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

by

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1. EXECUTIVE SUMMARY

This report presents the current stock assessment of bigeye tuna (*Thunnus obesus*) in the eastern Pacific Ocean (EPO). This assessment, and the previous ones, were conducted with A-SCALA, an age-structured catch-at-length analysis. The current version of A-SCALA is similar to that used for the most recent previous assessment. The assessment reported here is based on a single stock in the eastern Pacific Ocean.

The stock assessment requires a substantial amount of information. Data on retained catch, discards, fishing effort, and 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 differences between the assessments for 2005 and 2004 are as follows:

1. Catch and length-frequency data for the surface fisheries have been updated to include new data for 2005 and revised data for 1975-2004.
2. Effort data for the surface fisheries have been updated to include new data for 2005 and revised data for 1975-2004.
3. Monthly reporting of catch data for the longline fishery provided, at the time of the assessment, complete 2005 catch data for Vanuatu and partial catch data for Japan, China, Korea, and Chinese Taipei.
4. Catch data for the Japanese longline fisheries have been updated for 2000-2004.
5. Catch data for the longline fisheries of Chinese Taipei have been updated for 2002 and new data

for 2003 added.

6. Catch data for the longline fisheries of Korea have been updated to include new data for 2003.
7. Catch data for the longline fisheries of China have been updated for 2003 and 2004.
8. Longline catch-at-length data for 2002-2003 have been updated and new data for 2004 added.
9. Longline effort data are based on delta-lognormal general linear model standardization of catch per unit of effort have been updated to include data for 2004.

Analyses were carried out to assess the sensitivity to the steepness of the stock-recruitment relationship, the assumed value for the asymptotic length parameter of the Richards growth curve, to the inclusion of the Chinese Taipei longline length-frequcy data, and inclusion of a relationship between recruitment an the el Nino index. The base case assessment included an assumption that recruitment was independent of stock size, and a Beverton-Holt (1957) stock-recruitment relationship with steepness of 0.75 was used for the sensitivity analysis. Sensitivity to the assumed value for the asymptotic length parameter of the Richards growth curve was carried out using a lower value of 171.5, which is around the value estimated by stock assessments for the west and central Pacific Ocean (Adam Langley, Secretariat of the Pacific Community, pers. com.), and an upper value of 201.5. Sensitivity to including the Chinese Taipei longline fleet was carried out by treating it as a separate fishery with the associated length-frequency data.

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 18 quarters old has increased substantially since 1993, and that on fish more than about 18 quarters old has increased slightly 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.

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

There are several important features in the estimated time series of bigeye recruitment. First, estimates of recruitment before 1993 are very uncertain, as the floating-object fisheries, which catch small bigeye, were not operating. There was a period of above-average recruitment in 1995-1998, followed by a period of below-average recruitment in 1999-2000. The recruitments were above-average in 2001 to 2002 with spikes in 2004 and 2005. The most recent recruitment is very uncertain, due to the fact that recently-recruited bigeye are represented in only a few length-frequency data sets. The extended period of relatively large recruitments in 1995-1998 coincided with the expansion of the fisheries that catch bigeye in association with floating objects.

The biomass of 3+-quarter-old bigeye increased during 1980-1984, and reached its peak level of about 537,000 t in 1986, after which it decreased to an historic low of about 254,000 t at the start of 2004. The biomass has increased in 2004 and 2005 due to two recent spikes in recruitment. Spawning biomass has generally followed a trend similar to that for the biomass of 3+-quarter-olds, but lagged by 1-2 years. There is uncertainty in the estimated biomasses of both 3+-quarter-old bigeye and spawners. Nevertheless, it is apparent that fishing has reduced the total biomass of bigeye in the EPO. Both are predicted to have increased in recent years.

The estimates of recruitment and biomass were only moderately sensitive to the steepness of the stock-recruitment relationship. The estimates of recruitment and biomass were very sensitive to the assumed value of the asyptotic length in the Richards growth equation. A lower value gave higher biomass and recruitment. Estimates of recruitment and biomass were insensitive to the inclusion of the Chinese Taipei length-frequency data and the el Nino-recruitment relation. The relationship between recruitment and the el Nino index was found to be significant, but only explained a small portion of variation in recruitment.

At the beginning of January 2006, the spawning biomass of bigeye tuna in the EPO was increasing from a recent hitorical low level (Figure 5.1a). At that time the SBR was about 0.20, about 12% less than the level corresponding to the AMSY, with lower and upper confidence limits (±2 standard deviations) of about 0.13 and 0.26. The estimate of the upper confidence bound is greater than the estimate of SBR_{AMSY} (0.22).

The relatively narrow confidence intervals (±2 standard deviations) around the SBR estimates suggest that for most quarters during January 1975 to January 1993, and 2001-2002 the spawning biomass of bigeye in the EPO was probably greater than the corresponding to the AMSY. This level is shown as the dashed line at 0.22 in Figure 5.1a.

Recent catches are estimated to have been about 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 corresponding to the AMSY is about 68% of the current (2003-2004) level of effort. If this level of effort were maintained, the long term yield would be about 95% of AMSY. Decreasing the effort to 32% of its present level would increase the long-term average yield by about 5% and would increase the spawning biomass of the stock by about 75%. 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 that are close to the critical weight. Before the expansion of the floating object fishery that started in 1993, AMSY was greater than the current AMSY and the fishing mortality was less than that corresponding to AMSY (Figure 5.1c).

All analyses, except the low assumed value for the asymptotic length of the Richards growth curve, suggest that at the start of 2005 the spawning biomass was below the level corresponding to 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, except the low assumed value for the asymptotic length, fishing mortality is well above the level corresponding to the AMSY.

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

The effects of the Resolution C-04-09 are estimated to be insufficient to allow the stock to remain at levels that support AMSY. If the effort is reduced to levels that support AMSY, the stock will remain above S_{AMSY} within the 5-year projection period.

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

2. DATA

Catch, effort, and size-composition data for January 1975 through December 2005 were used to conduct the stock assessment of bigeye tuna, *Thunnus obesus*, in the eastern Pacific Ocean (EPO). The data for 2005, which are preliminary, include records that had been entered into the IATTC databases as of mid March, 2005. 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, 2005; Maunder and Hoyle 2006). 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 gear and by purse-seine vessels setting on dolphins and unassociated schools (Fisheries 6 and 7). Relatively few bigeye are captured by the first two methods, and the data from Fisheries 6 and 7 are dominated by information on catches from unassociated schools of bigeye. Given this latter fact, Fisheries 6 and 7 will be referred to as fisheries that catch bigeye in unassociated schools in the remainder of this report.

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 assessments of Harley and Maunder (2005) and Maunder and Hoyle (2006), 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 represent only 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 for which no species-composition samples are available. In this assessment we calculated average scaling factors for 2000-2005 by dividing the total catch for all years and quarters for the species composition estimates by the total catch for all years and quarters for the standard estimates and applied these to the cannery and unloading estimates for 1975-1999. For fisheries 1, 6, and 7 we used the average over fisheries 2-5, for fisheries 2 and 3 we used the average over fisheries 2 and 3, and for fisheries 4 and 5 we used the average over fisheries 4 and 5. Harley and Maunder (2005) provide a sensitivity analysis which compares the results from the stock assessment using the species composition estimates of purse-seine fishery landings with the results from the stock assessment using cannery unloading estimates. Watters and Maunder (2001) provide a brief description of the method that is used to estimate surface fishing effort.

Updates and new catch and effort data for the longline fisheries (Fisheries 8 and 9) have also been incorporated into the current assessment. Monthly reporting of catch data provided, at the time of the assessment, complete 2005 catch data for Vanuatu and partial catch data for Japan, China, Korea, and Chinese Taipei. Catch data for the Japanese fisheries have been updated for 2000-2004. Catch data for the fisheries of Chinese Taipei have been updated for 2002 and new data for 2003 added. Catch data for the fisheries of Korea have been updated to include new data for 2003. Catch data for the fisheries of China have been updated for 2003 and 2004.

As in the previous assessments of bigeye of the EPO (Watters and Maunder 2001, 2002; Maunder and Harley 2002; Harley and Maunder 2004, 2005; Maunder and Hoyle 2006), 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), by the habitat-based method (Hinton and Nakano 1996; Bigelow *et al*. 2003), neural networks (Harley and Maunder 2004, 2005), or statistical habitat based model (Maunder and Hoyle 2006). In this assessment we used delta-lognormal general model standardized CPUE for 1975–2004 using latitude, longitude, and hooks per basket as explanatory variables.

2.2.1. Catch

Trends in the catches of bigeye tuna taken from the EPO during each quarter from January 1975 through December 2005 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.

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 in 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, declined substantially after about 1991, increased after 2000, but then starting declined again in 2003.

For the longline fisheries, standardized CPUE was available to estimate effective effort for each quarter from 1975 to 2004. Total fishing effort of all nations was estimated by dividing the observed catches combined for all nations by the CPUE. It was assumed that quarterly effort in 2005 was the same as that estimated for the fishery in 2004. However, the abundance information in the catch and effort data for 2005 was greatly down weighted in the model.

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. Discard data for 2005 were not available for the analysis and it was assumed that the discard rate by quarter was the same as for 2004.

Estimates of discards resulting from inefficiencies in the fishing process are added to the catches made by purse-seine vessels (Table 2.1). No observer data are available to estimate discards 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 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 proportions of the catches discarded have been low for the last seven years compared to those observed during fishing on the strong cohorts produced in 1997. There is strong evidence that some of this is due to the weak year classes during that period. However, there have been two large recruitments recently (Figure 4.9). It is possible that regulations regarding discarding of tuna have played a role.

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

2.1. Size composition data

New length-frequency data for 2005 and updated data for 1975-2004 are available for the surface fisheries. New longline length-frequency data for the Japanese fleet are available for 2004, and data for 2002-2003 have been updated. Size composition data for the other longline fleets are not used in the assessment. Longline length-frequency data is available for the Chinese Taipei fleet from 1981 to 2003.

The fisheries of the EPO catch bigeye tuna of various sizes. The average size compositions of the catches from each fishery defined in Table 2.1 have been described in previous assessments (*e.g.* Watters and Maunder 2001, 2002). The fisheries that catch bigeye associated with floating objects typically catch small (<75 cm) and medium-sized (75 to 125 cm) 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 from fisheries that catch bigeye in association with floating objects have dominated the catches (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, but the size composition has a single mode (Figure 4.2, Fishery 9).

The length-frequency data for the Chinese Taipei fleet include more smaller fish than those for the Japanese fleet. However, there is concern about the representativeness of the length-frequency samples from the Chinese Taipei fleet (Anon 2006, Stocker 2005). A sensitivity analysis was conducted using the Chinese Taipei fleet as a separate fishery.

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.

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 28.8 cm and one quarter 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_∞ = 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. Previous assessments (*e.g.* Harley and Maunder 2005), the EPO yellowfin tuna assessments (*e.g.* Maunder 2002) and tuna assessments in the western and central Pacific Ocean (Hampton and Fournier 2001a, b; Lehodey *et al*. 1999) suggest that tuna growth does not follow a von Bertalanffy growth curve for the younger fish. 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, in previous assessments the variation at age estimated from the otolith data collected in the western and central Pacific Ocean was used. 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).

Schaefer and Fuller (2006) used both tag-recapture data and otolith daily increments to determine growth curves for bigeye tuna in the EPO. The two data sources provided similar estimates, with a bias in the tagging data, which is hypothesized to be due to shrinkage because the recaptured bigeye tuna were measured at unloading. The growth curve estimated by Schaefer and Fuller is substantially different from the growth curves used in previous assessments (Figure 4.14): it shows a much more linear growth, and produces larger bigeye for a given age. The asymptotic length of the von Bertalanffy growth curve estimated by Schaefer and Fuller is much greater than any recorded bigeye tuna. This is reasonable as long as no biological meaning is given to the asymptotic length parameter and that the model is only used as a representation of the ages of fish that they sampled. The maximum age of the bigeye tuna in their data set is around 4 years (16 quarters) and their von Bertalanffy growth curve is not considered appropriate for ages greater than this. We fit a Richards growth curve using a lognormal likelihood function with constant variance and the asymptotic length parameter set at about the largest-sized bigeye seen in the data (186.5 cm).

$$L_a = L_\infty \left(1 - \exp\left[-K\left(a - t_0\right)\right]\right)^b$$

The resulting growth curve was used as a prior for all ages in the stock assessment. This growth curve is also used to convert the other biological parameters to age from length and for the calculation of natural mortality.

Hampton and Maunder (2005) found that the results of the stock assessment are very sensitive to the assumed value for the asymptotic length parameter. Therefore, sensitivity analyses were conducted to investigate the influence of the assumed value of the the asymptotic length parameter. A lower value of 171.5, which is around the value estimated by stock assessments for the west and central Pacific Ocean (Adam Langley, Secretariat of the Pacific Community, pers. com.), and an upper value of 201.5 were investigated.

Another important component of growth used in age-structured statistical catch-at-length models is the variation of length-at-age. Age-length information contains information about variation of length-at-age in addition to information about mean length-at-age. Unfortunately, as in the case of the data collected by Schaefer and Fuller, the fish are sampled to provide the best information about mean length-at-age, and therefore sampling is aimed at getting fish of a range of lengths. Therefore, variation in length at a particular age from this sample is not a good representation of the variation of length-at-age. However, by applying conditional probability, the appropriate likelihood can be developed, and the data were included in the analysis to help provide information about variation of length-at-age.

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

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

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

3.1.2. 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 (biomass of mature females) 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, it is estimated to be close to 1. We also present a sensitivity analysis with steepness = 0.75. In addition to the assumptions required for the stock-recruitment relationship, 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 are based on results from biological studies undertaken by IATTC staff (Schaefer et al. 2005) and samples provided by Dr. N. Miyabe. Information on age-at-length (Schaefer and Fuller 2006) was used to convert the maturity, fecundity, and proportion mature at length into ages (Figure 3.2). Data from the Japanese longline fishery, provided by Dr. N. Miyabe, were used to determine proportion mature at length. The age-specific proportions of female bigeye and fecundity indices used in the current assessment are provided in Table 3.1.

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*) are based on fitting to age-specific proportions of females, maturity-at-age, and natural mortality estimates of Hampton (2000) (Figure 3.1). The previous observation that different levels of natural mortality had a large influence on the absolute population size and the population size relative to that corresponding to the average maximum sustainable yield (AMSY) (Watters and Maunder 2001) remains. Harley and Maunder (2005) assessed the sensitivity of increasing natural mortality for bigeye younger than 10 quarters.

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 Oceanic Fisheries Programme of the Secretariat of the Pacific Community, 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 biomass trends very similar to those estimated by Harley and Maunder (2004).

3.2. Environmental influences

Oceanographic conditions might influence the recruitment of bigeye tuna to fisheries in the EPO. 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. 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 were 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 the previous assessment (Maunder and Hoyle 2006) hypothesis tests indicated that the environmental index is no longer statistically significant and it is not used in the assessment. A sensitivity analysis is conducted to investigate the relationship between recruitment and the el Nino index.

In previous assessments (Watters and Maunder 2001 and 2002; Maunder and Harley 2002) it was assumed that oceanographic conditions might influence the efficiency of the fisheries that catch bigeye associated with floating objects (Fisheries 1-5). In the assessment of Maunder and Harley (2002) an environmental influence on catchability was assumed 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 four assessments of bigeye (Watters and Maunder 2001, 2002; Maunder and Harley 2002; Harley and Maunder 2005; Maunder and Hoyle 2006). 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 by 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) one quarter 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 of 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 2006 (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 as those assumed for the assessment of Harley and Maunder (2004). These values were determined by cross validation (Maunder and Harley 2003).

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 2003 and 2004, so 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 uncertain and should not be considered. Sensitivity of estimates of key management quantities to this assumption was tested.

There is uncertainty in the results of the current stock assessment. This uncertainty arises because the observed data do not perfectly represent the population of 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

CPUEs have been presented in previous assessments of bigeye tuna of the EPO (*e.g.* Watters and Maunder 2001, 2002; Maunder and Harley 2002; Harley and Maunder 2004; Maunder and Hoyle 2006). 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 for the southern longline fishery (Figure 4.1, Fishery 9).

Comparing the CPUEs of the surface fisheries of 2005 to those of 2004 indicates that performance of these fisheries is quite variable. There is no discernable pattern in the changes in CPUEs from 2004 to 2005. The CPUEs for the discard fisheries (Fisheries 10–13) have generally been low for the last seven years (Section 4.2.2).

4.2. Assessment results

Below we describe the important aspects of the base case assessment (1 below) and the four sensitivity analysis (2-5):

1. Base case assessment: steepness of the stock-recruitment relationship equals 1 (no relationship between stock and recruitment), species-composition estimates of surface fishery catches scaled back to 1975, delta-lognormal general linear model standardized CPUE, and assumed sample sizes for the length-frequency data.
2. Sensitivity to the steepness of the stock-recruitment relationship. The base case assessment included an assumption that recruitment was independent of stock size, and a Beverton-Holt (1957) stock-recruitment relationship with steepness of 0.75 was used for the sensitivity analysis.
3. Sensitivity to the assumed value for the asymptotic length parameter of the Richards growth curve. A lower value of 171.5, which is around the value estimated by stock assessments for the west and central Pacific Ocean (Adam Langley, Secretariat of the Pacific Community, pers. com.), and an upper value of 201.5 were investigated.
4. Sensitivity to including the Chinese Taipei longline fleet as a separate fishery with the associated length-frequency data.
5. Sensitivity to including a relationship between recruitment and the el Nino index. The monthly standard Tahiti – Darwin sea level pressure anomalies index obtained from the Climate Prediction Center of NOAA (http://www.cpc.ncep.noaa.gov/data/indices/soi) was averaged over the quarter and negated.

The results of the base case assessment are described in the text, and the sensitivity analyses are described in the text with figures and tables presented in Appendices B-D. More comprehensive presentations 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, 2005).

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). 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 evidence of two moderate-strength cohorts moving through the floating object length frequency in 2004 and 2005. 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. This following list indicates the major penalties (a large value indicates that the constraint was influential):

Total negative log-likelihood = -383389

Negative log-likelihood for catch data = 4.7

Negative log-likelihood for size-composition data = -384392

Constraints and priors on recruitment parameters = 34

Constraints and priors on growth parameters = 87

Constraints on fishing mortality rates = 0.0

Constraints and priors on catchability parameters = 550

Constraints on selectivity parameters = 65

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 18 quarters old has increased since 1993, and that on fish more than about 18 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 about 16 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 and uncertainty in recent estimates in Figure 4.6b. 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. An annual summary of the estimates of total fishing mortality is presented in Appendix E (Table C.1).

For one of the main surface fisheries (Fishery 5), there is a strong increasing trend in catchability in recent years (Figure 4.7), indicating that the effective effort (capacity) of the fleet is increasing. There has been little change in the catchability of bigeye tuna by the longline fleet (Figure 4.7, Fisheries 8 and 9). 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

Previous assessments found that abundance of bigeye tuna being recruited to the fisheries in the EPO appeared to be related to zonal-velocity anomalies at 240 m during the time that these fish are assumed to have hatched (Watters and Maunder 2002). The mechanism that is responsible for this relationship has not been identified, and correlations between recruitment and environmental indices are often spurious, so the relationship between zonal-velocity and bigeye recruitment should be viewed with skepticism. Nevertheless, this relationship tends to indicate that bigeye recruitment is increased by strong El Niño events and decreased by strong La Niña events. 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 may be useful for reducing uncertainty in estimates of the strengths of the most recent cohorts for which few size-composition samples are available. In the previous assessment (Maunder and Hoyle 2006) the environmental index was not statistically significant and therefore not included in the analysis.

Over the range of estimated spawning biomasses shown in Figure 4.11, the abundance of bigeye recruits appears to be unrelated to the spawning biomass 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. The base case estimate of steepness is fixed at 1, which produces a model with a weak assumption that recruitment is independent of stock size. The consequences of overestimating steepness, in terms of lost yield and potential for recruitment overfishing, are far worse than those of underestimating it (Harley *et al*. unpublished analysis). A sensitivity analysis is presented in Appendix B that assumes that recruitment is moderately related to stock size (steepness = 0.75).

The 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 several important features in the estimated time series of bigeye recruitment. First, estimates of recruitment before 1993 are very uncertain, as the floating-object fisheries, which catch small bigeye, were not operating. There was a period of above-average recruitment in 1995-1998, followed by a period of below-average recruitment in 1999-2000. The recruitments were above average in 2001 to 2002 with spikes in 2004 and 2005. The most recent recruitment is very uncertain, due to the fact that recently-recruited bigeye are represented in only a few length-frequency data sets. The extended period of relatively large recruitments in 1995-1998 coincided with the expansion of the fisheries that catch bigeye in association with floating objects.

4.2.3. Biomass

Trends in the biomass of 3+-quarter-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 3+-quarter-old bigeye increased during 1980-1984, and reached its peak level of about 537,000 t in 1986, after which it decreased to an historic low of about 254,000 t at the start of 2004. The biomass has increased in 2004 and 2005 due to two recent spikes in recruitment.

The trend in spawning biomass is also shown in Figure 4.11, 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 3+-quarter-old bigeye, but is lagged by 1 to 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 C (Figure C.1).

There is uncertainty in the estimated biomasses of both 3+-quarter-old bigeye and of spawners. The average CV of the biomass estimates of 3+-quarter-old bigeye is 0.12. The average CV of the spawning biomass estimates is 0.16.

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 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 3+-quarter-old bigeye (1986 and 2000; Figure 4.10) were preceded by peak levels of recruitment (1982-1983 and 1996-1998, respectively; Figure 4.9) as is the recent upturn in biomass.

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 33% 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) due to strong cohorts entering the fisheries. The increase in mean length is attributed to the growth of these cohorts. During 2001, however, the average weight of the fish taken decreased (Figures 4.13 and 5.2). Fisheries 7 and 8 have captured bigeye that are, on average, moderately less than the critical weight. The average weights of bigeye taken by Fishery 8 increased in 1999 and subsequently decreased (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 1999, and then decreased (Figure 4.13). The average weight of bigeye taken by both longline fisheries combined appears to have decreased during 1997 and 1998 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 1996–1998 moving through the surface fisheries and into the longline fisheries (Figure 4.9).

4.3. Comparisons to external data sources

No comparisons to external data were made in this assessment.

4.4. Diagnostics

Diagnostics are discussed 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), and the variability is greater 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 versus time are shown 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 effort deviations are higher in 2005, but this is because the associated standard deviation for the effort deviate penalty was increased due to the lack of CPUE data for 2005. 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).

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 2005 from yield calculations and projections.

Previous analyses (Harley and Maunder 2004) have shown that 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 as the assessment methods has not changed from the previous assessment (Maunder and Hoyle 2006), but the results of previous retrospective analyses are described by Harley and Maunder (2004).

4.5. Sensitivity analysis

Sensitivity to the stock–recruitment relationship (Appendix B), the assumed value for the asymptotic length parameter of the Richards growth curve (Appendix C), and to including the Chinese Taipei longline fleet as a separate fishery with the associated length-frequency data (Appendix D), were conducted for the current assessment. Watters and Maunder (2002) and Harley and Maunder (2004, 2005) 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.

The steepness of the Beverton-Holt (1957) stock-recruitment relationship was set equal to 0.75. The estimates of biomass (Figure B.1) and recruitment (Figure B.2) are higher than those for the base case assessment as estimated, but the trends are similar. In previous assessments (*e.g.* Harley and Maunder 2005), the estimates were much more similar. This may be due to the inclusion of the environmental relationship, which provided information on recruitment.

The assumed value for the asymptotic length parameter of the Richards growth curve was fixed at a lower value of 171.5, which is around the value estimated by stock assessments for the west and central Pacific Ocean (Adam Langley, Secretariat of the Pacific Community, pers. com.), and at an upper value of 201.5. The estimated biomass and recruitment is very sensitive to the value of the asymptotic length parameter (Figures C1 and C2). The biomass and recruitment is higher for a smaller value for the asymptotic length parameter. This can be explained by the need to fit to the length-frequency data with an asymptotic selectivity for the southern longline fishery. There are very few individuals in the length-frequency data larger than 186.5 cm (Figure C3). If the asymptotic length parameter is much larger than 186.5 cm, then the model estimates high exploitation rates to eliminate the older individuals and if the asymptotic length parameter is much less than 186.5 cm, then the model estimates low exploitation rates to ensure there are old individuals to predict the length-frequency data. The best fit to the data is from the model with the high value for the asymptotic length parameter with most of the improvement coming from a reduced penalties related to growth (Table C.1). However, this is maybe misleading because most of the penalty is from the prior on growth. Hampton and Maunder (2005) used fixed growth and found that lower vales for the asymptotic length parameter gave better fits to the data. The model with the higher value for the asymptotic length parameter still fits the length-frequency data well (Figure C4, Table C1), but the length-frequency likelihood is better for the lower value for the asymptotic length parameter (Table C.1). The variation of length-at-age is slightly greater for old ages in the analysis with the higher value of the asymptotic length parameter (Figure C.5).

The Chinese Taipei longline catch data was removed from the longline fisheries (Fisheries 8 and 9) and used to create a separate fishery (Fishery 14). The Chinese Taipei longline length-frequency data was included for this fishery. Effort was set to one for all years and the standard deviation for the penalty on the effort deviates was set to two to ensure that the catch and effort data for this fishery did not influence abundance. The estimates of biomass and recruitment were very similar to the base case (Figures D1 and D2). The Chinese Taipei longline length-frequency data does not include the large fish seen in the Japanese longline length-frequency data (Figure D4) and the estimated selectivity curve is correspondingly dome shaped (Figure D5).

The estimates of recruitment and biomass from the sensitivity analysis that included a relationship between recruitment and the el Nino index (the monthly index of standard Tahiti – Darwin sea level pressure anomalies obtained from the Climate Prediction Center of NOAA (http://www.cpc.ncep.noaa.gov/data/indices/soi) averaged over the quarter and negated.) were nearly identical. The analysis showed that there was a significant negative relationship between recruitment and the el Nino index, but this only explained a small portion of the total variability in recruitment (Figures E1 and E2).

4.6. Comparison to previous assessments

The trend in abundance is similar to the base case assessment for 2005 (Figure 4.15). The main differences occur at the start and the end of the time series.

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 18 quarters old has increased substantially since 1993, and that on fish more than about 18 quarters old has increased slightly 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.

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

There are several important features in the estimated time series of bigeye recruitment. First, estimates of recruitment before 1993 are very uncertain, as the floating-object fisheries, which catch small bigeye, were not operating. There was a period of above-average recruitment in 1995-1998, followed by a period of below-average recruitment in 1999-2000. The recruitments were above-average in 2001 to 2002 with spikes in 2004 and 2005. The most recent recruitment is very uncertain, due to the fact that recently-recruited bigeye are represented in only a few length-frequency data sets. The extended period of relatively large recruitments in 1995-1998 coincided with the expansion of the fisheries that catch bigeye in association with floating objects.

The biomass of 3+-quarter-old bigeye increased during 1980-1984, and reached its peak level of about 537,000 t in 1986, after which it decreased to an historic low of about 254,000 t at the start of 2004. The biomass has increased in 2004 and 2005 due to two recent spikes in recruitment. Spawning biomass has generally followed a trend similar to that for the biomass of 3+-quarter-olds, but lagged by 1-2 years. There is uncertainty in the estimated biomasses of both 3+-quarter-old bigeye and spawners. Nevertheless, it is apparent that fishing has reduced the total biomass of bigeye in the EPO. Both are predicted to have increased in recent years.

The estimates of recruitment and biomass were only moderately sensitive to the steepness of the stock-recruitment relationship. The estimates of recruitment and biomass were very sensitive to the assumed value of the asyptotic length in the Richards growth equation. A lower value gave higher biomass and recruitment. Estimates of recruitment and biomass were insensitive to the inclusion of the Chinese Taipei length-frequency data and the el Nino-recruitment relation. The relationship between recruitment and the el Nino index was found to be significant, but only explained a small portion of variation in recruitment.

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

Maintaining tuna stocks at levels that permit the AMSY to be taken 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 corresponding to the 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 SBR, described by Watters and Maunder (2001), is useful for assessing the status of a stock. It has a lower bound of zero. If it is near zero, the population has been severely depleted and is probably overexploited. If the SBR is one, or slightly less than that, the fishery has probably not reduced the spawning stock. If the SBR is greater than one, it is possible that the stock has entered a regime of increased production.

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 are capable of producing the AMSY when the SBR of about 0.3 to 0.5, and that some fish populations are not capable of producing 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 corresponding to 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 SBR corresponding to the AMSY ($\mathrm{SBR}_{\mathrm{AMSY}}$) is estimated to be about 0.22.

At the beginning of January 2006, the spawning biomass of bigeye tuna in the EPO was increasing from a recent historically low level (Figure 5.1a). At that time the SBR was about 0.20, about 12% less than the level corresponding to the AMSY, with lower and upper confidence limits (±2 standard deviations) of about 0.13 and 0.26. The estimate of the upper confidence bound is greater than the estimate of $\mathrm{SBR}_{\mathrm{AMSY}}$ (0.22). Previous assessments had predicted that the spawning biomass would decline below the $\mathrm{SBR}_{\mathrm{AMSY}}$ level (Watters and Maunder 2002; Maunder and Harley 2002; Harley and Maunder 2004) but not the recovery, which is due to recent spikes in recruitment.

At the start of 1975, the SBR was about 0.39 (Figure 5.1a). This is consistent with the fact that bigeye was being fished by longliners in the EPO for a long period prior to 1975 and that the spawning biomass is made up of older individuals that are vulnerable to longline gear. The SBR increased, particularly during 1984-1987, and by the middle of 1986 was 0.45. 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 that time (Figure 2.2, Fisheries 1 and 6). This peak in spawning biomass was soon followed by a peak in the longline catch (Figure 2.2, Fishery 9). After 1987 the SBR decreased to a level of about 0.18 by mid-1998. This depletion can be attributed mostly to a long period (1984-1993) during which recruitment was low. Also, it should be noted that the southern longline fishery took relatively large catches during 1985-1994 (Figure 2.2, Fishery 9). In 1999 the SBR began to increase and reached about 0.37 by mid 2001. This increase can be attributed to the relatively high levels of recruitment that are estimated to have occurred during 1994-1998 (Figure 4.9). During the later part of 2001 and through 2003, the SBR decreased rapidly, due to the weak year classes since 1998 and the high catches from surface fisheries and increases in longline catches. However, the SBR increased during 2004 and 2005 reaching 0.20 at the start of 2006.

The SBR over time shows a similar trend to the previous assessment with the greatest differences at the start and end of the modeling period (Figure 5.1b).

The SBR estimates are reasonably precise; the average CV of these estimates is about 0.13. The relatively narrow confidence intervals (±2 standard deviations) around the SBR estimates suggest that, for most quarters during January 1975 to January 1993, and 2001-2002, the spawning biomass of bigeye in the EPO was greater than S_{AMSY} (Section 5.3). The S_{AMSY} level is shown as the dashed line at 0.22 in Figure 5.1a.

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 weights of the fish taken by most of the fisheries is close to the critical weight, the fishery could be 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 4.14 respectively), the critical weight for bigeye tuna in the EPO is estimated to be about 63.3 kg. The critical age of 15 quarters is just above the age at which 50% of females are assumed to be mature.

The fishery was catching, on average, bigeye slightly below the critical weight during 1975-1993 (Figure 5.2), 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 that permit the AMSY to be taken 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 2003 and 2004. 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 2006, the spawning biomass of bigeye tuna in the EPO appears to have been about 12% less than the level corresponding to the AMSY and the recent catches are estimated to have been about that level (Table 5.1).

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 corresponding to the AMSY is about 68% of the current level of effort. If this level of effort were maintained, the long term yield would be about 95% of AMSY. Decreasing effort by 32% of its present level would increase the long-term average yield by about 5%, and would increase the spawning biomass of the stock by about 75% (Figure 5.3). The results of the sensitivity analysis (Section 5.4) give the results of an assessment with a stock-recruitment relationship.

The AMSY-based quantities are estimated by assuming that the stock is at equilibrium with fishing, but during 1995-1998 it 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. For example, the catches of bigeye taken by the surface fleet declined 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 group of fisheries (Table 5.3). If only the purse-seine fishery were operating the AMSY would be considerably less (62,116 t versus 106,722 t for the base case assessment). If bigeye were caught only by the longline fishery the AMSY would about 50% compared to that estimated for all gears combined (159,174 t versus 106,722 t for the base case assessment). To achieve this AMSY level longline effort would need to be increased by 120%. If only the purse seine fishery was modified (i.e. the longline effort was kept the same) the sustainable yield would require complete closure of the purse seine fishery and the AMSY would be only slightly less than the AMSY when only using the longline fisheries (Table 5.3). If only the longline fishery was modified (i.e. the purse seine effort was kept the same), the longline effort would be increased by 86%, but the sustainable yield would be about the same as the AMSY with the current allocation of effort among methods Table 5.3). However, the SBR would be greatly decreased.

The AMSY related quantities vary as the size composition of the catch varies. Figure 5.1c shows the evolution of four of these over the course of 1975-1995. Before the expansion of the floating object fishery that started in 1993, AMSY was greater than the current AMSY and the fishing mortality was less than that corresponding to AMSY (Figure 5.1c).

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 have more time in which to reproduce, and therefore may appear to have 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 estimate 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 2003 and 2004 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 39 quarters (Figure 5.4, upper panel). However, the benefit is still large for all individuals aged about 15 quarters and older. These calculations suggest 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 39 quarters is considerably heavier than an individual recruited to the fishery at age 1 quarter. 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 recruited to the fishery at age 1 quarter (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 three or four 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 often termed 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 ⅔ 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 196,068 t and SBR_{ref} is estimated to be 0.21 (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 (15 quarters) being just slightly greater than the age at which 50% of the females are assumed to be mature. MSY at the current effort allocation is only 54% of MSY_{ref}. If the fishery were exploited assuming the same selectivity patterns as the longline fisheries (Fisheries 8 and 9), MSY would be 81% of MSY_{ref}. More research is needed to determine if reference points based on MSY_{ref} and SBR_{ref} are appropriate.

5.5. 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 assessment used average fishing mortality for 2003 and 2004.

Including a stock-recruitment model with a steepness of 0.75, the SBR required if the population was capable of producing AMSY is estimated to be at 0.31, compared to 0.22 for the base case assessment (Table 5.1). This value is slightly higher for the increased asymptotic length and including Chinese Taipei as a separate fishery. The sensitivity analysis for steepness estimates an *F* multiplier considerably less than that for the base case assessment (0.51). The *F* multiplier is considerably more for the increased asymptotic length indicating effort should be increased, but considerably less for the reduced asymptotic length (Table 5.1). All analyses except that which assumes a high asymptotic length estimates the current SBR to be below the level that would support AMSY.

The management quantities are only moderately sensitive to the recent periods for fishing mortality used in the calculations (Table 5.2).

If a moderate stock-recruitment relationship exists, and bigeye were caught only by the purse-seine fishery, effort for this fishery should be kept about the same to allow the stock to produce the AMSY (Table 5.4). If bigeye were caught only by the longline fishery, effort for this fishery could be increased by 31% to allow the stock be at the level corresponding to the AMSY (Table 5.4).

The Chinese Taipei fleet is estimated to only have a minor impact on the population compared to the other fisheries, but its impact has increased over time (Figure D6).

5.6. Summary of stock status

At the beginning of January 2006, the spawning biomass of bigeye tuna in the EPO was increasing from a recent hitorical low level (Figure 5.1a). At that time the SBR was about 0.20, about 12% less than the level corresponding to the AMSY, with lower and upper confidence limits (±2 standard deviations) of about 0.13 and 0.26. The estimate of the upper confidence bound is greater than the estimate of SBR_{AMSY} (0.22).

The relatively narrow confidence intervals (±2 standard deviations) around the SBR estimates suggest that for most quarters during January 1975 to January 1993, and 2001-2002 the spawning biomass of bigeye in the EPO was probably greater than the corresponding to the AMSY. This level is shown as the dashed line at 0.22 in Figure 5.1a.

Recent catches are estimated to have been about 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 corresponding to the AMSY is about 68% of the current (2003-2004) level of effort. If this level of effort were maintained, the long term yield would be about 95% of AMSY. Decreasing the effort to 32% of its present level would increase the long-term average yield by about 5% and would increase the spawning biomass of the stock by about 75%. 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 that are close to the critical weight. Before the expansion of the floating object fishery that started in 1993, AMSY was greater than the current AMSY and the fishing mortality was less than that corresponding to AMSY (Figure 5.1c).

All analyses, except the low assumed value for the asymptotic length of the Richards growth curve, suggest that at the start of 2005 the spawning biomass was below the level corresponding to 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, except the low assumed value for the asymptotic length, fishing mortality is well above the level corresponding to 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 bigeye tuna in the EPO and the catches of bigeye by the various fisheries. Several scenarios were constructed to define how the various fisheries that take bigeye in the EPO would operate in the future and also to define the future dynamics of the bigeye stock. The assumptions that underlie these scenarios are outlined in Sections 6.1 and 6.2.

A method based on the normal approximation to the likelihood profile has been applied (Maunder et al. in press). The previously-used method (Maunder and Watters 2001) does not take into consideration parameter uncertainty. It considered 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, and 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 quarterly effort data equal to those for 2005 (except for the longline fishery, which uses 2004) scaled by the average catchability for 2003 and 2004 (except for the northern longline fishery, which uses 2003 for quarter 2, and 2002 and 2003 for quarter 3 due to lack of CPUE indices). No catch or length-frequency data are included for these years. The recruitments for the 5 years are estimated as in the assessment model, with a lognormal penalty with a standard deviation of 0.6. Normal approximations to the likelihood profile are generated for SBR, surface catch, and longline catch.

6.1. Assumptions about fishing operations

6.1.1. Fishing effort

Future projection studies were carried out to investigate the influence of different levels of fishing effort on the stock biomass and catch. The quarterly catchability is assumed equal to the average quarterly catchability for 2003 and 2004 (except for the northern longline fishery as noted above).

The scenarios investigated were:

1. Quarterly effort for each year in the future was set equal to the effort in 2005 (2004 for the longline fisheries), which reflects the reduced effort due to the conservation measures of Resolution C-04-09;
2. Quarterly effort for each year in the future and for 2004 and 2005 was set equal to the effort in (1) adjusted to remove the effect of the conservation measures. The purse-seine effort in the third quarter was increased by 86%. and the southern longline fishery effort was increased by 39%.
3. Effort in the future based on F_{AMSY}.

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 stock assessment model accurately describes the dynamics of the system and with no account taken of variation in catchability.

6.2.1. Current effort levels

Projections were undertaken, assuming that effort would remain at 2005 levels. This included the effort and catch restrictions from the Resolution C-04-09.

SBR is estimated to have been increasing in recent years (Figure 5.1a). This increase is attributed to two spikes in recenet recruitment. If recent levels of effort and catchability continue, SBR is predicted to increase to about the level that would support MSY in 2008 and then decline (Figure 6.1a). The total biomass is estimated to be currently at it peak and will decline in the future (Figure 6.2).

Purse-seine catches are predicted to decline during the projection period (Figure 6.3, upper panel). Longline catches are also predicted to increase moderately in 2006 but then decline under current effort (Figure 6.3, lower panel). The catches would decline further if a stock-recruitment relationship was included, due to reductions in the levels of recruitment that contribute to purse-seine catches.

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

6.2.2. No management restrictions

Resolution C-04-09 calls for restrictions on purse-seine effort and longline catches for 2004: a 6-week closure during the third OR fourth quarter of the year for purse-seine fisheries, and longline catches are not to exceed 2001 levels. To assess the utility of these management actions, we projected the population forward 5 years, assuming that these conservation measures were not implemented.

Comparison of the SBR predicted with and without the restrictions from the resolution show some difference (Table 6.1). Without the restrictions, SBR would only increase slightly and then decline to lower levels (0.09).

Clearly the reductions in fishing mortality that could occur as result of Resolution C-04-09 are insufficient to allow the population to maintain levels corresponding to the AMSY. This is supported by the F multiplier estimates that suggest that effort reductions of 32% (or larger if a stock-recruitment relationship exists) are necessary (Table 5.1).

6.2.3. Fishing at F_{AMSY}

If the future effort is reduced to levels that correspond to those that would support AMSY, the SBR quickly rebuilds above S_{AMSY} and stays above that level for the 5-year projection period (Table 6.1).

6.2.4. Sensitivity analysis

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

6.3. Summary of the simulation results

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

The effects of the Resolution C-04-09 are estimated to be insufficient to allow the stock to remain at levels that support AMSY. If the effort is reduced to levels that support AMSY, the stock will remain above S_{AMSY} within the 5-year projection period.

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

7. FUTURE DIRECTIONS

7.1. Collection of new and updated information

The IATTC staff intends to continue its collection of catch, effort, and size-composition data from the fisheries that catch bigeye tuna in the EPO. Updated data for 2005 and new data collected during 2005 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.

7.2. Refinements to the assessment model and methods

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

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

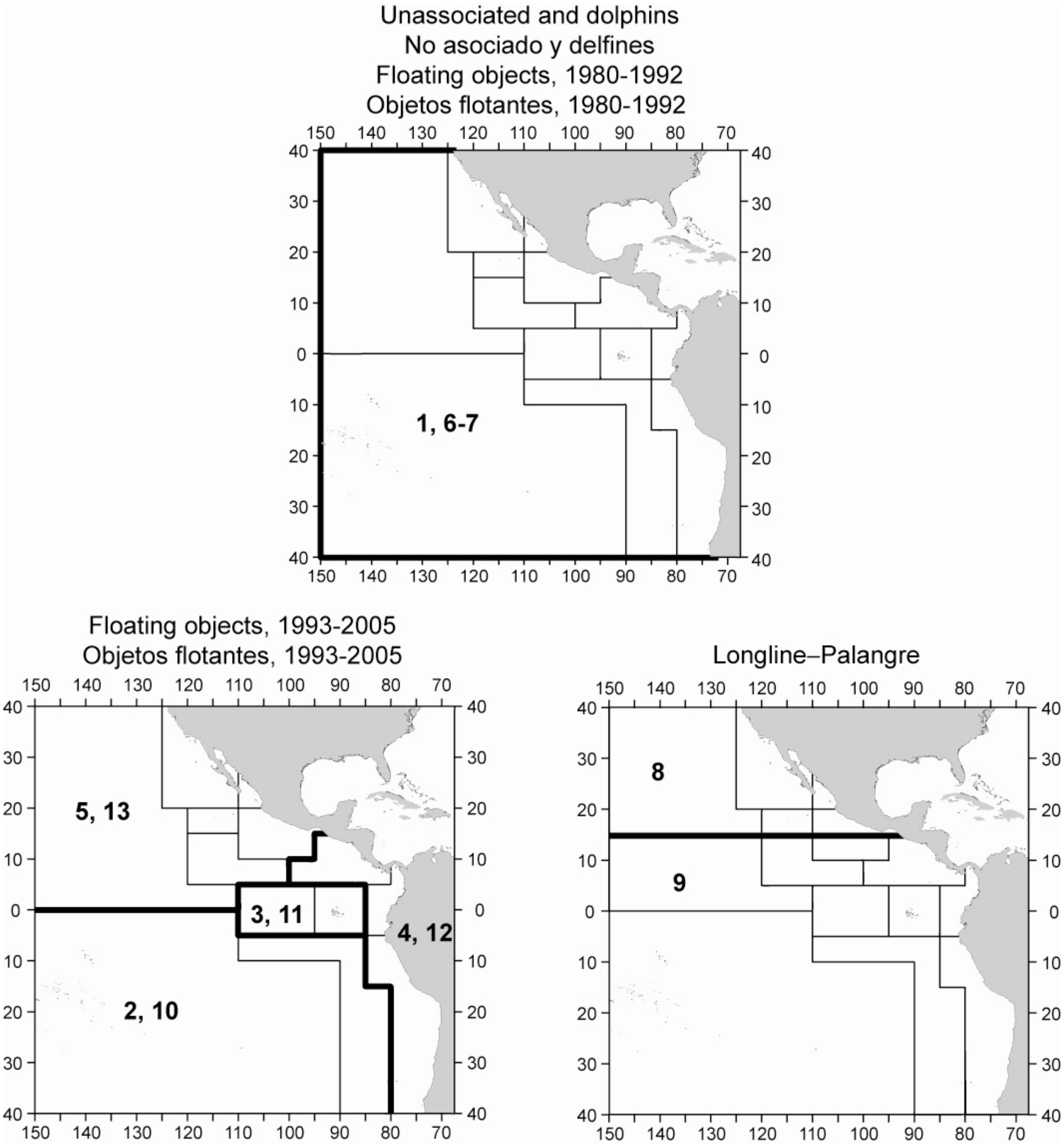


FIGURE 2.1. Spatial extents of the fisheries defined for the stock assessment of bigeye tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the bold numbers the fisheries to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

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

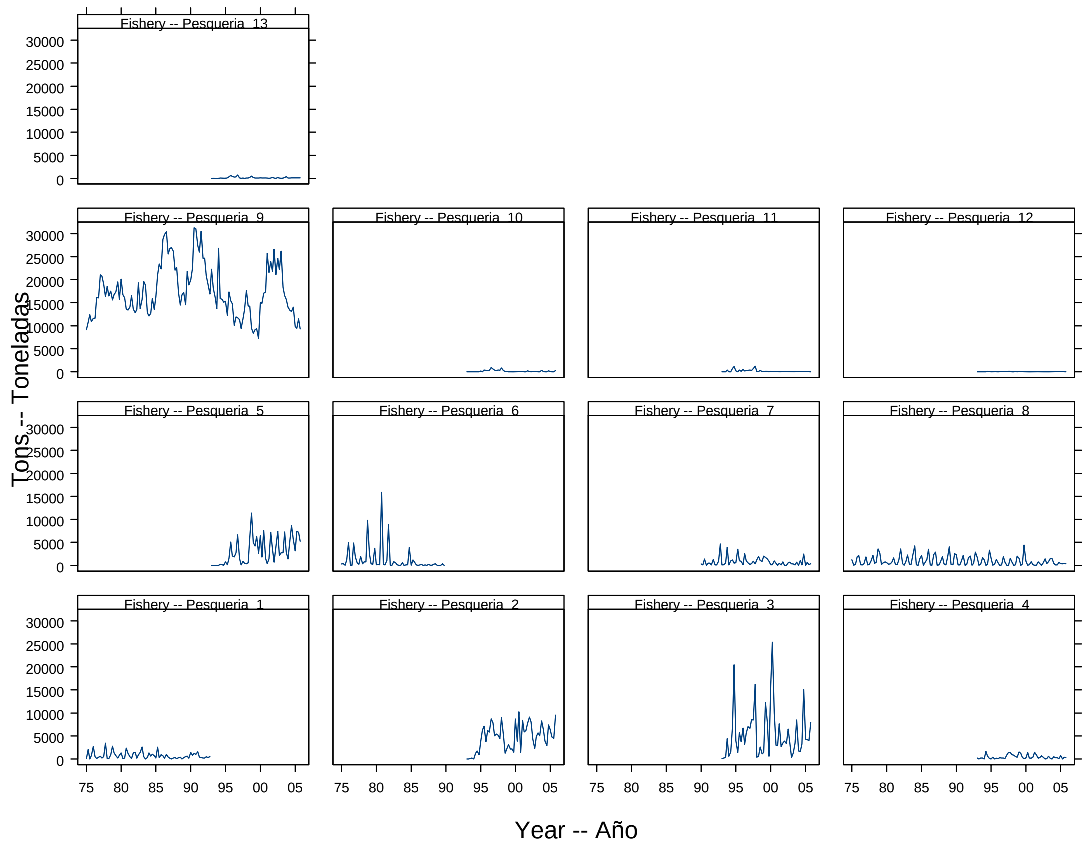


FIGURE 2.2. Catches of bigeye tuna taken by the fisheries defined for the stock assessment of that species in the EPO (Table 2.1). Since the data were analyzed on a quarterly basis, there are four observations of catch for each year. Although all the catches are displayed as weights, the stock assessment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

FIGURA 2.2. Capturas de atún patudo realizadas por las pesquerías definidas para la evaluación de la población de esa especie 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. t = toneladas métricas.

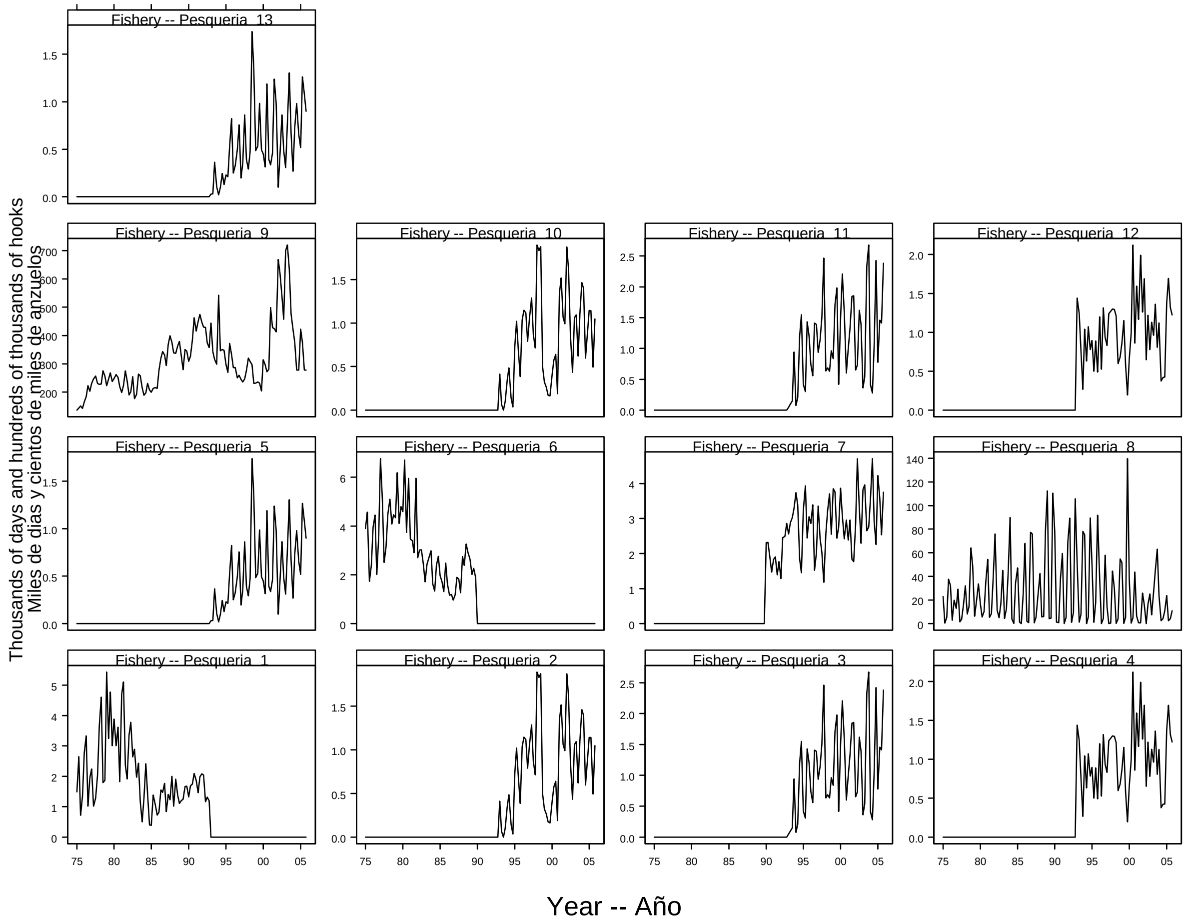


FIGURE 2.3. Fishing effort exerted by the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of effort for each year. The effort for Fisheries 1-7 and 10-13 is in days fished, and that for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

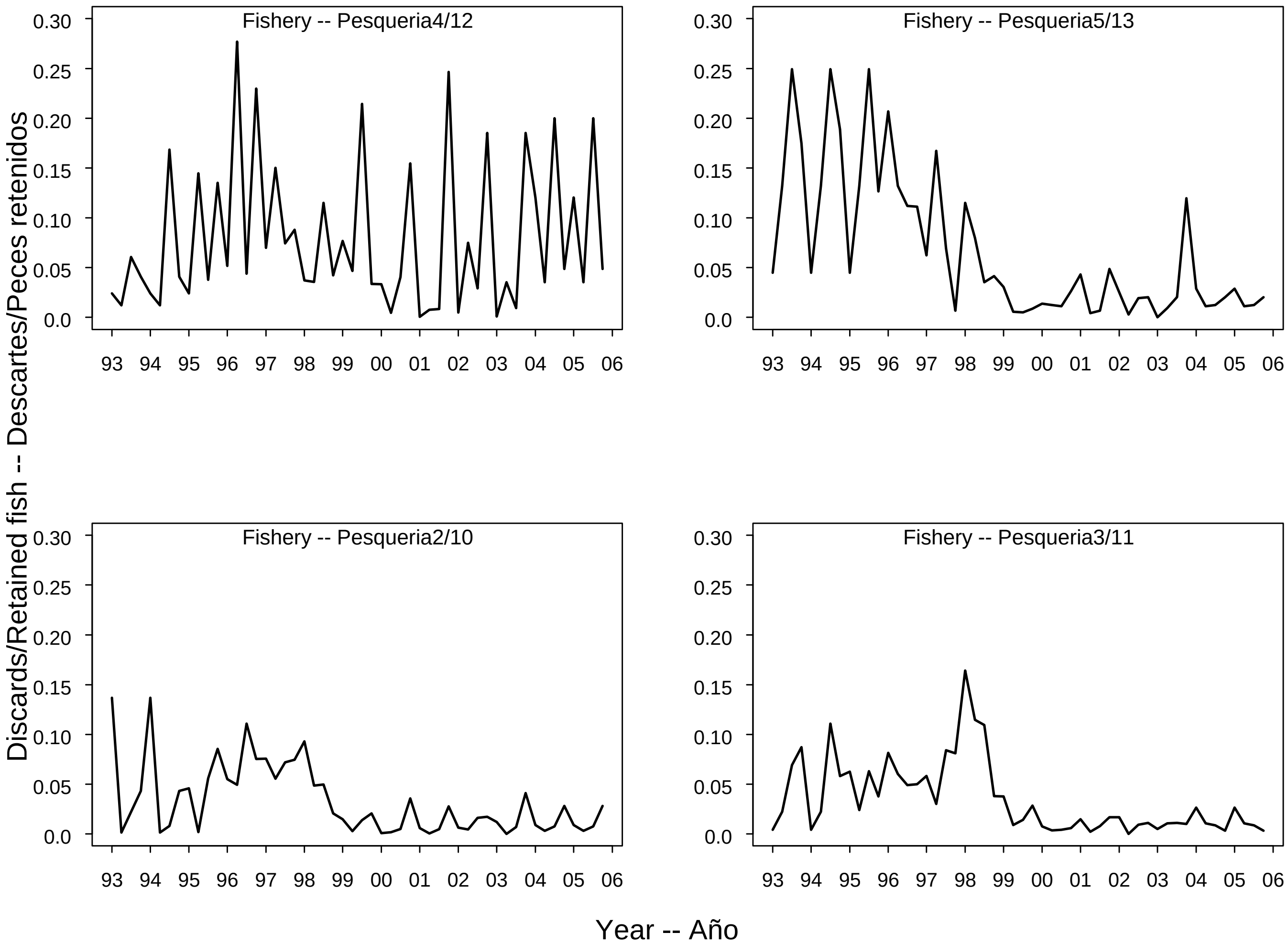


FIGURE 2.4. Weights of discarded bigeye tuna as proportions of the retained quarterly catches for the four floating-object fisheries. Fisheries 2, 3, 4, and 5 are the "real" fisheries, and Fisheries 10, 11, 12, and 13 are the corresponding discard fisheries.

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.

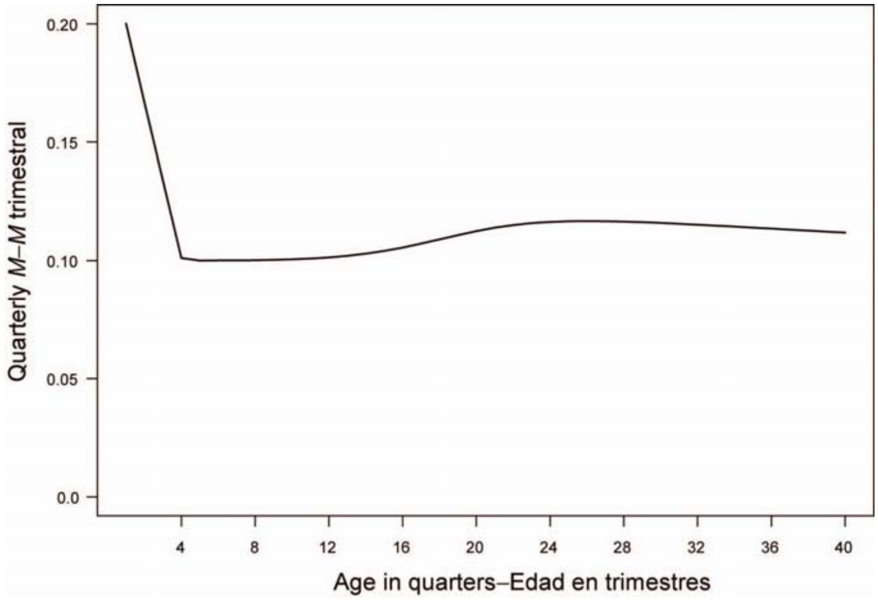


FIGURE 3.1. Quarterly natural mortality (*M*) rates used for the base case assessment of bigeye tuna in the EPO.
FIGURA 3.1. Tasas de mortalidad natural (*M*) trimestral usadas para la evaluación del caso base de atún patudo en el OPO.

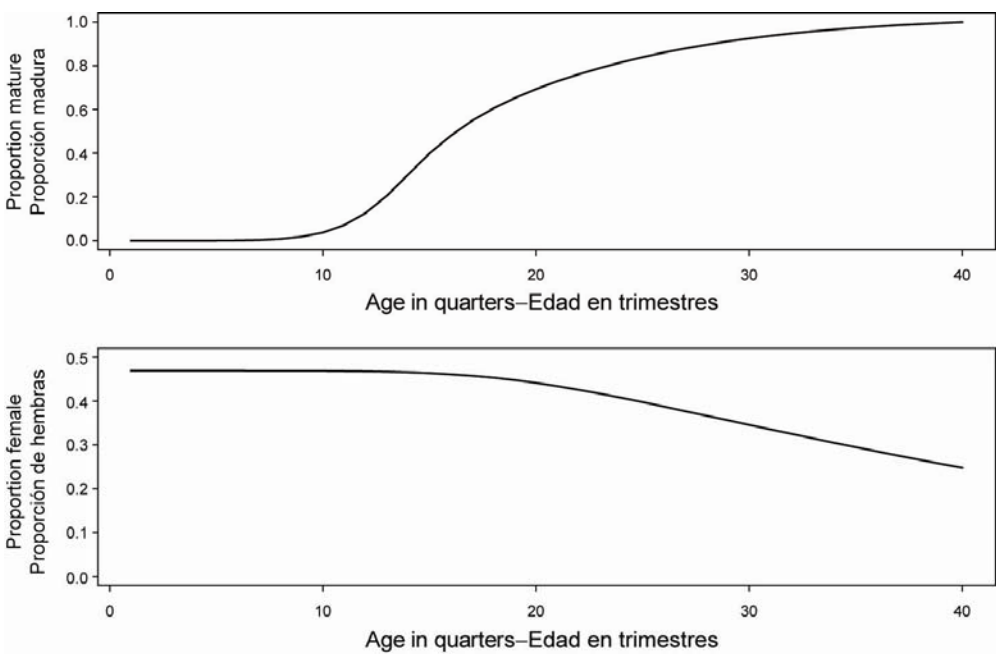


FIGURE 3.2. Age-specific index of fecundity of bigeye tuna (upper panel) and age-specific proportion of females in the population (lower panel), as assumed in the base case model and in the estimation of natural mortality.
FIGURA 3.2. Índice de fecundidad por edad del atún patudo (recuadro superior) y proporción de hembras en la población por edad (recuadro inferior), supuestos en el modelo de caso base y en la estimación de mortalidad natural.

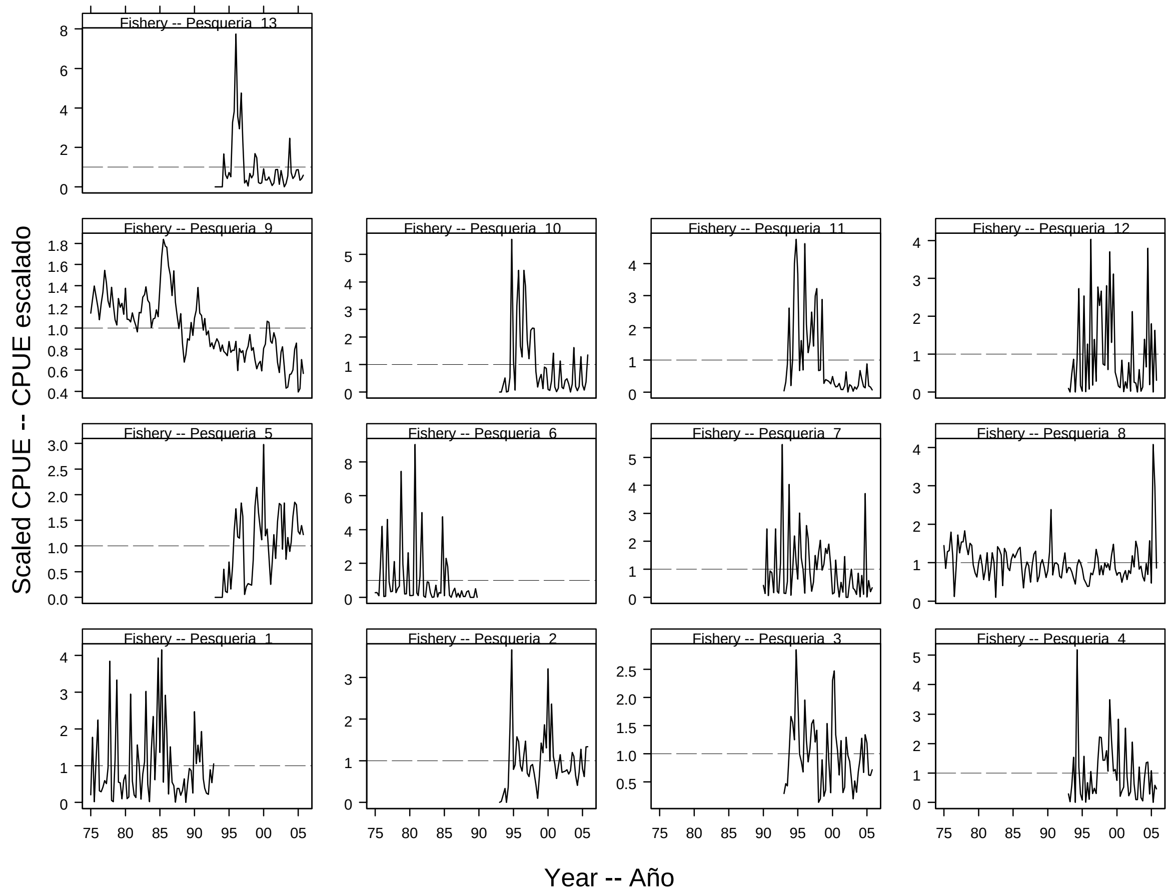


FIGURE 4.1. CPUEs of the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of CPUE for each year. The CPUEs for Fisheries 1-7 and 10-13 are in kilograms per day fished, and those for Fisheries 8 and 9 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 de 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.

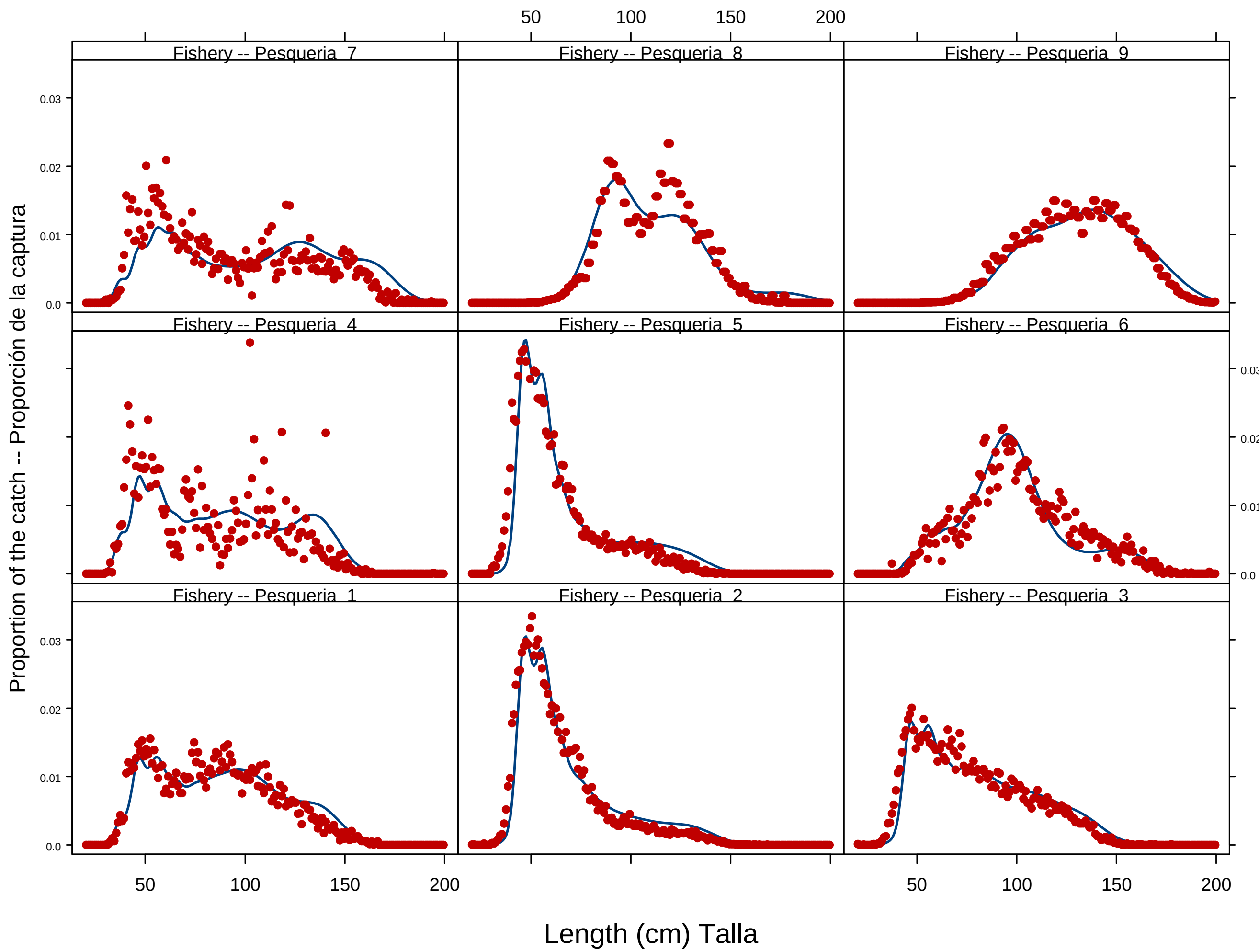


FIGURE 4.2. Average observed (dots) and predicted (curves) size compositions of the catches of bigeye tuna taken by the fisheries defined for the stock assessment of that species in the EPO.
FIGURA 4.2. Composición media por tamaño observada (puntos) y predicha (curvas) de las capturas de atún patudo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

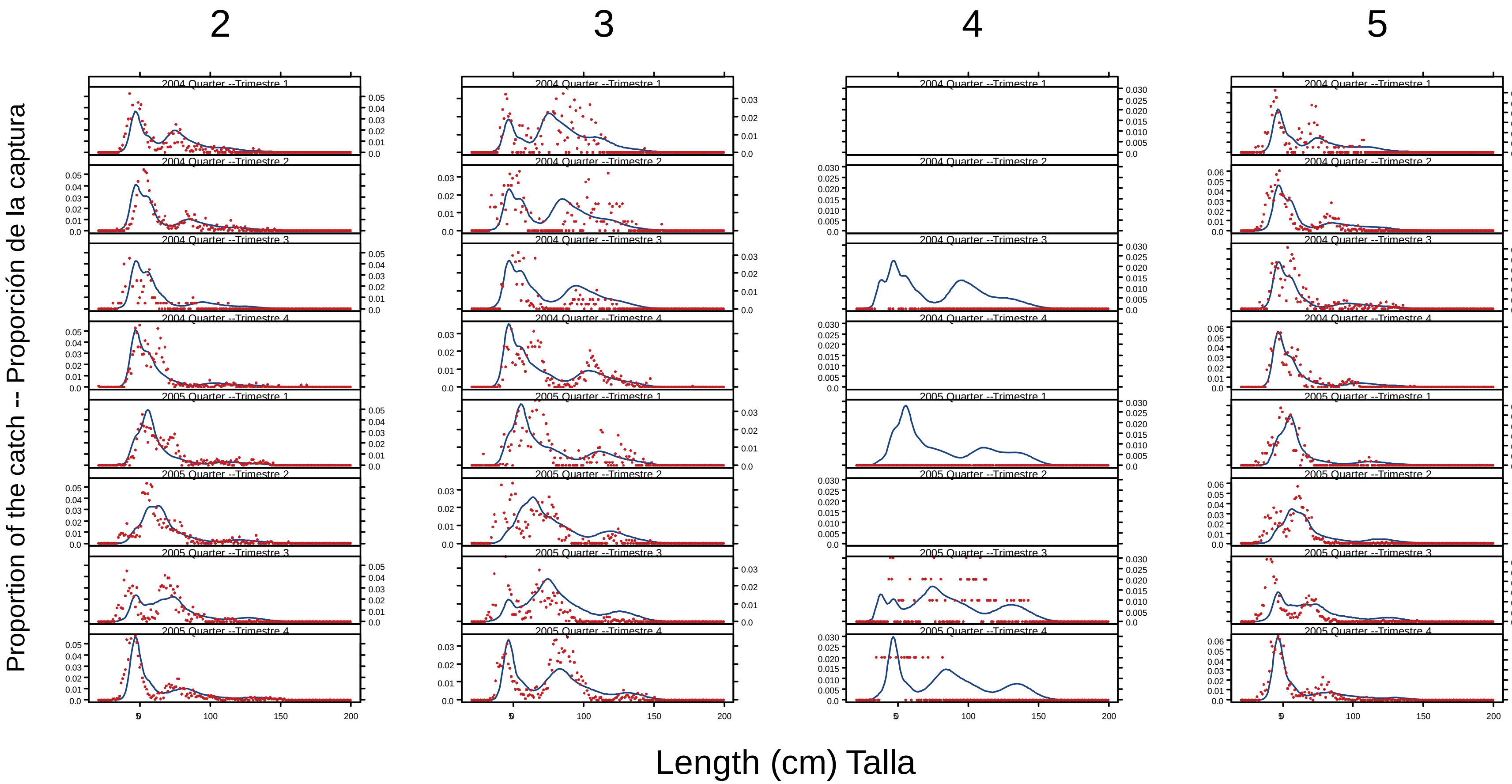


FIGURE 4.3. Size compositions of the recent catches of bigeye tuna taken by Fisheries 2-5 and 7-9. The dots are observations, and the curves are predictions from the base case assessment.

FIGURA 4.3. Composiciones por tamaño de las capturas recientes de atún patudo de las Pesquerías 2-5 y 7-9. Los puntos son observaciones y las curvas son las predicciones de la evaluación del caso base.

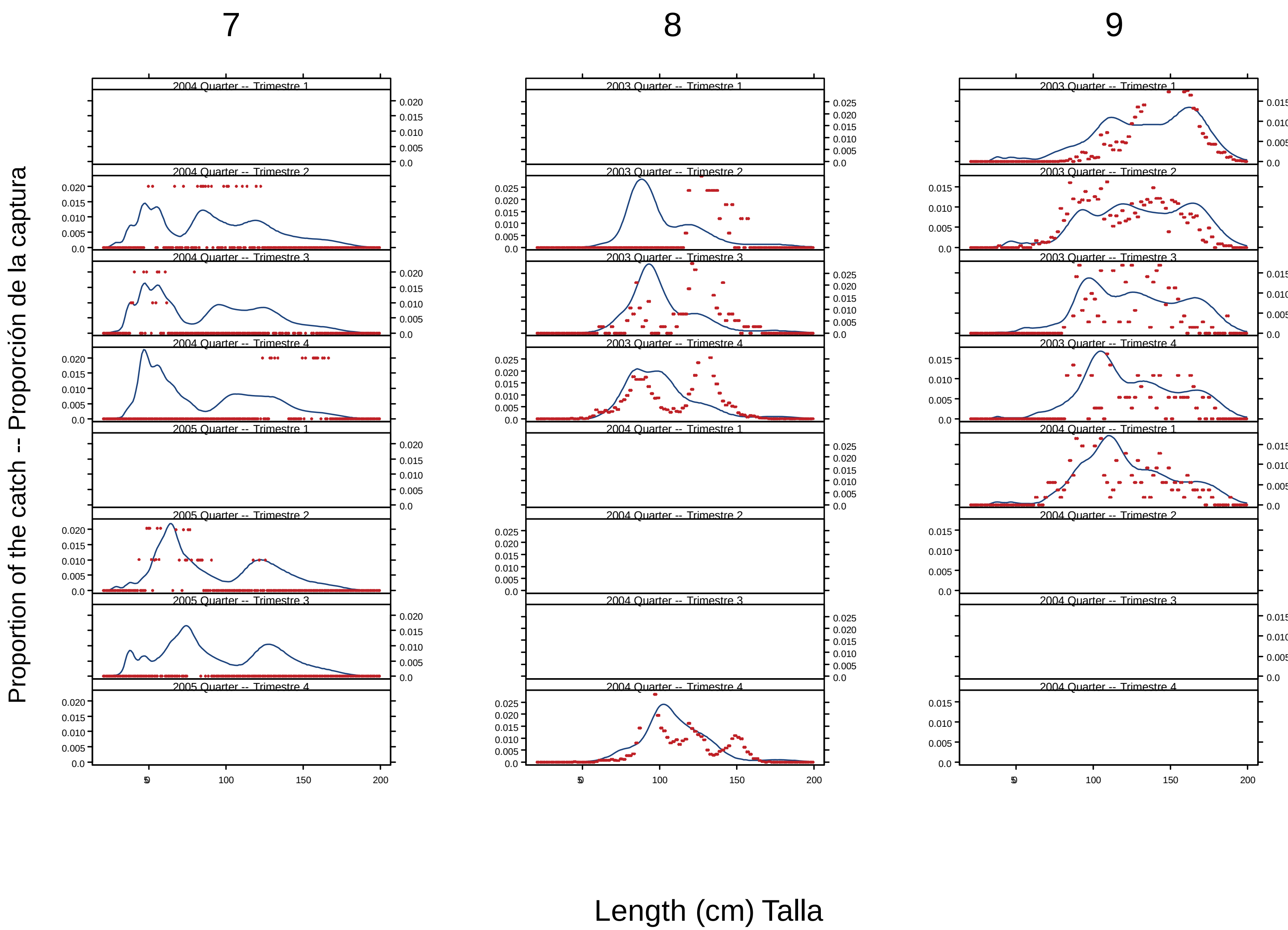


FIGURE 4.3. (continued)
FIGURA 4.3. (continuación)

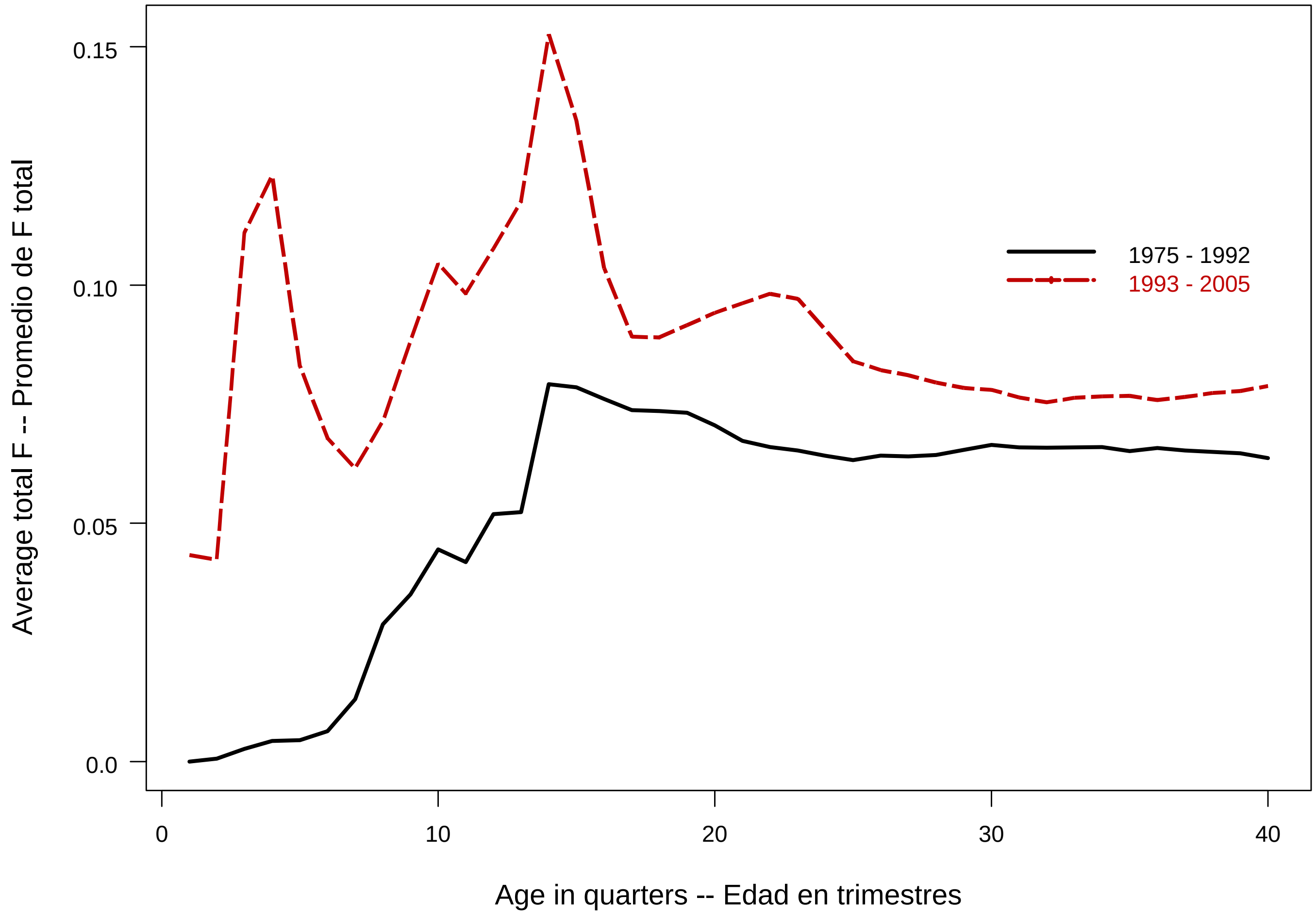


FIGURE 4.4. Average quarterly fishing mortality at age of bigeye tuna, by all gears, in the EPO. The curve for 1975-1992 displays averages for the period prior to the expansion of the floating-object fisheries, and that for 1993-2005 averages for the period since that expansion.
FIGURA 4.4. Mortalidad por pesca trimestral media a edad de atún patudo, por todos los artes, en el OPO. La curva de 1975-1992 indica los promedios del período previo a la expansión de la pesquería sobre objetos flotantes, y la curva de 1993-2005 los promedios del período desde dicha expansión.

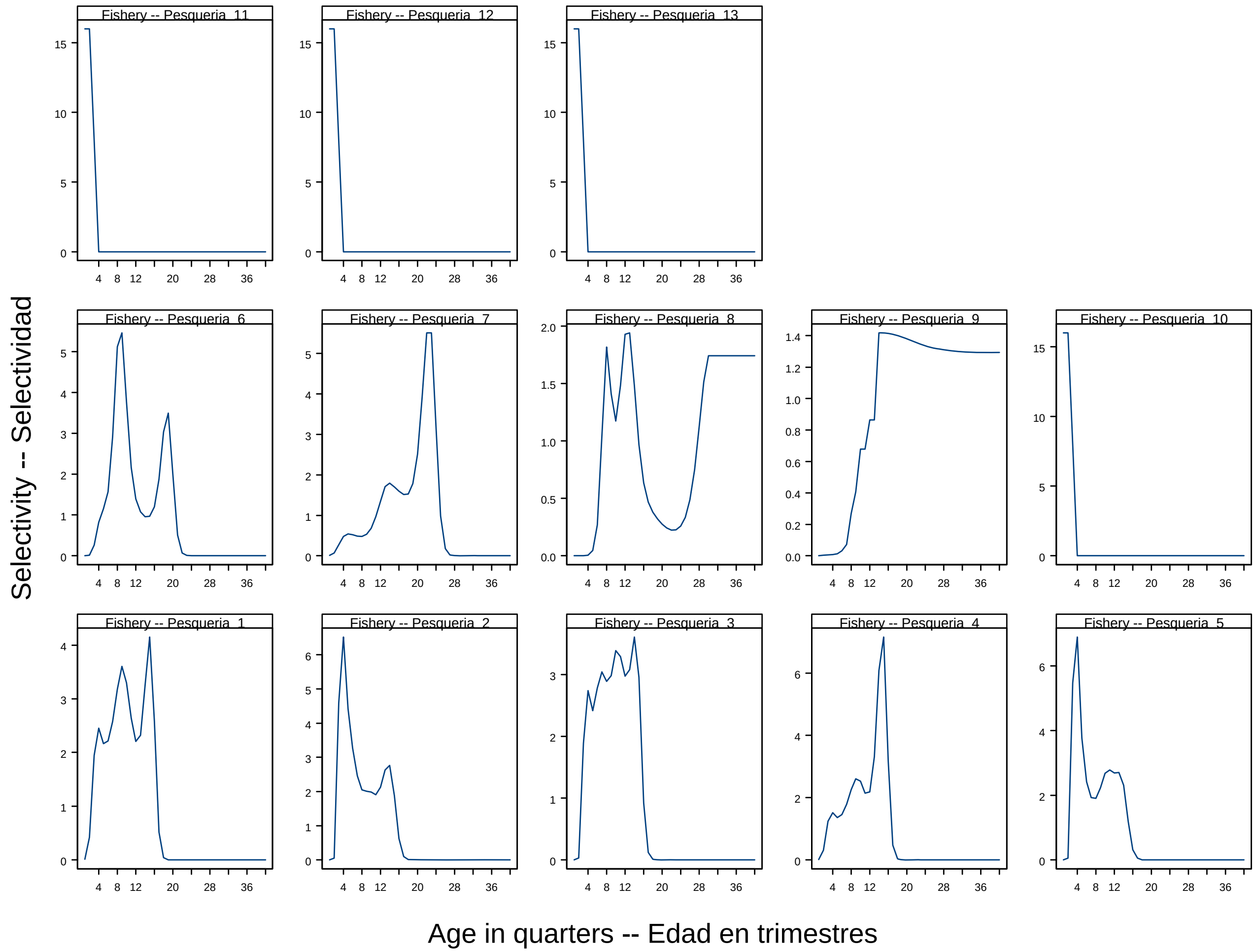


FIGURE 4.5. Selectivity curves for the 13 fisheries that take bigeye tuna in the EPO. The selectivity curves for Fisheries 1 through 9 were estimated with the A-SCALA method, and those for Fisheries 10-13 are based on assumptions.

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.

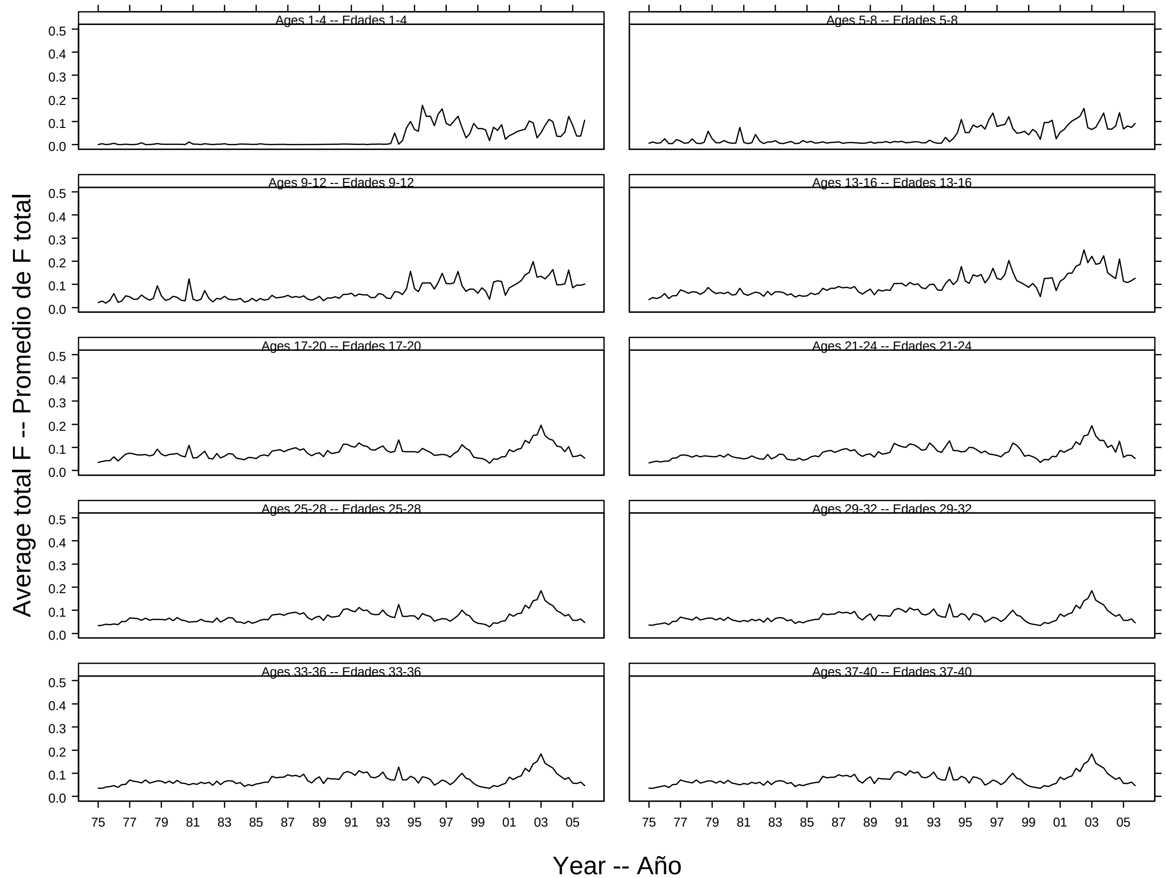


FIGURE 4.6a. Average quarterly fishing mortality, by all gears, on bigeye tuna recruited to the fisheries of the EPO. Each panel illustrates an average of four quarterly fishing mortality vectors that affected the fish within the range of ages indicated in the title of each panel. For example, the trend illustrated in the upper-left panel is an average of the fishing mortalities that affected the fish that were 1-4 quarters old.

FIGURA 4.6a. Mortalidad por pesca trimestral media, por todos los artes, 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 a los peces de entre 1-4 trimestres de edad.

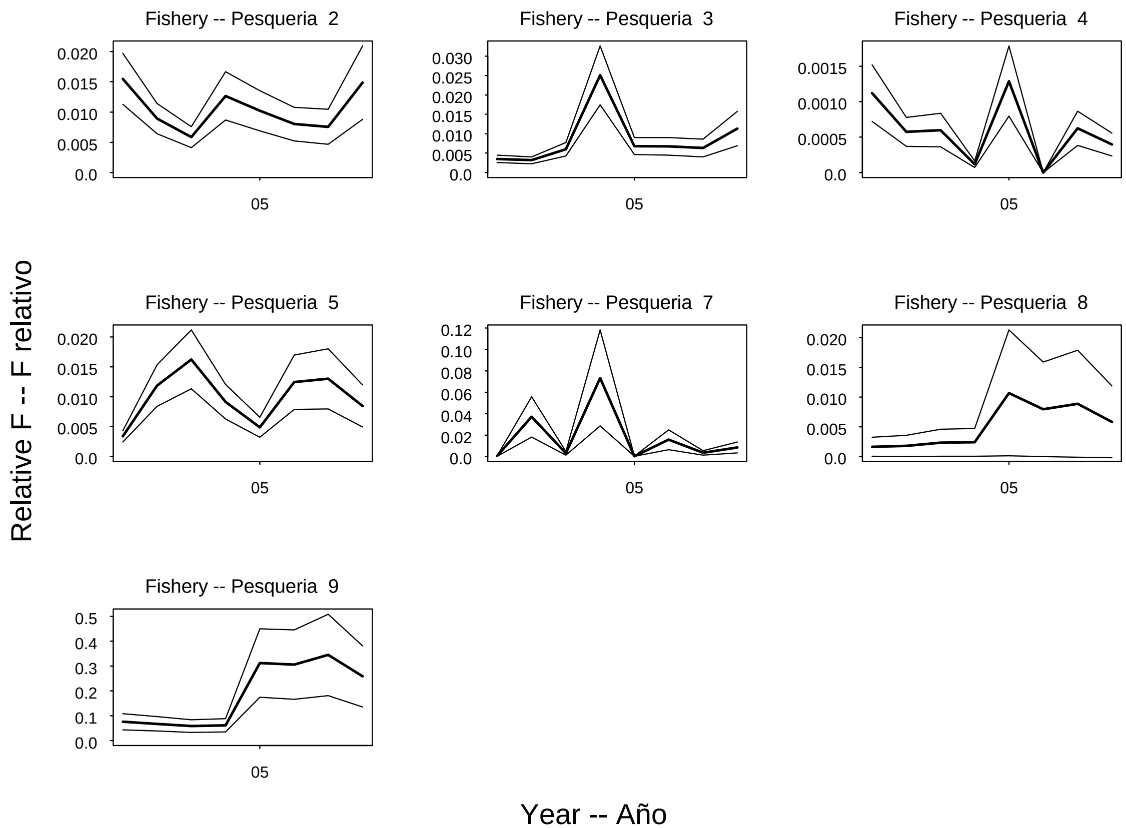


FIGURE 4.6b. Gear- and year-specific fishing mortality scalars (bold lines) for bigeye tuna for the most recent 16 quarters for fisheries currently operating in the EPO. The upper and lower 95% confidence intervals are indicated by thin lines.

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.

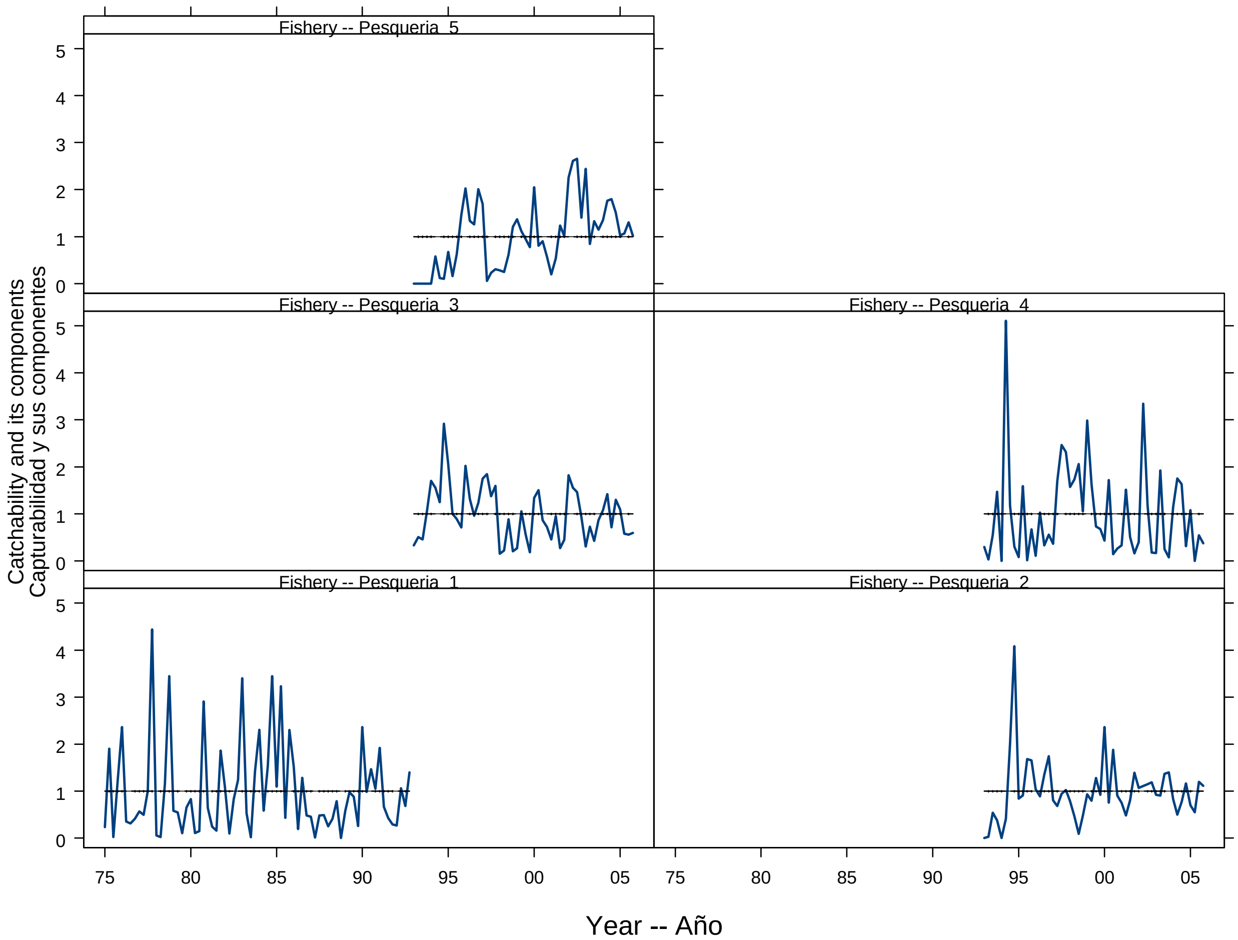


FIGURE 4.7. Trends in catchability for the 13 fisheries that take bigeye tuna in the EPO. The estimates are scaled to the first estimate of the catchability for each fishery (thin horizontal line). The bold lines include random effects, and illustrate the overall trends in catchability.

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

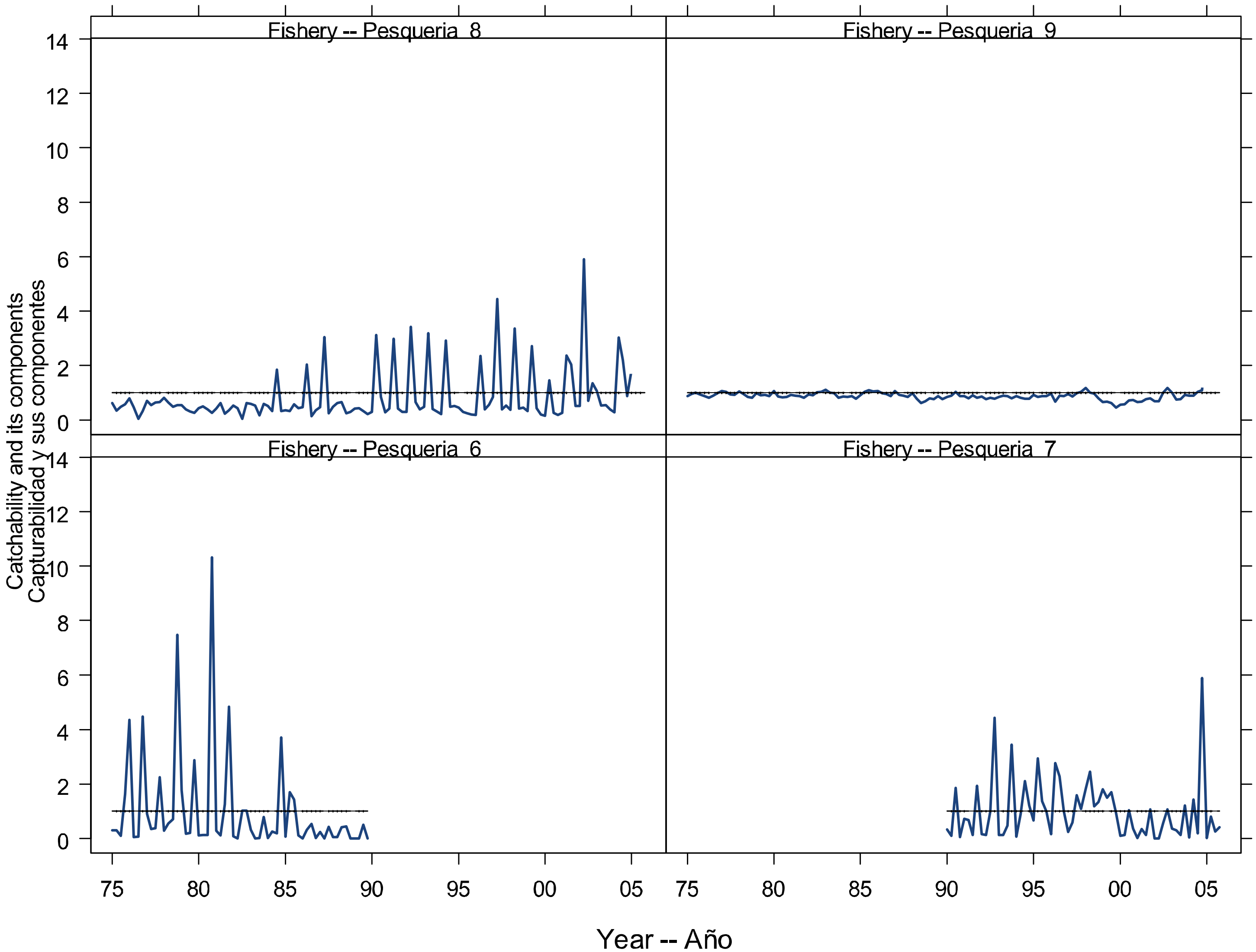


FIGURE 4.7. (continued)
FIGURA 4.7. (continuación)

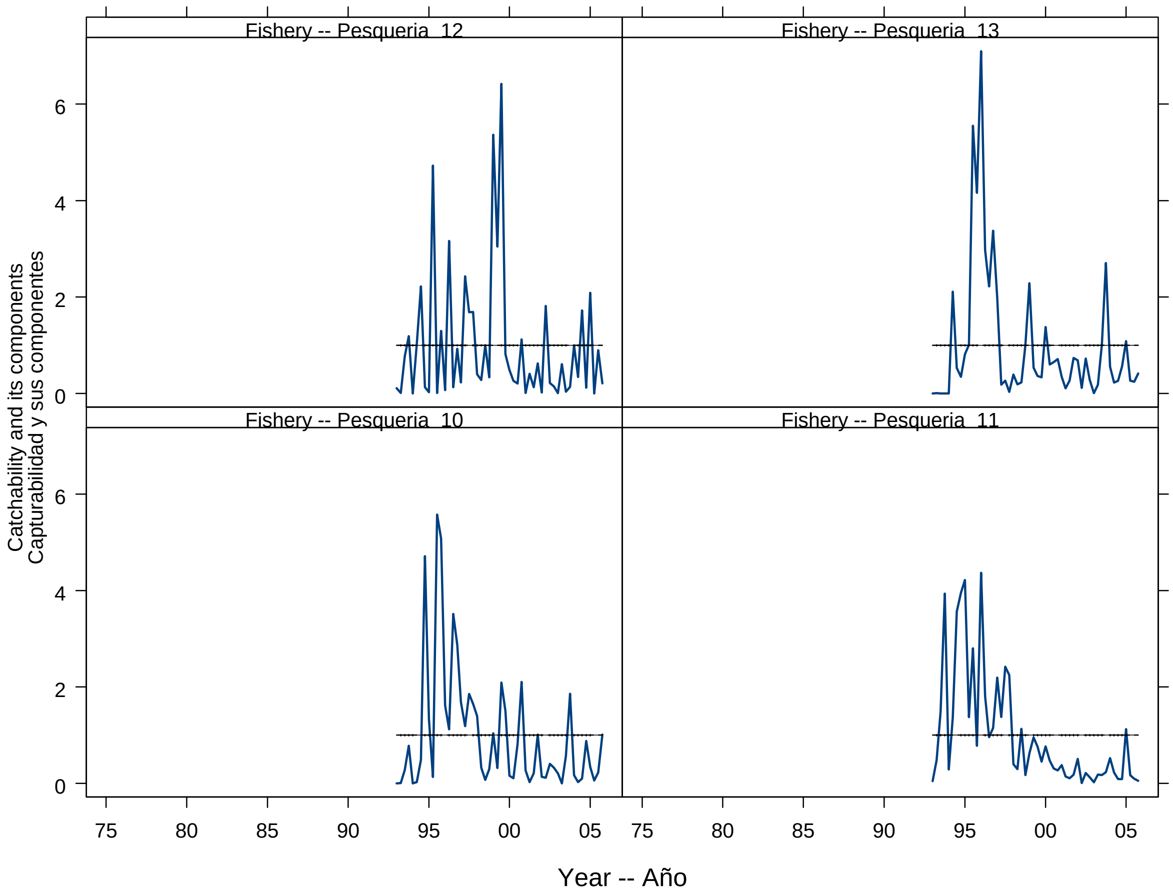


FIGURE 4.7. (continued)
FIGURA 4.7. (continuación)

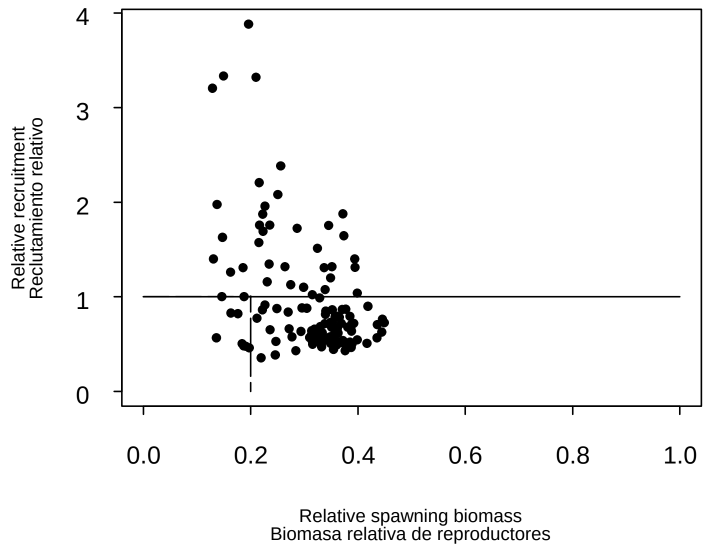


FIGURE 4.8. Estimated relationship between the recruitment of bigeye tuna and spawning biomass. The recruitment is scaled so that the estimate of virgin recruitment is equal to 1.0. Likewise, the spawning biomass is scaled so that the estimate of virgin spawning biomass is equal to 1.0. The horizontal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

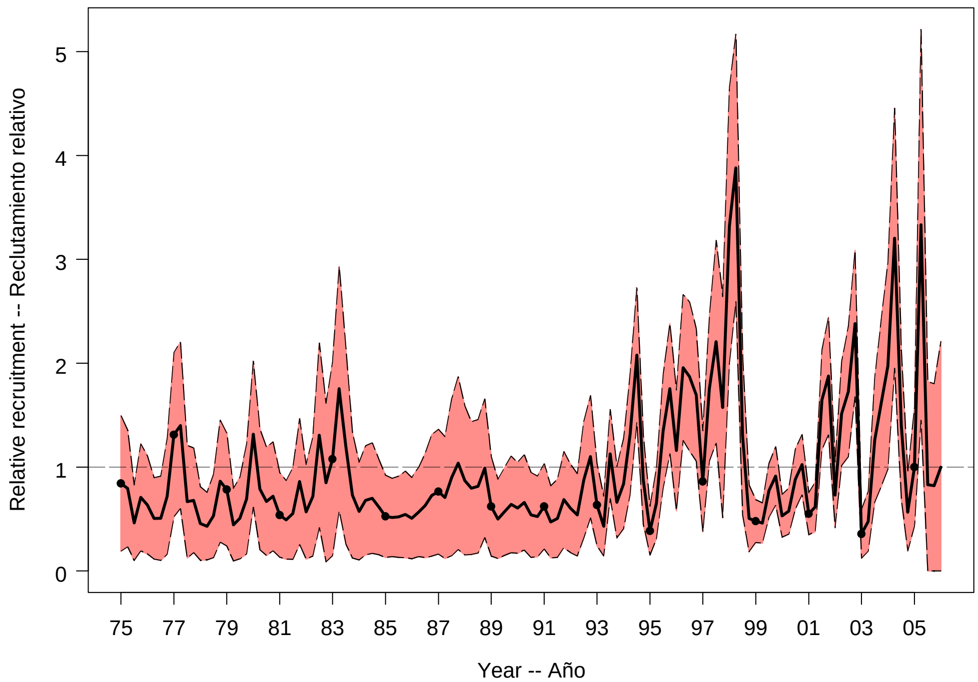


FIGURE 4.9. Estimated recruitment of bigeye tuna to the fisheries of the EPO. The estimates are scaled so that the estimate of virgin recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the thin dashed lines the confidence intervals (±2 standard deviations) around those estimates. The labels on the time axis are drawn at the 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 trazos los intervalos de confianza (±2 desviaciones estándar) alrededor de esas estimaciones. Se dibujan las leyendas en el eje de tiempo al principio de cada año, pero, ya que el modelo de evaluación representa el tiempo por trimestres, hay cuatro estimaciones de reclutamiento para cada año.

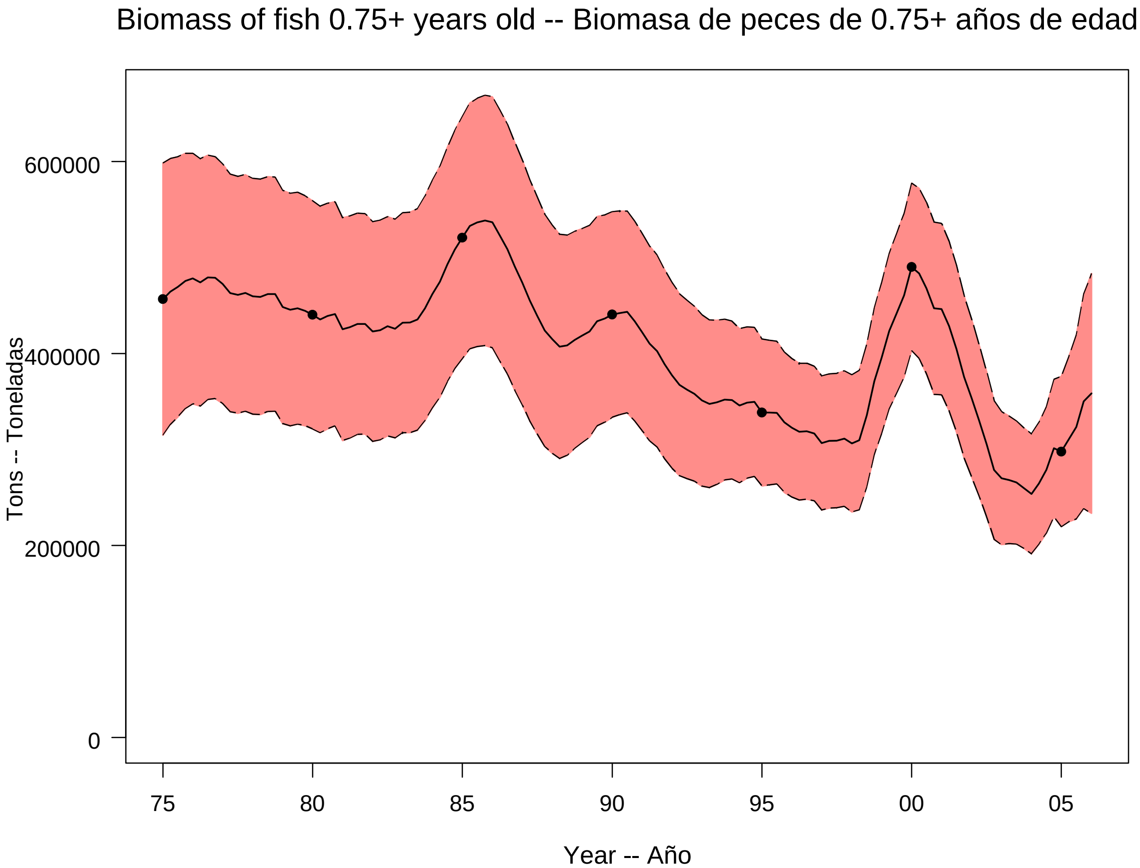


FIGURE 4.10. Estimated biomass of bigeye tuna 3+ quarters old in the EPO. The bold line illustrates the maximum likelihood estimates of the biomasses, and the thin dashed lines the confidence intervals (±2 standard deviations) around those estimates. Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year. t = metric tons.

FIGURA 4.10. Biomasa estimada de atún patudo de 1+ años de edad en el OPO. La línea gruesa ilustra las estimaciones de verosimilitud máxima de la biomasa, y las líneas delgadas de trazos los intervalos de confianza (±2 desviaciones estándar) alrededor de estas estimaciones. Ya que el modelo de evaluación representa el tiempo por trimestre, hay cuatro estimaciones de biomasa para cada año. t = toneladas métricas.

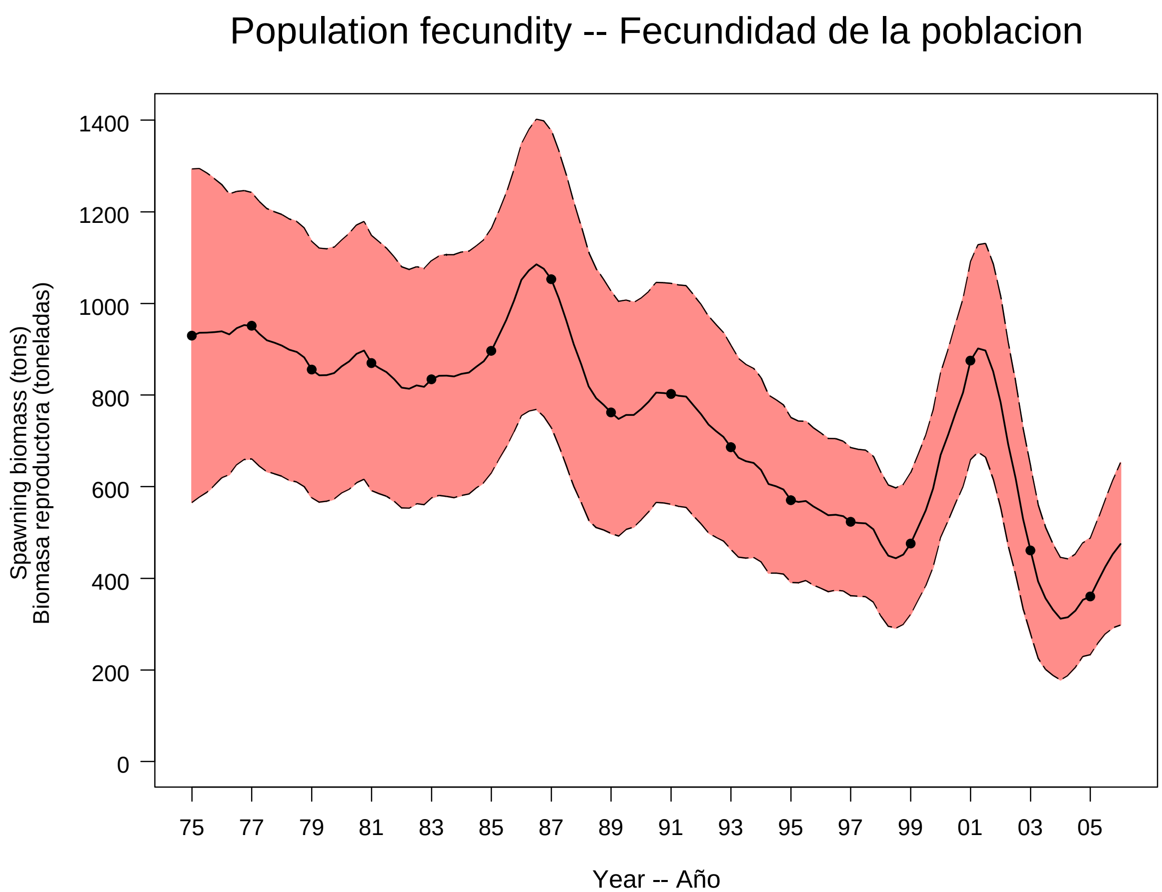


FIGURE 4.11. Estimated spawning biomass (see Section 3.1.2) of bigeye tuna in the EPO. The bold line illustrates the maximum likelihood estimates of the biomasses, and the thin dashed lines the confidence intervals (±2 standard deviations) around those estimates. Since the assessment model represents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

FIGURA 4.11. Estimada biomasa reproductora (ver Sección 3.12) de atún patudo en el OPO. La línea gruesa ilustra las estimaciones de verosimilitud máxima de la biomasa, y las líneas delgadas de trazos los intervalos de confianza (±2 desviaciones estándar) alrededor de estas estimaciones. Ya que el modelo de evaluación representa el tiempo por trimestre, hay cuatro estimaciones de biomasa para cada año. t = toneladas métricas.

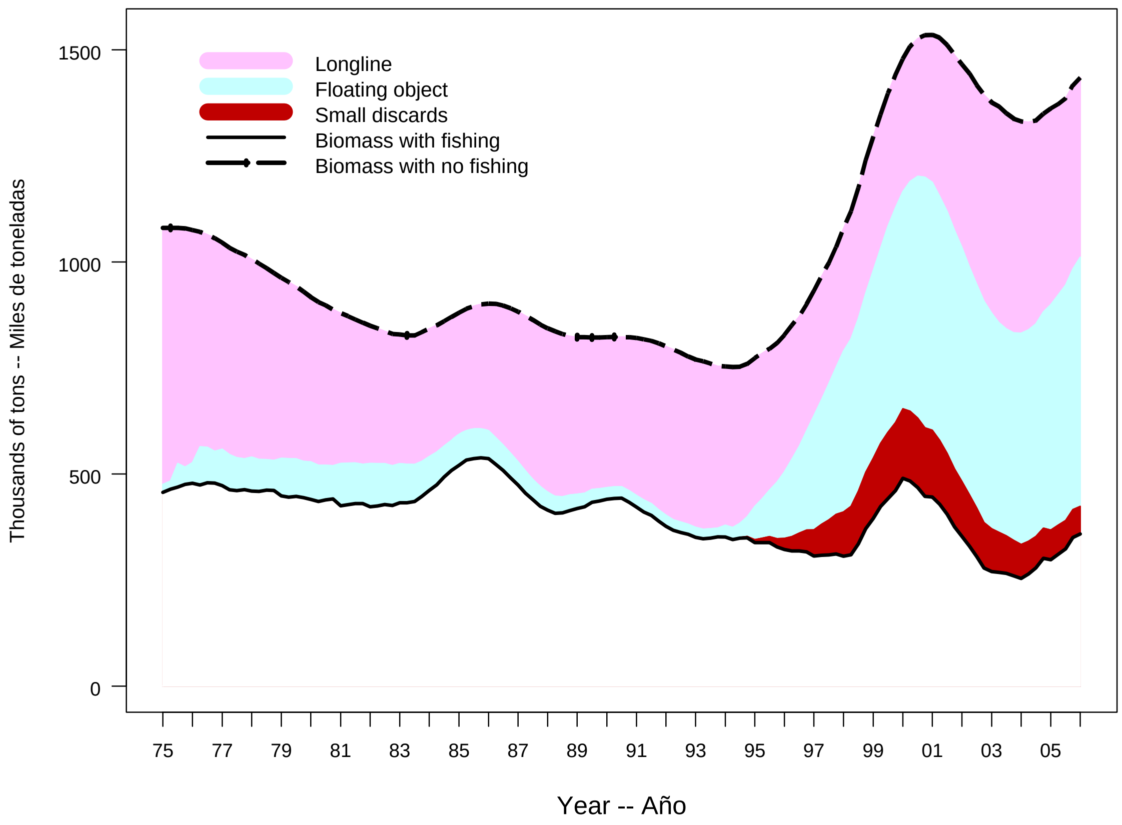


FIGURE 4.12. Biomass trajectory of a simulated population of bigeye tuna that was not exploited (dashed line) and that predicted by the stock assessment model (solid line). The shaded areas between the two lines show the portions of the impact attributed to each fishing method. t = metric tons.

FIGURA 4.12. Trayectoria de la biomasa de una población simulada de atún patudo no explotada (línea de trazos) y la que predice el modelo de evaluación (línea sólida). Las áreas sombreadas entre las dos líneas señalan la porción del efecto atribuida a cada método de pesca. t = toneladas métricas.

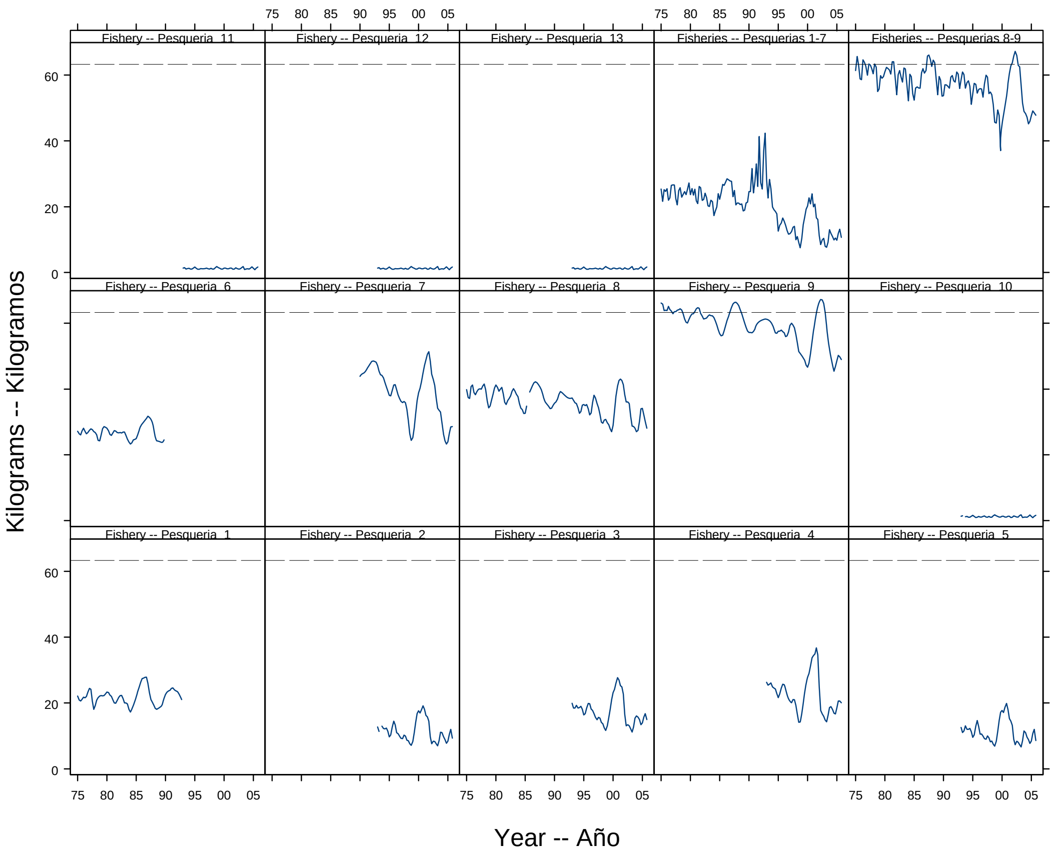


FIGURE 4.13. Estimated average weights of bigeye tuna caught by the fisheries of the EPO. The time series for "Fisheries 1-7" is an average of Fisheries 1 through 7, and that for "Fisheries 8-9" an average of Fisheries 8 and 9. The dashed horizontal line (at about 63.3 kg) identifies the critical weight.

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.

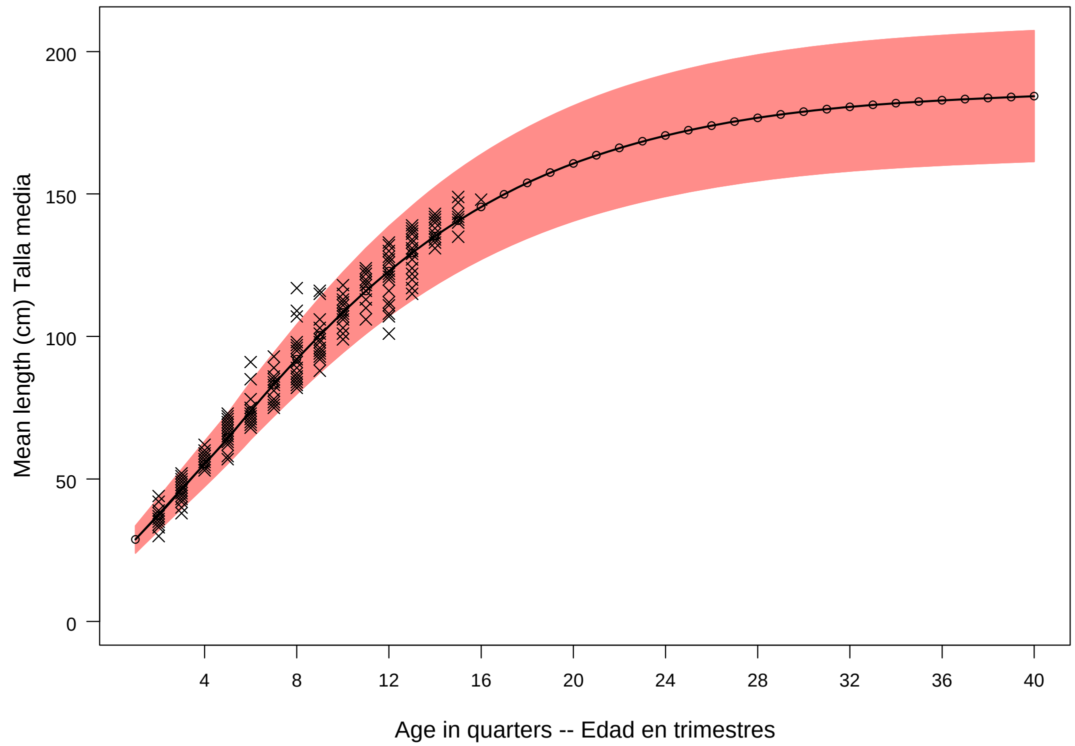


FIGURE 4.14. Estimated average lengths at age for bigeye tuna in the EPO (solid line without circles). The line with circles represents the prior. The crosses represent the otolith age-length data from Schaefer and Fuller (2006). The shaded area indicates the range of lengths estimated to be covered by two standard deviations of the length at age.

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

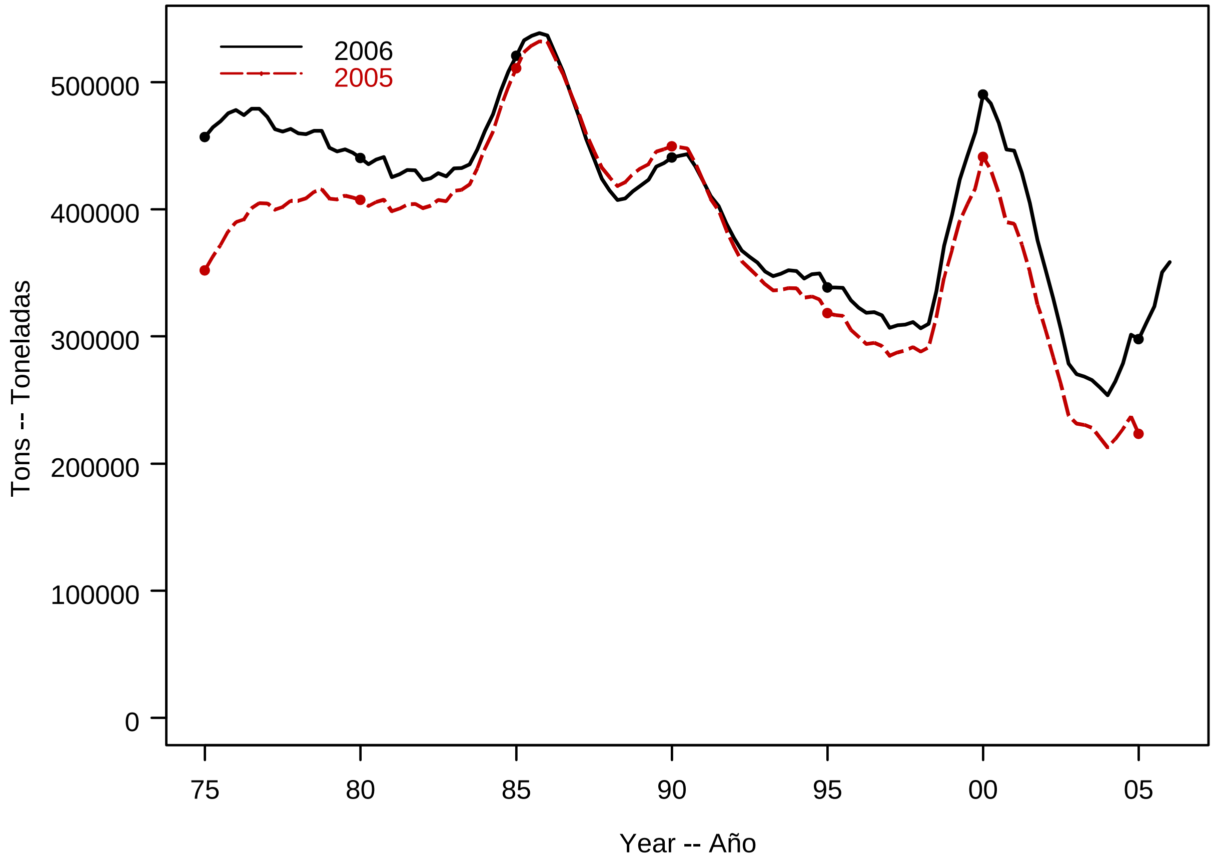


FIGURE 4.15. Comparison of estimates of the biomass of bigeye tuna from the most recent previous assessment (fish of age 4 quarters and older) and the current assessment (fish of age 3 quarters and older). t = metric tons.
FIGURA 4.15. Comparación de las estimaciones de la biomasa de atún patudo de la evaluación previa más reciente (peces de 4 trimestres o más de edad) y la evaluación actual (peces de 3 trimestres o más de edad). t = toneladas métricas.

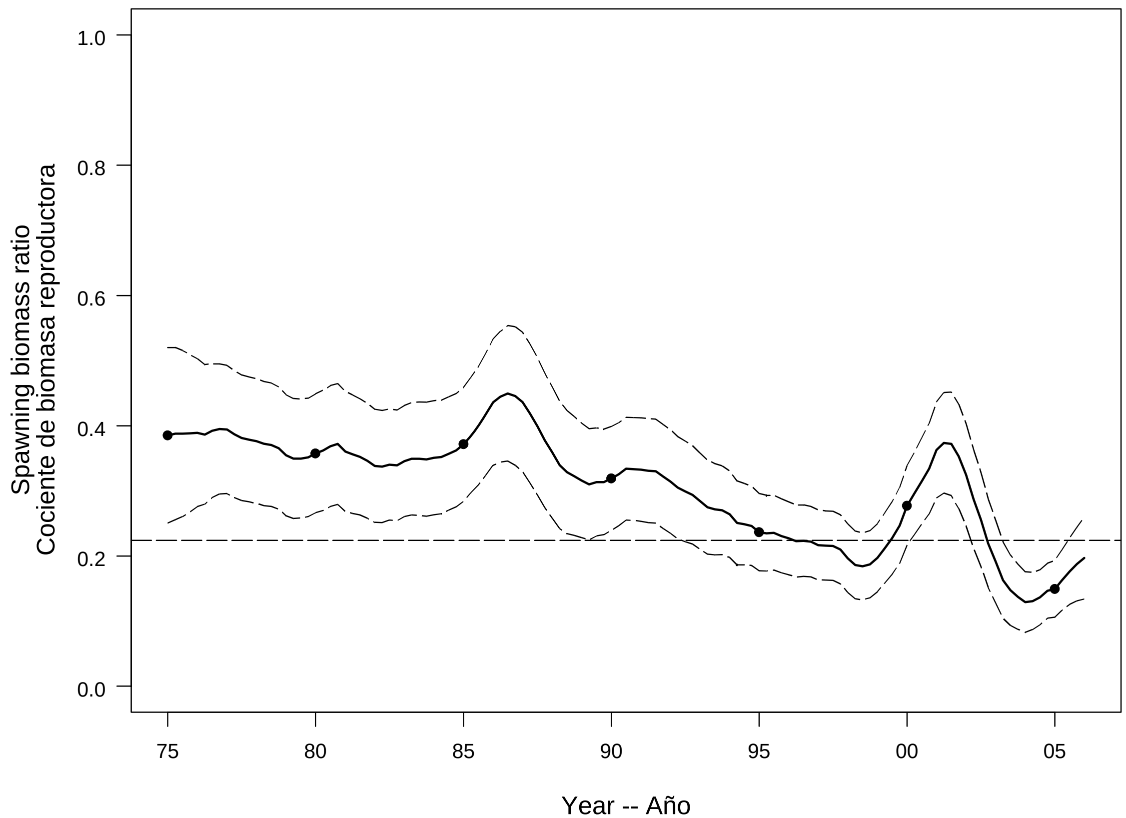


FIGURE 5.1a. Estimated spawning biomass ratios (SBRs) for bigeye tuna in the EPO. The dashed horizontal line (at about 0.22) identifies the SBR at AMSY. The solid lines illustrate the maximum likelihood estimates, and the thin dashed lines the confidence intervals (±2 standard deviations) around those estimates.

FIGURA 5.1a. Cocientes de biomasa reproductora (SBR) estimados para el atún patudo en el OPO. La línea de trazos horizontal (en aproximadamente 0,22) identifica el SBR en RMSP. Las líneas sólidas ilustran las estimaciones de verosimilitud máxima, y las líneas delgadas de trazos los intervalos de confianza (±2 desviaciones estándar) alrededor de esas estimaciones.

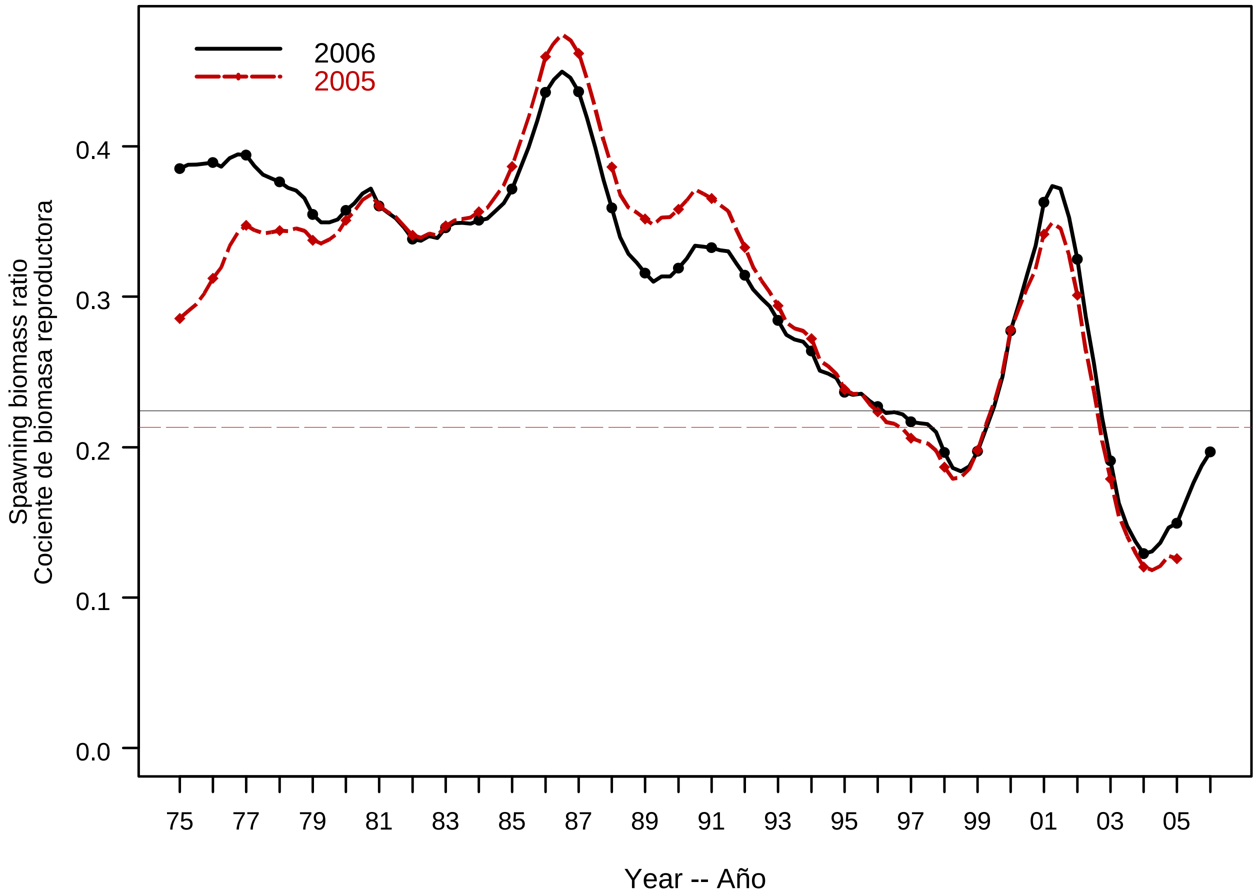


FIGURE 5.1b. Comparison of estimated spawning biomass ratios (SBRs) for bigeye tuna in the EPO from the current assessment and the most recent previous assessment. The horizontal lines (at about 0.22 and 0.21) indicate the SBRs at AMSY.
FIGURA 5.1b. Comparación de los cocientes de biomasa reproductora (SBR) estimados para el atún patudo en el OPO de la evaluación actual y la evaluación previa más reciente. Las líneas horizontales (en aproximadamente 0,22 y 0,21) identifican el SBR en RMSP.

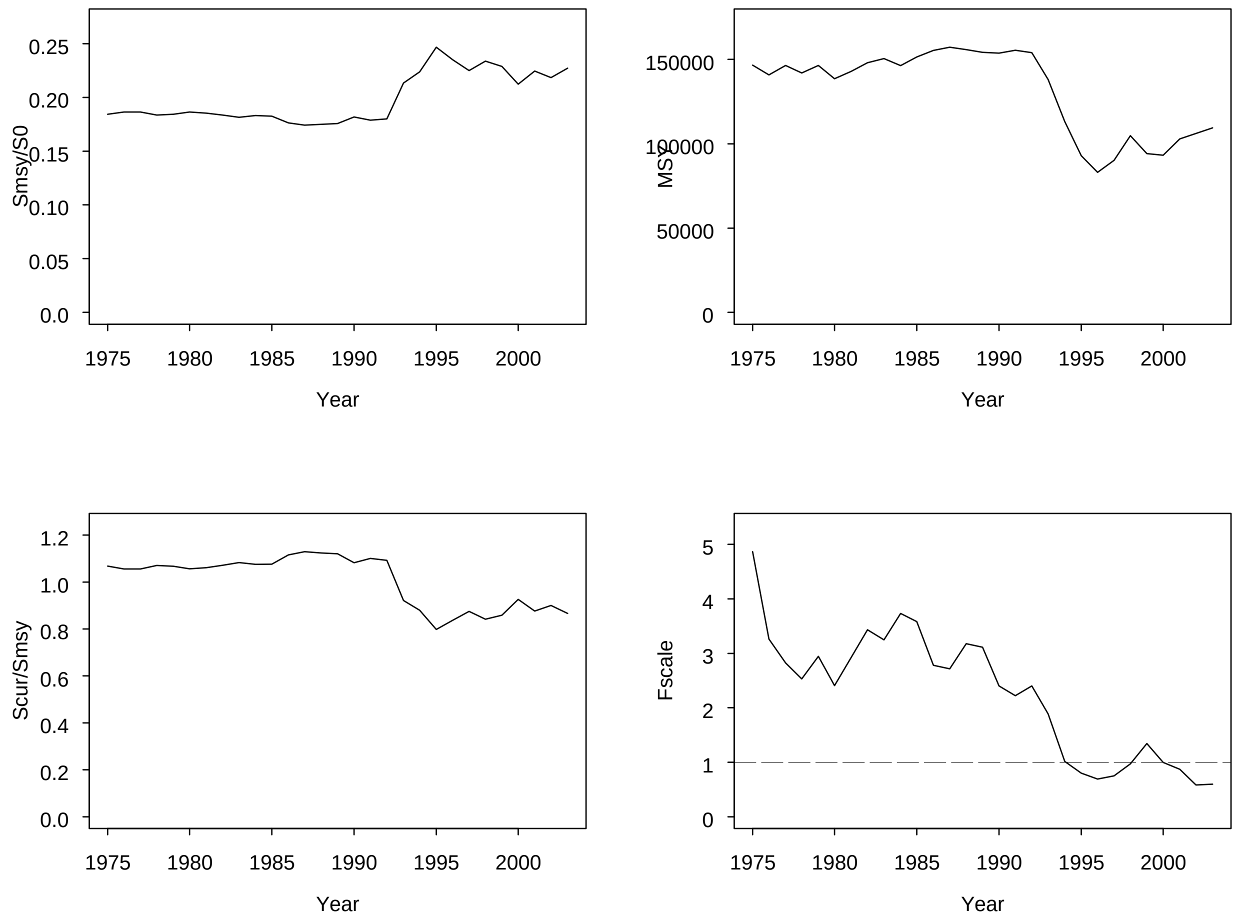


FIGURE 5.1c. Estimates of AMSY-related quantities calculated using the average age-specific fishing mortality for each year. (S_{recent} is the spawning biomass at the start of 2006.)

FIGURA 5.1c. Estimaciones de cantidades relacionadas con el RMSP calculadas usando la mortalidad por pesca por edad para cada año. (S_{recent} es la biomasa reproductora al principio de 2006.)

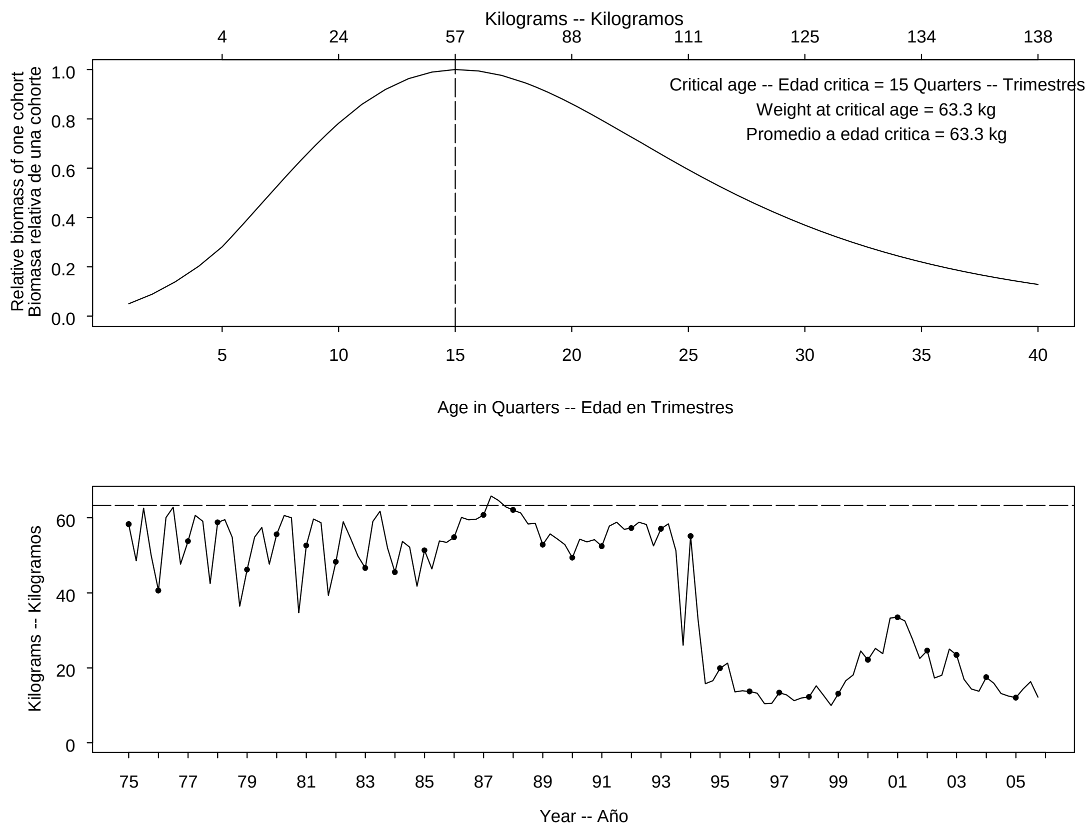


FIGURE 5.2. Combined performance of all fisheries that take bigeye tuna in the EPO at achieving the maximum yield per recruit. The upper panel illustrates the growth (in weight) of a single cohort, and identifies the critical age and critical weight (Section 5), and the lower panel shows the average weights of the fish in the catches by all gears combined. 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), y se muestran en el recuadro inferior los pesos promedios de los peces en las capturas por todos los artes combinados. 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.

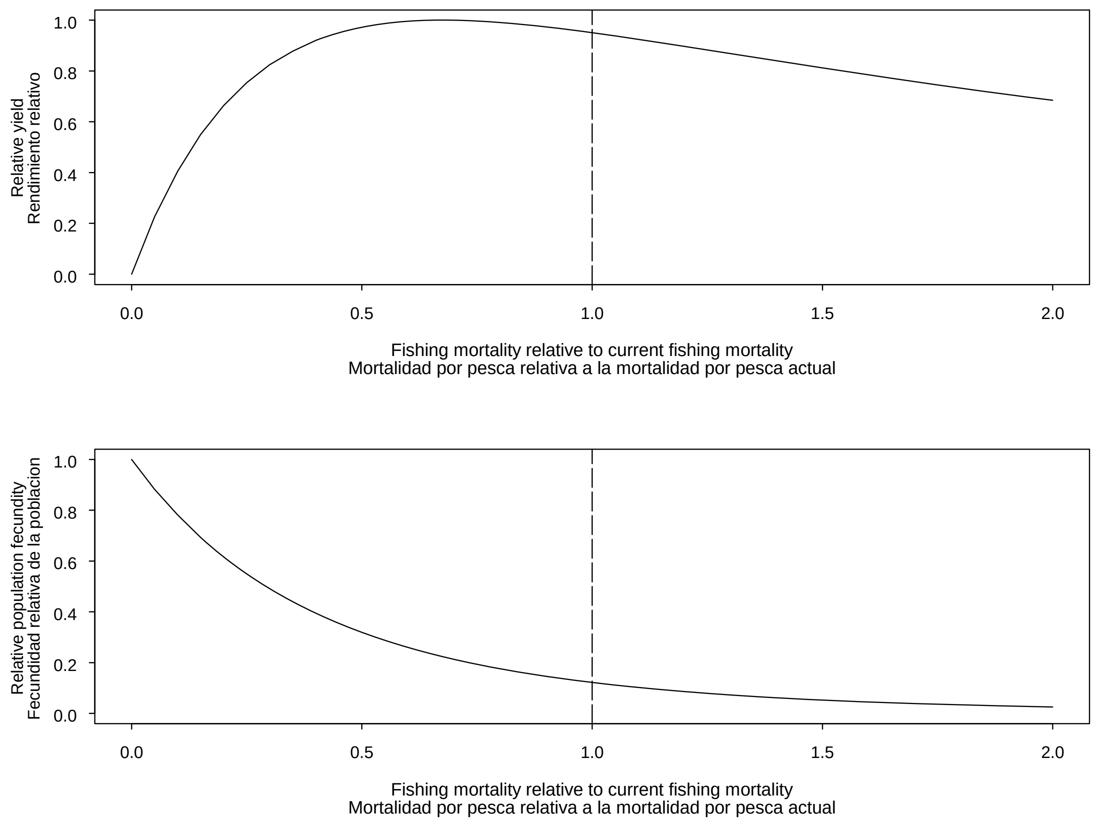


FIGURE 5.3. Predicted effects of long-term changes in fishing effort on the yield (upper panel) and spawning biomass (lower panel) of bigeye tuna under equilibrium conditions with average fishing mortality patterns from 2003 and 2004. The yield estimates are scaled so that the AMSY is at 1.0, and the 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 2003 y 2004. 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.

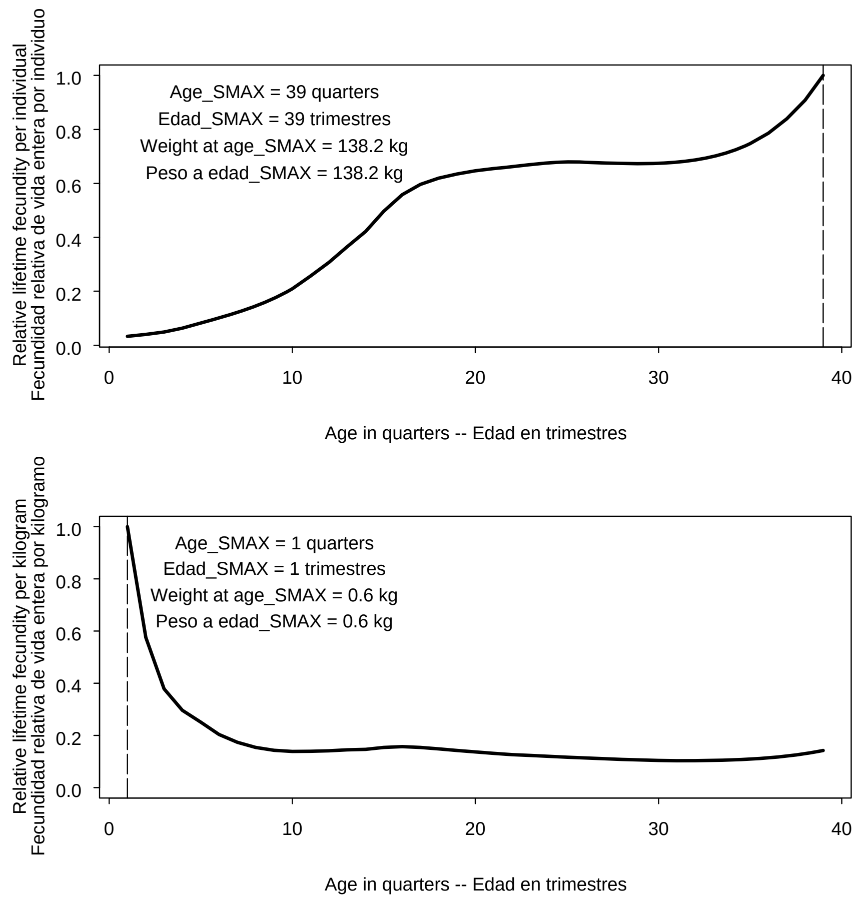


FIGURE 5.4. Marginal relative lifetime reproductive potential of bigeye tuna at age, based on individuals (upper panel) and weight (lower panel). It was assumed, for these calculations, that the quarterly fishing mortalities equaled the average quarterly fishing mortalities for 2003-2004. The vertical 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 por 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 2003-2004. Las líneas verticales representan la edad a la cual se logra el potencial de reproducción relativo marginal máximo.

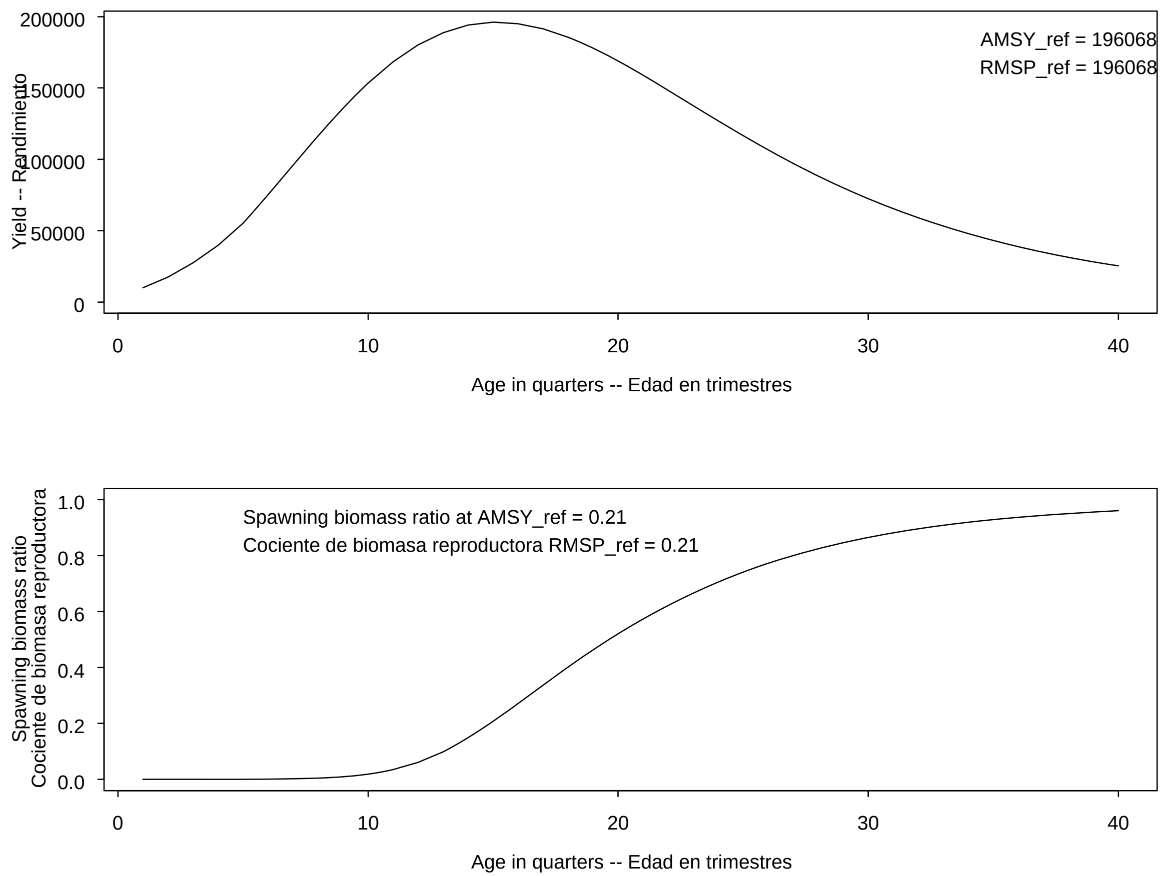


FIGURE 5.5. Yield of bigeye tuna calculated when catching only individuals at a single age (upper panel), and the associated spawning biomass ratio (lower panel). t = metric tons.
FIGURA 5.5. Rendimiento de atún patudo calculado si se capturara solamente individuos de una sola edad (recuadro superior), y el cociente de biomasa reproductora asociado (recuadro inferior). t = toneladas metricas.

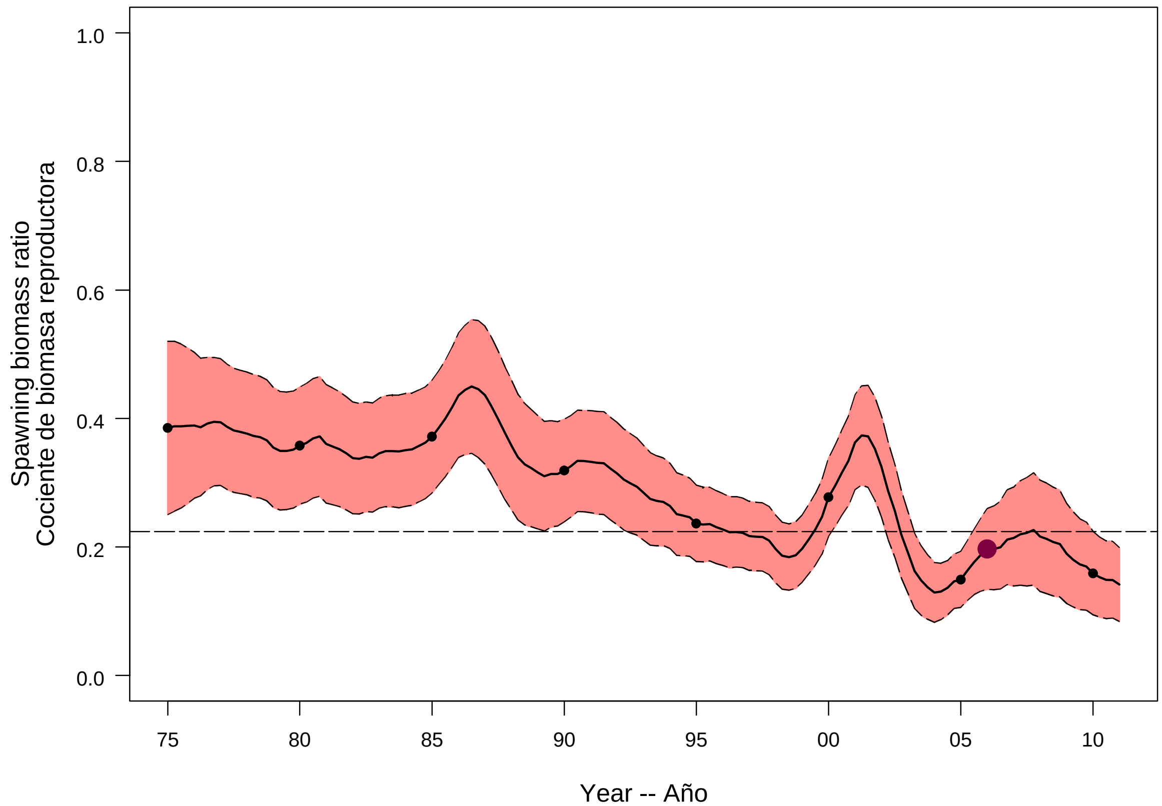


FIGURE 6.1a. Spawning biomass ratios (SBRs) of bigeye tuna in the EPO. The dashed horizontal line (at about 0.22) identifies the SBR at AMSY. The solid line illustrates the maximum likelihood estimates and the thin dashed lines the 95% confidence intervals around these estimates. The estimates after 2006 (the large dot) indicate the SBR predicted to occur if effort continues at the average of that observed in 2005.

FIGURA 6.1a. Cocientes de biomasa reproductora (SBR) para el atún patudo en el OPO. La línea de trazos horizontal (en aproximadamente 0.22) identifica el SBR en RMSP. La línea sólida ilustra las estimaciones de verosimilitud máxima, y las líneas delgadas de trazos los intervalos de confianza de 95% alrededor de esas estimaciones. Las estimaciones a partir de 2006 (el punto grande) señalan el SBR predicho si el esfuerzo continúa en el nivel observado en 2005.

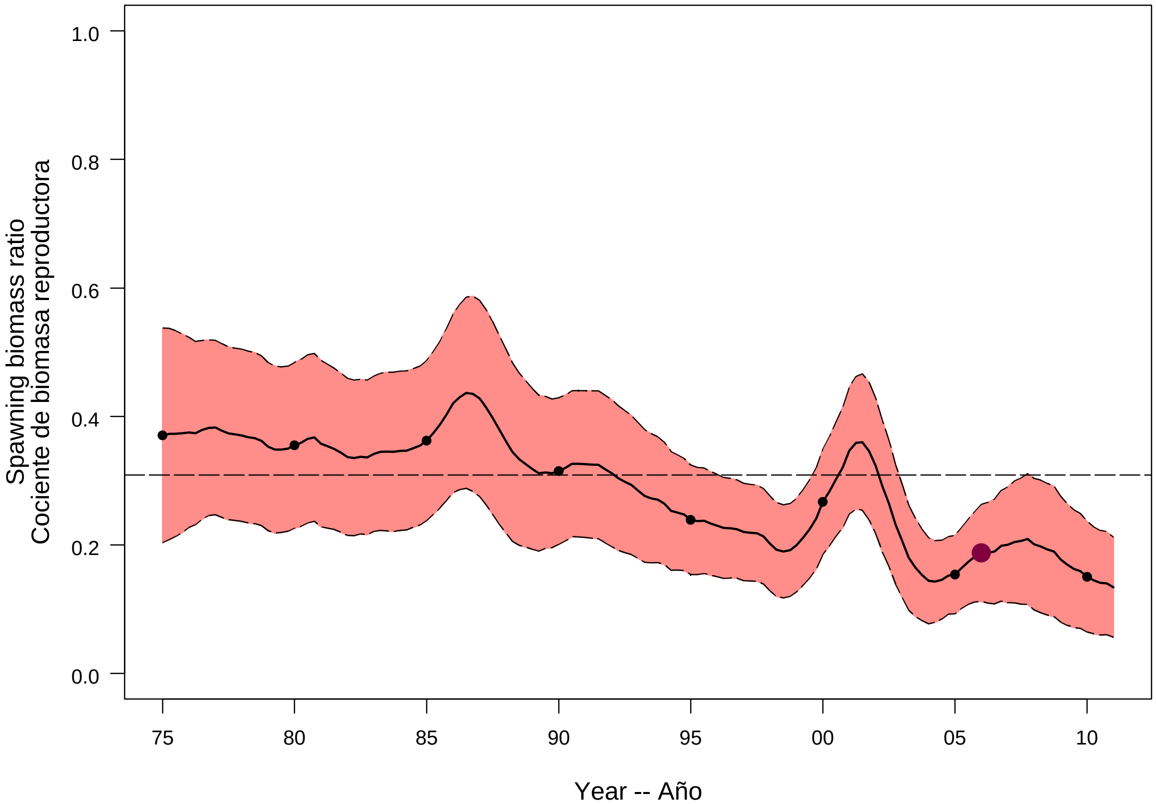


FIGURE 6.1b. Spawning biomass ratios (SBRs) of bigeye tuna in the EPO from the stock-recruitment sensitivity analysis. The dashed horizontal line (at about 0.31) identifies the SBR at AMSY. The solid line illustrates the maximum likelihood estimates and the thin dashed lines the 95% confidence intervals around these estimates. The estimates after 2006 (the large dot) indicate the SBR predicted to occur if effort continues at the average of that observed in 2005.

FIGURA 6.1b. Cocientes de biomasa reproductora (SBR) para el atún patudo en el OPO del análisis de sensibilidad de población-reclutamiento. La línea de trazos horizontal (en aproximadamente 0,31) identifica el SBR en RMSP. La línea sólida ilustra las estimaciones de verosimilitud máxima, y las líneas delgadas de trazos los intervalos de confianza de 95% alrededor de esas estimaciones. Las estimaciones a partir de 2006 (el punto grande) señalan el SBR predicho si el esfuerzo continúa en el nivel observado en 2005.

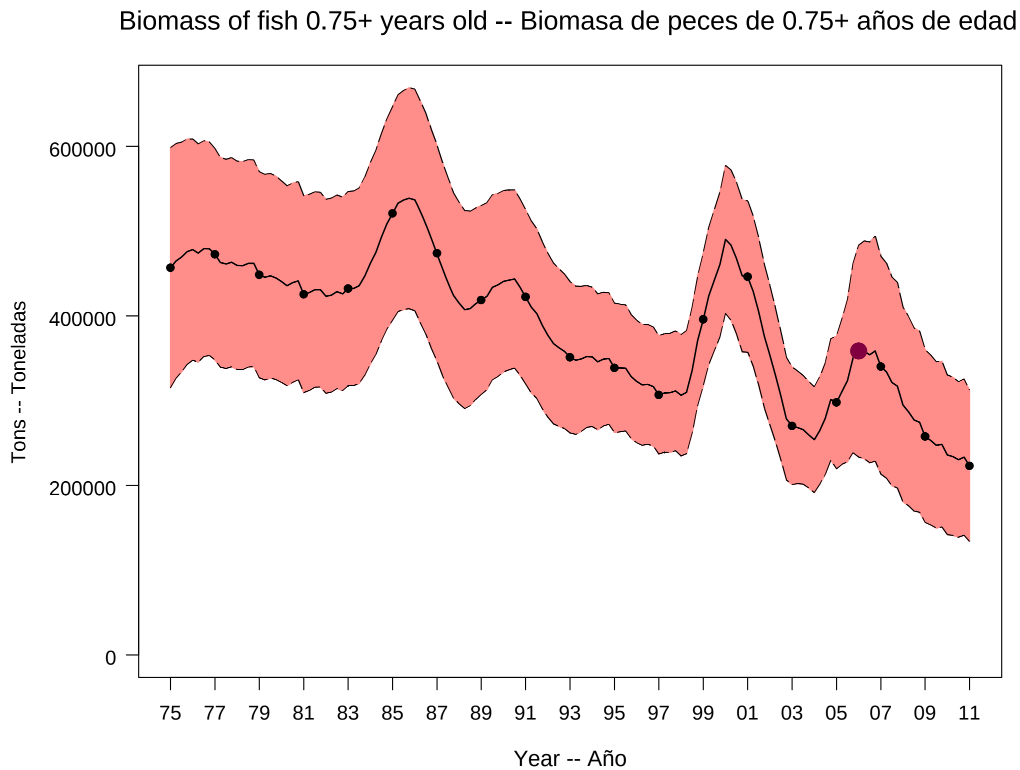


FIGURE 6.2. Estimated biomass of bigeye tuna of age three quarters and older, including projections for 2006-20010 with effort for 2005. These calculations include parameter estimation uncertainty and uncertainty about future recruitment. The areas between the dashed curves indicate the 95% confidence intervals, and the large dot indicates the estimate for the first quarter of 2006. t = metric tons.

FIGURE 6.2. Biomasa estimada de atún patudo de tres trimestres o más de edad, incluyendo proyecciones para 2006-20010 con el esfuerzo de 2005. Los cálculos incluyen incertidumbre en la estimación de los parámetros y sobre el reclutamiento futuro. Las zonas entre las curvas de trazos señalan los intervalos de confianza de 95%, y el punto grande indica la estimación correspondiente al primer trimestre de 2006. t = toneladas métricas.

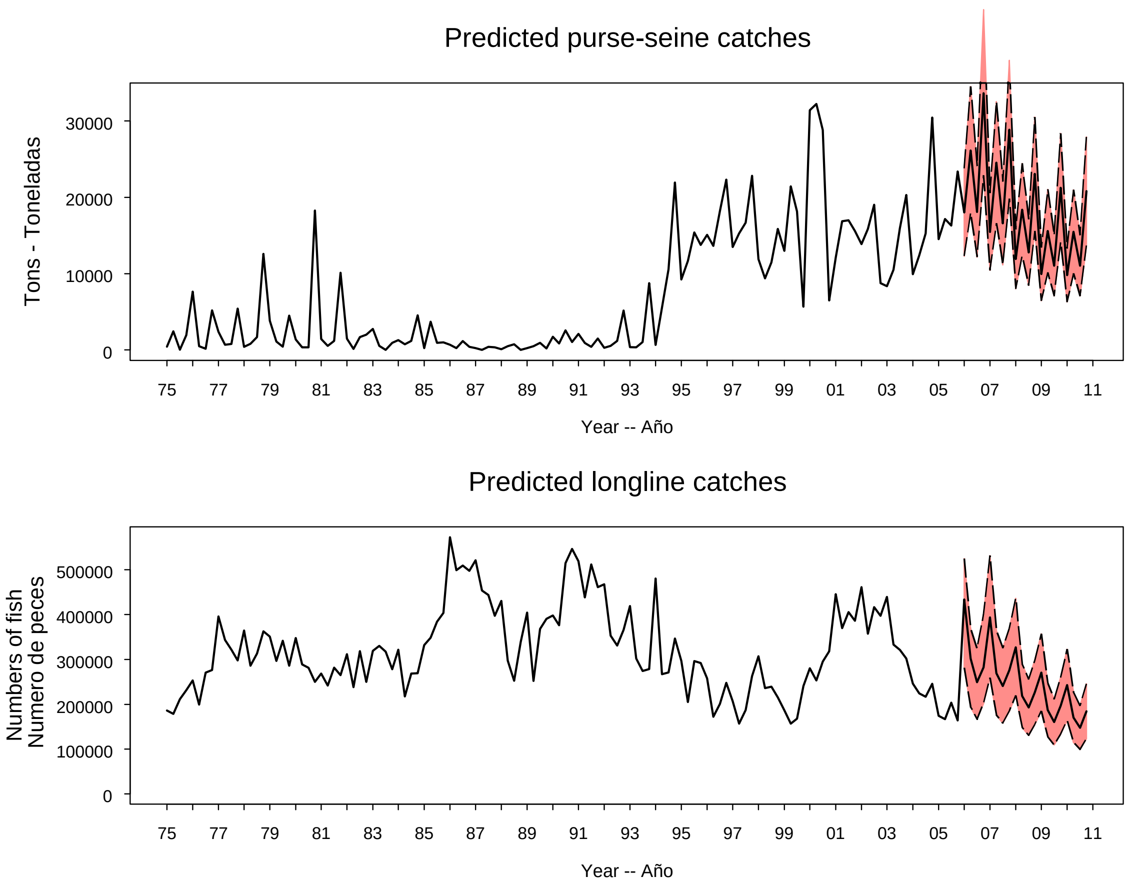


FIGURE 6.3. Predicted quarterly catches of bigeye tuna for the purse-seine and pole-and-line (upper panel) and longline fisheries (lower panel), based on effort for 2005. The predictions were undertaken using the maximum likelihood profile. The thin dashed lines represent the 95% confidence intervals for the predictions of future catches. Note that the vertical scales of the panels are different. t = metric tons.

FIGURA 6.3. Capturas trimestrales predichas de atún patudo en las pesquerías de cerco y caña (recuadro superior) y palangreras (recuadro inferior), basadas en el esfuerzo de 2005. Se realizaron las predicciones con el método de perfil de verosimilitud. Las líneas delgadas de trazos representan los intervalos de confianza de 95% para las predicciones de capturas futuras. Nótese que las escalas verticales de los recuadros son diferentes. t = toneladas métricas.

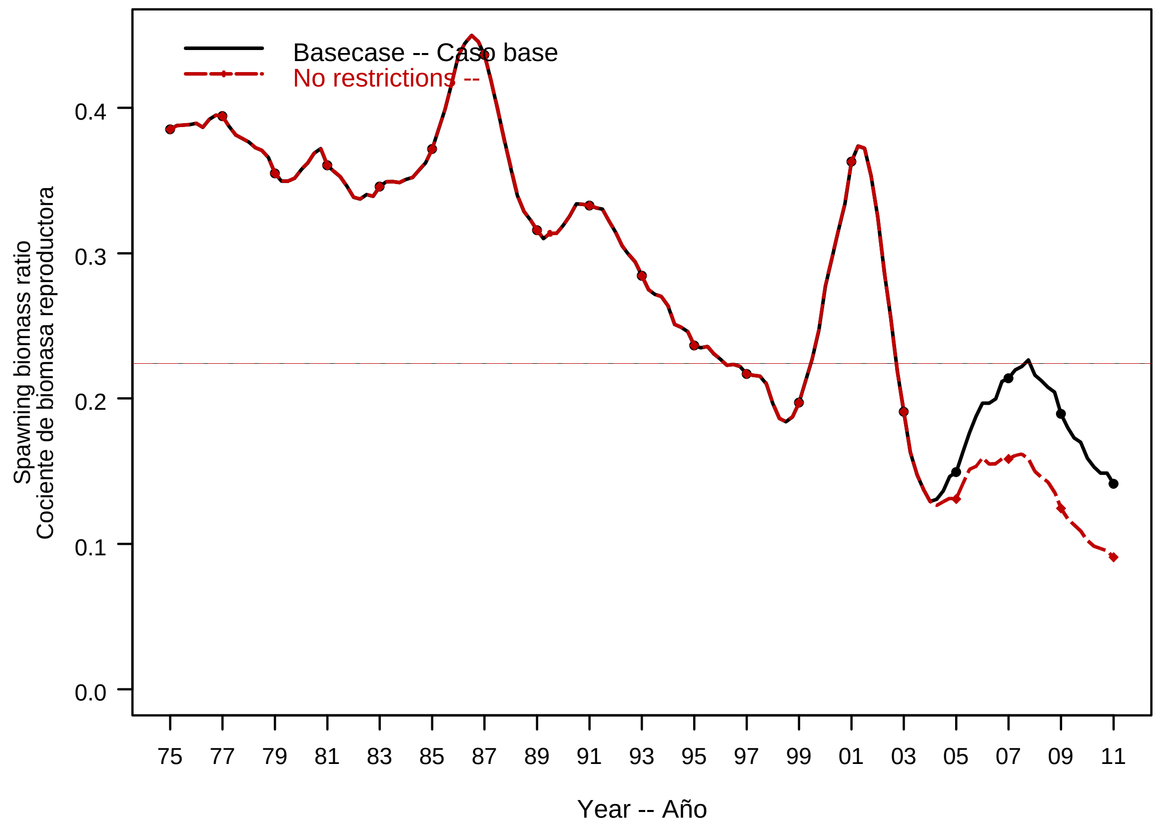


FIGURE 6.4. Maximum likelihood estimates of the projected spawning biomass ratios (SBRs) of bigeye tuna, with effort for 2005 and average catchability for 2003 and 2004 ("Base case") and with purse-seine effort in the third quarter increased by 86% and effort increased in all quarters by 39% for the southern longline fishery to approximate the effect of no restrictions ("No restrictions") for the years 2004 and later. The horizontal line indicates the SBR_{AMSY} (0.22).

FIGURA 6.4. Estimaciones de verosimilitud máxima de los cocientes de biomasa reproductora (SBR) proyectados de atún patudo, con el esfuerzo de 2005 y la capturabilidad media de 2003 y 2004 ("Caso base") y con el esfuerzo cerquero en el tercer trimestre incrementado un 86% y esfuerzo incrementado un 39% para la pesquería palangrera sureña para aproximar el efecto de ninguna restricción ("Sin veda"). La línea horizontal indica el SBR_{RMSP} (0,22).

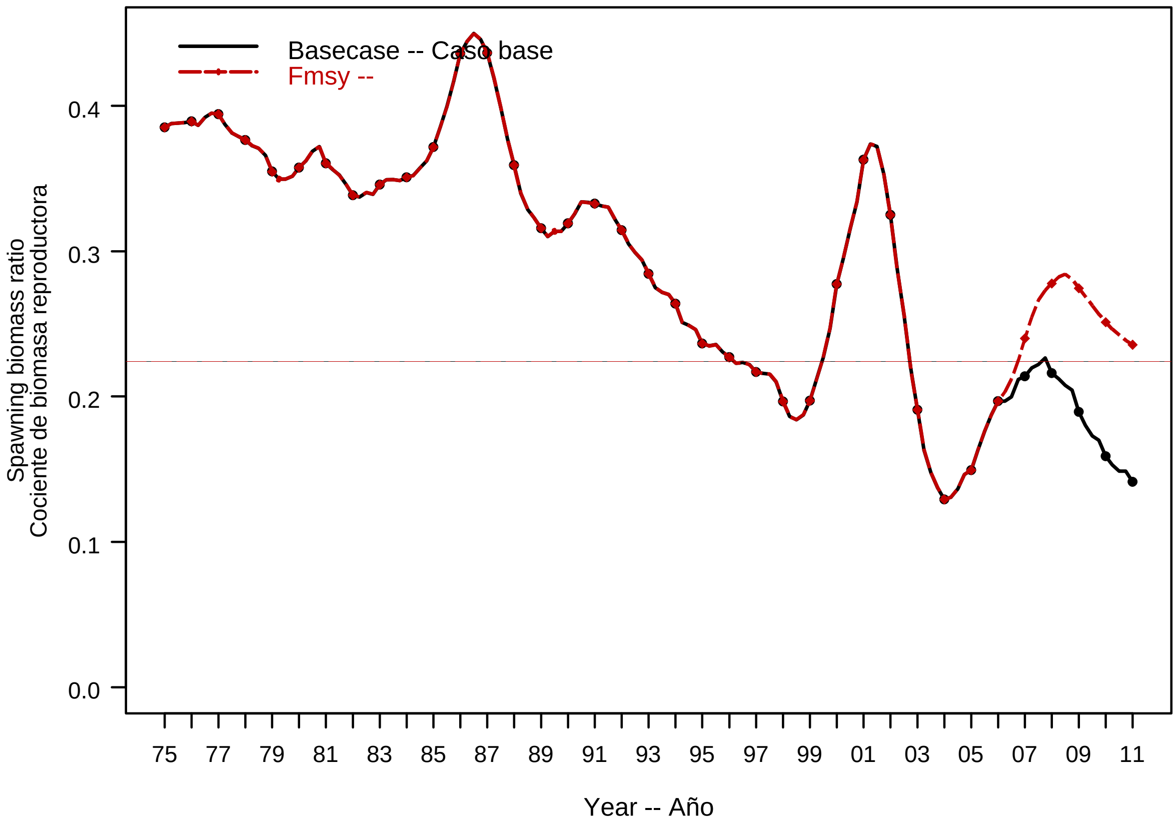


FIGURE 6.5. Simulated spawning biomass ratios (SBRs) during 2006-2010 for bigeye tuna in the EPO when fishing at F_{AMSY}, compared to the base case. The dashed horizontal line indicates the SBR_{AMSY} (0.22).

FIGURA 6.5. Cocientes de biomasa reproductora (SBR) simulados durante 2006-2010 para el atún patudo en el OPO con la pesca al nivel de F_{RMSP}, en comparación con el caso base. La línea de trazos horizontal señala el SBR_{RMSP} (0,22).

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**	**Años**	**Zonas de muestreo**	**Datos de captura**
1	PS	FLT	1980-1992	1-13	retained catch only–captura retenida solamente
2	PS	FLT	1993-2005	11-12	retained catch + discards from inefficiencies in fishing process–captura retenida + descartes de ineficacias en el proceso de pesca
3	PS	FLT	1993-2005	7, 9	
4	PS	FLT	1993-2005	5-6, 13	
5	PS	FLT	1993-2005	1-4, 8, 10	
6	PS LP	UNA DOL	1980-1989	1-13	retained catch only–captura retenida solamente
7	PS LP	UNA DOL	1990-2005	1-13	retained catch + discards from inefficiencies in fishing process–captura retenida + descartes de ineficacias en el proceso de pesca
8	LL		1980-2005	N of 15°N–N de 15°N	retained catch only–captura retenida solamente
9	LL		1980-2005	S of 15°N–S de 15°N	retained catch only–captura retenida solamente
10	PS	FLT	1993-2005	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	1993-2005	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	1993-2005	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	1993-2005	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	Age in quarters	Proportion female	Index of fecundity
Edad en trimestres	**Proporción hembra**	**Índice de fecundidad**	**Edad en trimestres**	**Proporción hembra**	**Índice de fecundidad**
1	0.47	0	21	0.43	0.73
2	0.47	0	22	0.43	0.76
3	0.47	0	23	0.42	0.79
4	0.47	0	24	0.41	0.82
5	0.47	0	25	0.4	0.84
6	0.47	0	26	0.39	0.86
7	0.47	0	27	0.38	0.88
8	0.47	0.01	28	0.37	0.9
9	0.47	0.02	29	0.36	0.91
10	0.47	0.04	30	0.35	0.93
11	0.47	0.07	31	0.34	0.94
12	0.47	0.13	32	0.33	0.95
13	0.47	0.21	33	0.31	0.96
14	0.47	0.3	34	0.3	0.97
15	0.46	0.4	35	0.29	0.97
16	0.46	0.48	36	0.29	0.98
17	0.46	0.55	37	0.28	0.99
18	0.45	0.61	38	0.27	0.99
19	0.45	0.65	39	0.26	1
20	0.44	0.69	40	0.25	1

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 2004 to 2005.

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 2004 a 2005.

Quarter	Fishery 2	Fishery 3	Fishery 4	Fishery 5
Trimestre	**Pesquería 2**	**Pesquería 3**	**Pesquería 4**	**Pesquería 5**
1	-5%	355%	778%	-42%
2	-46%	145%	12%	112%
3	-39%	110%	741%	59%
4	15%	96%	464%	102%

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	Total recruitment	Biomass of age-3 quarter+ fish	Spawning biomass
Año	**Reclutamiento total**	**Biomasa de peces de edad 3+ trimestres**	**Biomasa de peces reproductores**
1975	10,867	456,710	929
1976	9,164	478,115	939
1977	15,710	472,604	951
1978	8,837	459,585	908
1979	9,415	448,351	856
1980	13,525	440,245	862
1981	9,454	425,297	870
1982	13,322	422,874	816
1983	18,427	432,133	834
1984	9,947	461,788	846
1985	8,150	520,664	896
1986	9,404	536,653	1,052
1987	13,193	473,891	1,053
1988	13,440	414,900	867
1989	9,019	418,616	762
1990	9,013	440,644	770
1991	8,842	422,338	802
1992	12,082	377,255	758
1993	11,044	351,076	686
1994	19,792	351,491	637
1995	16,027	338,443	571
1996	25,869	322,607	548
1997	24,772	306,731	523
1998	34,909	306,301	474
1999	10,177	395,710	476
2000	11,661	490,215	669
2001	18,153	446,204	875
2002	24,585	353,460	784
2003	14,408	270,130	461
2004	27,662	253,766	312
2005	23,165	297,833	360
2006		358,408	475

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)**
1	28.8	0.64	21	163.59	98.22
2	37.63	1.39	22	166.17	102.79
3	46.46	2.56	23	168.48	106.98
4	55.29	4.23	24	170.53	110.81
5	64.13	6.5	25	172.36	114.3
6	73.93	9.82	26	173.99	117.45
7	83.14	13.8	27	175.43	120.3
8	92.01	18.51	28	176.71	122.87
9	100.45	23.88	29	177.85	125.17
10	108.46	29.83	30	178.86	127.24
11	115.95	36.2	31	179.75	129.09
12	122.88	42.84	32	180.54	130.73
13	129.31	49.67	33	181.23	132.2
14	135.22	56.54	34	181.85	133.51
15	140.59	63.3	35	182.39	134.67
16	145.47	69.88	36	182.87	135.7
17	149.89	76.21	37	183.3	136.62
18	153.88	82.25	38	183.67	137.44
19	157.47	87.94	39	184.01	138.18
20	160.7	93.27	40	184.36	138.92

TABLE 5.1. Estimates of the AMSY and its associated quantities for bigeye tuna for the base case assessment and sensitivity analyses. All analyses are based on average fishing mortality for 2003 and 2004. B_{recent} and B_{AMSY} are defined as the biomass of fish 3+ quarters old at the start of 2005 and at AMSY, respectively, and S_{recent} and S_{AMSY} are defined as indices of spawning biomass (therefore, they are not in metric tons). C_{recent} is the estimated total catch in 2005.

TABLA 5.1. 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 2003 y 2004. Se definen B_{recent} y B_{RMSP} como la biomasa de fish de edad 1+ años al principio de 2006 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 2005.

	Base case	**Steepness = 0.75**	**Linf = 171.5**	**Linf = 201.5**	**TWN length-frequency**
	Caso base	**Inclinación = 0.75**			
AMSY—RMSP	106,722	102,263	140,329	107,812	107,973
B_{AMSY}—B_{RMSP}	326,329	503,221	458,837	320,374	352,783
S_{AMSY}—S_{RMSP}	541	956	905	480	593
B_{AMSY}/B_0—B_{RMSP}/B_0	0.30	0.36	0.28	0.32	0.32
S_{AMSY}/S_0—S_{RMSP}/S_0	0.22	0.31	0.21	0.25	0.24
C_{recent}/AMSY—C_{recent}/RMSP	1.00	1.06	0.77	0.99	1.00
$B_{\mathrm{recent}}/B_{\mathrm{AMSY}}$—$B_{\mathrm{recent}}/B_{\mathrm{RMSP}}$	1.10	0.78	1.74	0.78	1.09
$S_{\mathrm{recent}}/S_{\mathrm{AMSY}}$—$S_{\mathrm{recent}}/S_{\mathrm{RMSP}}$	0.88	0.61	1.68	0.53	0.87
F multiplier—Multiplicador de F	0.68	0.51	1.44	0.41	0.65

TABLE 5.2. Estimates of the AMSY and its associated quantities for bigeye tuna based on alternative years used to calculate age specific fishing mortality. B_{recent} and B_{AMSY} are defined as the biomass of fish 3+ quarters old at the start of 2006 and at AMSY, respectively, and S_{recent} and S_{AMSY} are defined as indices of spawning biomass (therefore, they are not in metric tons). C_{recent} is the estimated total catch in 2005.

TABLA 5.2. 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 2006 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 2005.

	***F* 2003 and 2004 (Base case)**	***F* 2002 and 2003**	***F* 2004 and 2005**
	***F* 2003 y 2004 (Caso base)**	***F* 2002 y 2003**	***F* 2004 y 2005**
AMSY (t)—RMSP (t)	106,722	107,710	98,665
B_{AMSY} (t)—B_{RMSP} (t)	326,329	326,197	314,958
S_{AMSY}—S_{RMSP}	541	538	531
B_{AMSY}/B_0—B_{RMSP}/B_0	0.30	0.30	0.29
S_{AMSY}/S_0—S_{RMSP}/S_0	0.22	0.22	0.22
C_{recent}/AMSY—C_{recent}/RMSP	1.00	0.99	1.08
$B_{\mathrm{recent}}/B_{\mathrm{AMSY}}$—$B_{\mathrm{recent}}/B_{\mathrm{RMSP}}$	1.10	1.10	1.14
$S_{\mathrm{recent}}/S_{\mathrm{AMSY}}$—$S_{\mathrm{recent}}/S_{\mathrm{RMSP}}$	0.88	0.88	0.89
F multiplier—Multiplicador de F	0.68	0.59	0.86

TABLE 5.3. Estimates of the AMSY and its associated quantities for bigeye tuna, obtained by assuming that there is no stock-recruitment relationship (base case), that each fishery maintains its current pattern of age-specific selectivity (Figure 4.5), and that each fishery is the only fishery operating in the EPO. The estimates of the 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 2003 and 2004. "only" means that only that gear is used and the fishing mortality for the other gears is set to zero. "scaled" means that only that gear is scaled and the other gears are left at their current fishing mortality rates.

TABLA 5.3. Estimaciones del RMSP y sus cantidades asociadas para atún patudo, obtenidas suponiendo que no existe una relación población-reclutamiento (caso base), que cada pesquería mantiene su patrón actual de selectividad por edad (Figura 4.5), y que cada pesquería es la única que opera en el OPO. Se expresan RMSP, BRMSP, y SRMSP 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 años 2003 y 2004.

	All gears	**Purse-seine only**	**Longline only**	**Purse-seine scaled**	**Longline scaled**
	Todas las artes	**Cerco solamente**	**Palangre solamente**	**Cerco escalado**	**Palangre escalado**
AMSY—RMSP	106,722	62,116	159,174	145,593	104,371
B_{AMSY}—B_{RMSP}	326,329	247,230	335,377	495,020	171,896
S_{AMSY}—S_{RMSP}	541	436	415	852	177
B_{AMSY}/B_0—B_{RMSP}/B_0	0.30	0.23	0.31	0.46	0.16
S_{AMSY}/S_0—S_{RMSP}/S_0	0.22	0.18	0.17	0.35	0.07
F multiplier—Multiplicador de *F*	0.68	1.53	2.20	0.00	1.86

TABLE 5.4. Estimates of the AMSY and its associated quantities for bigeye tuna, obtained by assuming that there is a stock-recruitment relationship with a steepness of 0.75, 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 2003 and 2004. "only" means that only that gear is used and the fishing mortality for the other gears is set to zero. "scaled" means that only that gear is scaled and the other gears are left at their current fishing mortality rates.

TABLA 5.4. Estimaciones del RMSP y sus cantidades asociadas para atún patudo, obtenidas suponiendo que existe una relación población-reclutamiento, con una inclinación de 0.75, 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, BRMSP, y SRMSP 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 años 2003 y 2004.

	All gears	**Purse-seine only**	**Longline only**	**Purse-seine scaled**	**Longline scaled**
	Todas las artes	**Cerco solamente**	**Palangre solamente**	**Cerco escalado**	**Palangre escalado**
AMSY—RMSP	102,263	58,804	153,679	150,035	75,979
B_{AMSY}—B_{RMSP}	503,221	450,322	527,840	618,353	279,681
S_{AMSY}—S_{RMSP}	956	891	907	1,132	493
B_{AMSY}/B_0—B_{RMSP}/B_0	0.30	0.33	0.38	0.45	0.20
S_{AMSY}/S_0—S_{RMSP}/S_0	0.22	0.29	0.29	0.37	0.16
F multiplier—Multiplicador de *F*	0.51	1.01	1.31	0.00	0.44

TABLE 6.1. SBR from the projections under three different scenarios for future effort.

TABLA 6.1. SBR de las proyecciones con tres escenarios diferentes de esfuerzo futuro.

Year	**Base case**	**h = 0.75**	**No restrictions**	F_{AMSY}
Año	**Caso base**	**h = 0.75**	**Sin restricción**	F_{AMSY}
2006	0.20	0.19	0.16	0.20
2007	0.21	0.20	0.16	0.24
2008	0.22	0.20	0.15	0.28
2009	0.19	0.18	0.12	0.27
20010	0.16	0.15	0.10	0.25
2011	0.14	0.13	0.09	0.24

APPENDIX A: DIAGNOSTICS

ANEXO A: DIAGNOSTICOS

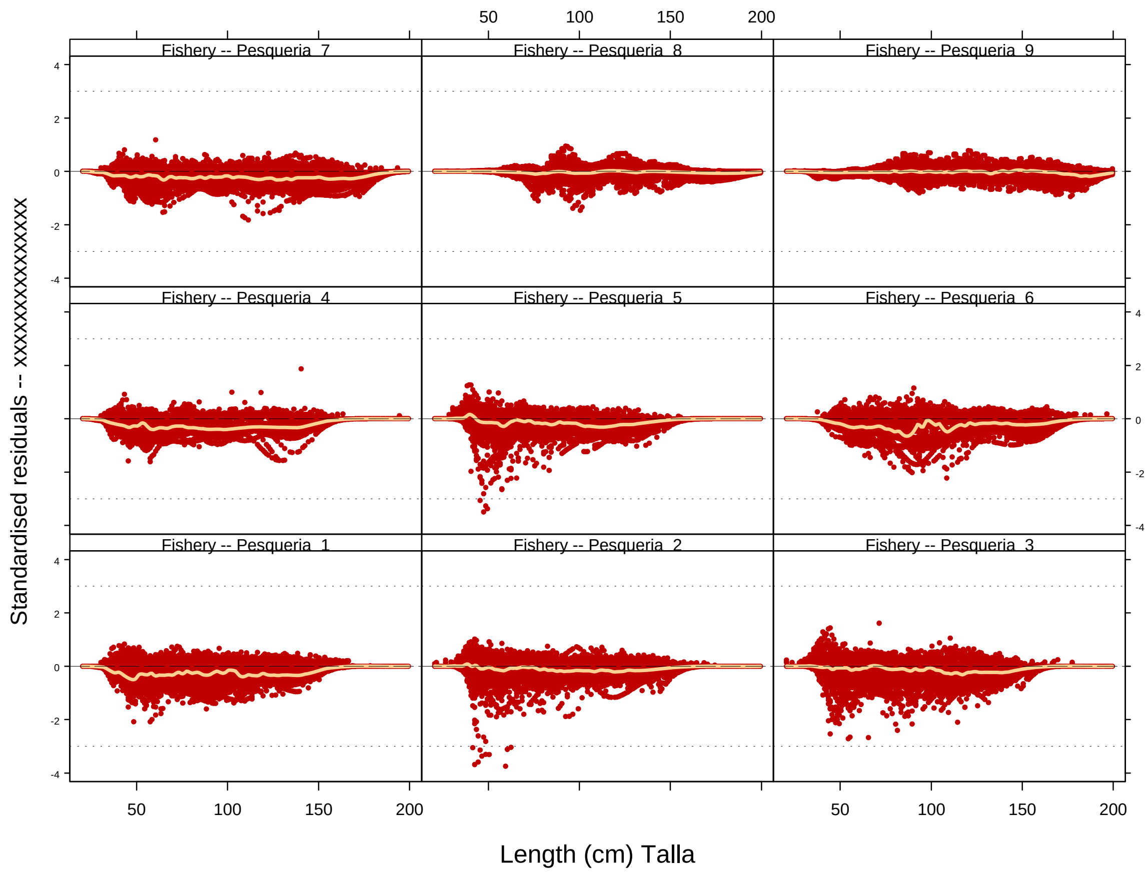


FIGURE A.1. Standardized residuals for the fit to the length-frequency data for bigeye tuna, by fishery and length class. The fitted line is a loess smoother. The dotted horizontal lines represent three standard deviations on either side of the mean.

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. Las líneas horizontales con puntos representan tres desviaciones a cada lado del promedio.

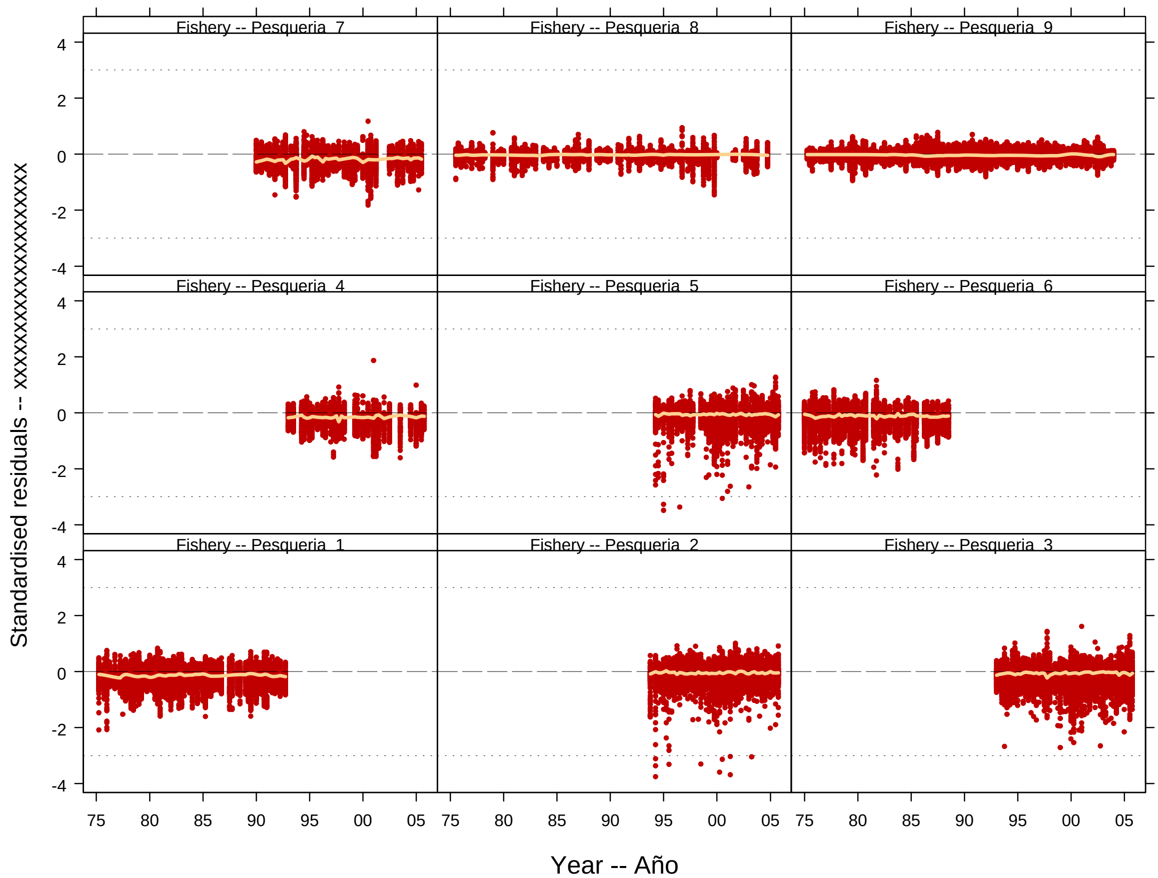


FIGURE A.2. Standardized residuals for the fit to the length-frequency data for bigeye tuna, by fishery and year. The fitted line is a loess smoother. The dotted horizontal lines represent three standard deviations on either side of the mean.

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. Las líneas horizontales con puntos representan tres desviaciones a cada lado del promedio.

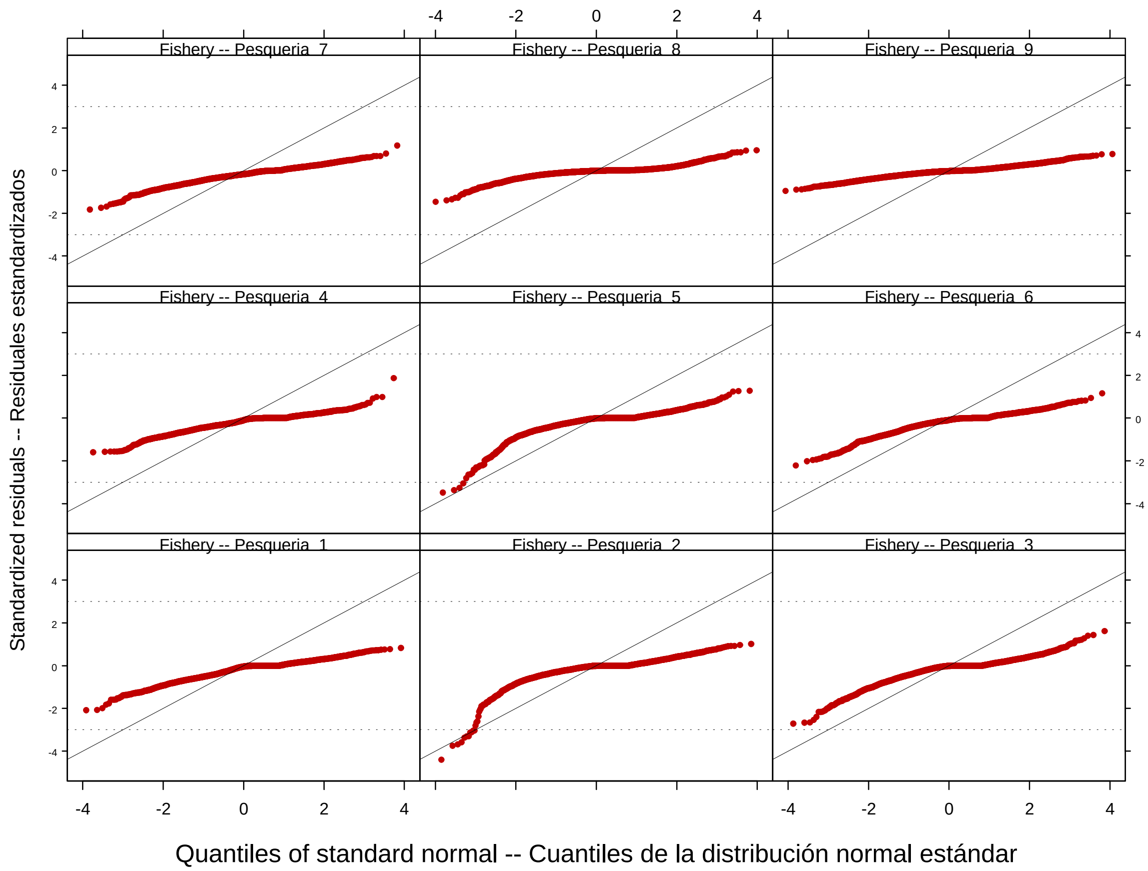


FIGURE A.3. Q-Q plot for the residuals of the fit to the length-frequency data for bigeye tuna, by fishery. The diagonal lines indicate the expectations for residuals following normal distributions. The dotted horizontal lines represent three standard deviations on either side of the mean.

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 horizontales con puntos representan tres desviaciones estándar a cada lado del promedio.

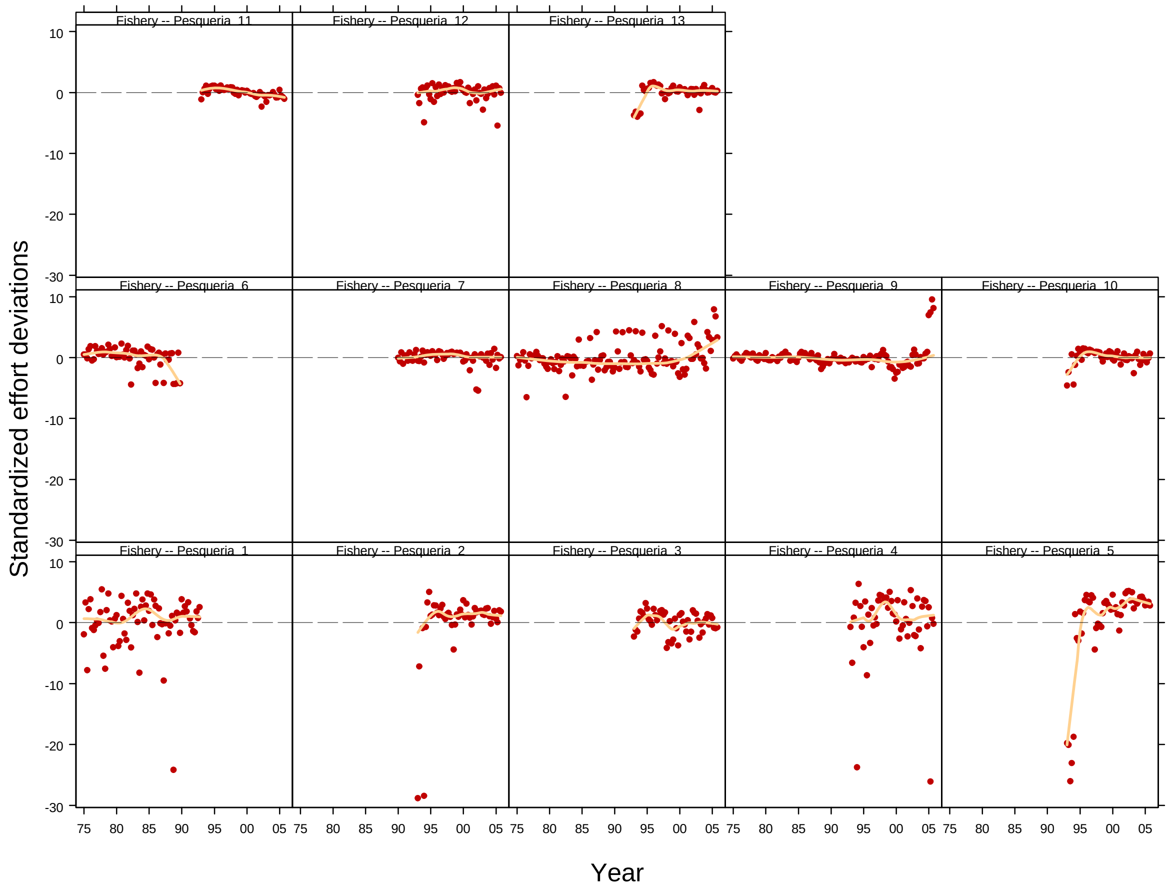


FIGURE A.4. Standardized effort deviates for bigeye tuna, by fishery and quarter. The fitted line is a loess smoother.
FIGURA A.4. Desvíos estandarizados del esfuerzo de atún patudo, por pesquería y trimestre. La línea ajustada es un suavizador loess.

8. APPENDICES

APPENDIX B: SENSITIVITY ANALYSIS FOR STEEPNESS

ANEXO B: ANÁLISIS DE SENSIBILIDAD A LA INCLINACIÓN

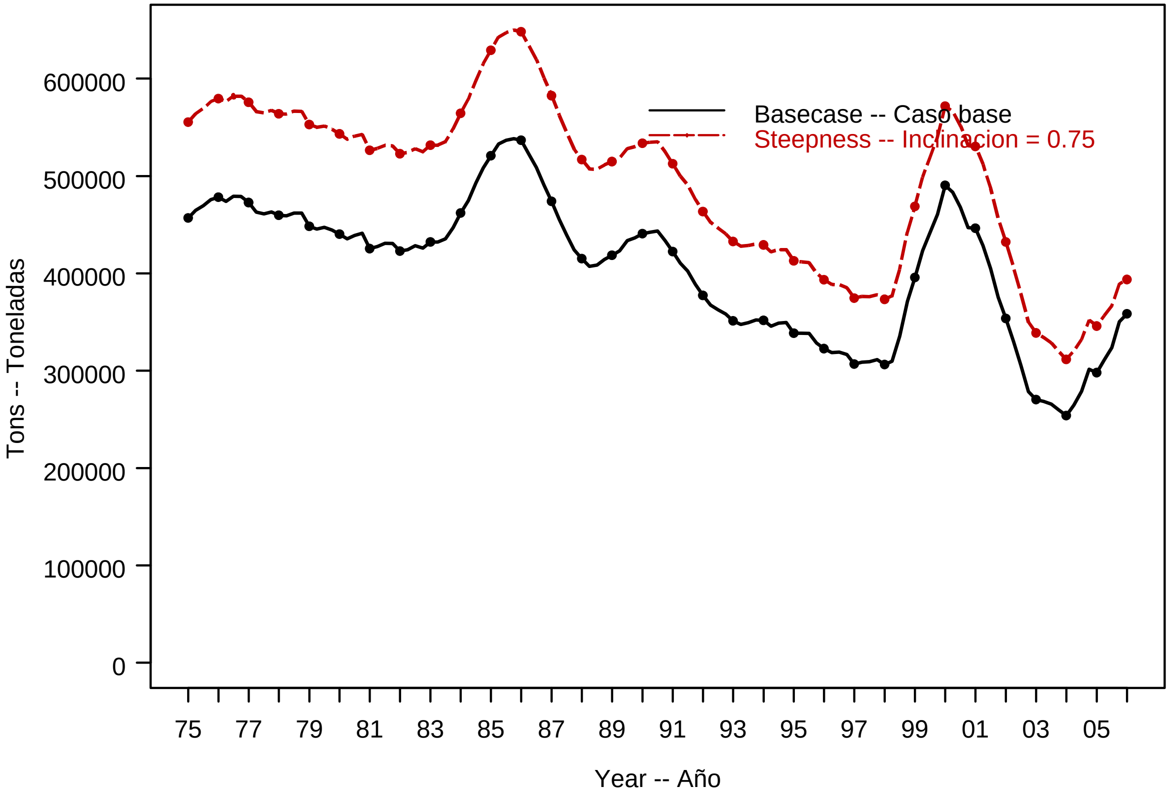


FIGURE B.1. Comparison of estimates of biomass of bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).
FIGURA B1. Comparación de las estimaciones de la biomasa del atún patudo del análisis sin (caso base) y con relación población-reclutamiento (inclinación = 0,75).

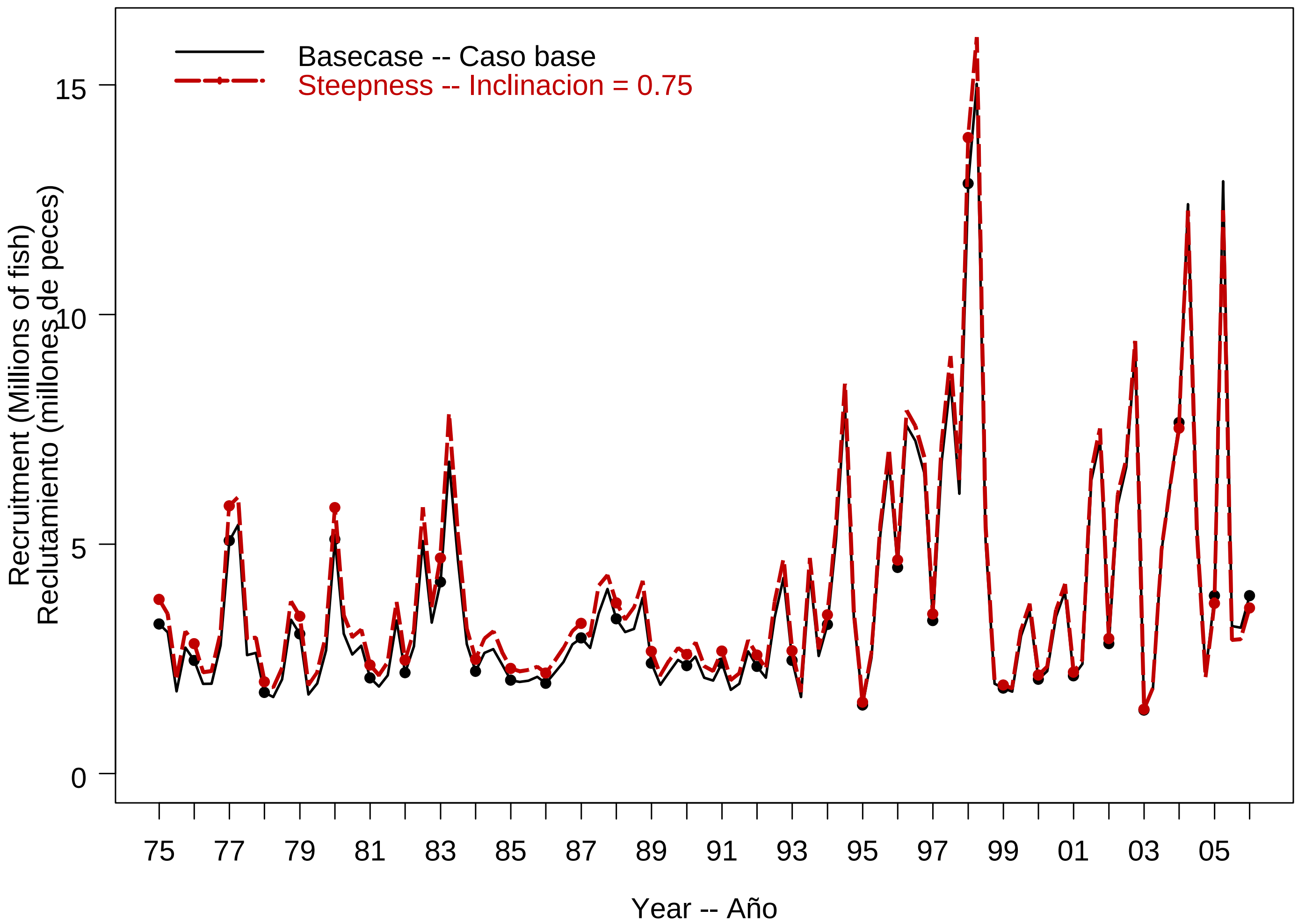


FIGURE B.2. Comparison of estimates of recruitment for bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).

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).

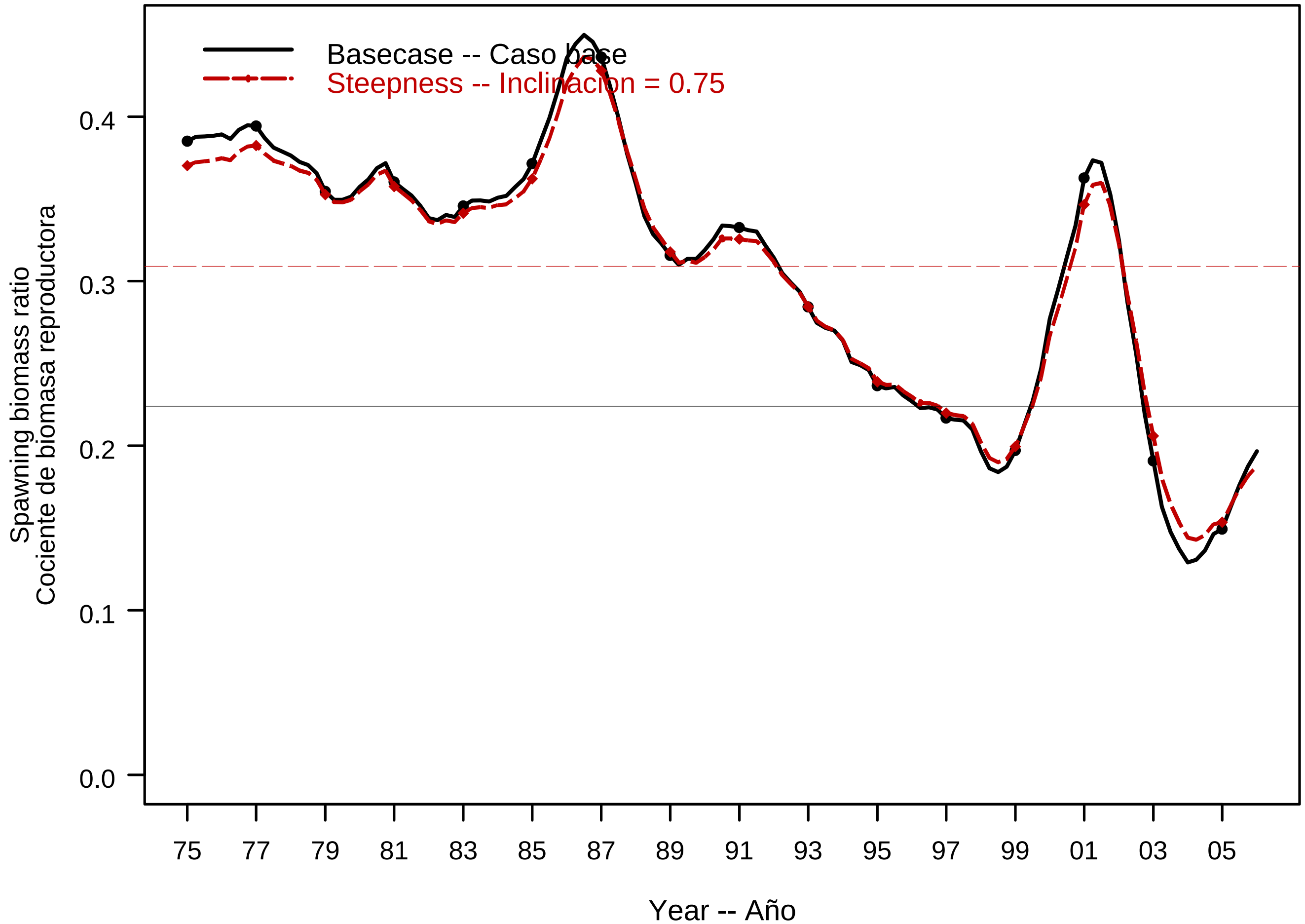


FIGURE B.3. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). The horizontal lines represent the SBRs associated with AMSY under the two scenarios.

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.

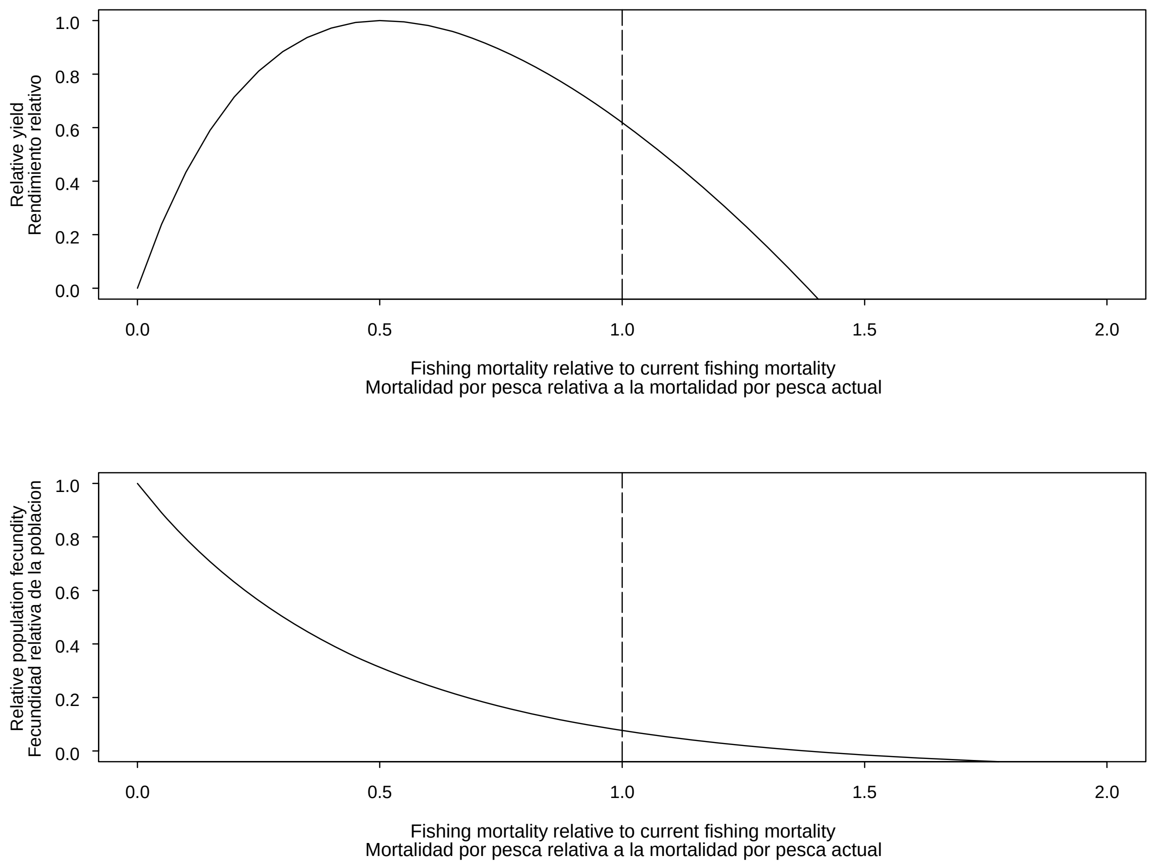


FIGURE B.4. Predicted effects of long-term changes in fishing effort on the yield (upper panel) and spawning biomass (lower panel) of bigeye tuna under equilibrium conditions with average fishing mortality patterns from 2003 and 2004 and a stock-recruitment relationship (steepness = 0.75). The yield 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 2003 y 2004 y un relación población-reclutamiento (inclinación = 0.75). 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.

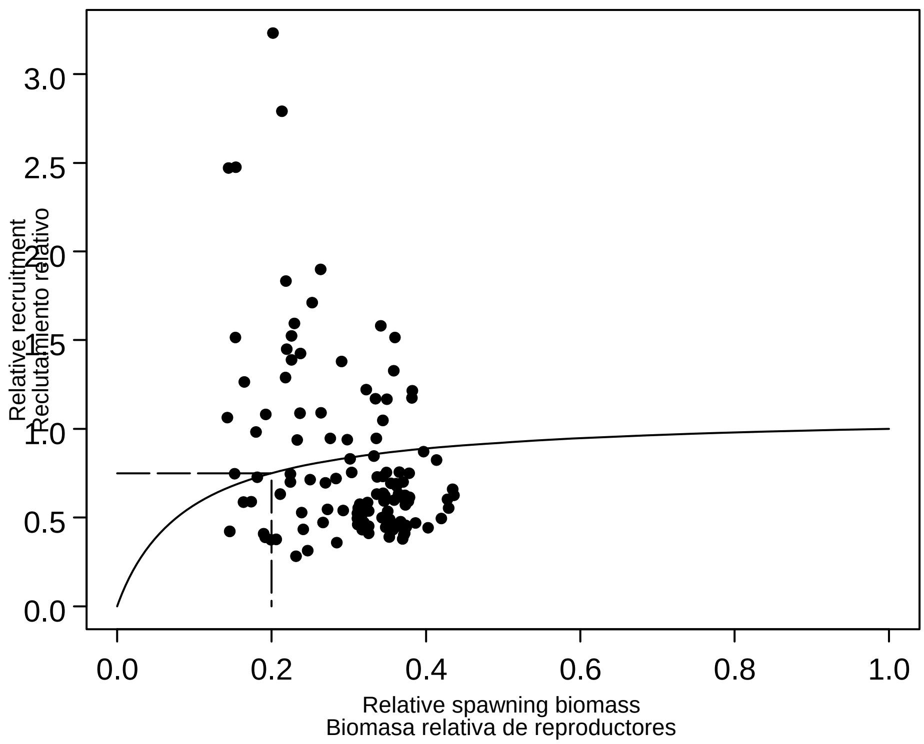


FIGURE B.5. Recruitment of bigeye tuna plotted against spawning biomass when the analysis has a stock-recruitment relationship (steepness = 0.75).
FIGURA B.5. Reclutamiento de atún patudo graficado contra biomasa reproductora cuando el análisis incluye una relación población-reclutamiento (inclinación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

APPENDIX C: SENSITIVITY ANALYSIS FOR LINF PARAMETER OF THE GROWTH CURVE
ANEXO C: ANÁLISIS DE SENSIBILIDAD A LA LINF

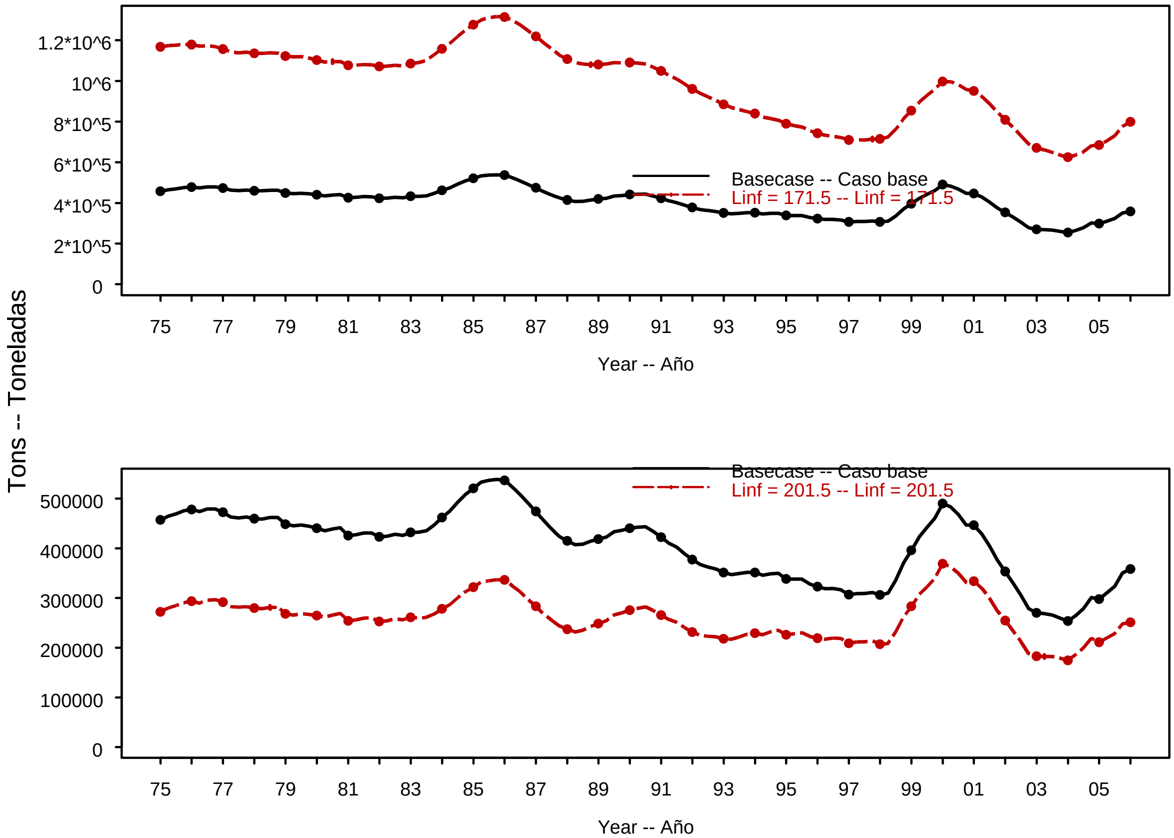
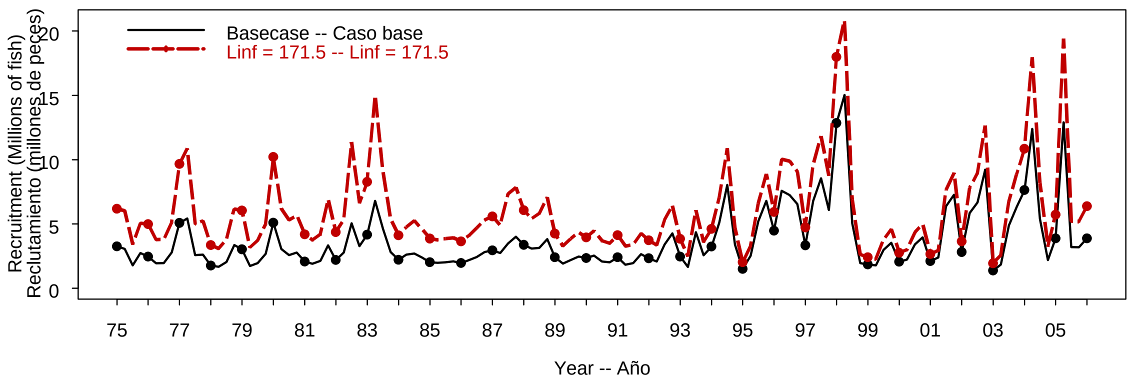


FIGURE C.1. Comparison of estimates of biomass of bigeye tuna from the analysis with Linf = 186.5 (base case) and with two alternatives (Linf = 171.5 and 201.5).



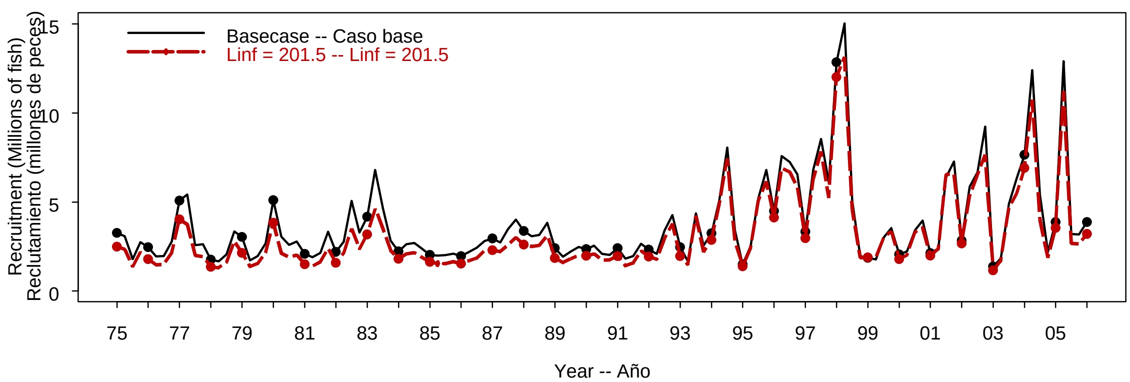


FIGURE C.2. Comparison of estimates of recruitment for bigeye tuna from the analysis with Linf = 186.5 (base case) and with two alternatives (Linf = 171.5 and 201.5).

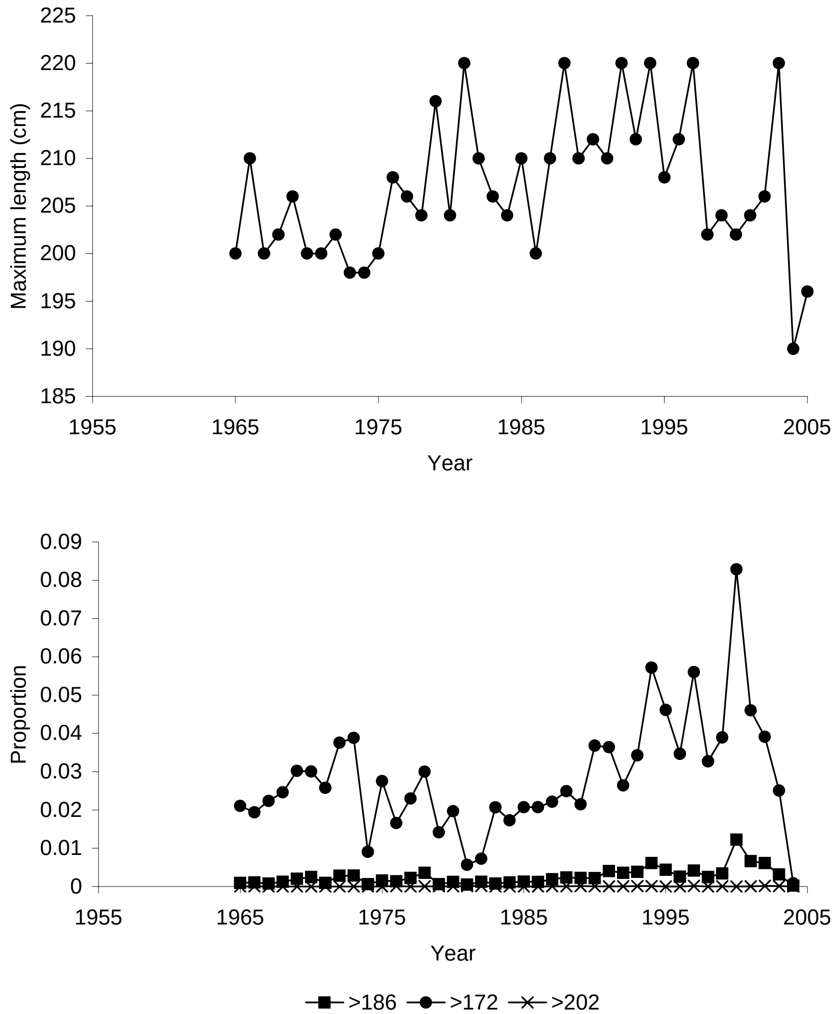


FIGURE C.3. Maximum length and proportion above a given size by year for the Japanese longline length-frequency data.

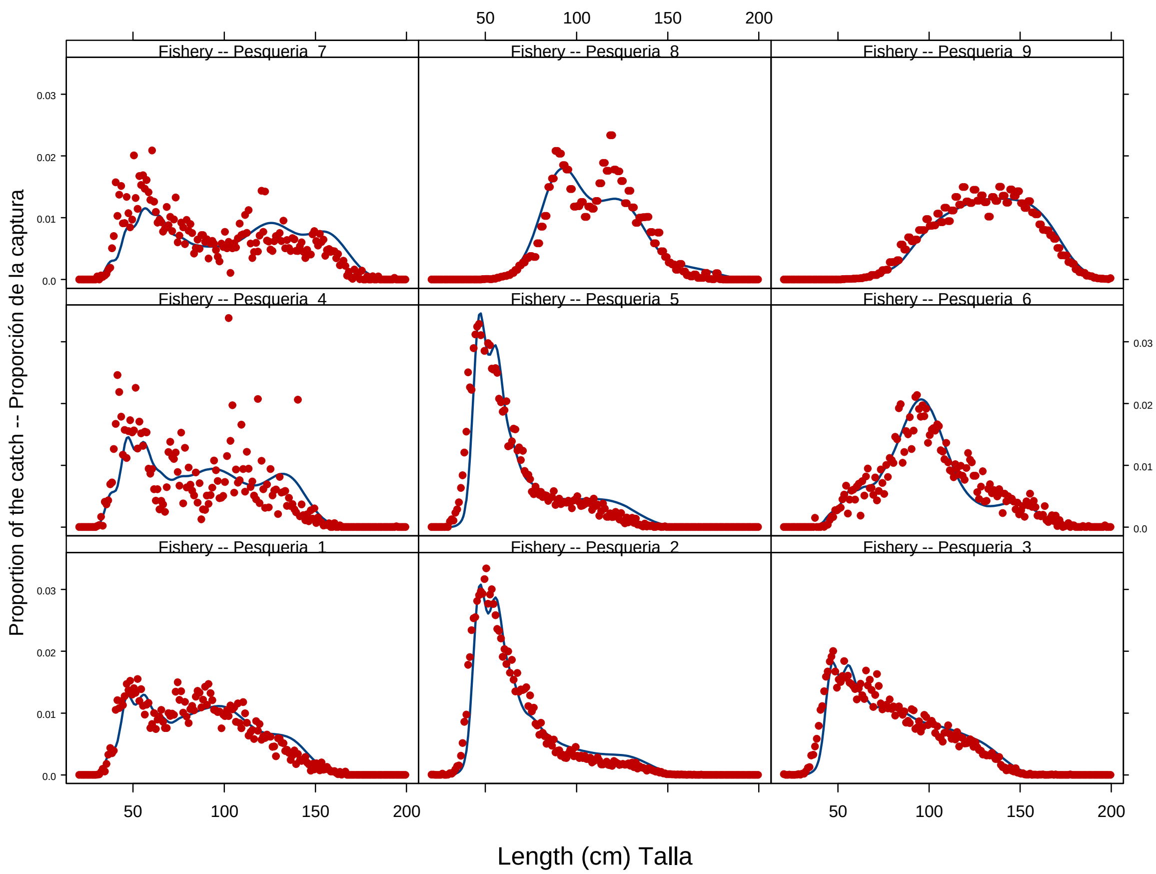


FIGURE C.4a. Average observed (dots) and predicted (curves) size compositions of the catches of bigeye tuna taken by the fisheries defined for the stock assessment of that species in the EPO with Linf = 171.5.

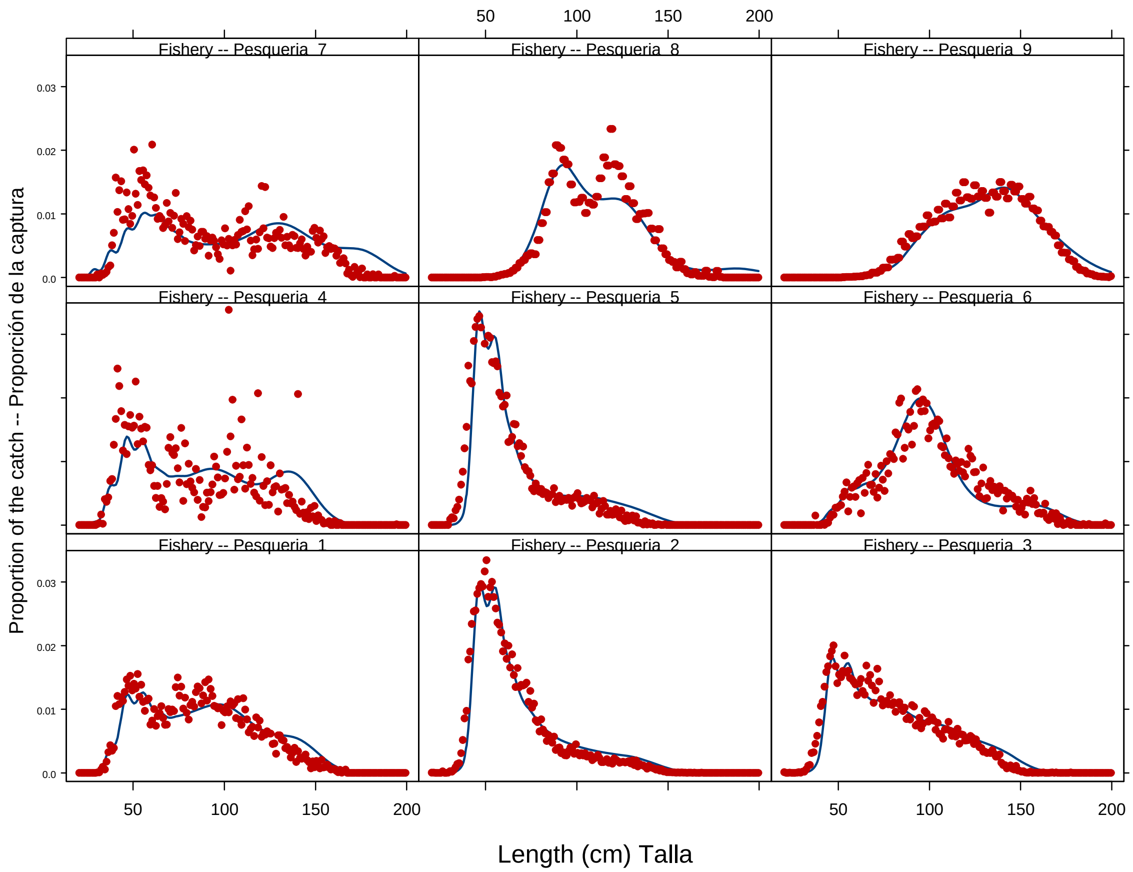


FIGURE C.4a. Average observed (dots) and predicted (curves) size compositions of the catches of bigeye tuna taken by the fisheries defined for the stock assessment of that species in the EPO with Linf = 201.5.

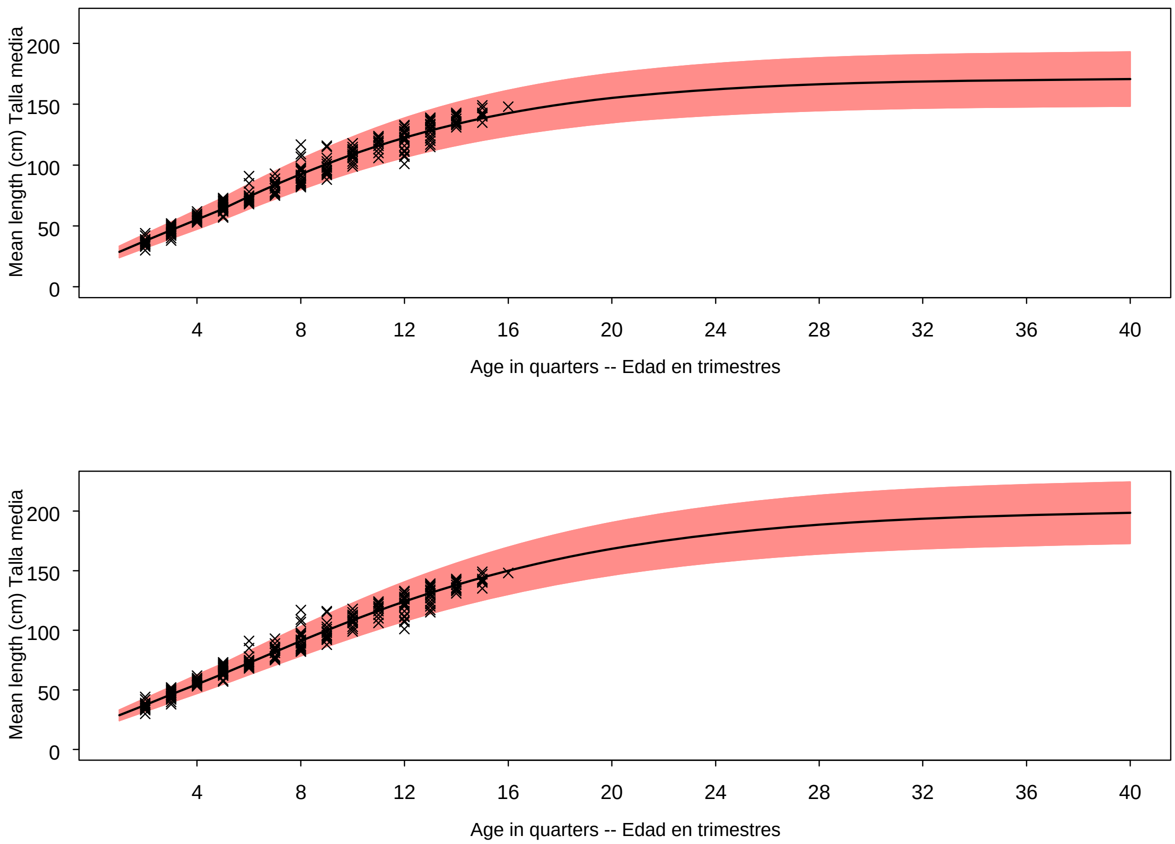
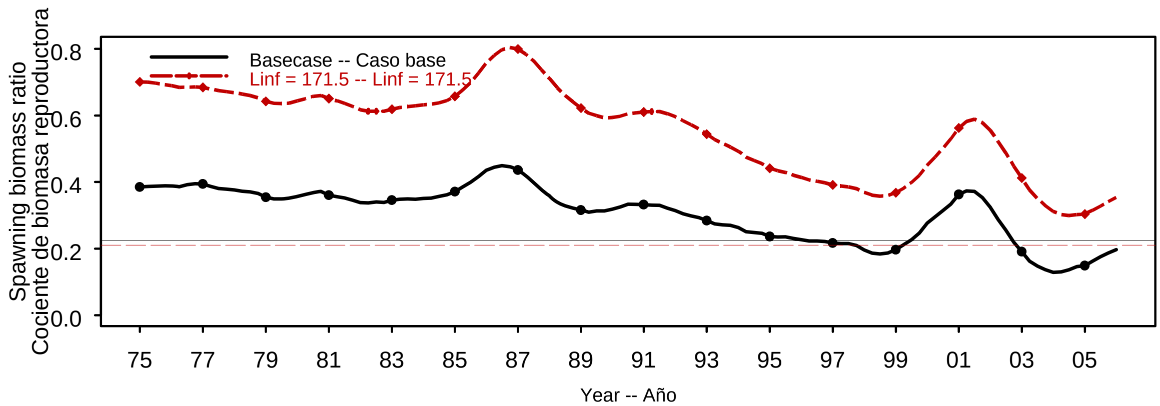


FIGURE C.5. Estimated average lengths at age for bigeye tuna in the EPO (solid line without circles) for two alternatives of Linf = 171.5 (top) and 201.5 (bottom). The crosses represent the otolith age-length data from Schaefer and Fuller (2006). The shaded area indicates the range of lengths estimated to be covered by two standard deviations of the length at age.



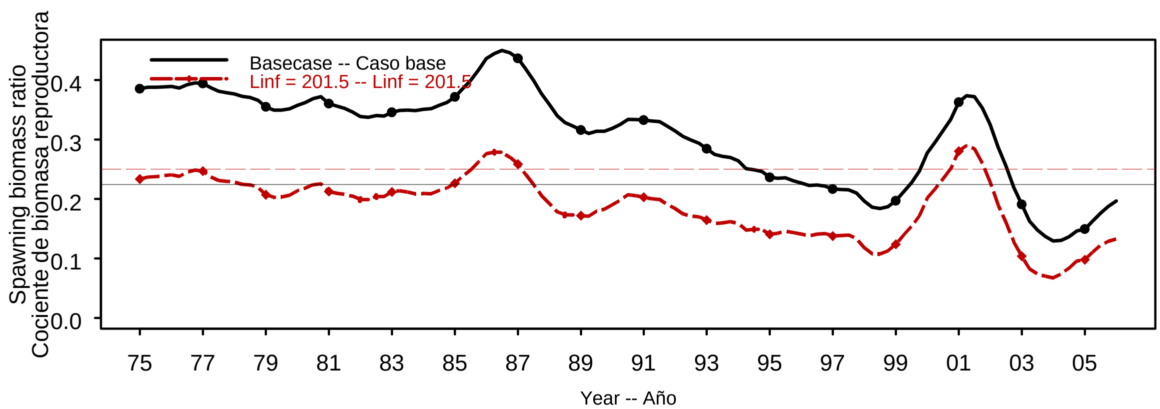


FIGURE C.6. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the analysis with Linf = 186.5 (base case) and with two alternatives (Linf = 171.5 and 201.5). The horizontal lines represent the SBRs associated with AMSY under the two scenarios.

TABLE C.1. Changes in negative log-likelihood from the analysis with Linf = 186.5 (base case) for the two alternatives (Linf = 171.5 and 201.5).

	Linf = 171.5	Ling = 201.5
Total	11.32	-14.03
Length-frequency	-13.19	0.34
Growth	27.33	-25.37
Selectivity	0.50	-0.75
Catch	-0.21	0.14
Effort	-0.10	4.43
Recruitment	-7.16	9.41

APPENDIX D: SENSITIVITY ANALYSIS FOR INCLUDING THE CHINESE TAIPEI LONGLINE LENGTH-FREQUENCY DATA

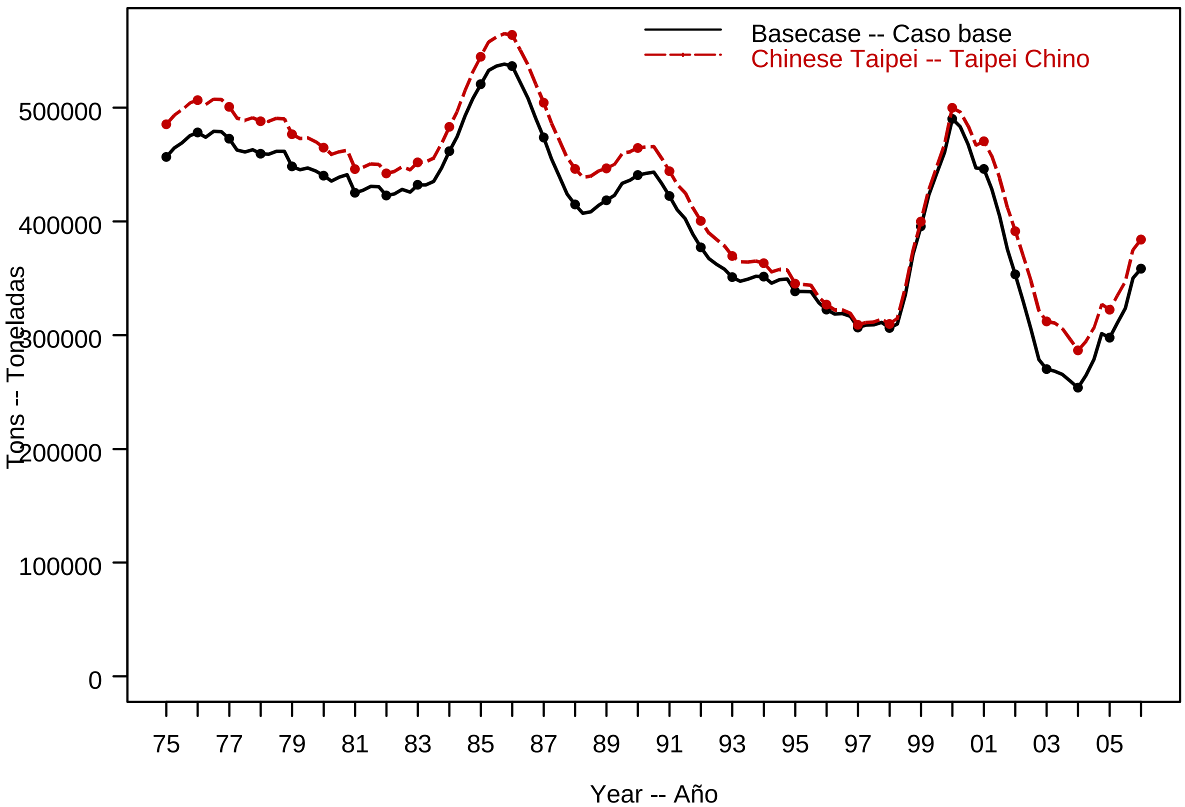


FIGURE D.1. Comparison of estimates of biomass of bigeye tuna from the base case analysis which groups the Chinese Taipei longline catch with the other longline catch to that with the Chinese Taipei longline data modeled as a separate fishery and fit to the Chinese Taipei length-frequency data.

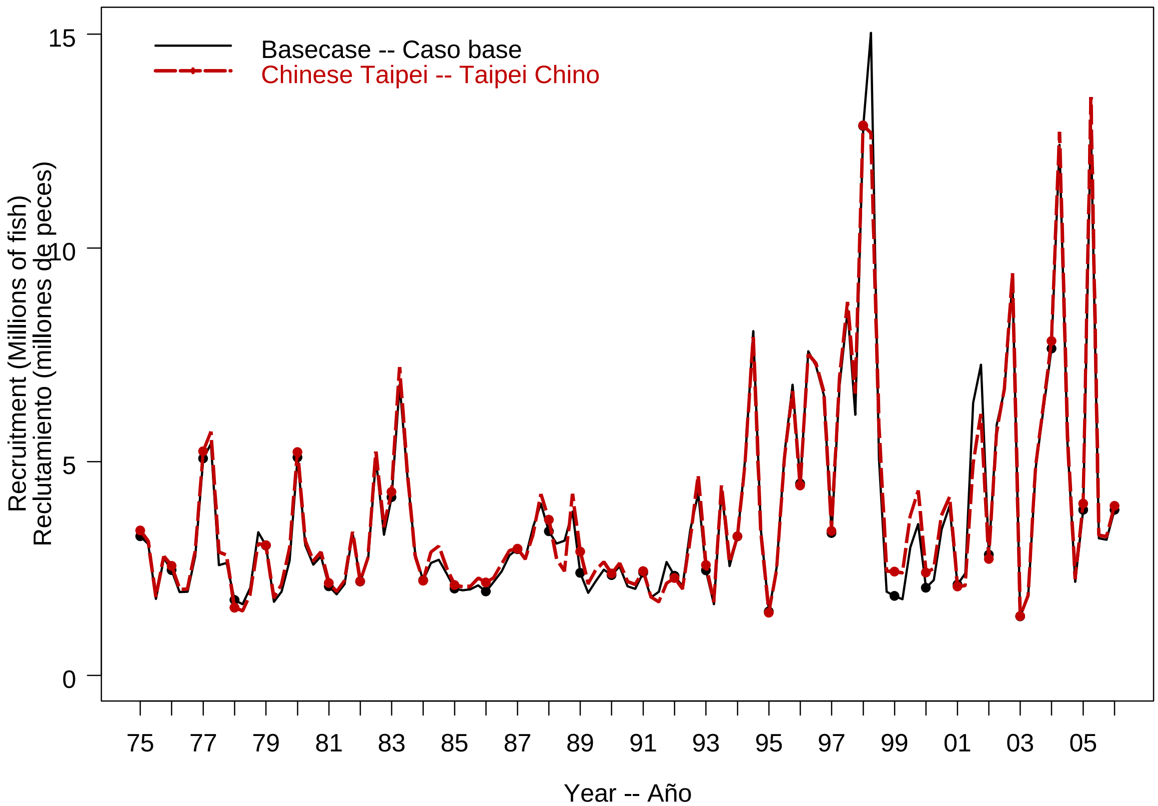


FIGURE D.2. Comparison of estimates of recruitment for bigeye tuna from the base case analysis which groups the Chinese Taipei longline catch with the other longline catch to that with the Chinese Taipei longline data modeled as a separate fishery and fit to the Chinese Taipei length-frequency data.

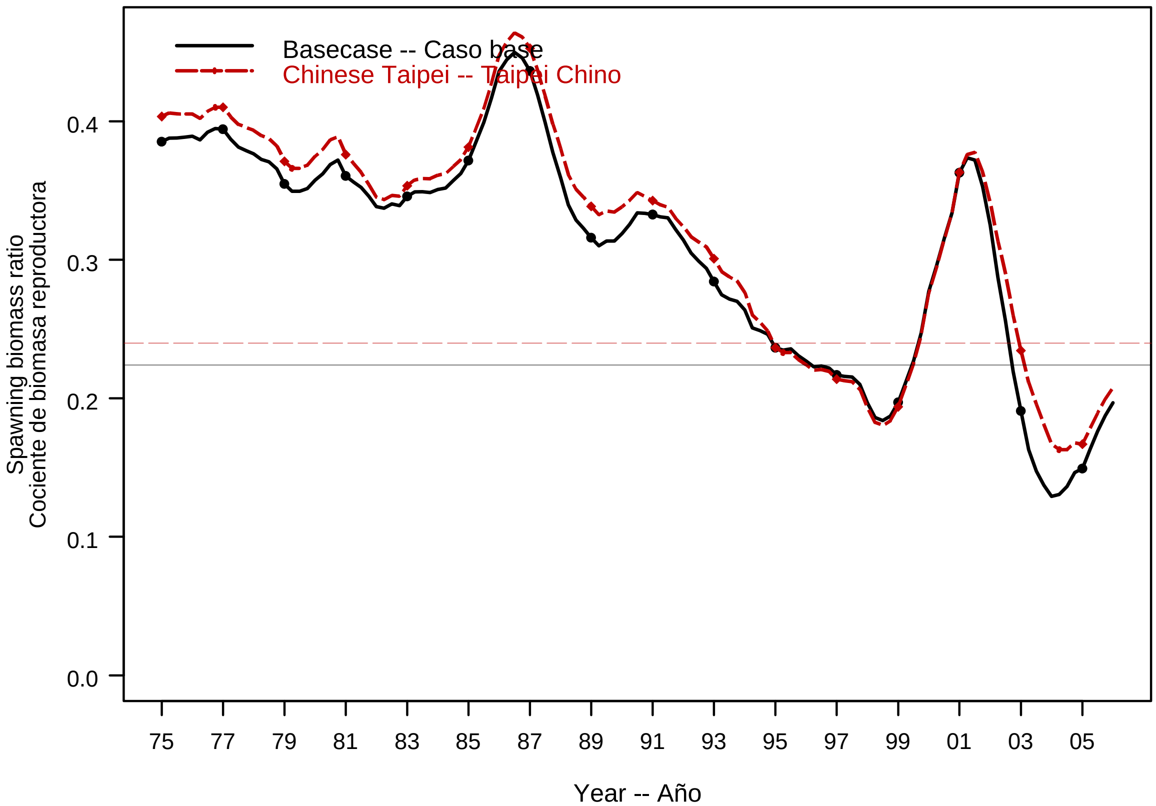


FIGURE D.3. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the base case analysis which groups the Chinese Taipei longline catch with the other longline catch to that with the Chinese Taipei longline data modeled as a separate fishery and fit to the Chinese Taipei length-frequency data.

The horizontal lines represent the SBRs associated with AMSY under the two scenarios.

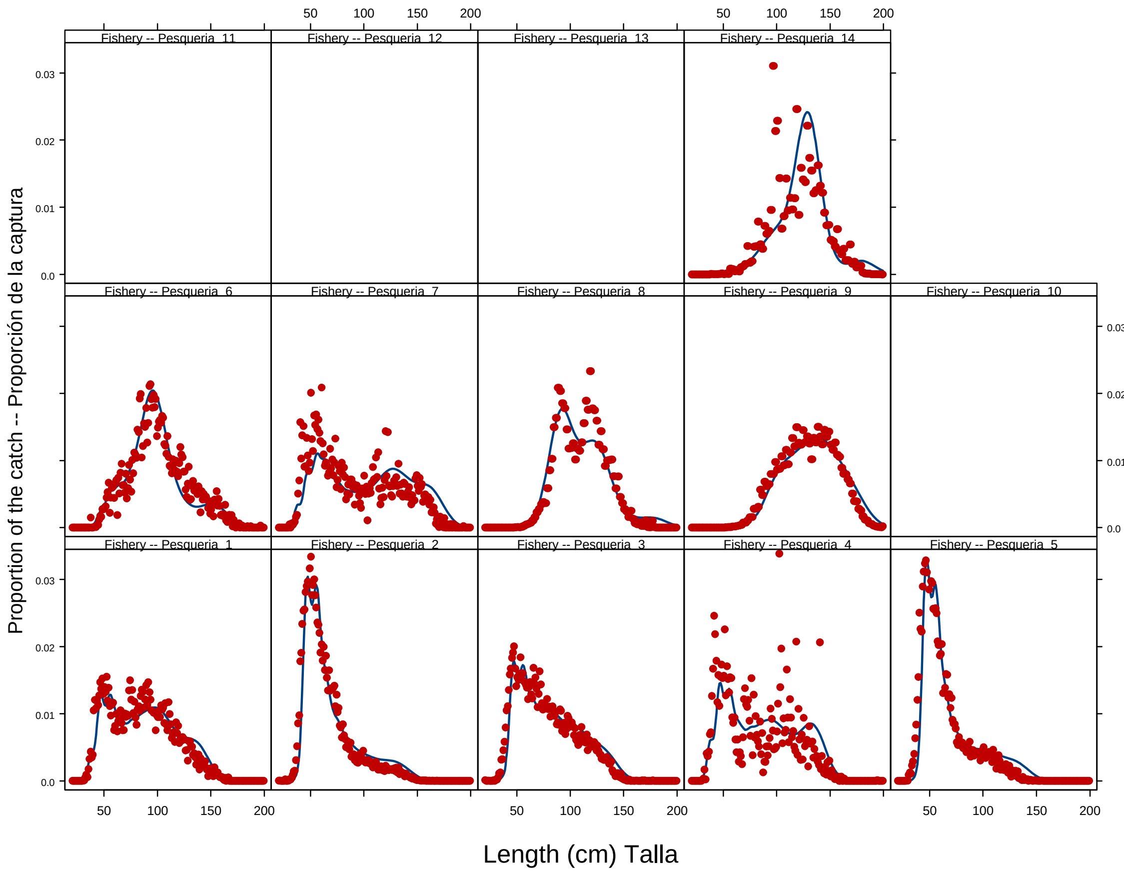


FIGURE D.4. Average observed (dots) and predicted (curves) size compositions of the catches of bigeye tuna taken by the fisheries defined for the stock assessment of that species in the EPO in the analysis for which the Chinese Taipei longline data modeled as a separate fishery (Fishery 14) and fit to the Chinese Taipei length-frequency data.

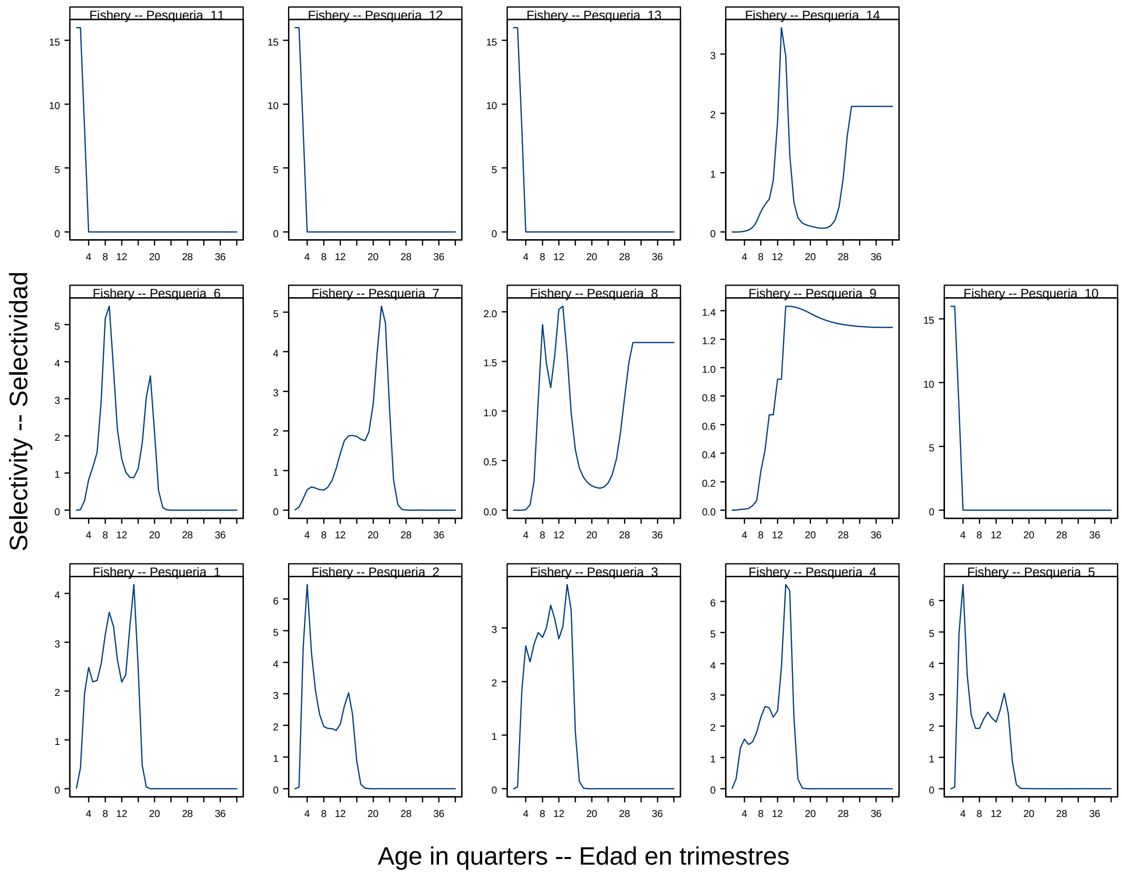


FIGURE D.5. Selectivity curves for the 14 fisheries that take bigeye tuna in the EPO in the analysis for which the Chinese Taipei longline data modeled as a separate fishery and fit to the Chinese Taipei length-frequency data. The selectivity curves for Fisheries 1 through 9 and the Chinese Taipei longline fishery (Fishery 14) were estimated with the A-SCALA method, and those for Fisheries 10-13 are based on assumptions.

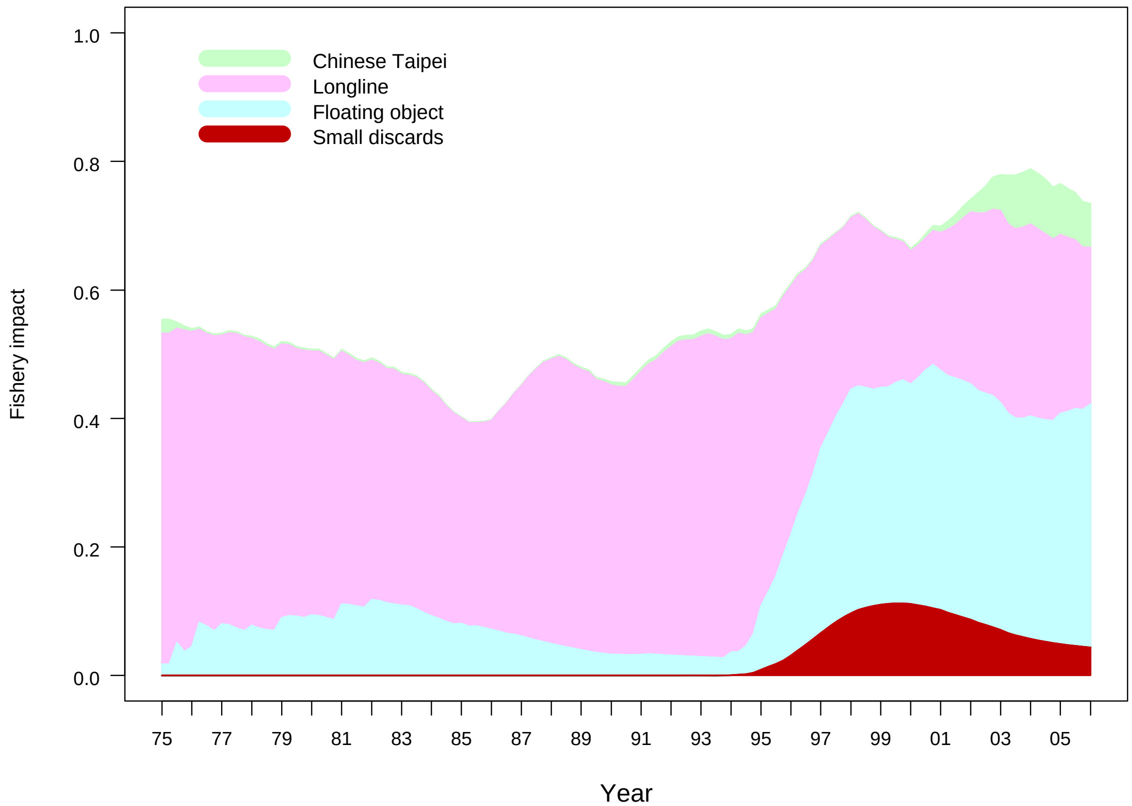


FIGURE D.6. Fishery impacts for the fisheries that take bigeye tuna in the EPO in the analysis for which the Chinese Taipei longline data modeled as a separate fishery and fit to the Chinese Taipei length-frequency data.

APPENDIX E: SENSITIVITY ANALYSIS INCLUDING A RELATIONSHIP BETWEEN RECRUITMENT AND THE EL NINO INDEX

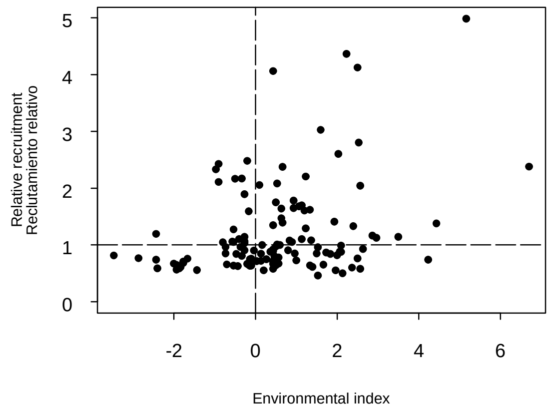


FIGURE E.1. Estimated relationship between the recruitment of bigeye tuna and the el Nino ndex. The recruitment is scaled so that the estimate of virgin recruitment is equal to 1.0. Likewise, the el Nino index is scaled so that the estimate of virgin spawning biomass is equal to 1.0.

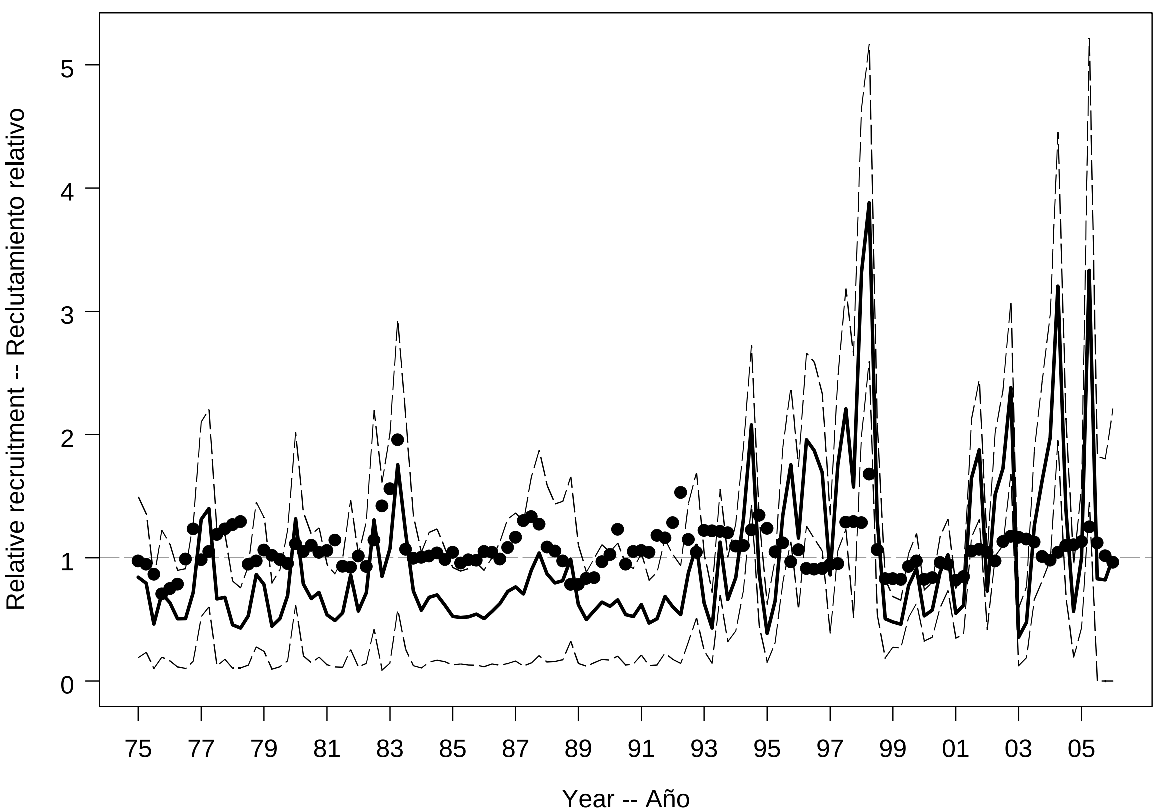


FIGURE E.2. Estimated recruitment of bigeye tuna to the fisheries of the EPO. The estimates are scaled so that the estimate of virgin recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the thin dashed lines the confidence intervals (±2 standard deviations) around those estimates. The 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. The circles represents the component of recruitment predicted by the el Nino index.

APPENDIX F: 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 F: 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.

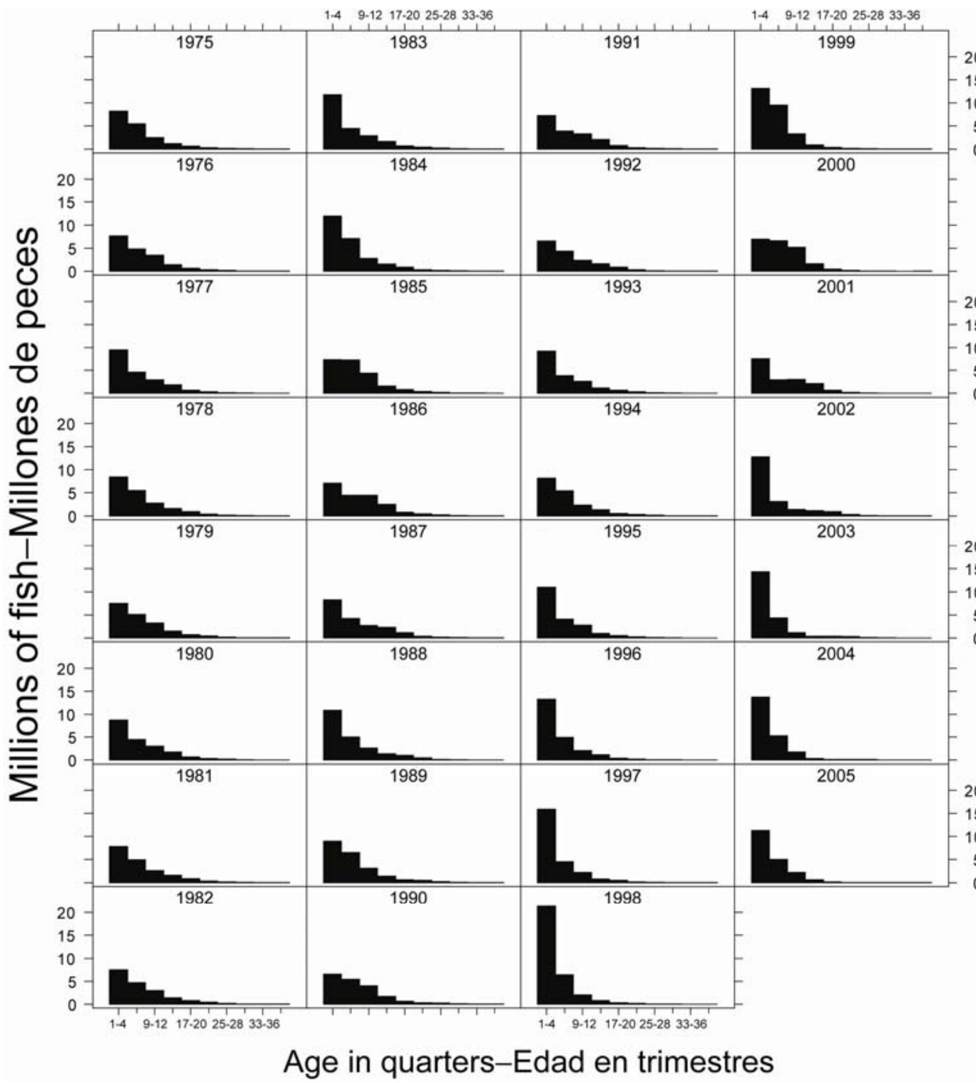


FIGURE F.1. Estimated numbers of bigeye tuna present in the EPO on 1 January of each year.
FIGURA F.1. Número estimado de atunes patudo presentes en el OPO el 1 de enero de cada año.

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

Year	Age—Edad									
Año	1-4	5-8	9-12	13-16	17-20	21-24	25-28	29-32	33-36	37+
1975	0.01	0.07	0.15	0.20	0.18	0.17	0.18	0.18	0.18	0.18
1976	0.02	0.08	0.19	0.25	0.22	0.20	0.20	0.20	0.20	0.20
1977	0.02	0.10	0.21	0.31	0.29	0.27	0.27	0.28	0.28	0.28
1978	0.03	0.11	0.22	0.30	0.27	0.26	0.26	0.27	0.27	0.27
1979	0.01	0.10	0.20	0.28	0.26	0.24	0.24	0.25	0.25	0.25
1980	0.02	0.12	0.21	0.28	0.26	0.24	0.24	0.24	0.24	0.24
1981	0.02	0.09	0.18	0.26	0.24	0.22	0.22	0.22	0.22	0.22
1982	0.01	0.08	0.18	0.25	0.22	0.21	0.21	0.23	0.23	0.23
1983	0.01	0.08	0.20	0.28	0.25	0.24	0.24	0.25	0.25	0.25
1984	0.02	0.07	0.16	0.22	0.19	0.18	0.18	0.20	0.20	0.20
1985	0.01	0.08	0.17	0.24	0.22	0.21	0.21	0.21	0.21	0.21
1986	0.01	0.09	0.25	0.34	0.32	0.31	0.31	0.32	0.32	0.32
1987	0.01	0.08	0.25	0.36	0.35	0.33	0.33	0.34	0.34	0.34
1988	0.01	0.07	0.20	0.29	0.28	0.27	0.27	0.28	0.28	0.28
1989	0.01	0.07	0.20	0.28	0.26	0.25	0.25	0.27	0.27	0.27
1990	0.01	0.10	0.26	0.36	0.34	0.32	0.31	0.32	0.32	0.32
1991	0.01	0.10	0.30	0.42	0.40	0.39	0.38	0.38	0.38	0.38
1992	0.01	0.10	0.27	0.38	0.38	0.35	0.34	0.35	0.35	0.35
1993	0.03	0.09	0.26	0.36	0.36	0.34	0.33	0.33	0.33	0.33
1994	0.16	0.23	0.41	0.45	0.39	0.38	0.36	0.37	0.37	0.36
1995	0.32	0.28	0.44	0.46	0.34	0.34	0.29	0.30	0.30	0.30
1996	0.53	0.39	0.53	0.48	0.29	0.29	0.26	0.26	0.26	0.26
1997	0.41	0.39	0.57	0.50	0.28	0.27	0.26	0.26	0.26	0.26
1998	0.28	0.26	0.39	0.45	0.35	0.36	0.30	0.30	0.30	0.30
1999	0.25	0.22	0.32	0.31	0.18	0.19	0.15	0.15	0.15	0.15
2000	0.37	0.40	0.49	0.41	0.18	0.17	0.17	0.17	0.17	0.17
2001	0.37	0.33	0.51	0.46	0.30	0.29	0.28	0.28	0.28	0.28
2002	0.58	0.58	0.80	0.63	0.47	0.45	0.44	0.45	0.45	0.45
2003	0.48	0.44	0.69	0.69	0.50	0.49	0.48	0.49	0.49	0.49
2004	0.42	0.42	0.60	0.51	0.36	0.32	0.29	0.29	0.29	0.29

TABLE F.2. Number of days fished in the four floating object fisheries that operated since 1993 by quarter and totals for each year.

Year	Quarter	Fishery 2	Fishery 3	Fishery 4	Fishery 5	Total
1993	1	413	49	1439	30	1931
	2	67	98	1243	33	1440
	3	0	150	764	364	1279
	4	102	940	266	107	1415
1993 Total		581	1237	3712	534	6065
1994	1	336	76	1043	19	1474
	2	486	207	632	97	1421
	3	140	1200	1072	243	2655
	4	37	1549	782	128	2496
1994 Total		999	3031	3529	487	8046
1995	1	733	419	895	230	2277
	2	1021	305	500	212	2039
	3	666	1433	888	532	3519
	4	386	1203	492	822	2904
1995 Total		2806	3361	2775	1796	10738
1996	1	1035	741	1201	251	3228
	2	1145	558	528	327	2559
	3	1118	1410	1316	494	4338
	4	790	1388	936	756	3869
1996 Total		4087	4097	3980	1828	13993
1997	1	1063	936	831	197	3027
	2	1288	1143	1240	354	4026
	3	866	1505	1271	861	4502
	4	715	2461	1300	392	4868
1997 Total		3932	6046	4642	1803	16423
1998	1	1894	635	1294	292	4114
	2	1830	686	1211	473	4201
	3	1876	633	599	1737	4846
	4	492	962	682	1344	3480
1998 Total		6092	2916	3786	3847	16641
1999	1	322	837	866	486	2512
	2	264	1710	1152	532	3658
	3	173	1980	582	984	3719
	4	163	418	196	493	1269
1999 Total		922	4945	2796	2495	11158
2000	1	401	1498	655	452	3005
	2	575	2208	991	314	4088
	3	640	1591	2122	1189	5543
	4	191	600	862	393	2046
2000 Total		1806	5897	4630	2348	14682
2001	1	1343	996	1596	337	4272
	2	1517	1332	1166	461	4475
	3	1064	1845	1991	1236	6136
	4	993	1855	1260	980	5088
2001 Total		4917	6028	6012	3014	19971
2002	1	1874	654	1692	100	4319

	2	1617	732	651	453	3453
	3	853	1617	1219	863	4553
	4	435	1390	780	484	3088
2002 Total		4779	4393	4341	1900	15413
2003	1	1061	362	1128	309	2861
	2	1094	542	962	772	3370
	3	622	2339	1361	1303	5624
	4	1104	2675	808	675	5261
2003 Total		3880	5918	4260	3059	17117
2004	1	1463	408	1124	270	3265
	2	1397	279	377	730	2783
	3	596	1053	421	979	3050
	4	854	2423	427	657	4360
2004 Total		4310	4164	2348	2636	13458
2005	1	1143	778	1376	517	3814
	2	1142	1458	1693	1264	5556
	3	495	1415	1319	1082	4311
	4	1048	2381	1224	900	5553
2005 Total		3828	6032	5611	3763	19234

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