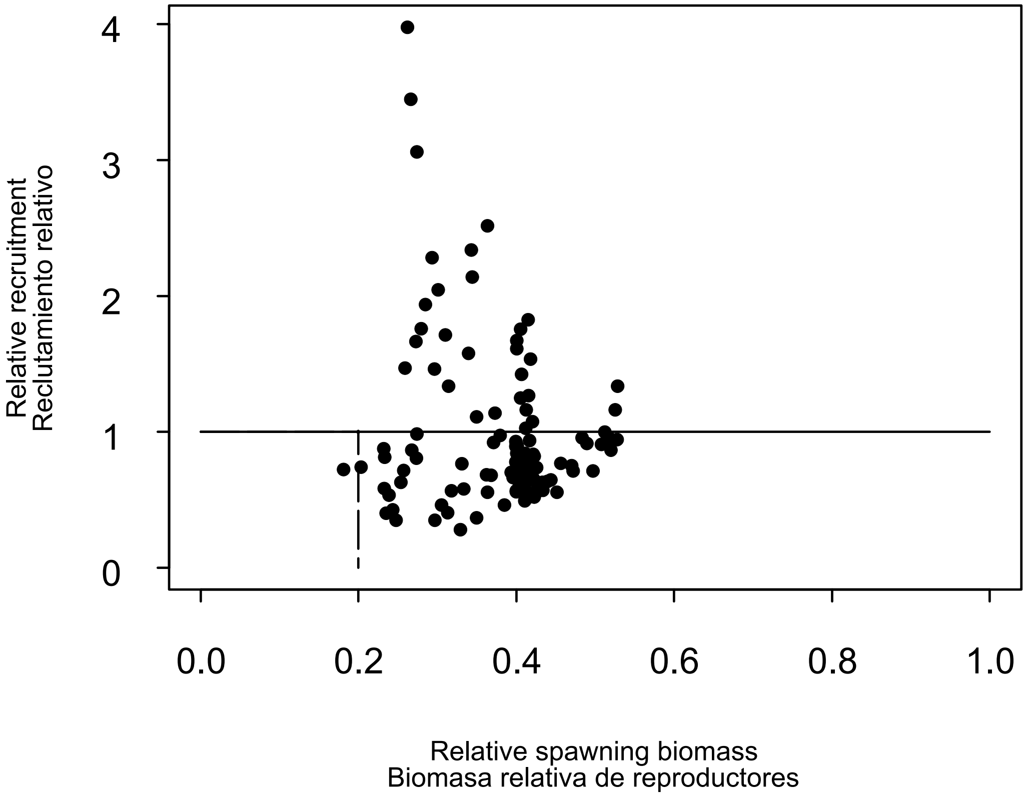

FIGURE 4.8. Estimated relationship between the recruitment of bigeye tuna and spawning biomass. The recruitment is scaled so that the estimate of virgin recruitment is equal to 1.0. Likewise, the spawning biomass is scaled so that the estimate of virgin spawning biomass is equal to 1.0. The horizontal line represents the assumed stock-recruitment relationship.

FIGURA 4.8. 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.

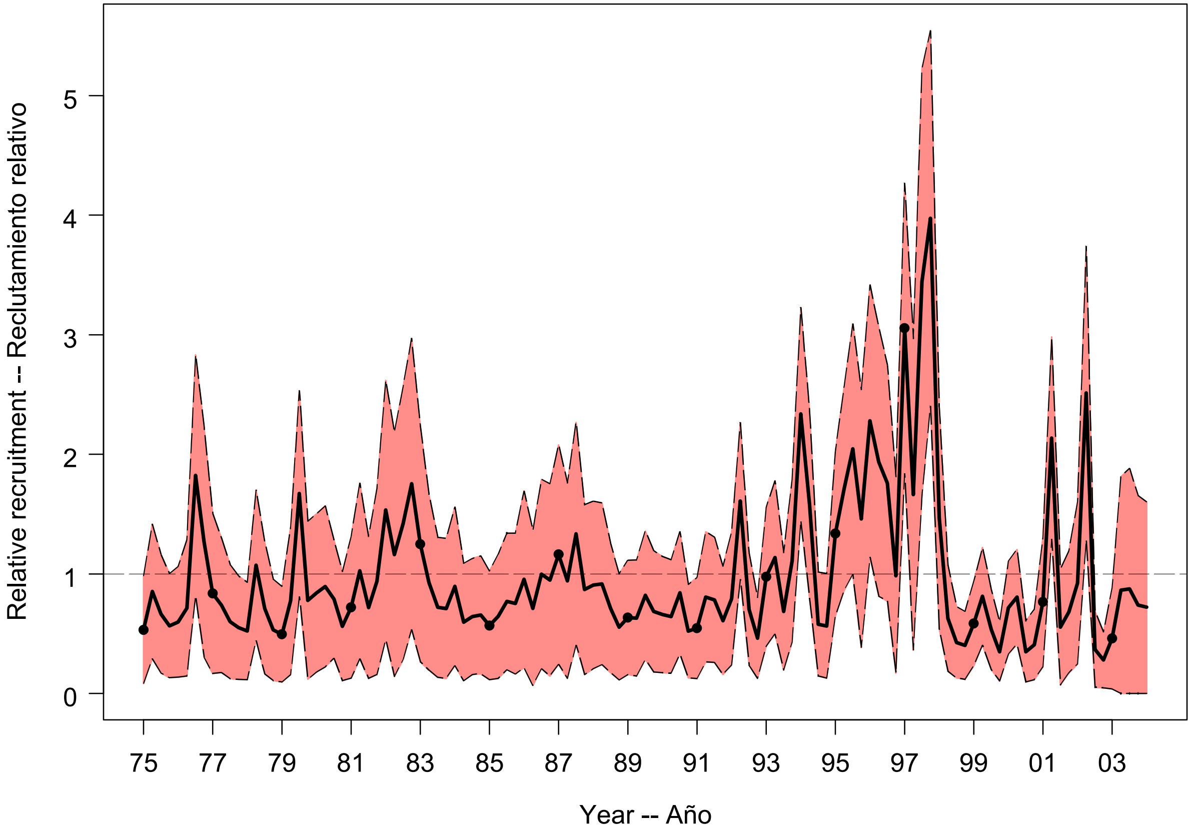

FIGURE 4.9. Estimated recruitment of bigeye tuna to the fisheries of the EPO. The estimates are scaled so that the estimate of virgin recruitment is equal to 1.0. The heavy line illustrates the maximum likelihood estimates of recruitment, and the thin dashed lines are confidence intervals (±2 standard deviations) around those estimates. The labels on the time axis are drawn at the start of each year, but, since the assessment model represents time on a quarterly basis, there are four estimates of recruitment for each year.

FIGURA 4.9. 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 trazosrepresentan los intervalos de confianza (±2 desviaciones estándar) alrededor de esas estimaciones. Se dibujan las leyendas en el eje de tiempo al principio de cada año, pero, ya que el modelo de evaluación representa el tiempo por trimestres, hay cuatro estimaciones de reclutamiento para cada año.

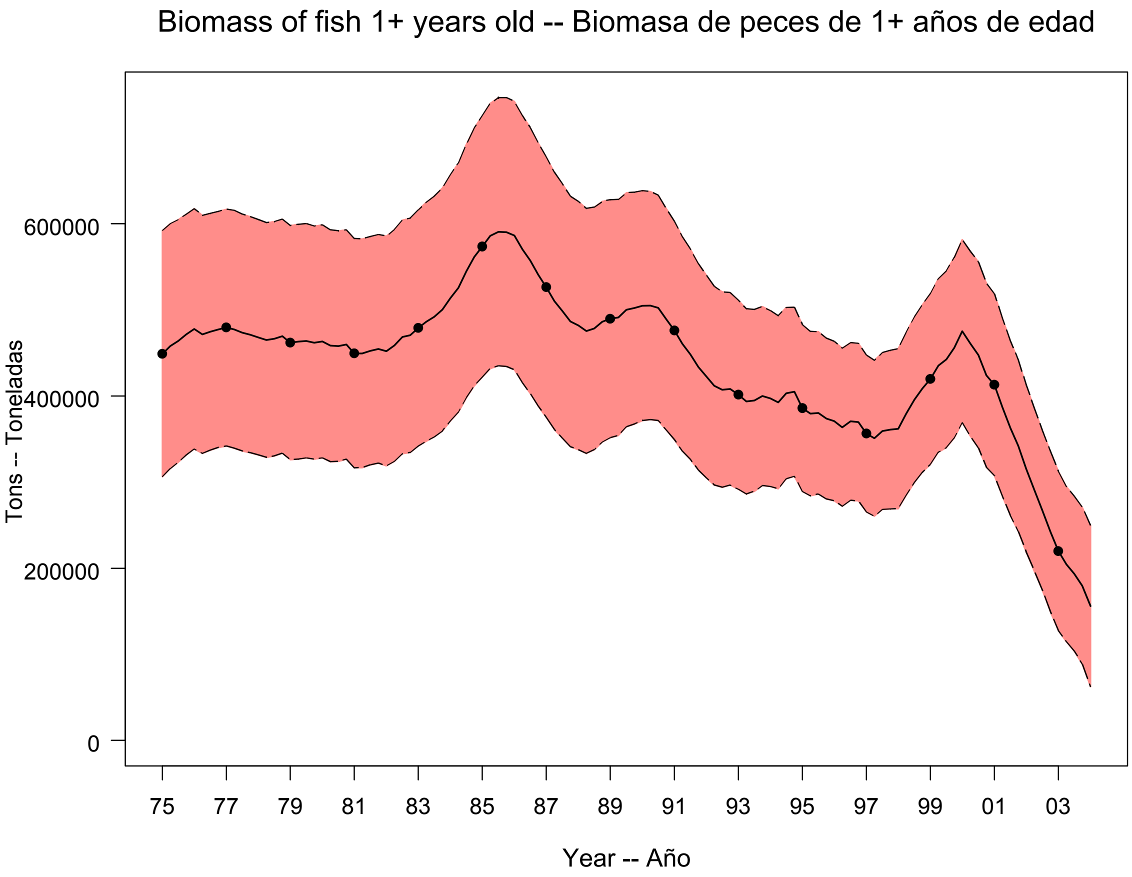

FIGURE 4.10. Estimated biomass of bigeye tuna in the EPO. The heavy lines illustrate the maximum likelihood estimates of the biomasses, and the thin dashed lines are confidence intervals (±2 standard deviations) around those estimates. Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year.

FIGURA 4.10. Biomasa estimada de atún patudo en el OPO. Las líneas gruesas ilustran las estimaciones de verosimilitud máxima de la biomasa, y las líneas delgadas de trazos son 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 de biomasa para cada año.

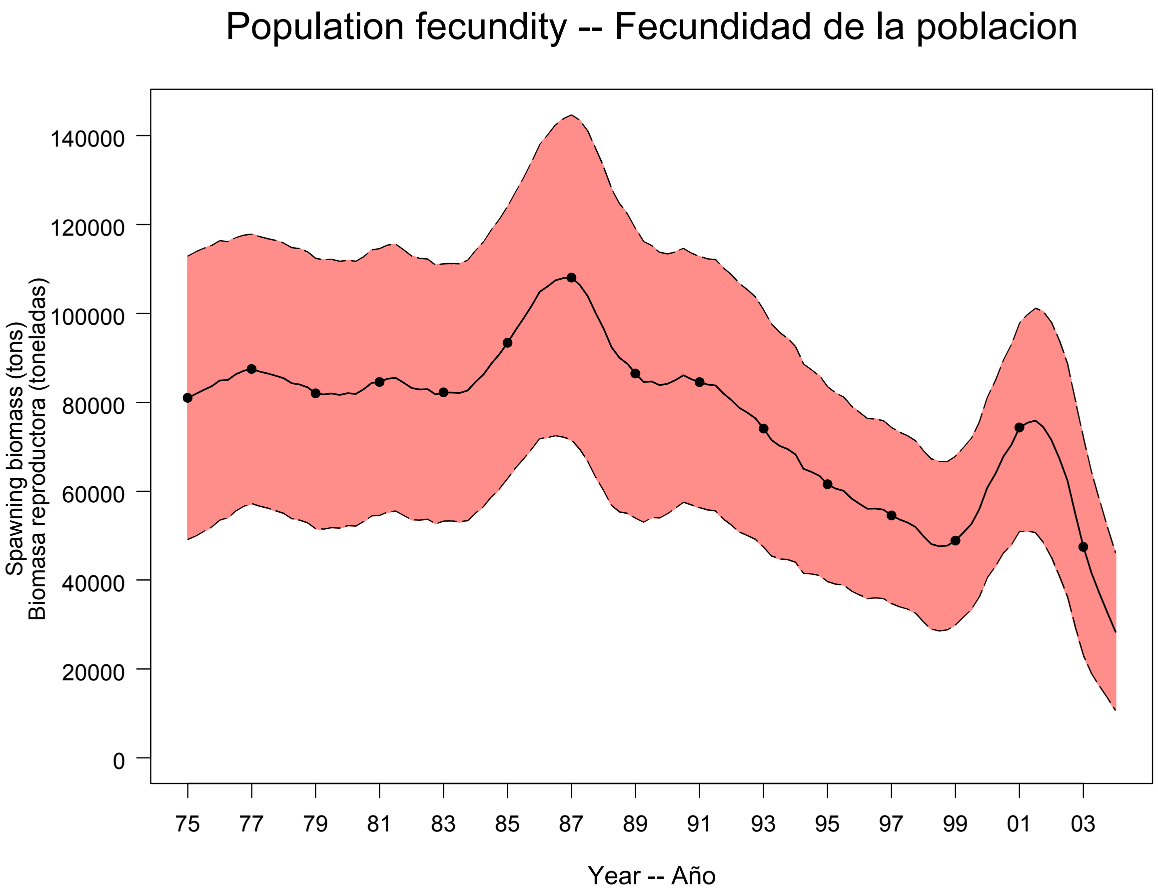

FIGURE 4.11. Estimated spawning biomass (see Section 3.1.2) of bigeye tuna in the EPO. The heavy lines illustrate the maximum likelihood estimates of the biomasses, and the thin dashed lines are confidence intervals (±2 standard deviations) around those estimates. Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year.

FIGURA 4.11. Estimada biomasa reproductora (ver Sección 3.12) de atún patudo en el OPO. Las líneas gruesas ilustran las estimaciones de verosimilitud máxima de la biomasa, y las líneas delgadas de trazos son 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 de biomasa para cada año.

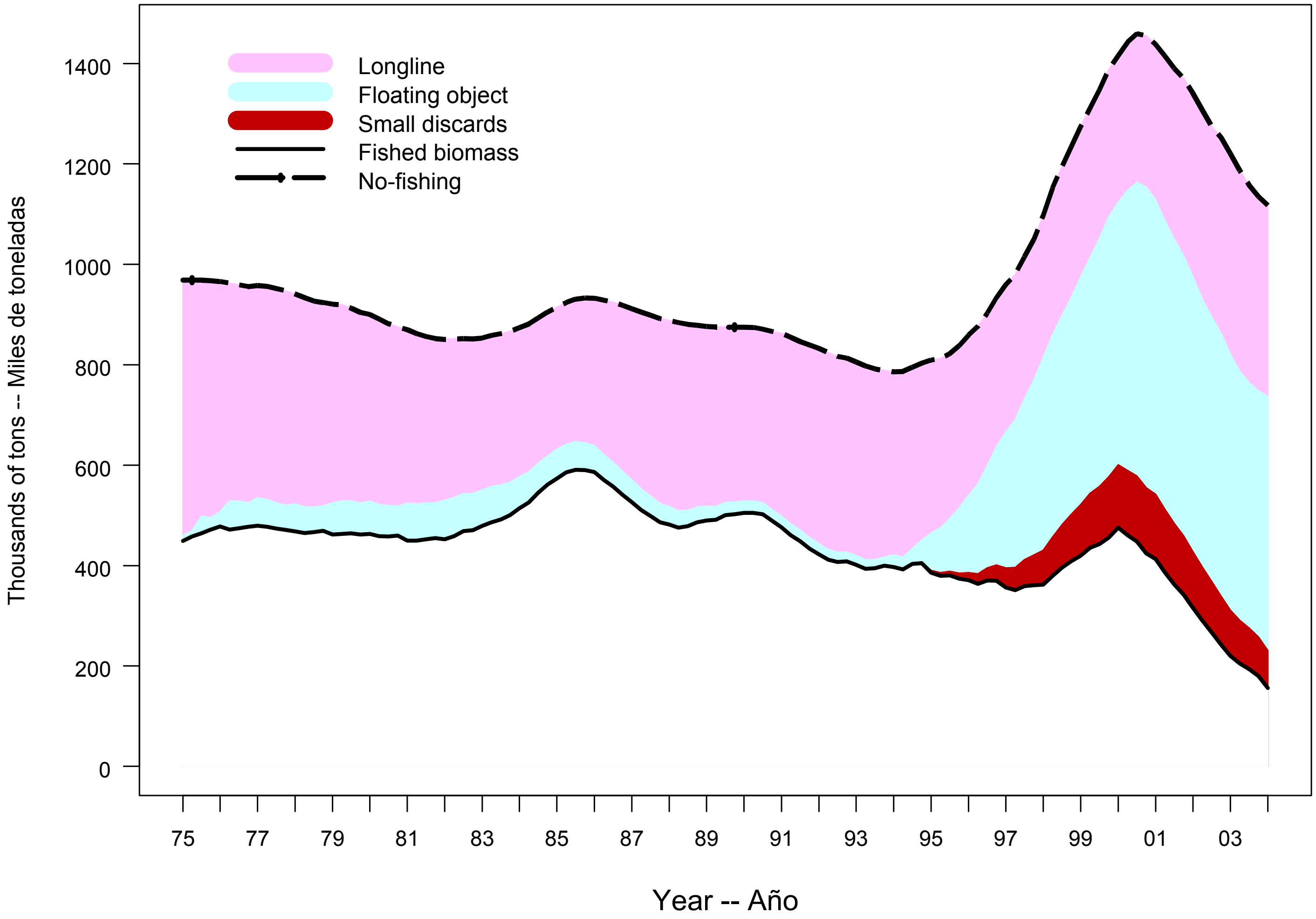

FIGURE 4.12. Biomass trajectory of a simulated population of bigeye tuna that was not exploited through December 2003 ("no fishing") and that predicted by the stock assessment model ("fishing"). The shaded regions between the two lines indicate the contribution of each group of fishing gears to the depletion of the stock.

FIGURA 4.12. Trayectoria de biomasa de una población simulada de atún patudo no explotada durante enero de 1975 a diciembre de 2002 ("sin pesca") y la predicha por el modelo de evaluación de la población ("con pesca").

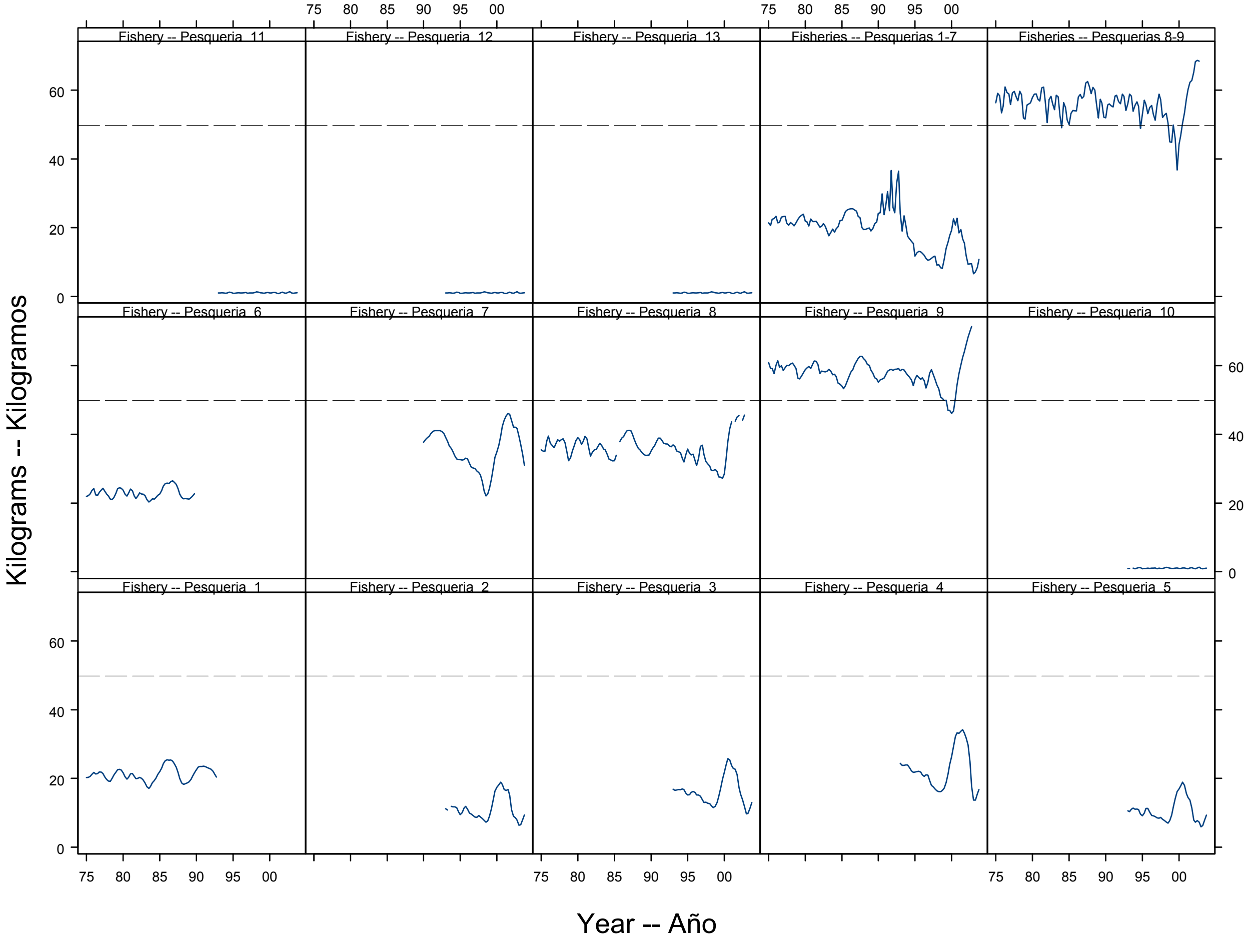

FIGURE 4.13. Estimated average weights of bigeye tuna caught by the fisheries of the EPO. The time series for "Fisheries 1-7" is an average of Fisheries 1 through 7, and that for "Fisheries 8-9" is an average of Fisheries 8 and 9. The dashed horizontal line (at about 49.8 kg) identifies the critical weight.

FIGURA 4.13. Peso medio estimado de atún patudo capturado en las pesquerías del OPO. La serie de tiempo de "Pesquerías 1-7" es un promedio de las Pesquerías 1 a 7, y la de "Pesquerías 8-9" un promedio de las Pesquerías 8 y 9. La línea de trazos horizontal (en aproximadamente 49,8 kg) identifica el peso crítico.

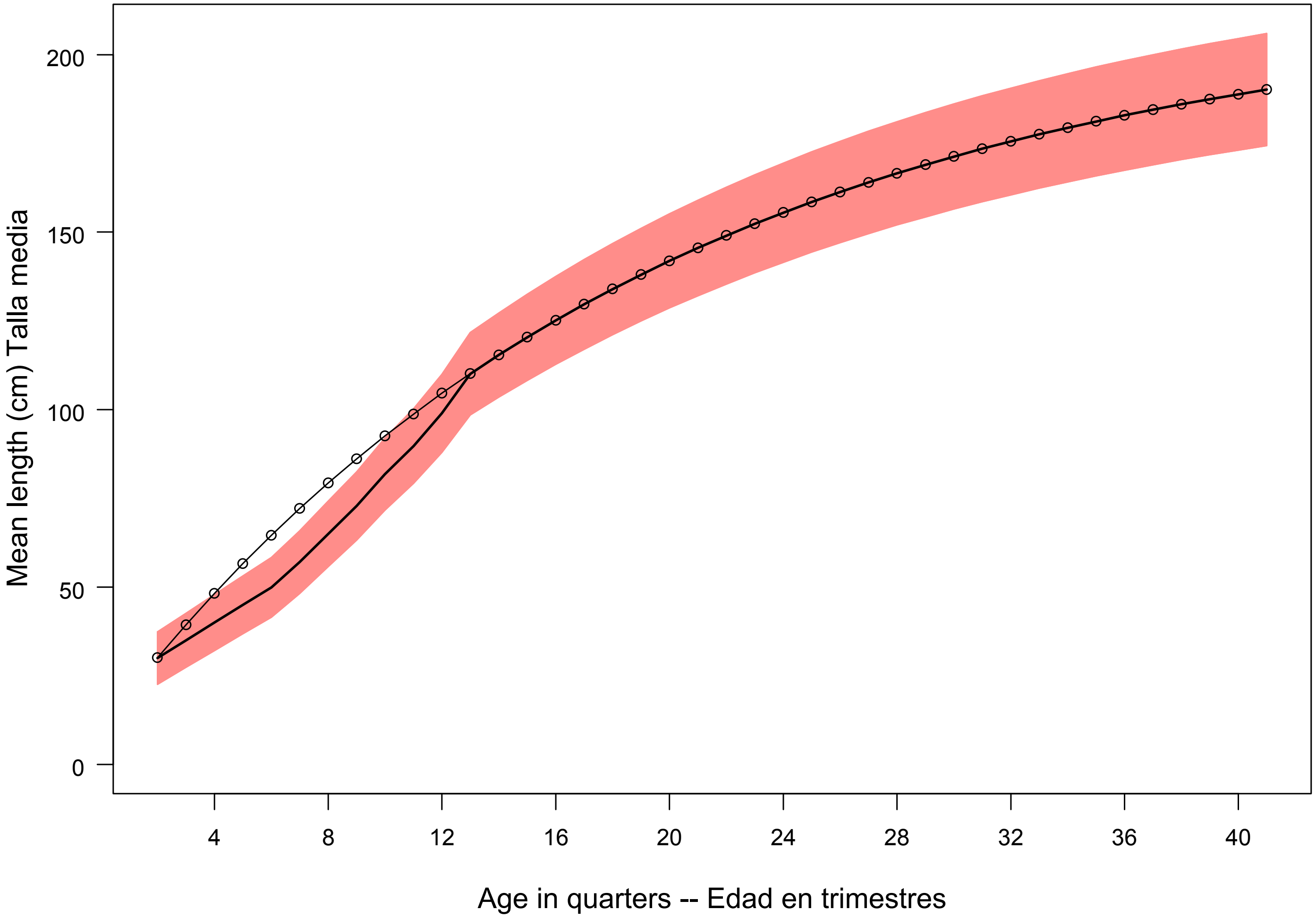

FIGURE 4.14. Estimated average lengths at age for bigeye tuna in the EPO. The shaded area indicates the range of lengths estimated to be covered by two standard deviations of the length at age. The line with circles represent the growth curve from Suda and Kume (1967), which is used as a prior.

FIGURA 4.14. Talla a edad media estimada para el atún patudo en el OPO. El área sombreada indica el rango de tallas que se estima ser abarcado por dos desviaciones estándar de la talla a edad. La línea con círculos representa la curva de crecimiento de Suda y Kume (1967), usada como distribución previa.

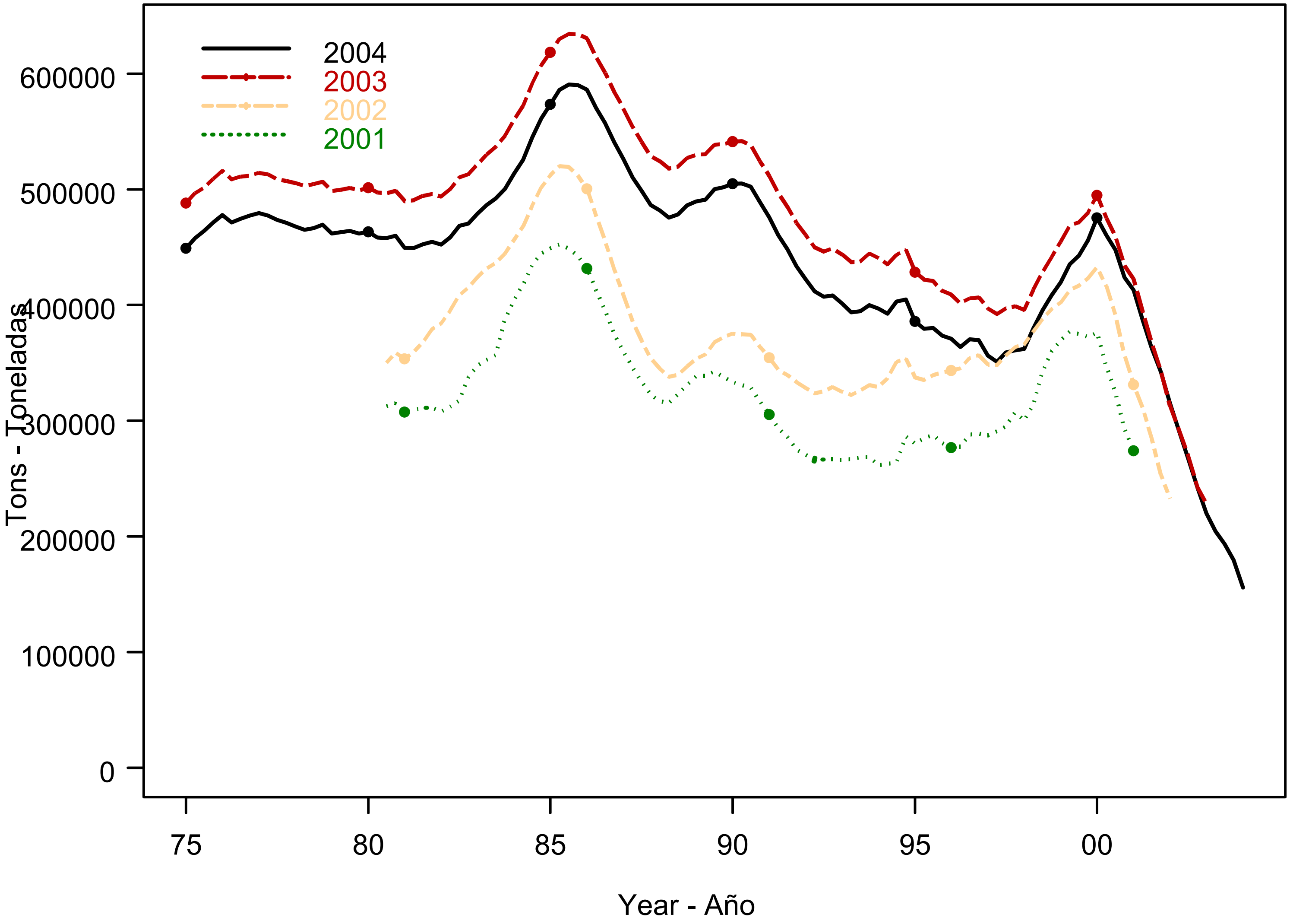

FIGURE 4.15. Comparison of biomass of bigeye tuna (fish of ages 1 year and older) from previous assessments and the current assessment.
FIGURA 4.15. Comparación de biomasa de atún patudo (peces de 1 año o más de edad) de evaluaciones previas y la evaluación actual.

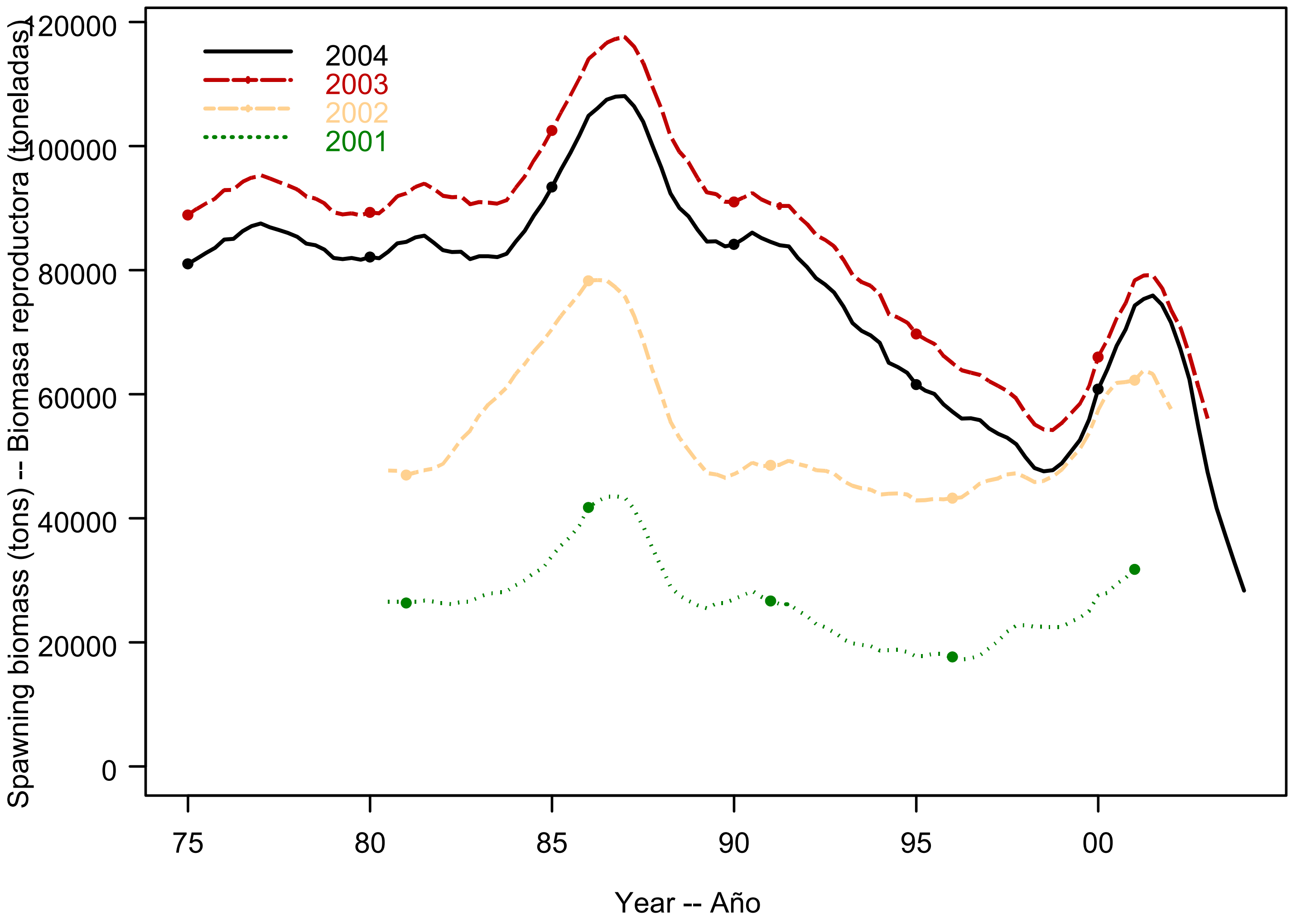

FIGURE 4.16. Comparison of spawning biomass of bigeye tuna from previous assessments based on current assumptions regarding maturity, fecundity, and proportions of females in each age class.

FIGURA 4.16. Comparación de biomasa reproductora de atún patudo de evaluaciones previas basada en premisas actuales sobre madurez, fecundidad, y proporciones de hembras en cada clase de edad.

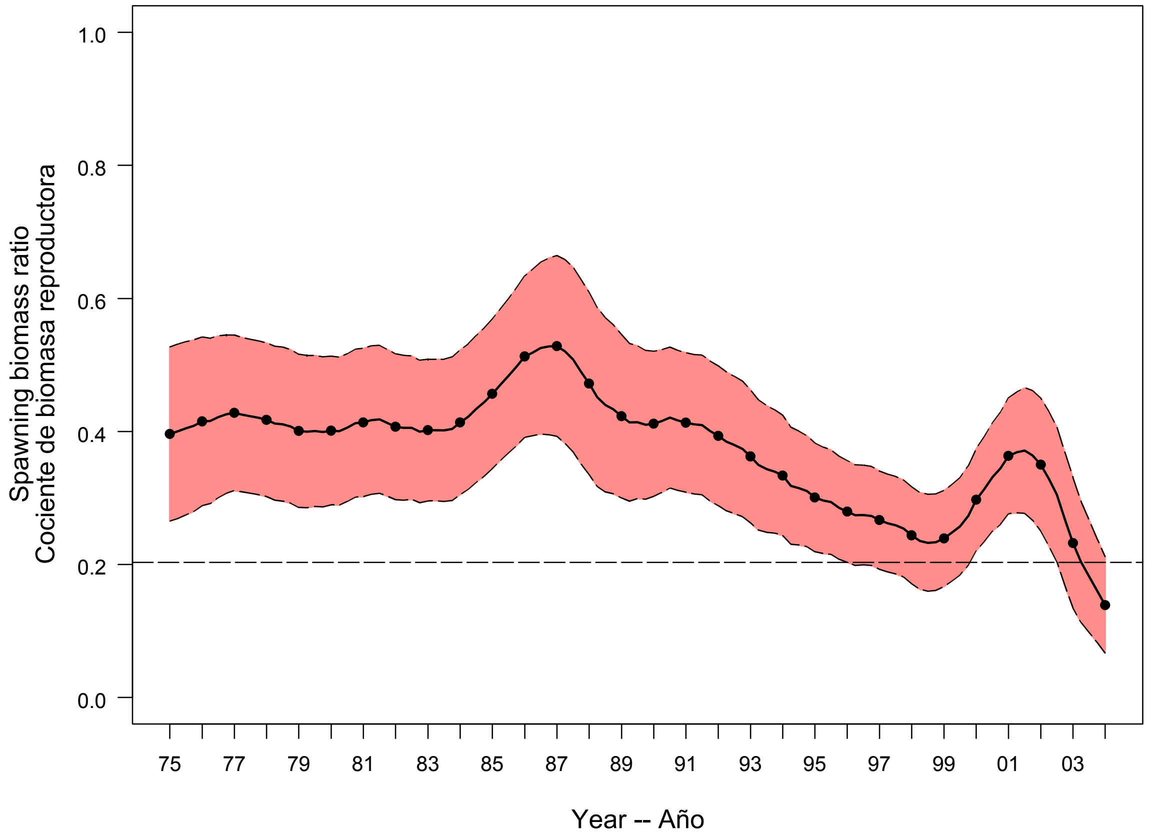

FIGURE 5.1. Estimated time series of spawning biomass ratios (SBRs) for bigeye tuna in the EPO. The dashed horizontal line (at about 0.20) identifies the SBR at AMSY. The solid lines illustrate the maximum likelihood estimates, and the dashed lines are confidence intervals (±2 standard deviations) around those estimates.

FIGURA 5.1. Serie de tiempo estimada de los cocientes de biomasa reproductora (SBR) para el atún patudo en el OPO. La línea de trazos horizontal (en aproximadamente 0,18) identifica el SBR en RMSP. Las líneas sólidas ilustran las estimaciones de verosimilitud máxima, y las líneas de trazos representan los intervalos de confianza (±2 desviaciones estándar) alrededor de esas estimaciones. La línea de trazos que extiende la tendencia del SBR indica el SBR predicho si el esfuerzo sigue al promedio de aquél observado en 2001 y 2002, la capturabilidad (con desvios de esfuerzo) sigue como el promedio para 2000 y 2001, y si ocurren condiciones ambientales promedio durante los próximos cinco años (ver Sección 6).

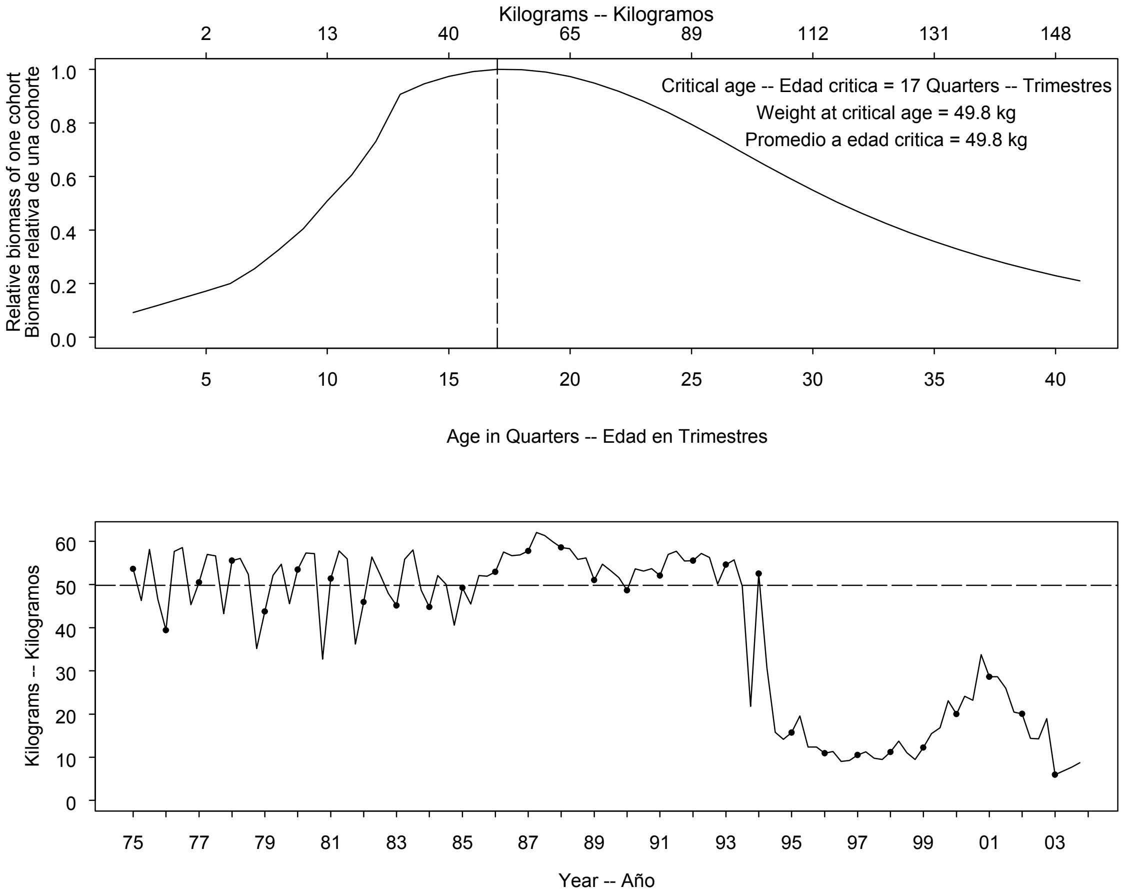

FIGURE 5.2. Combined performance of all fisheries that take bigeye tuna in the EPO at achieving the maximum yield per recruit. The upper panel illustrates the growth (in weight) of a single cohort, and identifies the critical age and critical weight (Section 5). The critical weight is drawn as the horizontal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

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

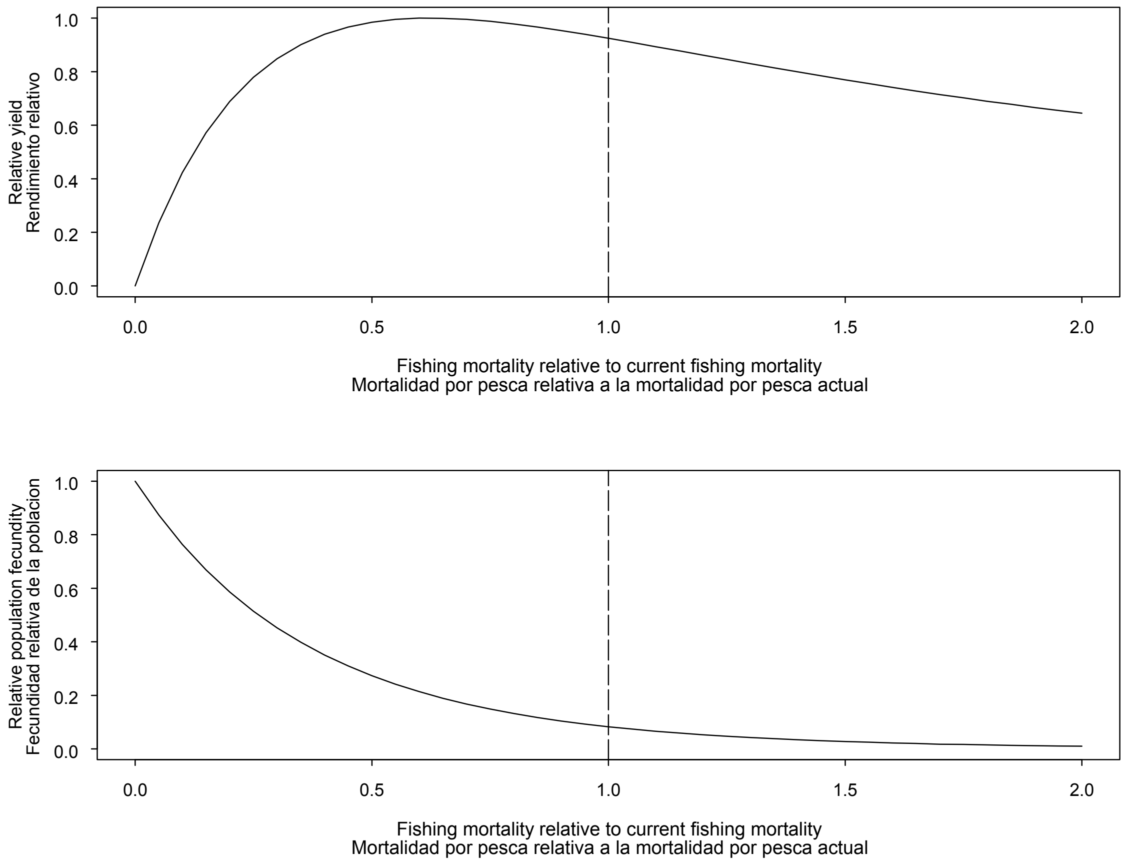

FIGURE 5.3. Predicted effects of long-term changes in fishing effort on the yield (upper panel) and spawning biomass (lower panel) of bigeye tuna under equilibrium conditions with average fishing mortality patterns from 2001 and 2002. The yield estimates are scaled so that the AMSY is at 1.0, and the spawning biomass estimates so that the spawning biomass is equal to 1.0 in the absence of exploitation.

FIGURA 5.3. Efectos predichos de cambios a largo plazo en el esfuerzo de pesca sobre el rendimiento (recuadro superior) y biomasa reproductora (recuadro inferior) de atún patudo bajo condiciones de equilibrio con patrones promedio de mortalidad por pesca de 2000 y 2001. Se escalan las estimaciones de rendimiento para que el RMSP esté en 1,0, y las de biomasa reproductora para que la biomasa reproductora equivalga a 1,0 si no hay explotación.

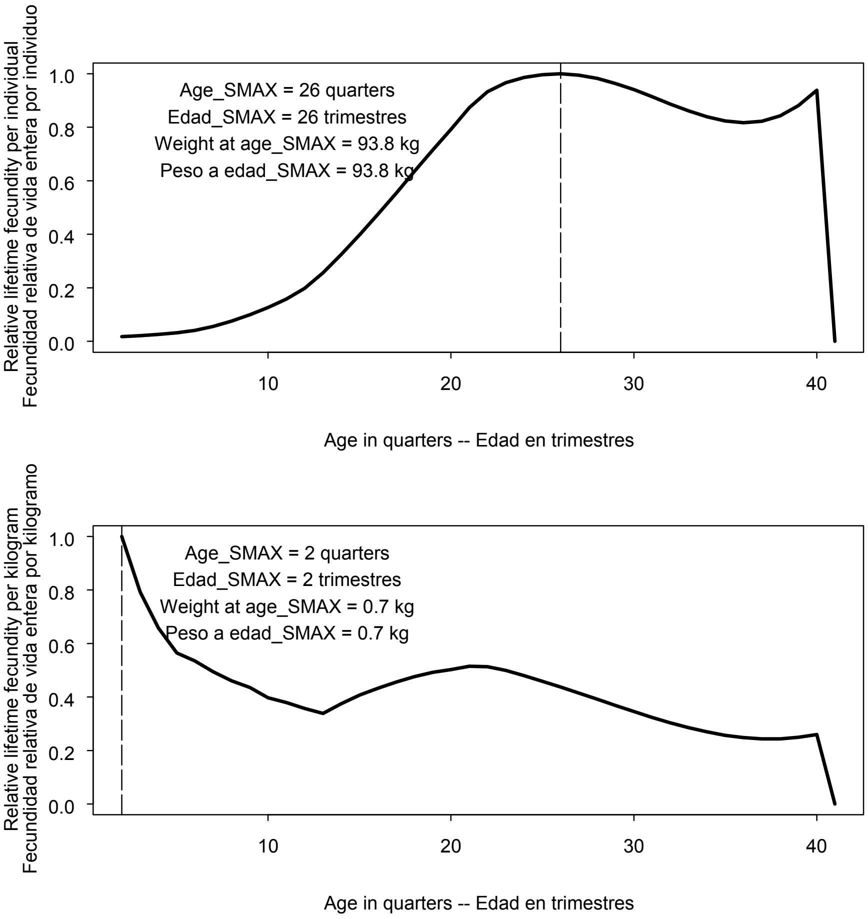

FIGURE 5.4. Marginal relative lifetime reproductive potential of bigeye tuna at age, based on individuals (upper panel) and weight (lower panel). It was assumed, for these calculations, that the quarterly fishing mortalities equaled the average quarterly fishing mortalities for 2001-2002. The vertical lines represent the ages at which marginal relative lifetime reproductive potential is maximized.

FIGURA 5.4. Potencial de reproducción de vida entera relativo marginal de atún patudo a edad, basado en individuos (recuadro superior) y peso (recuadro inferior). Para estos cálculos, se supuso que las mortalidades de pesca trimestrales eran iguales a las mortalidades de pesca trimestrales medias de 2001-2001. Las líneas verticales representan la edad a la cual se logra el potencial de reproducción relativo marginal máximo.

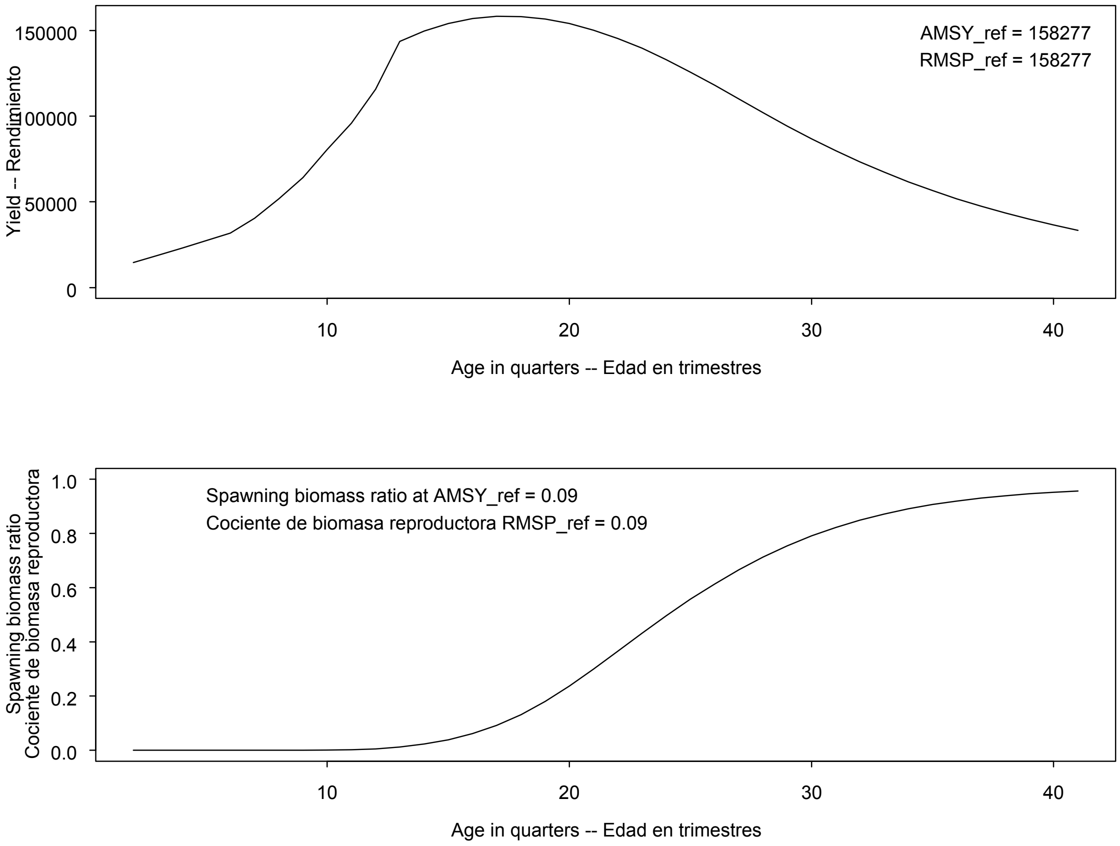

FIGURE 5.5. Yield of bigeye tuna calculated when catching only individuals at a single age (upper panel), and the associated spawning biomass ratio (lower panel).

FIGURA 5.5. Rendimiento de atún patudo calculado si se capturara solamente individuos de una sola edad (recuadro superior), y el cociente de biomasa reproductora asociado (recuadro inferior).

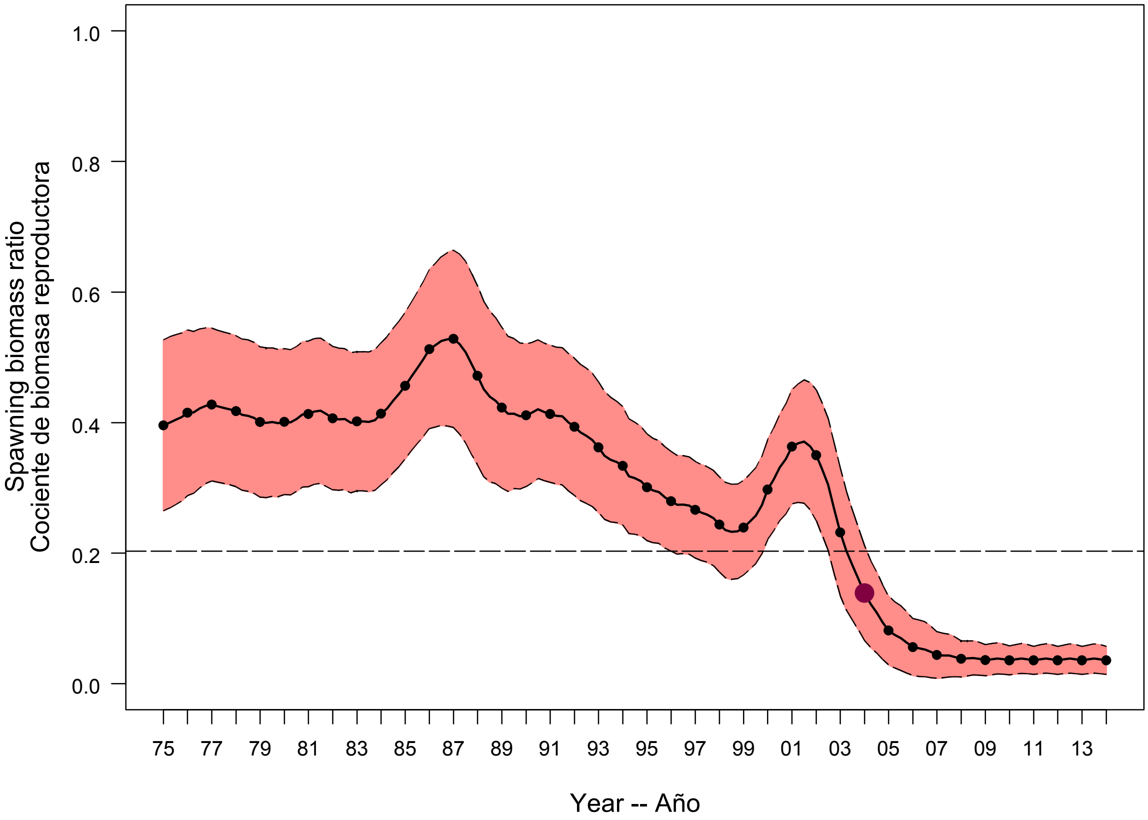

FIGURE 6.1. Spawning biomass ratios (SBRs) of bigeye tuna, including projections for 2004-2014 under effort for 2003 and average catchability for 2001 and 2002 in the EPO. These calculations include parameter estimation uncertainty and uncertainty about future recruitment. The areas between the dashed curves indicate the 95% confidence intervals, and the large dot indicates the estimate for the first quarter of 2004. The dashed horizontal line indicates the SBR_{AMSY} (0.20).

FIGURA 6.1. Cocientes de biomasa reproductora (SBR) simulados durante 2003-2007 para atún patudo en el OPO. Cada recuadro ilustra los resultados de 101 simulaciones usando los diferentes escenarios descritos en las Secciones 6.1 y 6.2. Las estimaciones medianas de los SBR simulados son indicadas por las curvas a la derecha de cada punto. Las zonas sombreadas indican las regiones delimitadas por los cuantiles de 20% y 80% de los SBR simulados. Las líneas de trazos horizontales señalan el SBR_{RMSP} (0,18).

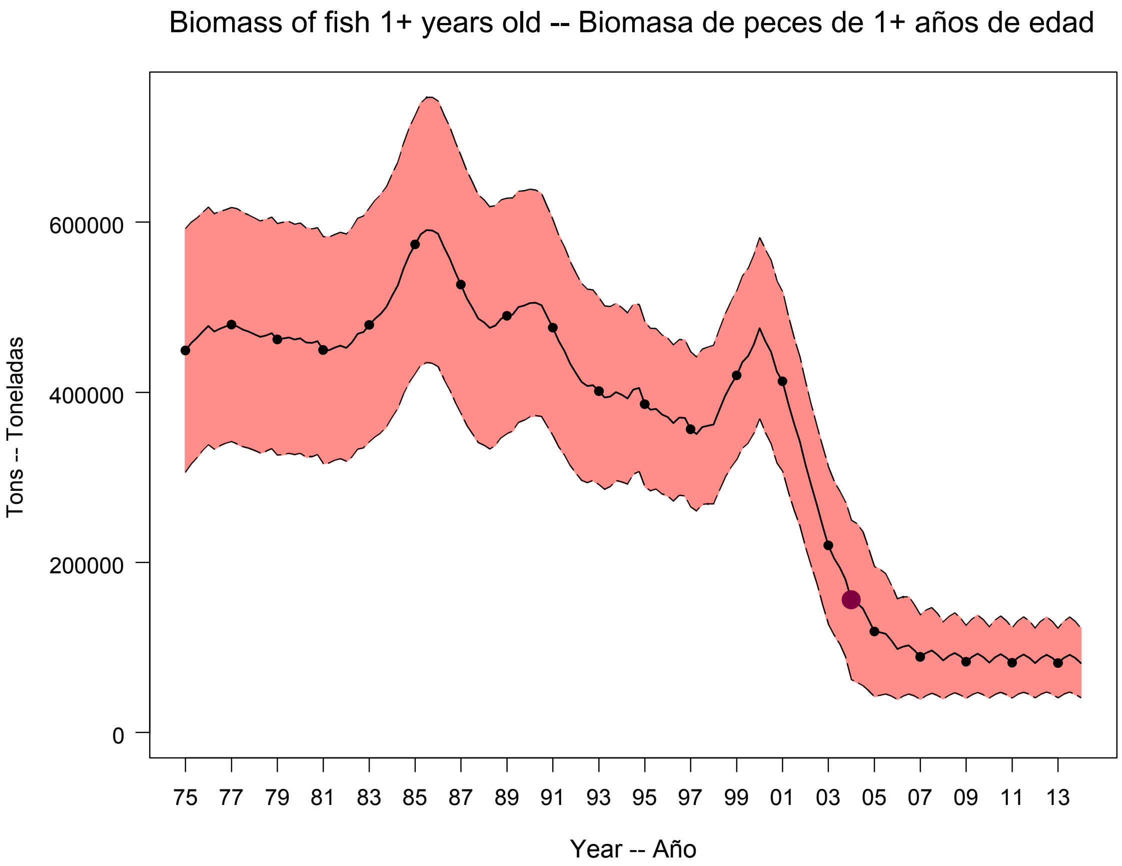

FIGURE 6.2. Estimated biomass of bigeye tuna one year and older, including projections for 2004-2013 under effort for 2003 and average catchability for 2001 and 2002 in the EPO. These calculations include parameter estimation uncertainty and uncertainty about future recruitment. The areas between the dashed curves indicate the 95% confidence intervals, and the large dot indicates the estimate for the first quarter of 2004.

FIGURE 6.2. Cocientes de biomasa reproductora (SBR) de atún patudo, incluyendo proyecciones para 2003-2007 con esfuerzo y capturabilidad promedio de 2000 y 2001 en el OPO. Los cálculos incluyen incertidumbre en la estimación de parámetros y sobre 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 2003. La línea de trazos horizontal señala el SBR_{RMSP} (0,38).

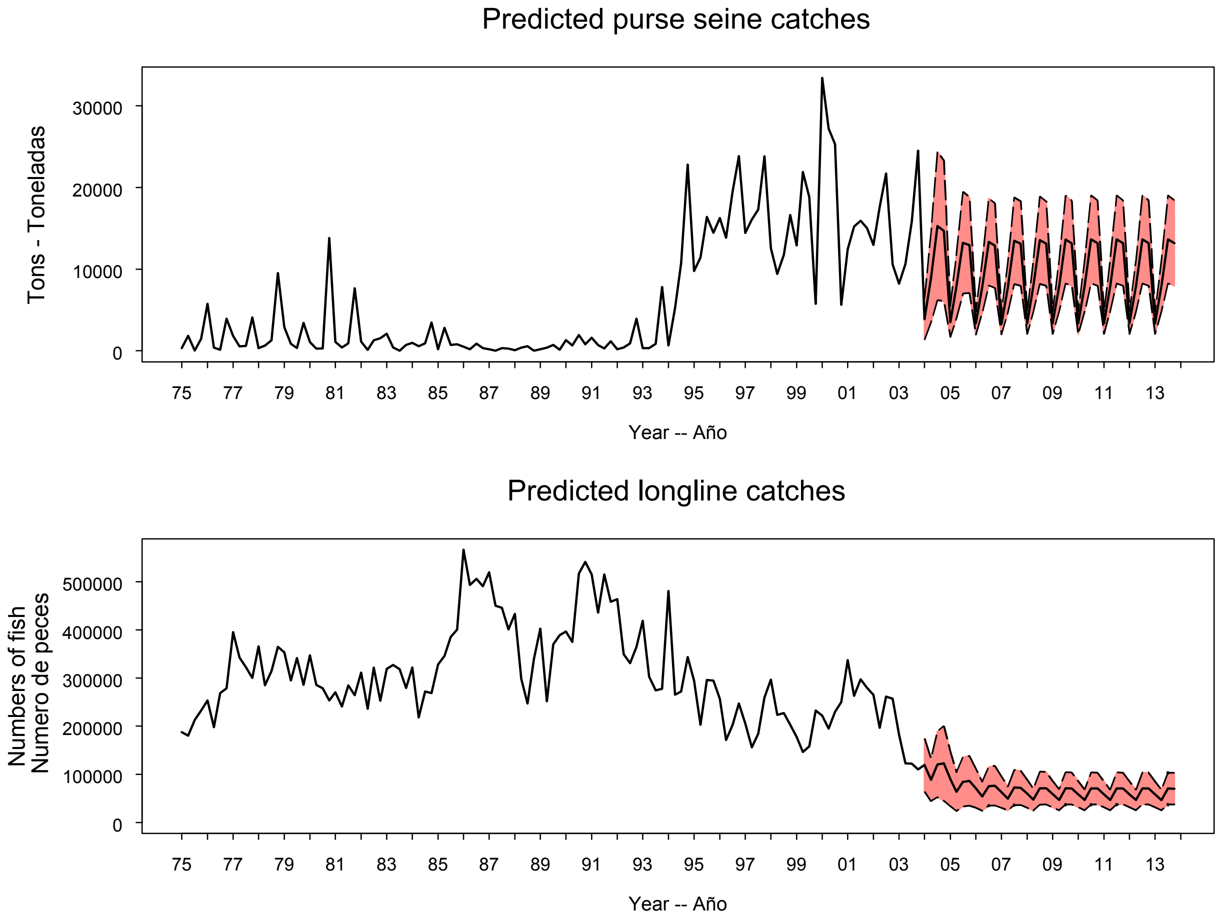

FIGURE 6.3. Predicted catches of bigeye tuna for the surface (Fisheries 2, 3, 4, 5, and 7) and longline (Fisheries 8 and 9) fisheries based on effort for 2003 and average catchability for 2001 and 2002. The shaded areas represent 95% confidence intervals for the predictions of future catches. Note that the vertical scales of the panels are different.

FIGURA 6.3. Capturas predichas de atún patudo en las pesquerías de superficie (Pesquerías 2, 3, 4, 5, y 7) y palangreras (Pesquerías 8 y 9), basadas en esfuerzo promedio de 2002 y 2001 y capturabilidad promedio de 2000 y 2001. Se realizaron las predicciones con el método de perfil de verosimilitud descrito en la Sección 6. Las zonas sombreadas representan intervalos de confianza de 95% para las predicciones de capturas futuras. Nótese que las escalas verticales de los recuadros son diferentes.

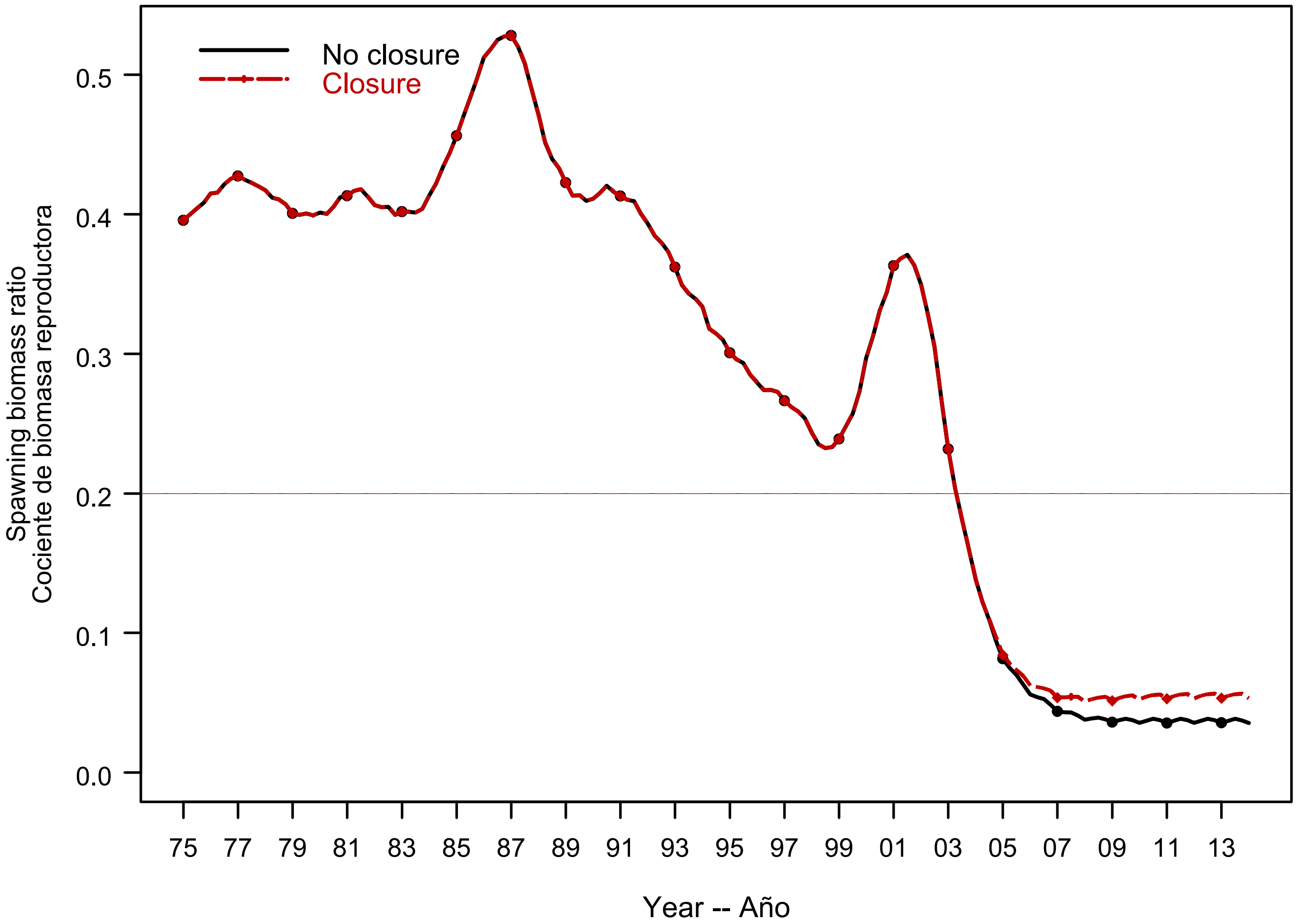

FIGURE 6.4. Maximum likelihood estimates of the projected spawning biomass ratios (SBRs) of bigeye tuna, under effort for 2003 and average catchability for 2001 and 2002 ("No closure") and with purse-seine effort in the third quarter reduced by 50% to approximate the affect of the 2003 Resolution on the Conservation of Tunas in the EPO ("Closure"). The horizontal line indicates the $\mathrm{SBR}_{\mathrm{AMSY}}$ (0.20).

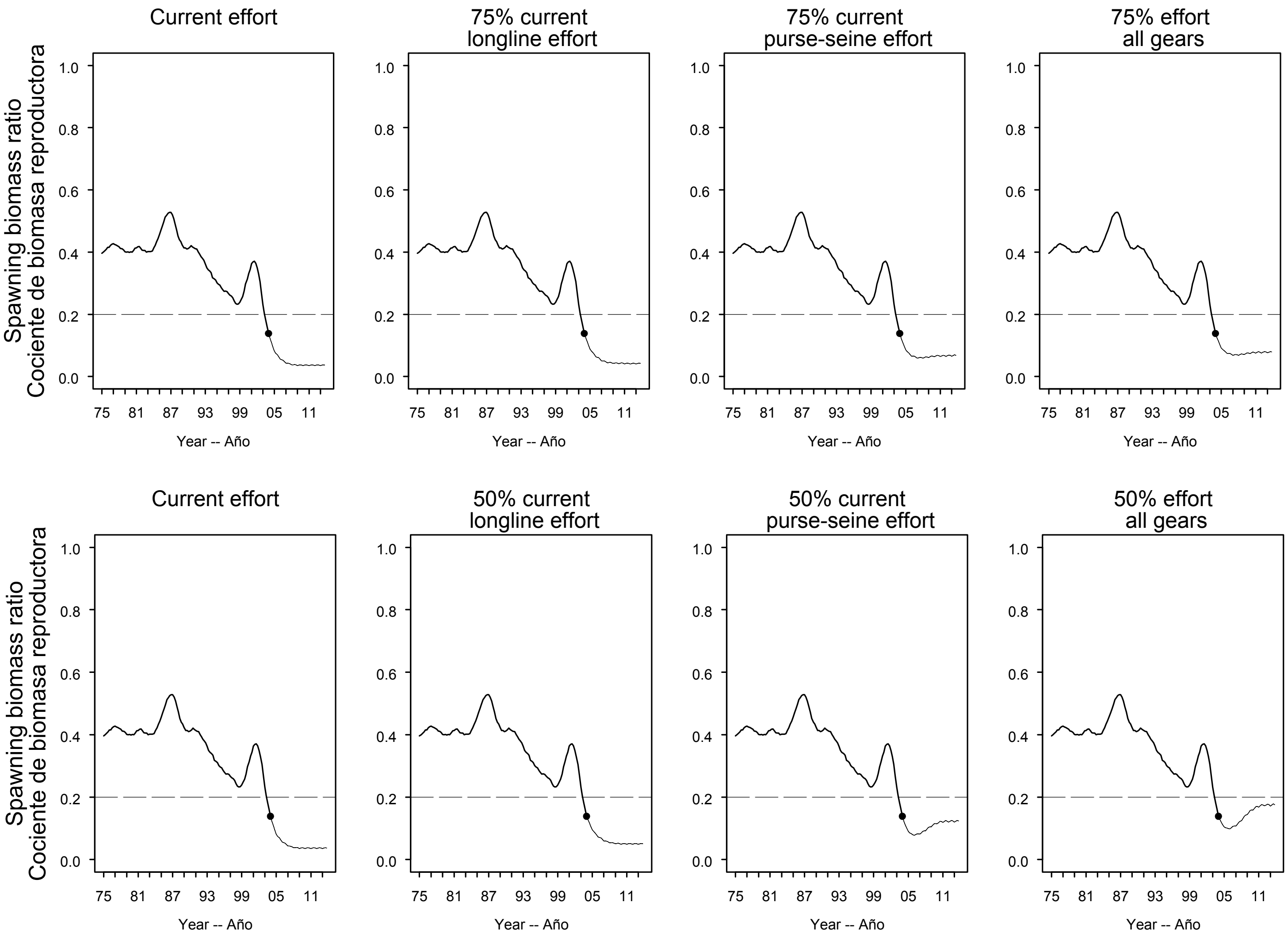

FIGURE 6.5. Simulated spawning biomass ratios (SBRs) during 2004-2014 for bigeye tuna in the EPO. Each panel illustrates the median of 501 simulations using the different scenarios described in Sections 6.1.1. The dashed horizontal lines indicate the SBR_{AMSY} (0.20).

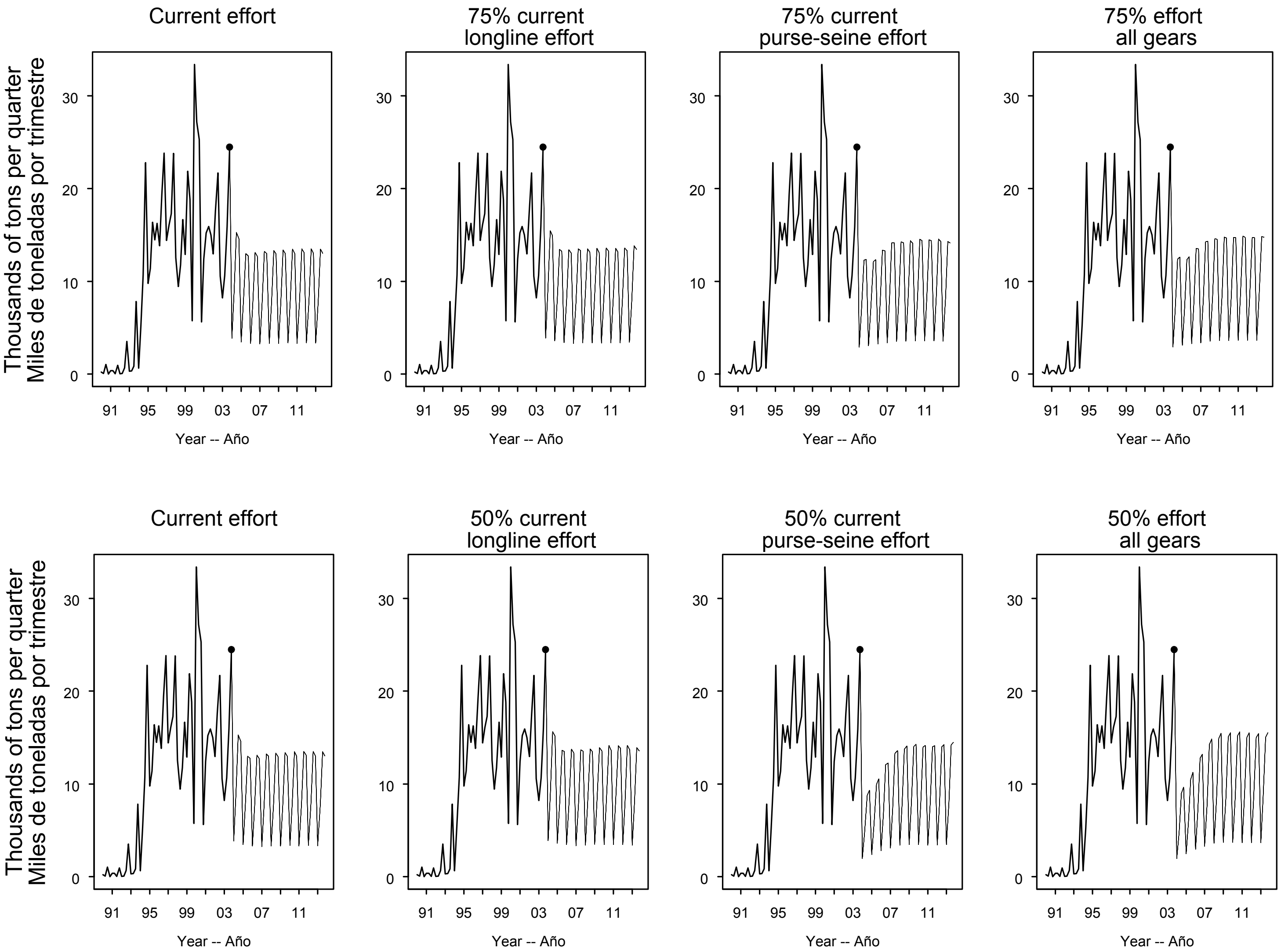

FIGURE 6.6. Simulated catches of bigeye tuna taken by the primary surface fleet (Fisheries 2-5 and 7). Each panel illustrates the median of 501 simulations using the different scenarios described in Sections 6.1.1.

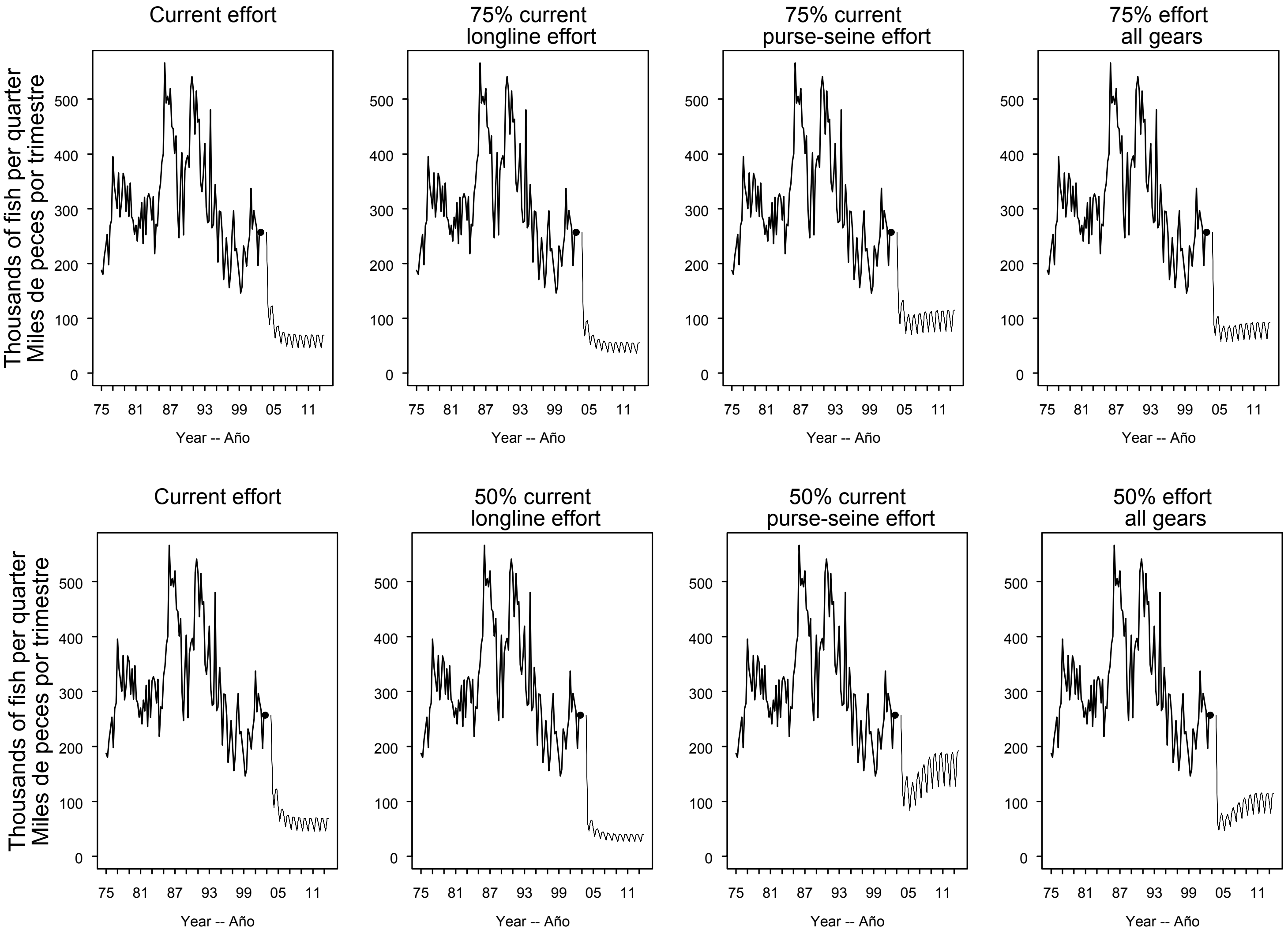

FIGURE 6.7. Simulated catches of bigeye tuna taken by the longline fleet (Fisheries 8 and 9). Each panel illustrates the median of 501 simulations using the different scenarios described in Sections 6.1.1.

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; FLT = sets on floating objects; UNA = sets on unassociated fish; DOL = 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 del stock de atún patudo en el OPO. PS = red de cerco; LP = carnada; LL = palangre; FLT = lances sobre objeto flotante; UNA = lances sobre atunes no asociados; DOL = 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**	**Año**	**Zonas de muestreo**	**Datos de captura**
1	PS	FLT	1980-1992	1-13	retained catch only–capturas retenidas solamente
2	PS	FLT	1993-2003	11-12	retained catch + discards from inefficiencies in fishing process–capturas retenidas + descartes de ineficacias en el proceso de pesca
3	PS	FLT	1993-2003	7, 9	
4	PS	FLT	1993-2003	5-6, 13	
5	PS	FLT	1993-2003	1-4, 8, 10	
6	PS LP	UNA DOL	1980-1989	1-13	retained catch only–capturas retenidas solamente
7	PS LP	UNA DOL	1990-2003	1-13	retained catch + discards from inefficiencies in fishing process–capturas retenidas + descartes de ineficacias en el proceso de pesca
8	LL		1980-2003	N of–de 15°N	retained catch only–capturas retenidas solamente
9	LL		1980-2003	S of–de 15°N	
10	PS	FLT	1993-2003	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	FLT	1993-2003	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	FLT	1993-2003	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	FLT	1993-2003	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

TABLE 3.1. Age-specific proportions of female bigeye tuna, and fecundity indices used to define the spawning biomass.

TABLA 3.1. Proporciones de atún patudo hembra por edad, e índices de fecundidad usados para definir la biomasa reproductora.

Age in quarters	Proportion female	Index of fecundity
Edad en trimestres	**Proporción hembra**	**Índice de fecundidad**
2	0.43	0.00
3	0.43	0.00
4	0.43	0.00
5	0.43	0.00
6	0.43	0.00
7	0.43	0.01
8	0.43	0.02
9	0.43	0.06
10	0.43	0.16
11	0.43	0.44
12	0.43	1.13
13	0.43	2.94
14	0.43	4.89
15	0.43	7.84
16	0.43	12.15
17	0.43	18.15
18	0.43	25.97
19	0.43	35.39
20	0.43	45.66
21	0.43	55.74
22	0.42	64.96
23	0.42	73.02
24	0.42	80.05
25	0.41	86.27
26	0.40	91.90
27	0.39	97.12
28	0.38	102.03
29	0.36	106.70
30	0.34	111.18
31	0.32	115.49
32	0.30	119.64
33	0.28	123.65
34	0.25	127.52
35	0.23	131.26
36	0.21	134.86
37	0.18	138.34
38	0.16	141.70
39	0.15	144.93
40	0.13	148.05
41	0.11	151.03

TABLE 4.1. Recent changes in the quarterly CPUEs achieved by the surface fisheries that currently take bigeye tuna from the EPO. The values indicate the percentage change in quarterly CPUEs from 2001 to 2002.

TABLA 4.1. Cambios recientes en las CPUE trimestrales de las pesquerías de superficie que actualmente capturan atún patudo en el OPO. Los valores indican el cambio porcentual en las CPUE trimestrales de 2001 a 2002.

Quarter Trimestre	Fishery 2 Pesquería 2	Fishery 3 Pesquería 3	Fishery 4 Pesquería 4	Fishery 5 Pesquería 5
1	-3	-81	-86	-14
2	-2	-64	-65	-64
3	69	-65	-81	-41
4	14	10	13	8

TABLE 4.2. Estimated total annual recruitment of bigeye tuna (thousands of fish), initial biomass (metric tons present at the beginning of the year), and spawning biomass (metric tons) in the EPO.

TABLA 4.2. Reclutamiento anual total estimado de atún patudo (miles de peces), biomasa inicial (toneladas métricas presentes al inicio del año), y biomasa de peces reproductores (toneladas métricas) en el OPO.

Year Año	Total recruitment Reclutamiento total	Biomass of age-1+ fish Biomasa de peces de edad 1+	Spawning biomass Biomasa reproductora
1975	12,961	448,941	80,993
1976	21,831	477,881	84,937
1977	13,491	479,377	87,511
1978	14,066	468,041	85,404
1979	18,437	461,885	81,991
1980	15,288	463,310	82,092
1981	16,852	449,450	84,562
1982	29,107	452,171	83,227
1983	17,882	478,906	82,229
1984	13,833	513,711	84,633
1985	13,549	573,477	93,407
1986	17,911	586,174	104,866
1987	21,346	526,365	108,089
1988	15,314	481,737	96,573
1989	13,729	489,556	86,510
1990	13,208	504,755	84,177
1991	13,607	475,923	84,552
1992	17,692	422,574	80,506
1993	19,369	401,301	74,115
1994	25,073	396,961	68,295
1995	32,491	385,799	61,565
1996	34,502	370,811	57,204
1997	60,172	356,383	54,515
1998	14,500	361,946	49,883
1999	11,308	419,661	48,909
2000	11,298	475,259	60,819
2001	20,513	412,912	74,328
2002	20,243	315,327	71,599
2003	14,568	219,879	47,462
2004		155,865	28,356

TABLE 4.3. Estimates of the average sizes of bigeye tuna. The ages are quarters after hatching.
TABLA 4.3. 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)**
2	30.00	0.74	22	149.02	74.56
3	34.98	1.14	23	152.33	79.46
4	39.96	1.67	24	155.48	84.30
5	44.94	2.34	25	158.47	89.08
6	49.92	3.16	26	161.30	93.78
7	57.03	4.64	27	163.99	98.39
8	64.97	6.76	28	166.55	102.90
9	72.84	9.40	29	168.98	107.31
10	81.80	13.14	30	171.28	111.60
11	89.74	17.17	31	173.48	115.79
12	98.92	22.76	32	175.56	119.86
13	110.08	31.02	33	177.53	123.81
14	115.37	35.53	34	179.41	127.64
15	120.38	40.18	35	181.19	131.35
16	125.13	44.95	36	182.88	134.94
17	129.64	49.80	37	184.49	138.40
18	133.93	54.72	38	186.01	141.75
19	138.00	59.68	39	187.46	144.97
20	141.87	64.66	40	188.84	148.08
21	145.54	69.62	41	190.14	151.06

TABLE 5.1. Estimates of the AMSY and its associated quantities for bigeye tuna for the base case and sensitivity analyses. All analyses are based on average fishing mortality for 2001 and 2002. B_{recent} and B_{AMSY} are defined as the biomass of fish 1+ years old at the start of 2004 and at AMSY, respectively, and S_{recent} and S_{AMSY} are defined as indices of spawning biomass (therefore, they are not in metric tons). C_{recent} is the estimated total catch in 2003.
TABLA 5.1. Estimaciones del RMSP y sus valores asociados para atún patudo para el caso base y los análisis de sensibilidad. Todos los análisis se basan en la mortalidad por pesca media de 2000 y 2001. Se definen B_{recent} y B_{RMSP} como la biomasa de fish de edad 1+ años al principio de 2003 y en RMSP, respectivamente, y S_{recent} y S_{RMSP} como índices de biomasa reproductora (y por lo tanto no se expresa en toneladas métricas). C_{recent} es la captura total estimada en 2002.

	Base case	Steepness = 0.75	Purse-seine unloading data	Juvenile M
	Caso base	**Inclinación = 0.75**	**Datos de descargas cerqueras**	
AMSY—RMSP	77,747	62,849	76,113	69,910
B_{AMSY}—B_{RMSP}	274,683	361,770	264,732	239,050
S_{AMSY}—S_{RMSP}	41,588	64,090	39,877	34,924
B_{AMSY}/B_0—B_{RMSP}/B_0	0.28	0.36	0.30	0.28
S_{AMSY}/S_0—S_{RMSP}/S_0	0.20	0.30	0.22	0.20
C_{recent}/AMSY—C_{recent}/RMSP	1.26	1.56	1.16	1.41
$B_{\mathrm{recent}}/B_{\mathrm{AMSY}}$—$B_{\mathrm{recent}}/B_{\mathrm{RMSP}}$	0.57	0.42	0.77	0.69
$S_{\mathrm{recent}}/S_{\mathrm{AMSY}}$—$S_{\mathrm{recent}}/S_{\mathrm{RMSP}}$	0.68	0.43	0.80	0.80
F multiplier—Multiplicador de F	0.62	0.38	0.80	0.65

TABLE 5.2. Estimates of the AMSY and its associated quantities for bigeye tuna based on alternative assumptions about current fishing mortality. B_{recent} and B_{AMSY} are defined as the biomass of fish 1+ years old at the start of 2004 and at AMSY, respectively, and S_{recent} and S_{AMSY} are defined as indices of spawning biomass (therefore, they are not in metric tons). C_{recent} is the estimated total catch in 2003.

TABLA 5.1. Estimaciones del RMSP y sus valores asociados para atún patudo basadas en distintos supuestos sobre la mortalidad de pesca actual. Se definen B_{recent} y B_{RMSP} como la biomasa de peces de edad 1+ años al principio de 2003 y en RMSP, respectivamente, y S_{recent} y S_{RMSP} como índices de biomasa reproductora (y por lo tanto no se expresa en toneladas métricas). C_{recent} es la captura total estimada en 2002.

	***F* 2001 and-y 2002 (Base case—Caso base)**	***F* 2000 and-y 2001**	***F* 2002and-y 2003**
AMSY (t)—RMSP (t)	77,747	78,027	73,517
B_{AMSY} (t)—B_{RMSP} (t)	274,683	277,013	266,276
S_{AMSY}—S_{RMSP}	41,588	42,009	40,753
B_{AMSY}/B_0—B_{RMSP}/B_0	0.28	0.29	0.28
S_{AMSY}/S_0—S_{RMSP}/S_0	0.20	0.21	0.20
C_{recent}/AMSY—C_{recent}/RMSP	1.26	1.26	1.34
$B_{\text{recent}}/B_{\text{AMSY}}$—$B_{\text{recent}}/B_{\text{RMSP}}$	0.57	0.56	0.59
$S_{\text{recent}}/S_{\text{AMSY}}$—$S_{\text{recent}}/S_{\text{RMSP}}$	0.68	0.68	0.70
F multiplier—Multiplicador de *F*	0.62	0.87	0.50

TABLE 5.3. Estimates of the AMSY and its associated quantities for bigeye tuna, obtained by assuming 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 AMSY and B_{AMSY} are in metric tons. The *F* multiplier indicates how many times effort would have to be effectively increased to achieve the AMSY based on the average fishing mortality over 2001 and 2002.

TABLA 5.3. Estimaciones del RMSP y sus cantidades asociadas para atún patudo, obtenidas suponiendo 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 RMSP, B_{RMSP}, y S_{RMSP} en toneladas métricas. El multiplicador de *F* indica cuántas veces se tendría que aumentar efectivamente el esfuerzo para lograr el RMSP basado en la mortalidad por pesca media en los dos últimos años.

	All gears	**Purse-seine**	**Longline**
AMSY—RMSP	77,747	55,319	132,426
B_{AMSY}—B_{RMSP}	274,683	214,799	299,713
S_{AMSY}—S_{RMSP}	41,588	32,752	27,625
B_{AMSY}/B_0—B_{RMSP}/B_0	0.28	0.22	0.31
S_{AMSY}/S_0—S_{RMSP}/S_0	0.20	0.16	0.14
F multiplier—Multiplicador de *F*	0.62	1.05	3.54

TABLE 5.4. Same as above but for steepness sensitivity.
TABLA 5.4.

	All gears	Purse-seine	Longline
AMSY—RMSP	62,849	42,650	102,386
B_{AMSY}—B_{RMSP}	361,770	327,776	401,998
S_{AMSY}—S_{RMSP}	64,090	58,972	62,351
B_{AMSY}/B_0—B_{RMSP}/B_0	0.36	0.33	0.40
S_{AMSY}/S_0—S_{RMSP}/S_0	0.30	0.28	0.30
F multiplier—Multiplicador de F	0.38	0.61	1.42

TABLE 6.1. Median of the outcomes from 501 simulations for bigeye tuna, using the scenarios described in Sections 6.1.1.
TABLA 6.1. Resumen de los resultados de 101 simulaciones para atún patudo, usando los escenarios descritos en las Secciones 6.1 y 6.2. Los “cuantiles” identifican los niveles en los cuales el 20%, 50%, y 80% de los resultados predichos inferiores o iguales al valor en la tabla. El cuantil de 50% es igual a la mediana.

Reduction	No reductions	Longline effort reduction	Purse-seine effort reduction	Both reduce
Average quarterly SBR for 2013–SBR para el cuarto trimestre de 2007				
25%	0.04	0.04	0.07	0.08
50%	0.04	0.05	0.12	0.18
Median of quarterly catches (mt) by the primary surface fleet (Fisheries 2-5 and 7) during 2013–Mediana de las capturas trimestrales (tm) por la flota primaria de superficie (Pesquerías 2-5 y 7) durante 2007				
25%	10,114	10,150	10,832	11,093
50%	10,114	10,592	10,752	11,387
Median of quarterly catches, in thousands of fish, by the longline fleet (Fisheries 8 and 9) during 2013–Mediana de las capturas trimestrales, en miles de peces, por la flota palangrera (Pesquerías 8 y 9) durante 2007				
25%	61	49	101	82
50%	61	36	169	104

APPENDIX A: DIAGNOSTICS

ANEXO A: DIAGNOSTICOS

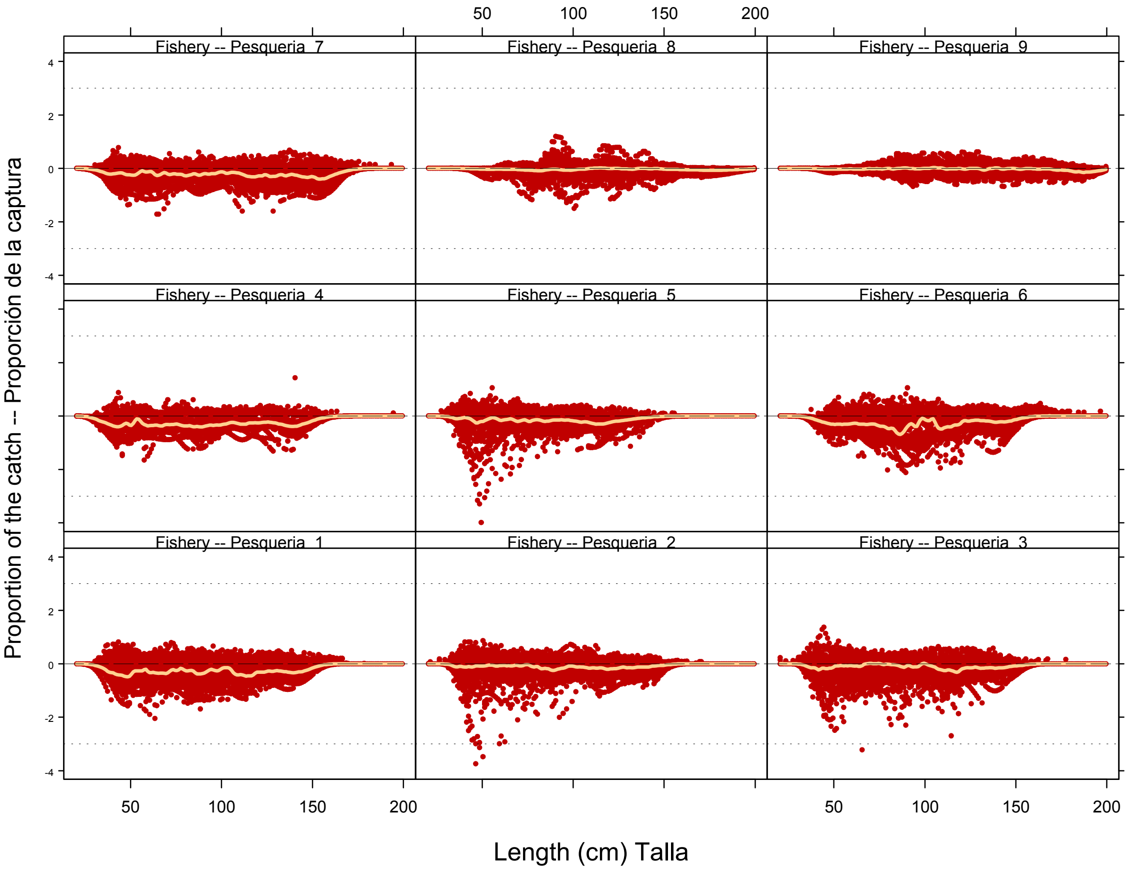

FIGURE A.1. Standardized residuals for the fit to the length-frequency data for bigeye tuna, by fishery and length class. The fitted line is a loess smoother.

FIGURA A.1. Residuales estandarizados del ajuste a los datos de frecuencia de talla de atún patudo, por pesquería y clase de talla. La línea ajustada es un suavizador loess.

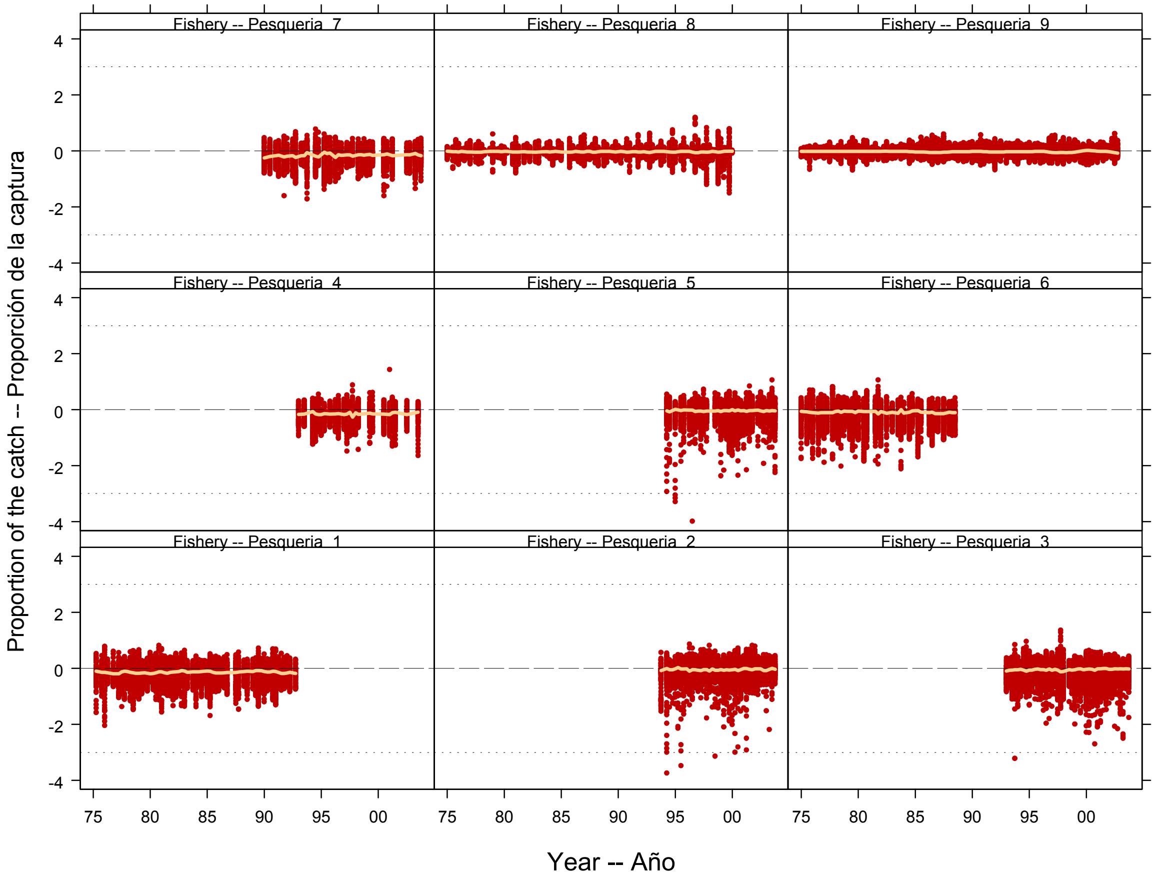

FIGURE A.2. Standardized residuals for the fit to the length-frequency data for bigeye tuna, by fishery and year. The fitted line is a loess smoother.

FIGURA A.2. Residuales estandarizados del ajuste a los datos de frecuencia de talla de atún patudo, por pesquería y año. La línea ajustada es un suavizador loess.

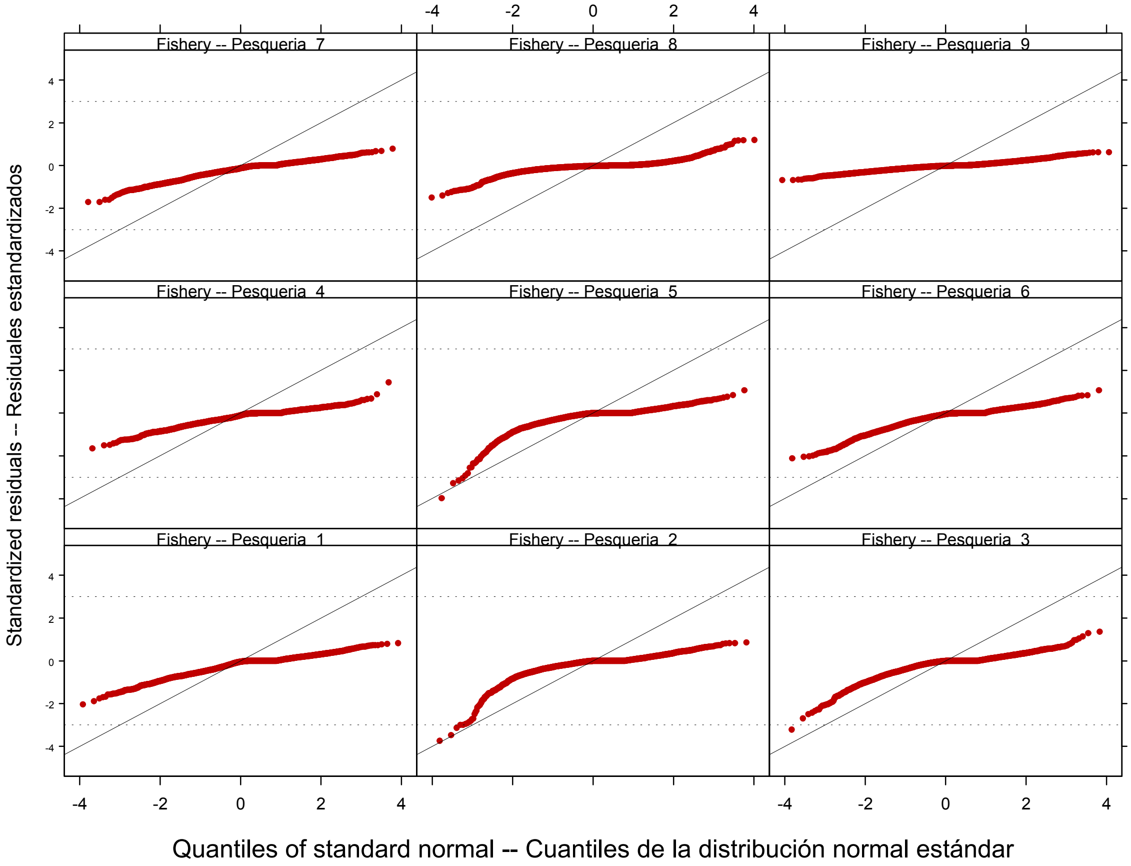

FIGURE A.3. Q-Q plot for the residuals of the fit to the length-frequency data for bigeye tuna, by fishery. The diagonal lines indicate the expectations for residuals following normal distributions. The dotted horizontal lines represent three standard deviations on either side of the mean.

FIGURA A.3. Gráficos Q-Q de los residuales de los ajustes a los datos de frecuencia de talla de atún patudo, por pesquería. Las líneas diagonales indican las expectativas de los residuales siguiendo distribuciones normales. Las líneas con puntos representan tres desviaciones estándar en cualquier lado del medio.

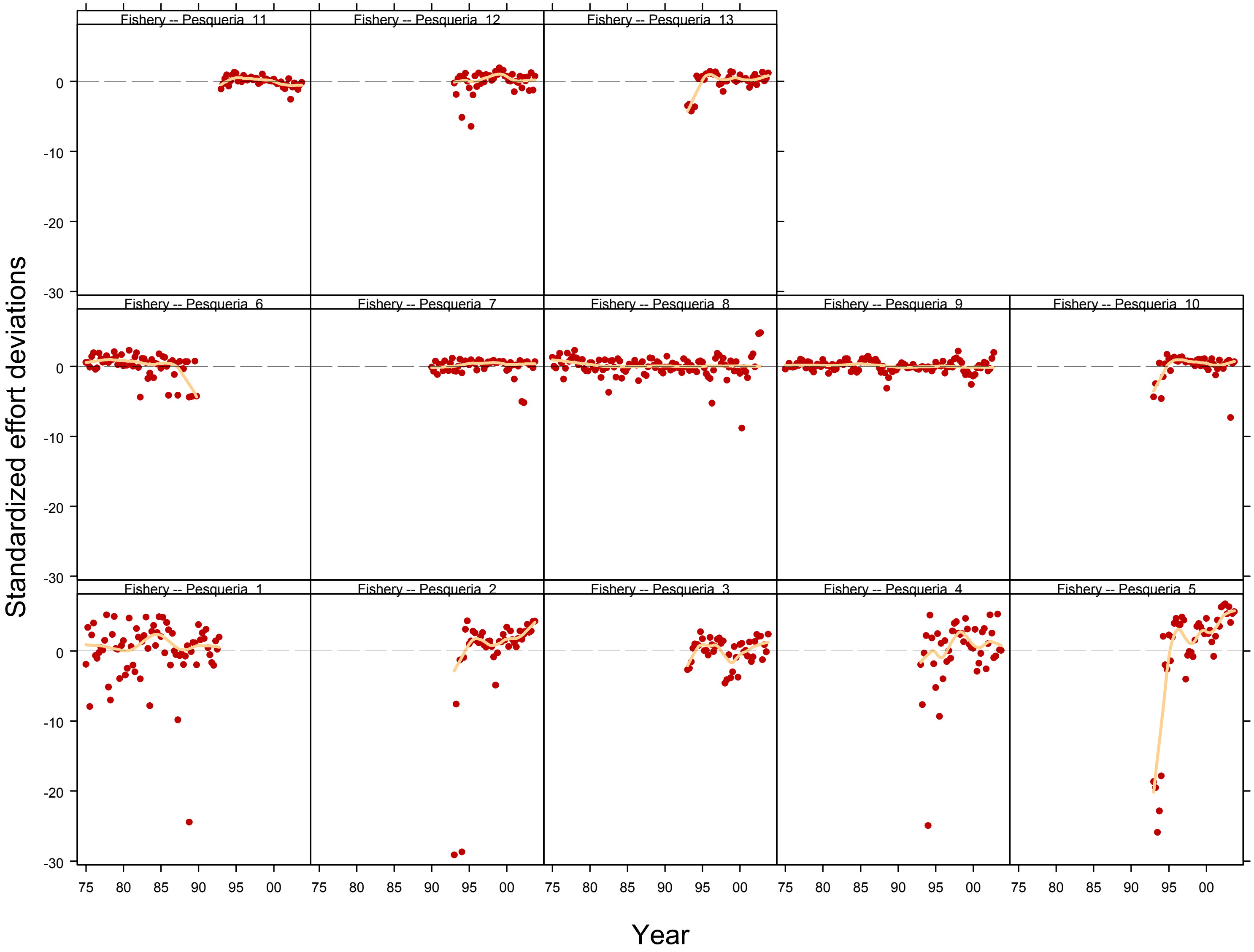

FIGURE A.4. Standardized effort deviates for bigeye tuna, by fishery and quarter. The fitted line is a loess smoother.

FIGURA A.4. Desvíos estandarizados del esfuerzo de atún patudo, por pesquería y clase de talla. La línea ajustada es un suavizador loess.

APPENDIX B: STEEPNESS SENSITIVITY ANALYSIS

ANEXO B: ANÁLISIS DE SENSIBILIDAD A LA INCLINACIÓN

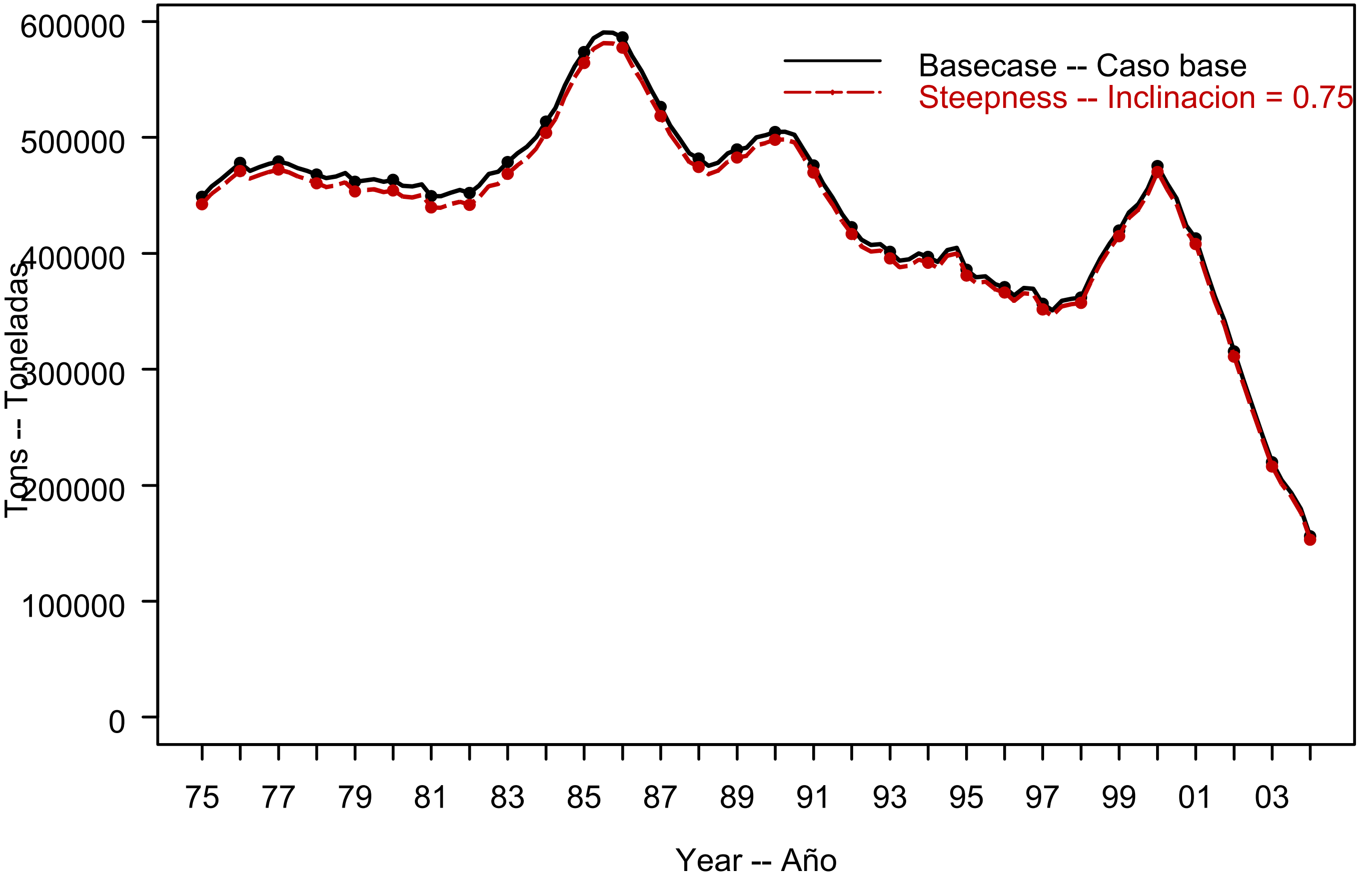

FIGURE B.1. Comparison of estimates of biomass of bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).

FIGURA B1. Comparación de las estimaciones de la biomasa del atún patudo del análisis sin (caso base) y con relación población-reclutamiento (inclinación = 0,75).

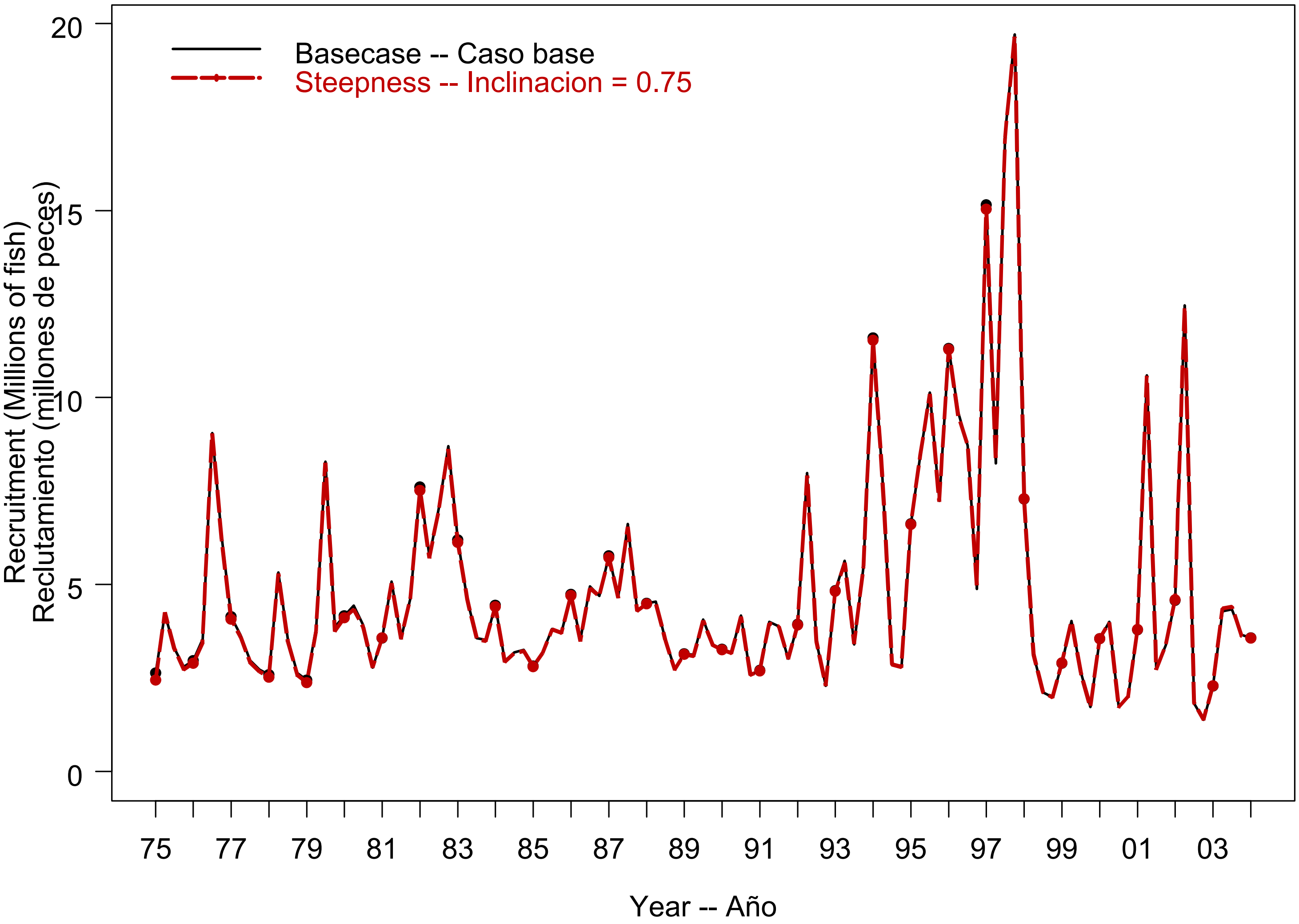

FIGURE B.2. Comparison of estimates of recruitment for bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).

FIGURA B.2. Comparación de las estimaciones del reclutamiento del atún patudo del análisis sin (caso base) y con relación población-reclutamiento (inclinación = 0,75).

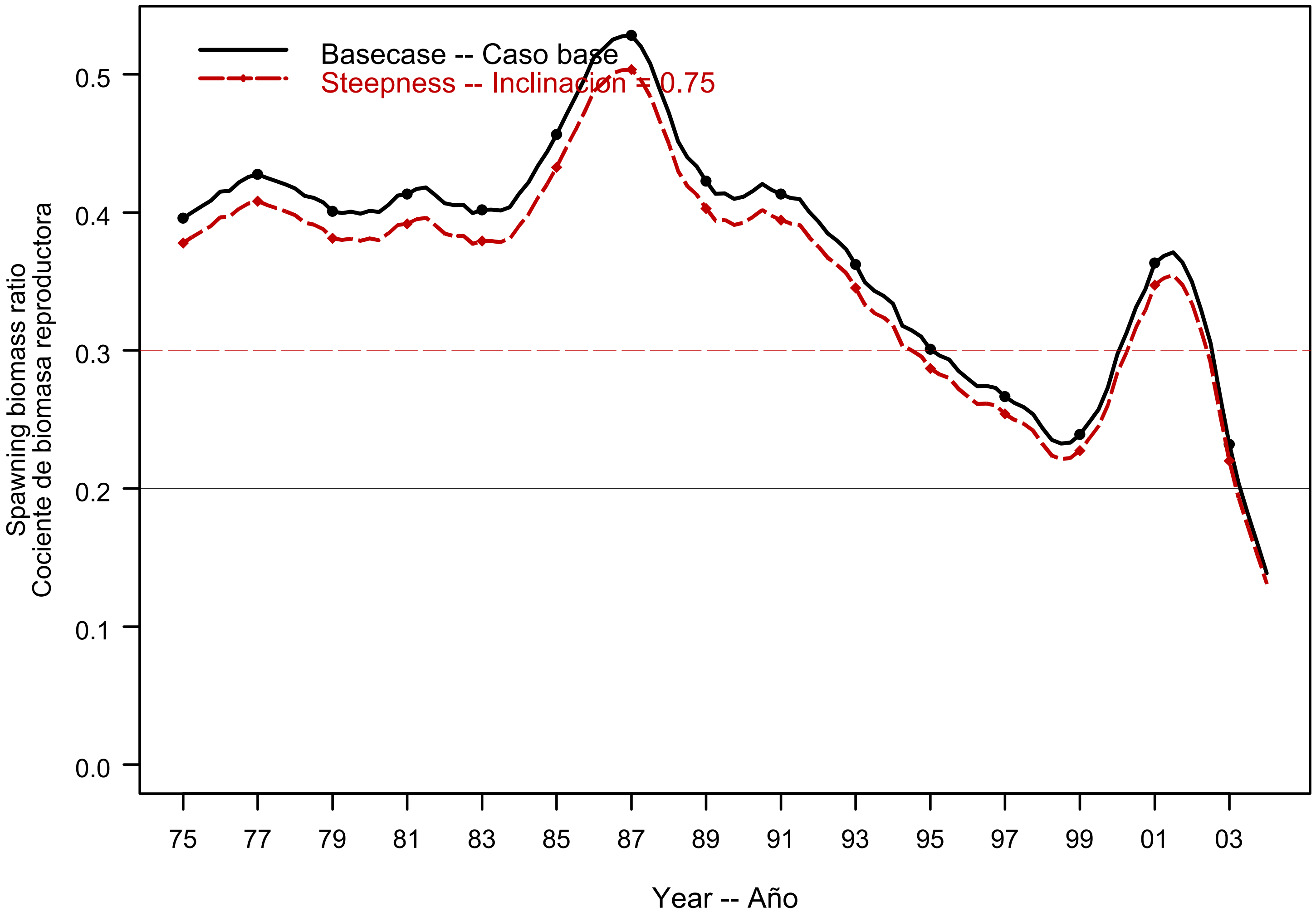

FIGURE B.3. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). The horizontal lines represent the SBRs associated with AMSY under the two scenarios.

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

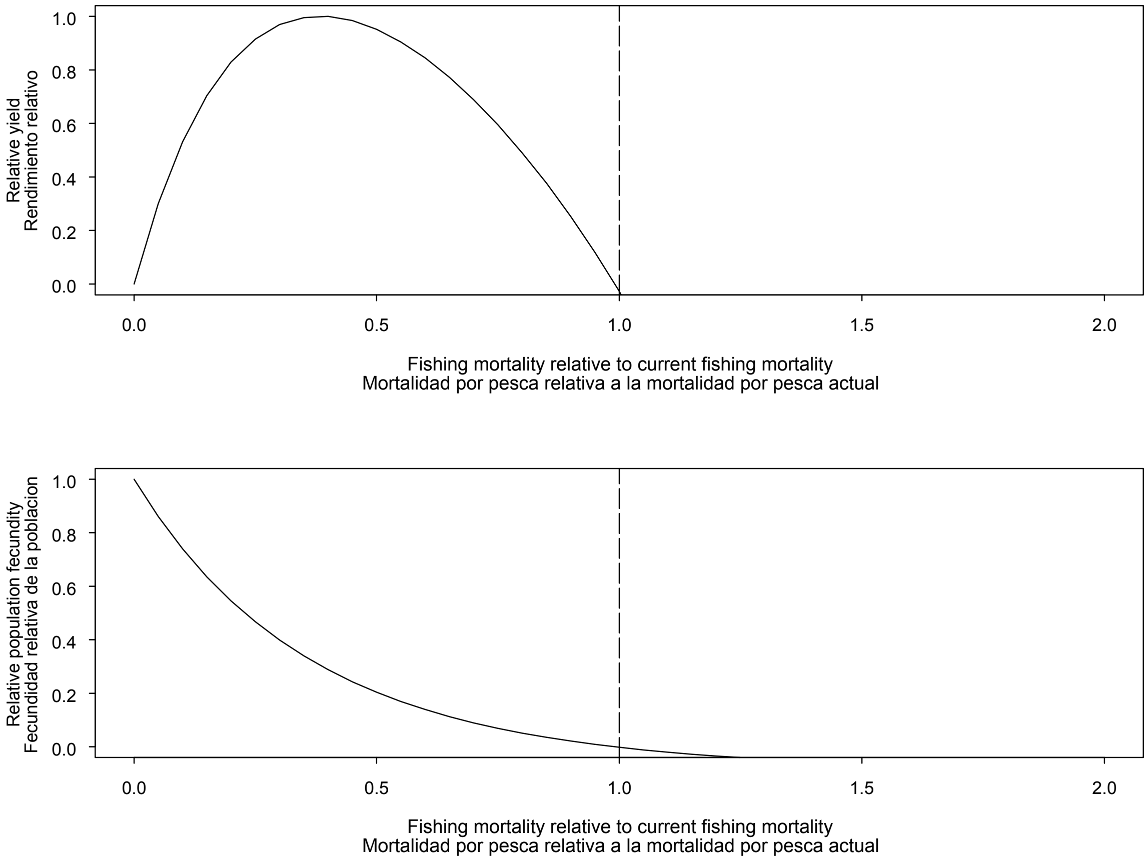

FIGURE B.4. Predicted effects of long-term changes in fishing effort on the yield (upper panel) and spawning biomass (lower panel) of bigeye tuna under equilibrium conditions with average fishing mortality patterns from 2001 and 2002 and a stock-recruitment relationship (steepness = 0.75) is included. The yield estimates are scaled so that the AMSY is at 1.0, and the spawning biomass estimates so that the spawning biomass is equal to 1.0 in the absence of exploitation.

FIGURA B.4. Efectos predichos de cambios a largo plazo en el esfuerzo de pesca sobre el rendimiento (recuadro superior) y biomasa reproductora (recuadro inferior) de atún patudo bajo condiciones de equilibrio con los patrones medios de mortalidad por pesca de 2000 y 2001 y datos de SPC para la pesquería coreana palangrera incluidos. Se escalan las estimaciones de rendimiento para que el RMSP esté en 1,0, y las de biomasa reproductora para que la biomasa reproductora equivalga a 1,0 si no hay explotación.

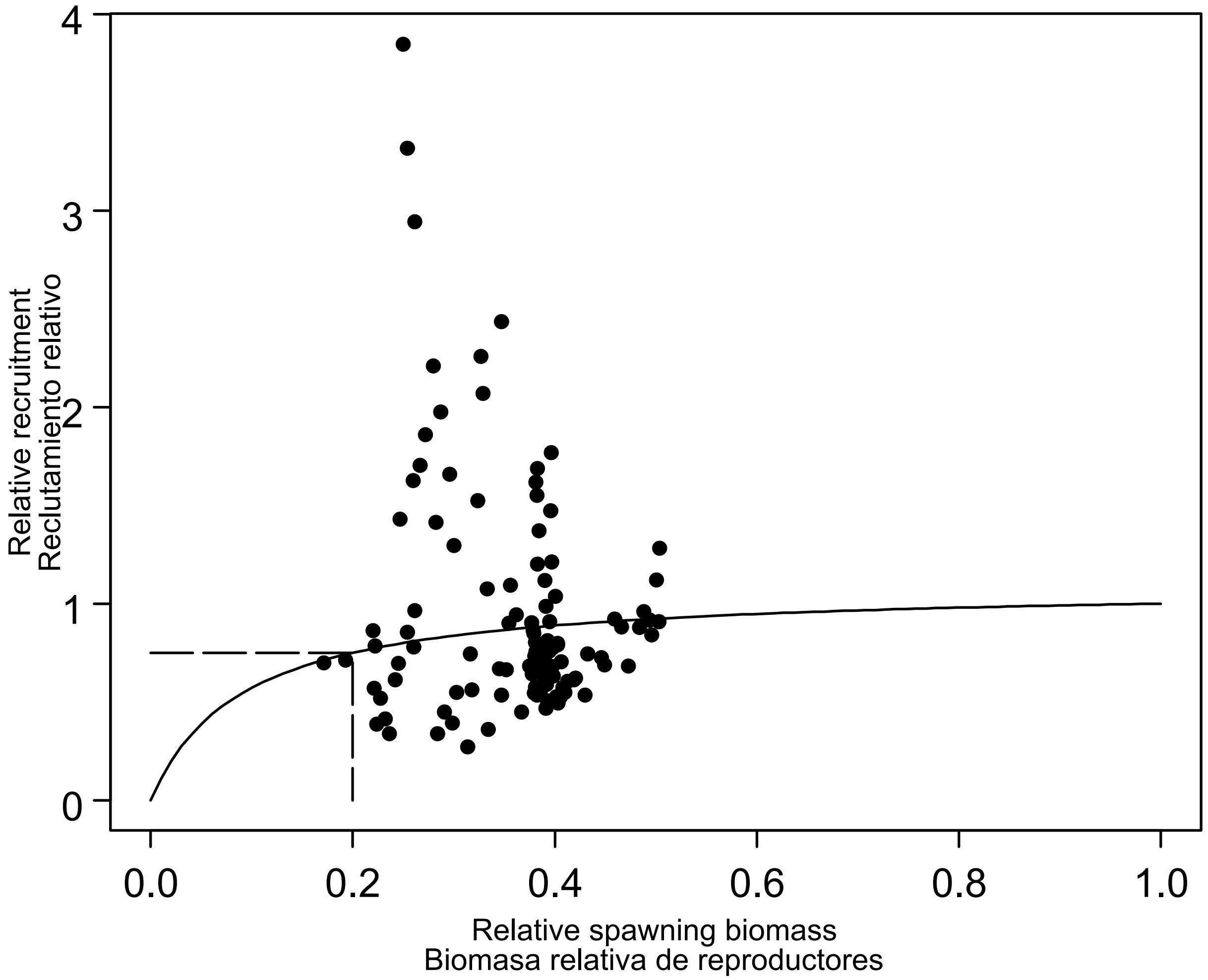

FIGURE B.5. Recruitment of bigeye tuna plotted against spawning biomass when the analysis has a stock-recruitment relationship (steepness = 0.75).
FIGURA B.5. Reclutamiento de atún patudo graficado contra biomasa reproductora cuando el análisis incluye una relación población-reclutamiento (inclinación = 0,75).

APPENDIX C: PURSE-SEINE CATCH SENSITIVITY ANALYSIS

ANEXO C: ANÁLISIS DE SENSIBILIDAD A LAS CAPTURAS CERQUERAS

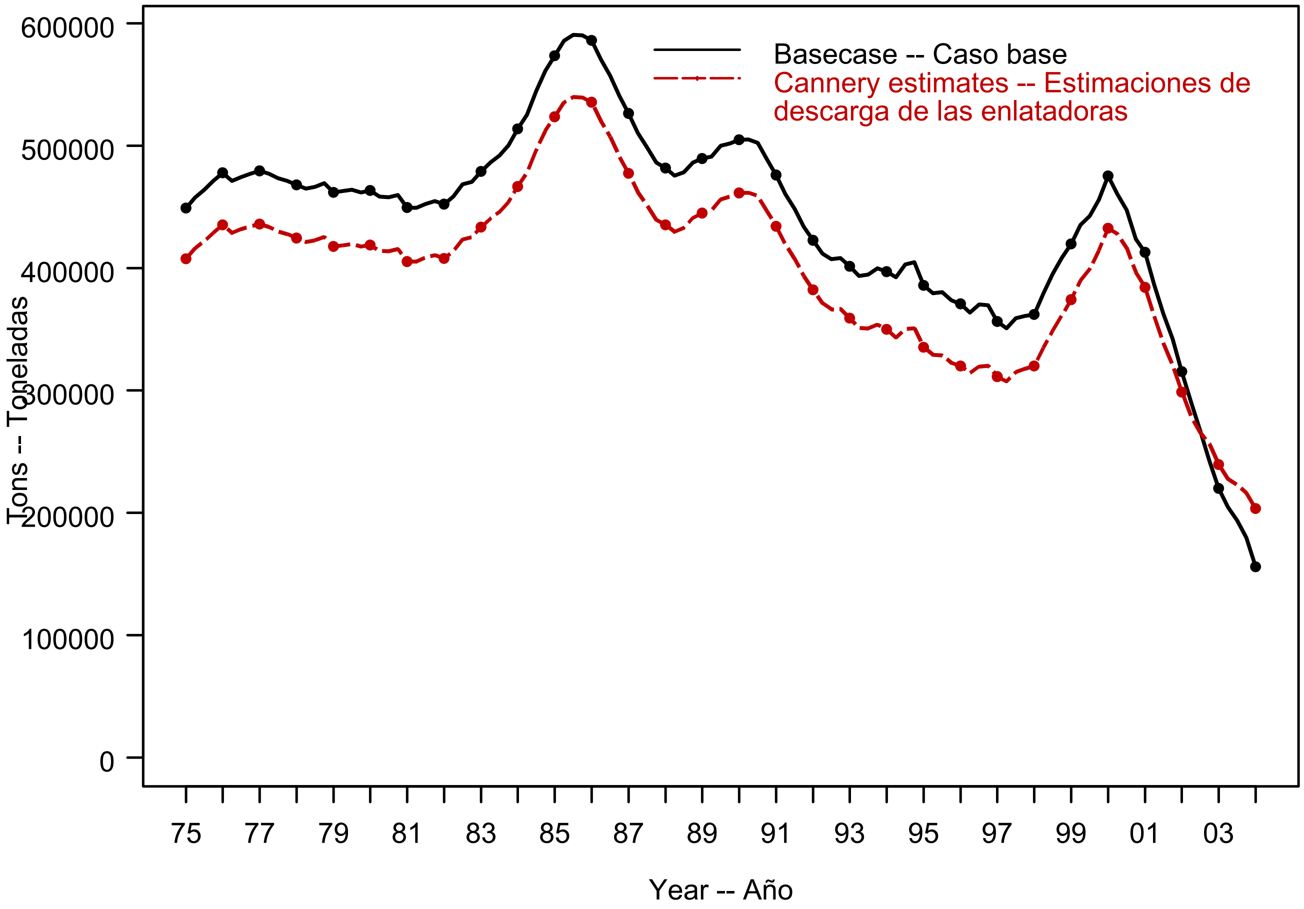

FIGURE C.1. Comparison of estimates of biomass of bigeye tuna from the base case and with the cannery estimates of purse-seine catch.
FIGURA C1. Comparación de las estimaciones de biomasa de atún patudo del caso base y con las estimaciones de enlatadoras de la captura cerquera.

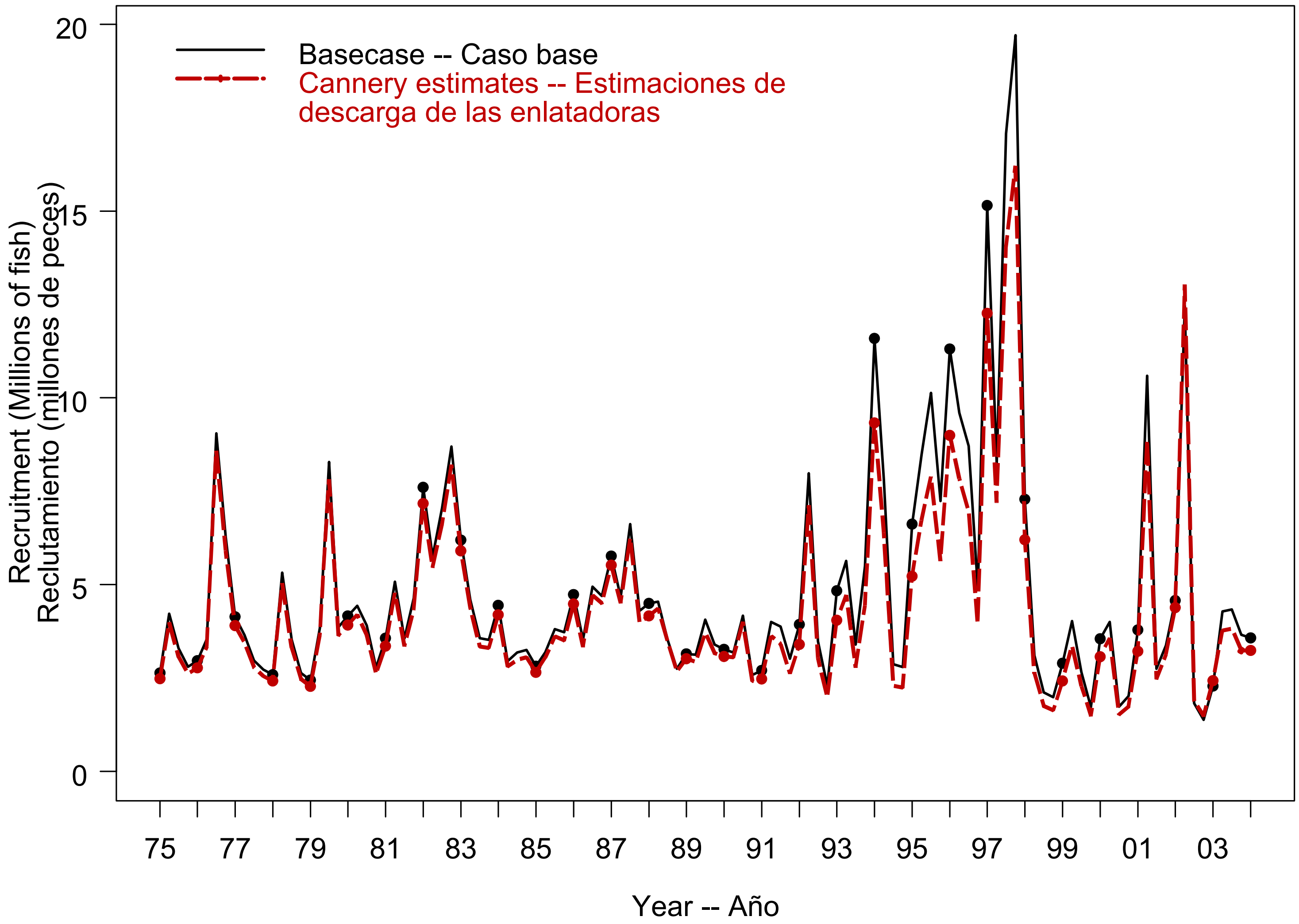

FIGURE C2. Comparison of estimates of recruitment of bigeye tuna from the base case and with the cannery estimates of purse-seine catch.

FIGURA C2. Comparación de las estimaciones de biomasa de atún patudo del caso base y con las estimaciones de enlatadoras de la captura cerquera.

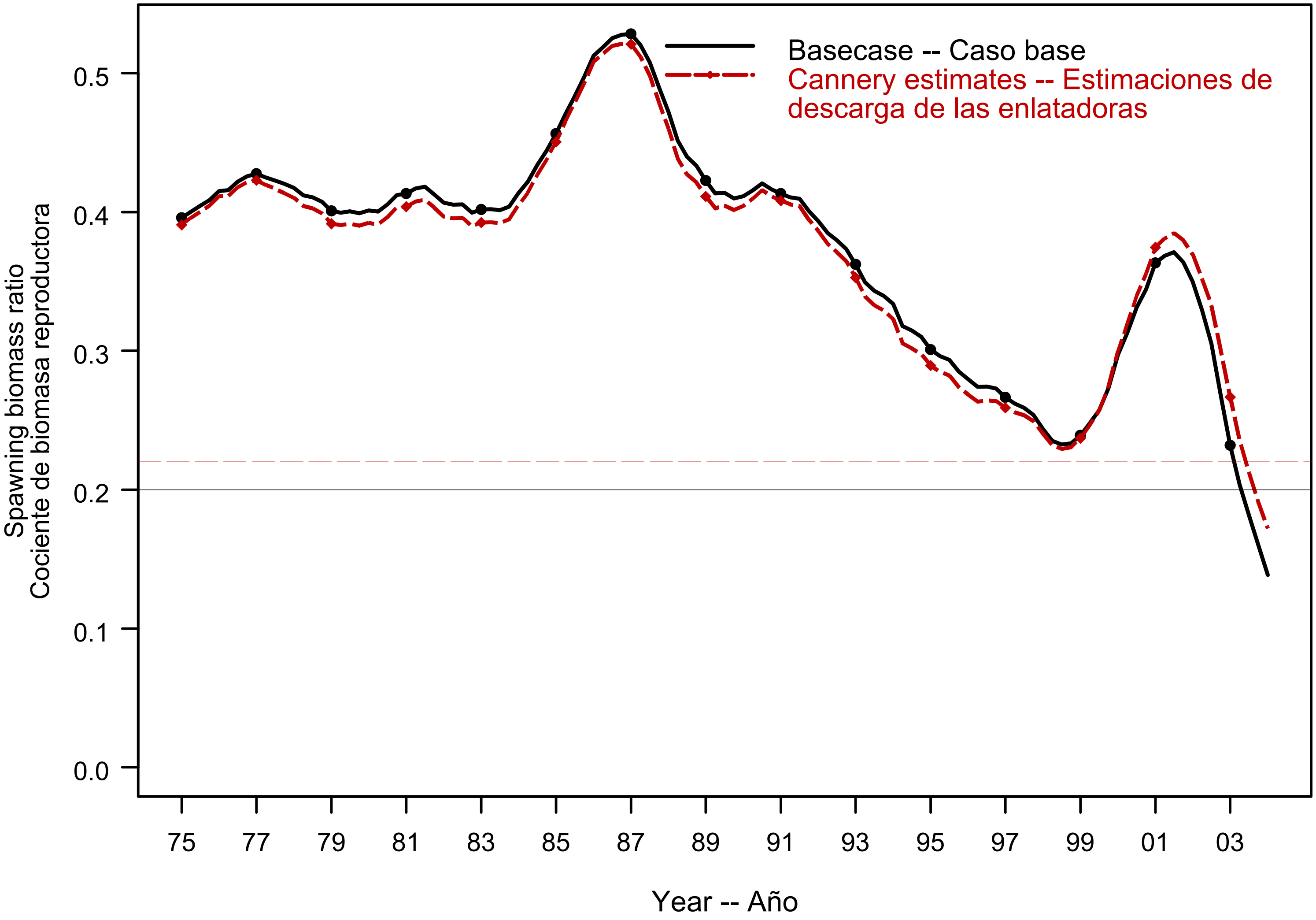

FIGURE C.3. Comparison of estimates of the spawning biomass ratios (SBRs) of bigeye tuna from the base case and with the cannery estimates of purse-seine catch. The horizontal lines represent the SBRs associated with AMSY under the two scenarios.

FIGURA C.3 Comparación de las estimaciones del cociente de biomasa reproductora (SBR) de atún patudo del caso base y con las estimaciones de enlatadoras de la captura cerquera. Las líneas horizontales indican el SBR asociado con el RMSP en los dos escenarios.

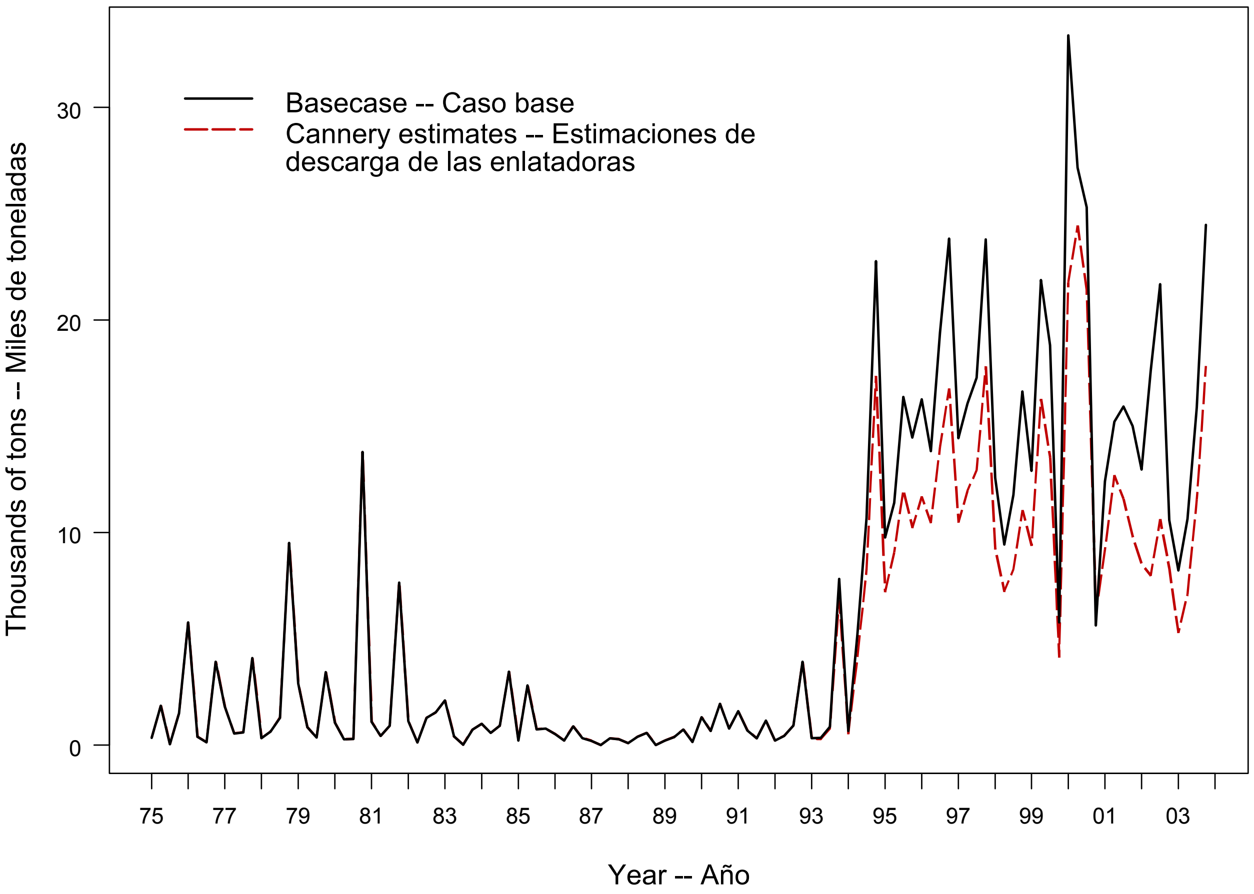

FIGURE C.5. Total purse-seine catch of bigeye tuna used in the base case (solid line) and the sensitivity analysis based on the cannery estimates of purse-seine catch (dashed line).

FIGURA C.5. Captura total cerquera de atún patudo usada en el caso base (línea sólida) y el análisis de sensibilidad basado en las estimaciones de enlatadoras de la captura cerquera (línea de trazos).

APPENDIX D: JUVENILE NATURAL MORTALITY SENSITIVITY ANALYSIS

ANEXO D:

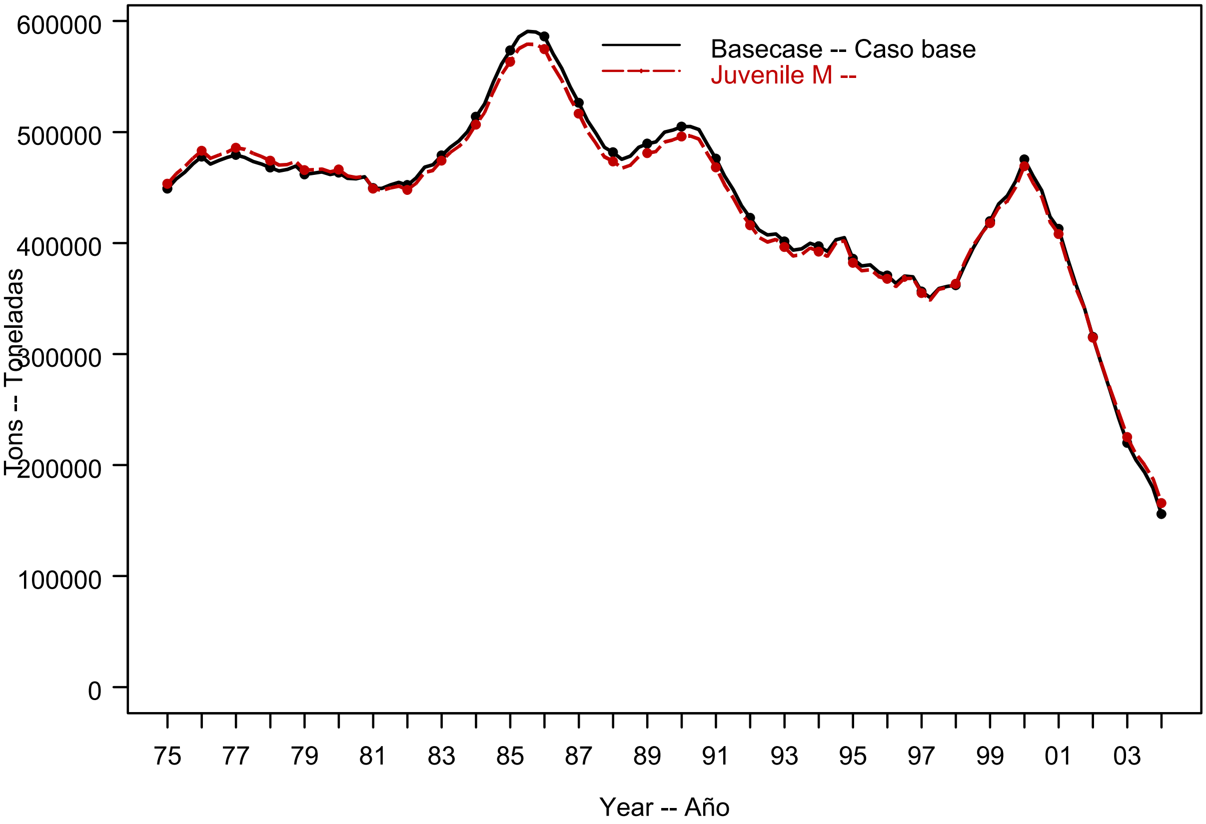

FIGURE D.1. Comparison of estimates of biomass of bigeye tuna from the base case and with greater levels of natural mortality for bigeye younger than ten quarters.
FIGURA D.1.

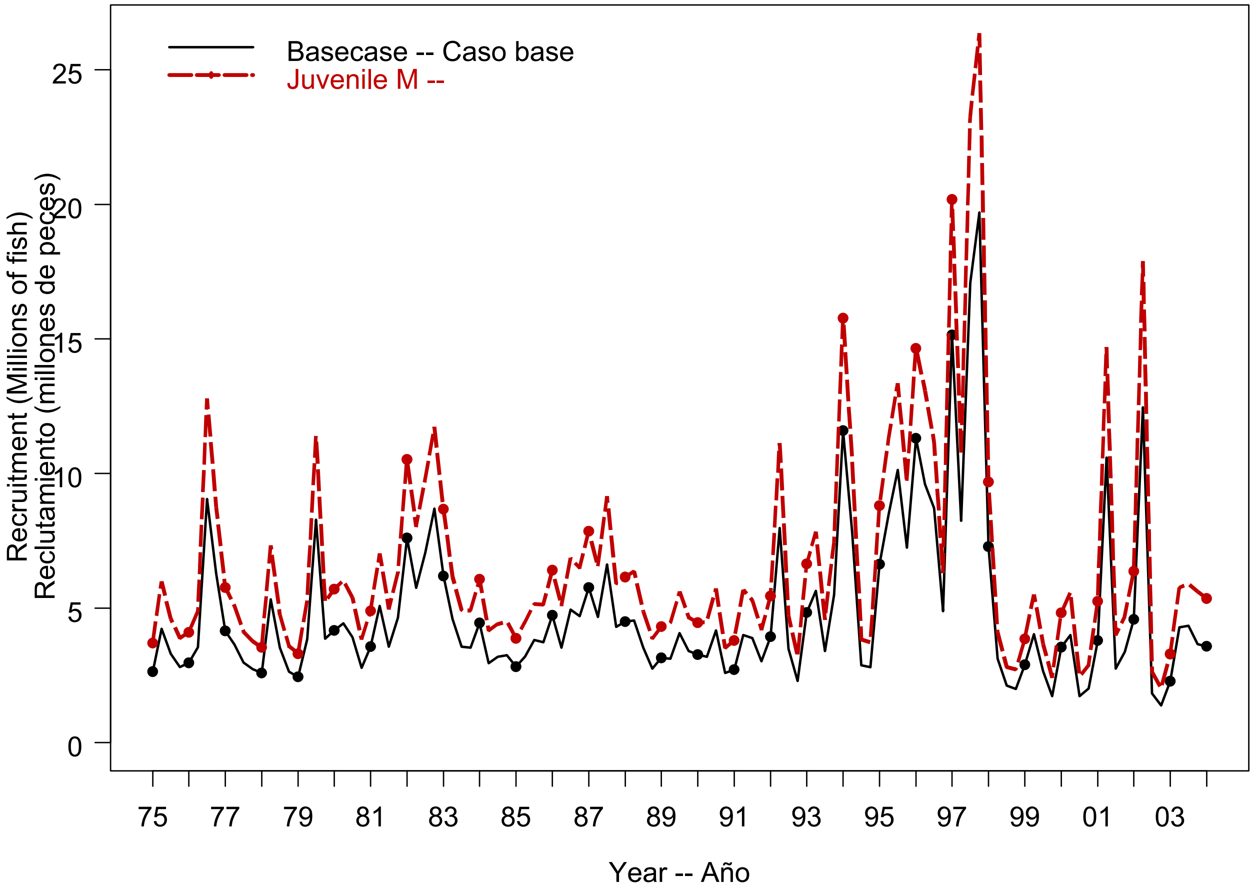

FIGURE D.2. Comparison of estimates of recruitment of bigeye tuna from the base case and with greater levels of natural mortality for bigeye younger than ten quarters.

FIGURA D.2.

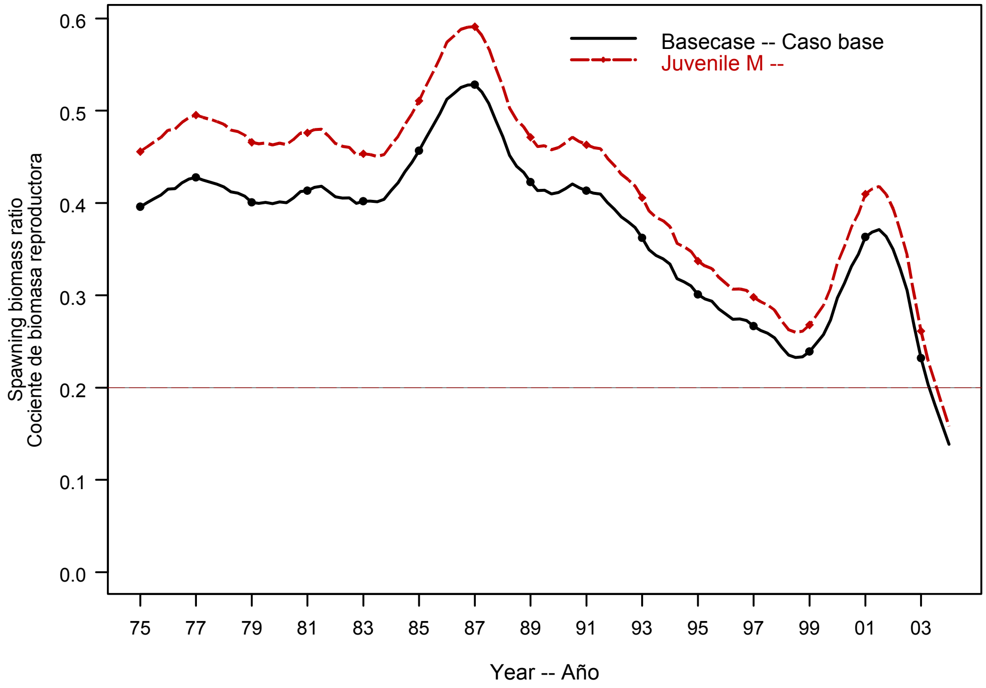

FIGURE D.3. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the base case and with greater levels of natural mortality for bigeye younger than quarters.. The horizontal lines represent the SBR associated with AMSY for the two scenarios.

FIGURA D.3. Las líneas horizontales indican el SBR asociado con el RMSP en los dos escenarios.

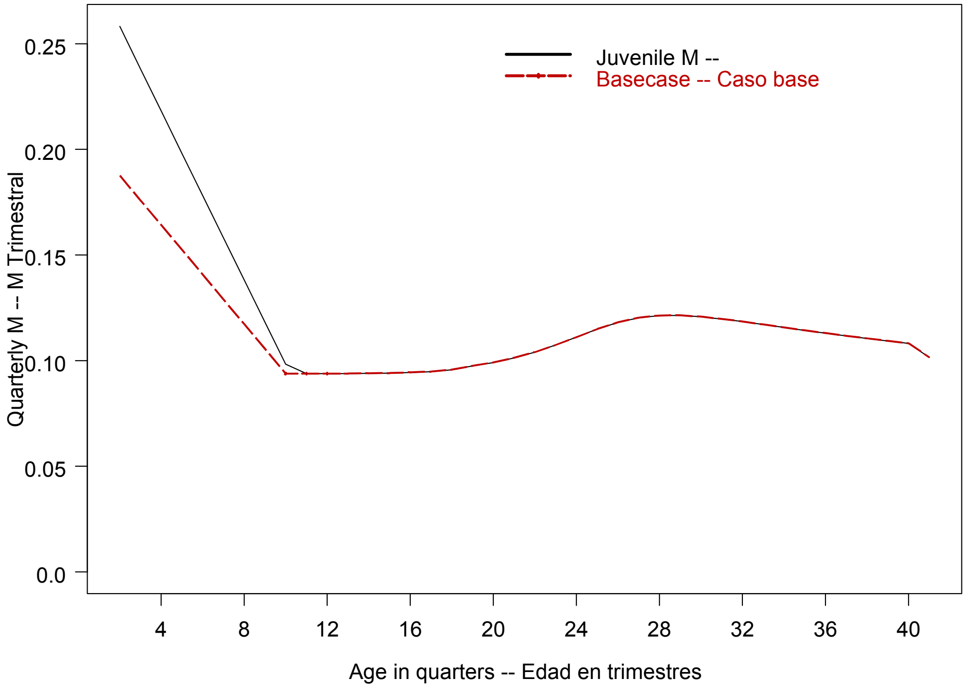

FIGURE D.4. Comparison of the assumed quarterly rates of natural mortality from the base case and the sensitivity analysis.

FIGURA D.4.

APPENDIX E: ADDITIONAL RESULTS FROM THE BASE CASE ASSESSMENT

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

ANEXO E: RESULTOS ADICIONALES DE LA EVALUACIÓN DEL CASO BASE

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

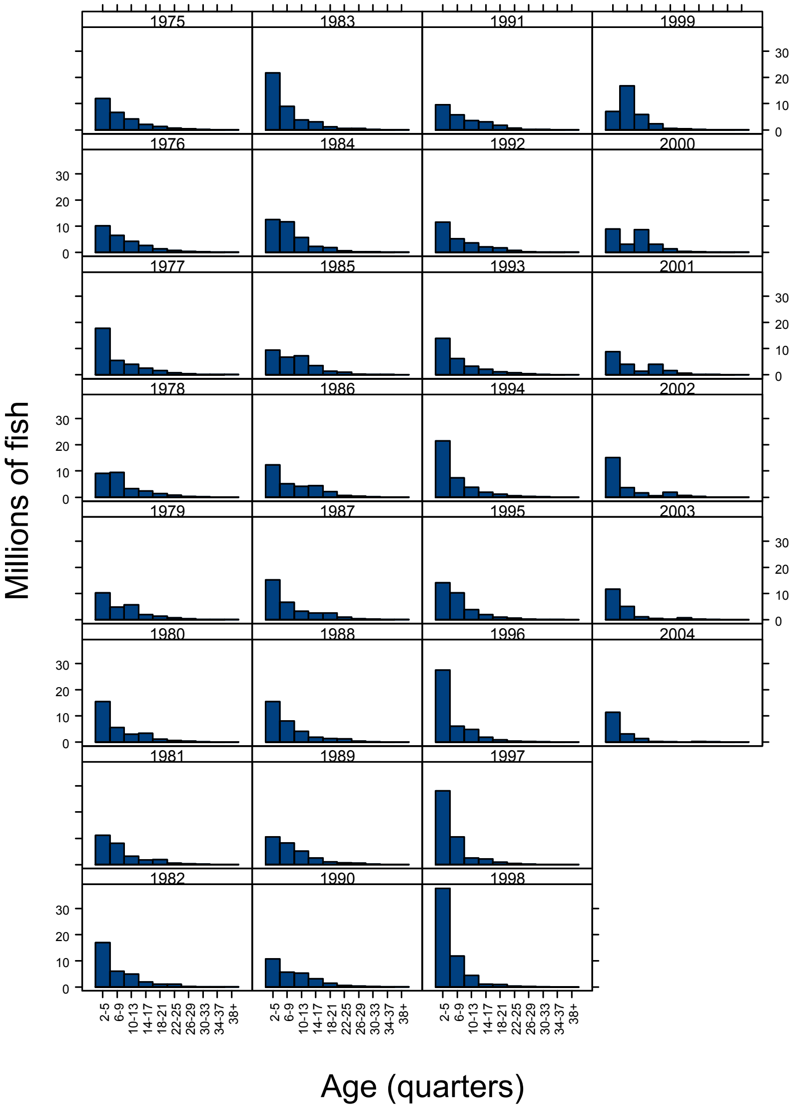

FIGURE E.1. Estimated numbers of bigeye tuna present in the EPO on 1 January of each year.
FIGURA E.1. Número estimado de atunes patudo presentes en el OPO el 1 de enero de cada año.

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

Year	Age—Edad									
Año	**2-5**	**6-9**	**10-13**	**14-17**	**18-21**	**22-25**	**26-29**	**30-33**	**34-37**	**38+**
1975	0.00	0.03	0.09	0.10	0.16	0.17	0.17	0.17	0.17	0.17
1976	0.01	0.04	0.14	0.14	0.21	0.21	0.20	0.21	0.20	0.20
1977	0.01	0.04	0.15	0.18	0.26	0.29	0.29	0.29	0.29	0.29
1978	0.01	0.07	0.16	0.18	0.26	0.28	0.28	0.28	0.28	0.28
1979	0.01	0.04	0.14	0.16	0.25	0.26	0.26	0.26	0.26	0.26
1980	0.01	0.10	0.15	0.17	0.25	0.27	0.27	0.26	0.26	0.26
1981	0.01	0.06	0.13	0.15	0.23	0.23	0.23	0.23	0.23	0.23
1982	0.00	0.03	0.12	0.15	0.22	0.23	0.22	0.23	0.23	0.23
1983	0.00	0.02	0.13	0.16	0.25	0.26	0.26	0.26	0.26	0.26
1984	0.00	0.03	0.10	0.12	0.18	0.19	0.19	0.19	0.19	0.19
1985	0.00	0.02	0.11	0.14	0.22	0.23	0.23	0.23	0.23	0.23
1986	0.00	0.03	0.15	0.20	0.31	0.35	0.35	0.35	0.35	0.35
1987	0.00	0.02	0.15	0.20	0.32	0.36	0.36	0.36	0.36	0.36
1988	0.00	0.02	0.11	0.16	0.25	0.28	0.28	0.28	0.28	0.28
1989	0.00	0.02	0.12	0.16	0.25	0.27	0.27	0.27	0.27	0.27
1990	0.00	0.04	0.16	0.21	0.32	0.35	0.34	0.34	0.34	0.34
1991	0.00	0.03	0.18	0.25	0.38	0.43	0.42	0.42	0.42	0.42
1992	0.00	0.03	0.16	0.22	0.33	0.38	0.36	0.36	0.36	0.36
1993	0.02	0.05	0.16	0.21	0.31	0.35	0.33	0.33	0.33	0.33
1994	0.08	0.19	0.28	0.29	0.36	0.38	0.37	0.37	0.36	0.36
1995	0.21	0.28	0.33	0.32	0.35	0.34	0.30	0.30	0.30	0.30
1996	0.30	0.41	0.42	0.36	0.34	0.29	0.26	0.26	0.25	0.25
1997	0.22	0.40	0.45	0.37	0.35	0.27	0.26	0.26	0.26	0.26
1998	0.17	0.26	0.29	0.28	0.34	0.35	0.31	0.31	0.31	0.30
1999	0.19	0.23	0.27	0.22	0.22	0.19	0.16	0.16	0.16	0.16
2000	0.19	0.41	0.43	0.32	0.30	0.19	0.18	0.18	0.18	0.18
2001	0.23	0.42	0.44	0.37	0.40	0.34	0.32	0.32	0.32	0.32
2002	0.44	0.75	0.71	0.55	0.51	0.39	0.37	0.37	0.37	0.37
2003	0.61	0.76	0.69	0.56	0.46	0.36	0.35	0.34	0.34	0.34