STATUS OF BIGEYE TUNA IN THE EASTERN PACIFIC OCEAN IN 2002 AND OUTLOOK FOR 2003

by

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1. EXECUTIVE SUMMARY

This document presents the most current stock assessment of bigeye tuna (*Thunnus obesus*) in the eastern Pacific Ocean (EPO). A-SCALA, an age-structured, catch-at-length analysis, was used to conduct this assessment. Previous assessments of bigeye in the EPO were also conducted using the A-SCALA method. The version of A-SCALA is the similar to that used for the previous assessment with modifications to one of the assumptions. A-SCALA now allows missing values in environmental indices thought to be related to recruitment. There are a number of other changes between this assessment and the previous assessment carried out for 2001:

1. The model is extended back to 1975 as was done by Watters and Maunder (2001). Catch, effort, and length frequency data for the period 1975 – 1980 are now included.
2. Revised inputs for maturity, fecundity, age-specific proportions of females in the population, and age-specific natural mortality vectors are included based on recent biological studies and re-analysis of earlier data.
3. Catch, effort, and length-frequency data for the surface fisheries have been updated to include new data for 2002 and revised data for 2000 and 2001.
4. Catch and length frequency data for the Japanese longline fisheries have been updated to include new data for 2001 and updated data for 1998 and 2000.
5. Catch data for the Taiwan longline fisheries have been updated for 1998 and new data added for 1999.
6. New discard data for 2002 are included and previous data for 2000 and 2001 were updated.
7. Longline effort data are based on neural-network-standardization of CPUE.
8. The smoothness penalties for selectivity were chosen using cross-validation.
9. Iterative re-weighting was used to determine the sample size for catch-at-length data in a sensitivity analysis.
10. The years used to average catchability for the projections and management quantities were calculated using retrospective analysis.
11. Diagnostics including residual plots, correlation plots, and retrospective analysis were carried out.

A mid-year technical meeting on diagnostics was held in La Jolla, October 2-4. The outcome from this meeting was 1) a set of diagnostics that should be evaluated regularly, 2) a set of diagnostics that should be evaluated periodically, and 3) a list of specific research questions. Several of the recommendations have been included in this assessment.

Five sensitivity analyses were carried out this year to assess sensitivity to model assumptions and data:

1. Sensitivity to the steepness of the stock-recruitment relationship. The base case included an assumption that recruitment was independent of stock size and a Beverton-Holt stock-recruitment relationship with steepness of 0.75 was used for the sensitivity analysis.
2. Sensitivity to estimates of purse seine catches. In the basecase, estimates of purse seine catches were based on species composition estimates for 2000 – 2002 and scaled estimates back to 1993. For sensitivity we compared this to cannery and unloading estimates of bigeye catches in the purse fisheries as used by Maunder and Harley (2002).
3. Sensitivity to estimates of Korean longline catch. In addition to the data held by the IATTC, which is used in the basecase analysis, a sensitivity analysis was conducted with the greater estimates of Korean longline catch estimated by the Secretariat for the Pacific Community (SPC).
4. Sensitivity to assumed CPUE for the longline fisheries. In the basecase longline CPUE was standardized using a neural network chosen for its improved performance in cross-validation trials. For sensitivity we used the same habitat standardized longline CPUE used by Maunder and Harley (2002).
5. Sensitivity to the sample sizes assumed for the length frequency samples. An iterative reweighting procedure was used to determine the effective sample size in the sensitivity analysis.

Two alternative scenarios were considered to assess the sensitivity of yield estimates and reference points to the period assumed to represent current (and future) fishing mortality and catchability. In the basecase, we used estimates of fishing mortality and catchability (plus effort deviates) for 2000 and 2001 in projections and yield calculations. For sensitivity we compared:

1. Using estimates of fishing mortality and catchability for 1999 and 2000. These estimates are more certain than recent estimates but may be biased if there have been trends in fishing mortality and catchability in recent years.
2. Using estimates of fishing mortality and catchability for 2001 and 2002. These estimates are the most uncertain and correlated with recent estimates of recruitment. This assumption is similar to sensitivity analysis presented by Maunder and Harley (2002).

There have been important changes in the amount of fishing mortality caused by the fisheries that catch bigeye tuna in the EPO. On average, the fishing mortality on bigeye less than about 20 quarters old has increased substantially since 1993, and that on fish more than about 24 quarters old has decreased 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. The basecase assessment suggests that (1) the use of FADs has substantially increased the catchability of bigeye by fisheries that catch tunas associated with floating objects, and (2) that bigeye are substantially more catchable when they are associated with floating objects in offshore areas.

Recruitment of bigeye tuna to the fisheries in the EPO is variable, and the mechanisms that explain variation in recruitment have not been identified. Nevertheless, the abundance of bigeye tuna being recruited to the fisheries in the EPO appears to be related to zonal-velocity anomalies at 240 m during the time that these fish were assumed to have hatched. Over the range of spawning biomasses estimated by the basecase assessment, the abundance of bigeye recruits appears to be unrelated to the spawning potential of adult females at the time of hatching.

There are two important features in the estimated time series of bigeye. First, greater-than-average recruitments occurred in 1977, 1979, 1982-1983, 1992, 1994, and 1995-1997. However, that the lower confidence bounds of these estimates were only greater than the estimate of virgin recruitment for 1994 and 1997, so it is uncertain whether these recruitments were, in fact, greater than the virgin recruitment. An above average cohort is estimated for the first quarter of 2001 but this estimate is uncertain. Second, recruitment has been much lower than average for most of the recent period from the second quarter of 1998 to the end of 2000, and the upper confidence bounds of many of these recruitment estimates are below the virgin recruitment. Evidence for these low recruitments comes from the decreased CPUEs achieved by some of the floating-object and discard fisheries, the length frequency data, and by poor environmental conditions for recruitment. The extended sequence of low recruitments is important because it is likely to produce a sequence of years in which the spawning biomass ratio will be below the level that would support the average maximum sustainable yield (AMSY).

The biomass of 1+-year-old bigeye increased during 1980-1984, and reached its peak level of about 530,000 mt in 1986. After reaching this peak, the biomass of 1+-year-olds decreased to an historic low of about 185,000 mt at the start of 2003. Spawning biomass has generally followed a trend similar to that for the biomass of 1+-year-olds but lagged by 1-2 years. There is uncertainty in the estimated biomasses of both 1+-year-old bigeye and of spawners. Nevertheless, it is apparent that fishing has reduced the total biomass of bigeye present in the EPO both are predicted to be at their lowest levels by the end of 2003. There has been an accelerated decline in biomass since the small peak in 2000.

The estimates of recruitment and biomass are sensitive both to the way in which the assessment model is parameterized and to the data that are included in the assessment. Including the SPC-estimated Korean longline catch increased estimates of biomass and recruitment. However, including a stock-recruitment relationship did not change the estimates of biomass or recruitment. The re-weighting of the length frequency sample sizes produced the greatest differences in biomass trajectories. However, trends in effort deviates for the longline fisheries were inconsistent with CPUE data had been standardized. In general, the results of the sensitivity analysis and those presented by Watters and Maunder (2002) support the view that the basecase estimates of biomass are uncertain.

At the beginning of January 2003, the spawning biomass of bigeye tuna in the EPO was beginning to decline from a recent high level. At that time the SBR was about 0.27, about 49% greater than the level that would be expected to produce the AMSY, with lower and upper confidence limits (± 2 standard deviations) of about 0.15 and 0.39. The estimate of the lower confidence bound is only slightly less than the estimate of SBR_{AMSY} (0.18), suggesting that, at the start of January 2003, the spawning biomass of bigeye in the EPO was greater than the level that is required to produce the AMSY.

Estimates of the average SBR projected to occur during 2003-2007 indicate that the SBR is likely to reach an historic low level in 2006 and remain below the level required if the population were to produce the AMSY until 2007 and probably after that. This decline is likely to occur regardless of environmental conditions and the amounts of fishing that occur in the near future because the projected estimates of SBR are driven by the small cohorts that were produced during 1998 to 2000.

The average weight of fish in the catch of all fisheries combined has been below the critical weight (about 54.7 kg) since 1993, suggesting that the recent age-specific pattern of fishing mortality is not satisfactory from a yield-per-recruit perspective.

The distribution of effort among fishing methods affects both the equilibrium yield per recruit and the equilibrium yield. When floating-object fisheries take a large proportion of the total catch, the maximum possible yield per recruit is less than that when longline catches are dominant. Also, if longline catches are dominant, the maximum yield per recruit (or a value close to it) can be obtained over a wide range of *F* multipliers. When floating-object fisheries take a large proportion of the total catch, a more narrow range of *F* multipliers provides a yield per recruit that is close to the maximum. When floating-object fisheries take a large proportion of the total catch and a stock-recruitment relationship exists, extremely large amounts of fishing effort would cause the population to crash. When longline catches are dominant, the population can sustain substantially greater fishing mortality rates. These conclusions are valid only if the age-specific selectivity pattern of each fishery is maintained.

Recent catches are estimated to have been about 40% above the AMSY level. If fishing mortality is proportional to fishing effort, and the current patterns of age-specific selectivity are maintained, the level of fishing effort that is estimated to produce AMSY is about 79% of the current level of effort. Decreasing the effort to 79% of its present level would only increase the long-term average yield by 2%, but such an action would increase the spawning potential of the stock by about 50%. The catch of bigeye by the surface fleet may be determined largely by the strength of recruiting cohorts. Thus, the catches of bigeye taken by the surface fleet will probably decline when the large cohorts recruited during 1995-1998 are no longer vulnerable to the surface fisheries. 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.

With the exception of the steepness sensitivity, analyses suggest that at the start of 2003 the spawning biomass was above the level that would be present if the stock were producing the AMSY. MSY and the *F* multiplier are sensitive to how the assessment model is parameterized, the data that are included in the assessment, and the periods assumed to represent average fishing mortality.

The small cohorts of bigeye tuna that were apparently recruited to the fisheries in the EPO during 1998-2000 should cause the SBR to decrease throughout 2003 and to be substantially less than SBR_{AMSY}. During 2003, the spawning biomass of bigeye in the EPO should decline to historically low levels and continue to decline further. This decline is predicted to occur regardless of the amount of fishing effort and environmental conditions that occur in the near future. The SBR is projected to further decrease during 2004-2006.

Preventing the discards of small bigeye tuna from catches taken around floating objects (or ensuring that discarded fish survive) would increase the SBR, the yield per recruit, the catch taken by the surface fleet, and the catch taken by the longline fleet. Thus, any measure that effectively reduces the kill of bigeye that are about 2-5 quarters old may help to achieve a variety of management objectives.

The sensitivity analysis indicates that if fishing mortality rates continue at their recent (2001 and 2002) levels, longline catches and SBR will decrease dramatically to extremely low levels. As the basecase does not include a stock recruitment model, recruitment will not decline so purse seine catches are predicted to stay at moderate levels.

2. DATA

Catch, effort, and size-composition data for January 1975 through December 2002 were used to conduct the stock assessment of bigeye tuna, *Thunnus obesus*, in the eastern Pacific Ocean (EPO). The data for 2002, which are preliminary, include records that had been entered into the IATTC databases as of 11th April 2002. 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). The spatial extent of each fishery and the boundaries of the length-frequency sampling areas are shown in Figure 2.1.

In general, fisheries are defined so that, over time, there is little change in the average size composition of the catch. Fishery definitions for purse-seine sets on floating objects are also stratified to provide a rough distinction between sets made mostly on flotsam (Fishery 1), sets made mostly on fish-aggregating devices (FADs) (Fisheries 2-3, 5, 10-11, and 13), and sets made on a mix of flotsam and FADs (Fisheries 4 and 12). It is assumed that it is appropriate to pool data relating to catches by pole and line and by purse-seine vessels setting on dolphins and unassociated schools (Fisheries 6 and 7). Relatively few bigeye are captured by the first two methods, and the data from Fisheries 6 and 7 are dominated by information on catches from unassociated schools of bigeye. Given this latter fact, Fisheries 6 and 7 will be referred to as fisheries that catch bigeye in unassociated schools throughout 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 throughout 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 IATTC terminology used in other reports. The correct 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 caught 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 2.2.2). Removals by Fisheries 10-13 are discards resulting only from sorting the catch taken by Fisheries 2-5 (see Section 2.2.2).

New and updated catch and effort data for the surface fisheries (Fisheries 1-7 and 10-13) have been incorporated into the current assessment and a new method has been used to estimate landings from the surface fisheries that catch bigeye. In previous assessments, purse seine landings were based on unloading estimates obtained from the canneries. Since 2000, the IATTC has also been sampling landings directly to obtain estimates of the species composition of the landings to help overcome some of the problems encountered distinguishing small yellowfin tuna and bigeye tuna. These new estimates are referred to as species composition estimates (SC). Watters and Maunder (2001) presented a sensitivity analysis using the SC estimates of purse seine landings for 2000. For this assessment, three years of SC estimates are available and these are much higher (average 38%) than previous estimates. As we believe that the SC estimates are more reliable, they are now included in the basecase model. It is not appropriate to only include the SC estimates for the last three years, but analyses to determine appropriate scaling factors for historical estimates were not completed in time for consideration for this assessment. For the three main surface fisheries (Fisheries 2, 3 and 5), the proportional increase in landings estimated by the SC method was relatively constant by quarter and did not vary greatly. We used the average quarterly proportional scalar (38%) to scale surface fishery landings estimates for Fisheries 2, 3, 4, 5, and 7 back to 1993, the beginning of the FAD fishery in the EPO. We present a sensitivity analysis where we use the unloading/cannery estimates of surface fishery landings in Appendix C. It is important to note that the assumed effort does not change. Watters and Maunder (2001) provide a brief description of the method that is used to estimate surface fishing effort.

New and updated catch and effort data for the longline fisheries (Fisheries 8 and 9) have also been incorporated into the current assessment. New catch and effort data have been obtained from Japan (2001) and Taiwan (1999). Catch data for Japan were also updated for 1999 and 2000. As in the previous assessment for bigeye (Maunder and Harley 2002), two sets of Korean longline catch data were investigated. The first set was based on data in the IATTC database. The second set was data supplied by the Secretariat for the Pacific Community (SPC), which is raised to represent the total catch estimated by the Korean National Fisheries Research and Development Institute (NFRDI). (Aggregated logsheet data, stratified by month and 5° latitude x 5° longitude were provided to SPC by NFRDI, but these data do not represent full coverage of the activities of the Korean long-range longline fleet; hence the need for raising these data). The catch and effort have been raised for each year by the ratio of combined albacore, bigeye, and yellowfin catch estimates for the western and central Pacific Ocean, to the combined albacore, bigeye, and yellowfin catch from the aggregated logsheet data for the western and central Pacific Ocean. Revised Korean longline catch and effort data for 1987 to 2001 and Chinese longline catch and effort data for 2001 were received too late to be included in this assessment. Preliminary investigations indicate the these revised Korean landings are more similar to were more similar to the SPC-raised estimates in most years. The IATTC is working to include landings for a number of smaller and new longline fleets into the database for inclusion in future assessments.

As in the previous assessments of bigeye from the EPO (Watters and Maunder 2001, 2002), the amount of longlining effort was estimated by dividing standardized estimates of the catch per unit of effort (CPUE) from the Japanese longline fleet into the total longline landings. In previous assessments (Watters and Maunder 2001, 2002, Maunder and Harley 2002), estimates of standardized CPUE were obtained with regression trees (Watters and Deriso 2000) or by the habitat-based method (Hinton and Nakano 1996, Bigelow *et al*. (2003)). In this assessment standardized CPUE were estimated for the period 1975 – 2000 using a neural network as described by Maunder and Hinton (submitted). For sensitivity we compare the results from the basecase to those based on the habitat-based method as used in the previous assessment (Maunder and Harley 2002) (Appendix E).

The following is a brief description of the neural network effort standardization method (see Maunder and Hinton submitted). The effectiveness of longline effort with respect to bigeye tuna is strongly affected by the fishing depth of the gear, due to the preferences of the species with regard to habitat characteristics (*e.g*. temperature and oxygen levels). Since the mid-1970s, longlines have fished at greater depths in attempts to increase catches of bigeye. Therefore, it is important that standardized longline effort, which is used with catch to provide information on abundance, take into consideration the depth of the longline and the relationship between this depth and the habitat preference of bigeye. Analyses using several different methods to standardize CPUE (habitat based methods, statistical habitat based methods, GLMs, and neural networks) indicated that neural networks performed best based on cross-validation. The neural networks takes multiple explanatory variables and develops a nonlinear relationship between these variables and the catch. Time in quarters is integrated with the neural network as a categorical variable and this is used to represent the standardized CPUE. The variables included in the neural network were hooks per basket (a measure of depth), latitude, longitude, and the water temperature and oxygen levels at a series of depths. Only Japanese catch and effort data is used in the CPUE analysis, because it includes information on the number of hooks per basket, provides the only consistent large area coverage of the distribution of bigeye, and represents the majority of the effort. The effort data is calculated by dividing the total catch for a fishery and time period by the CPUE.

2.2.1. Catch

Trends in the catches of bigeye tuna taken from the EPO during each quarter from January 1975 through December 2002 are illustrated in Figure 2.2. There has been substantial annual and quarterly variation in the catches of bigeye made by all fisheries operating in the EPO (Figure 2.2). Prior to 1996, the longline fleet (Fisheries 8 and 9) removed more bigeye (in weight) from the EPO than did the surface fleet (Fisheries 1-7 and 10-13) (Figure 2.2). Since 1996, however, the catches by the surface fleet have mostly been greater than those by the longline fleet (Figure 2.2). It should be noted that the assessment presented in this report uses data starting from January 1, 1975, and substantial amounts of bigeye were already being removed from the EPO by that time.

For this assessment, the longline landings data are available through 2001. In the assessment, the estimated longline landings in 2002 are a function of the longline effort in 2000, the estimated abundance in 2002, and the estimated selectivities and catchabilities for the longline fisheries (Fisheries 8 and 9).

The catches taken by Fisheries 3 and 5 during 2002 were greater than those taken during 2001. As percentages of the catches taken in 2001, these increases were, respectively, about 8%, and 57%. The catches for Fisheries 2, 4, and 7 were less than that in 2001. Their catches decreased by about 10%, 27%, and 2%, for these fisheries, respectively. The longline catch was 83% lower, and 24% greater in 2001 compared to 2000, for Fisheries 8 and 9, respectively. Predicted longline catch for 2002 was 22% greater, and 51% lower compared to 2001, for Fisheries 8 and 9, respectively. The differences for the longline fisheries are based on catch in numbers. As the model is predicting an increase in the mean weight of the catch in 2002, the decline in weight for Fishery 9 will be less than 50%.

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

2.2.2. Effort

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

Compared to 2001, the total amount of fishing effort expended by Fisheries 2, and 7 increased during 2002. As percentages of the effort expended in 2001, these increases were, respectively, about 8%, and 15%. The total amount of fishing effort expended by Fisheries 3 (-11%), 4 (-11%) and 5 (-15%) decreased from 2001 to 2002. These results indicate that the floating-object fishery in the southern offshore area (Fishery 2) continued to expand during 2002, as was also the case in 2001 and 2000. Effort in the floating-object fishery off the Galapagos Islands (Fishery 3) declined for the second straight year. It should be noted, however, that the spatial expansion and contraction of effort in the fisheries that catch bigeye in association with floating objects vary greatly among years (Watters 1999).

As standardized CPUE indices were not available for the longline fisheries in 2001, we assumed the same quarterly CPUE as estimated for 2000 and calculated effective effort based on the assumed CPUE and reported landings. The assumed effective longline fishing effort further decreased in the north (Fishery 8, -44%) and increased in the south (Fishery 9, 28%) from 2000 to 2001.

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

As previously noted (Section 2.2.1), the IATTC databases do not contain catch and effort information from Japanese longlining operations conducted in the EPO during 2002 and standardized CPUE indices were only available to the end of 2000. We assumed that the quarterly CPUE in 2001 was the same as for 2000. Effective effort for 2001 was calculated by dividing the reported landings by the assumed CPUE. Effective quarterly effort in 2002 was assumed to be the same as that exerted during the corresponding quarter of 2000. Examination of nominal effort for 2000 and 2001 suggests that this is a reasonable assumption.

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 observers, applying methods described by Maunder and Watters (2003). Regardless of why bigeye are discarded, it is assumed that all discarded fish die. New discard data for 2001 and 2002 are included in the analysis.

Estimates of discards resulting from inefficiencies in the fishing process are added to the catches made by purse-seine vessels (Table 2.1). No observer data are available to estimate discards for surface fisheries that operated prior to 1993 (Fisheries 1 and 6), and it is assumed that there were no discards from these fisheries. For surface fisheries that have operated since 1993 (Fisheries 2-5 and 7), there are periods when 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 preceding year.

Discards that result from the process of sorting the catch are treated as separate fisheries (Fisheries 10-13), and the catches taken by these fisheries are assumed to be composed only of fish that are 2-4 quarters old (see Figure 4.5). Watters and Maunder (2001) provide a short rationale for treating such discards as separate fisheries. Estimates of the amounts of fish discarded during sorting are made only for fisheries that take bigeye associated with floating objects (Fisheries 2-5) because sorting is thought to be infrequent in the other purse-seine fisheries.

Time series of discards as a proportion of the retained catch for the surface fisheries that catch bigeye tuna in association with floating-object is presented in Figure 2.4. With the exception of one quarter for Fishery 2, the proportion of the catch discarded has been low for the last four years compared to that observed during fishing on the strong cohorts produced in 1997. There is strong evidence that some of this is due to the weak year classes estimated in recent years. It is also possible that regulations regarding discarding of tuna has also played a role.

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

2.3. Size composition data

New length-frequency data are available for the surface fisheries for 2002. Data for 2000 and 2001 have also been updated. New longline length-frequency data from the Japanese fleet are available for 2001 and data for previous years have been updated.

The fisheries of the EPO catch bigeye tuna of various sizes. The average size compositions of the catches from each fishery defined in Table 2.1 have been described in two previous assessments (Watters and Maunder 2001, 2002). The fisheries that catch bigeye associated with floating objects typically catch small (<75 cm long) and medium-sized (75 to 125 cm long) bigeye (Figure 4.2, Fisheries 1-5). Prior to 1993, the catch of small bigeye was roughly equal to that of medium bigeye (Figure 4.2, Fishery 1). Since 1993, however, small bigeye have dominated the catches of fisheries that catch bigeye in association with floating objects (Figure 4.2, Fisheries 2-5). Prior to 1990, mostly medium-sized bigeye were captured from unassociated schools (Figure 4.2, Fishery 6). Since 1990, more small- and large-sized (>125 cm long) bigeye have been captured in unassociated schools (Figure 4.2, Fishery 7). The catches taken by the two longline fisheries (Fisheries 8 and 9) have distinctly different size compositions. In the area north of 15°N, longliners catch mostly medium-sized bigeye, and the average size composition has two distinct peaks (Figure 4.2, Fishery 8). In the southern area, longliners catch substantial numbers of both medium- and large-sized bigeye, and the size composition has a single peak (Figure 4.2, Fishery 9).

During any given quarter, the size-composition data collected from a fishery will not necessarily be similar to the average conditions illustrated in Figure 4.2. The data presented in Figures 4.3a and 4.3b illustrate this point. The most recent (2002) size-compositions for the fisheries that catch bigeye in association with floating objects contain more smaller bigeye than observed in samples from 2001 and a lack of middle and large-sized bigeye. This is due to the strong cohorts passing through the fisheries and the weak recruitment from 1998 to 2001.

3. ASSUMPTIONS AND PARAMETERS

3.1. Biological and demographic information

3.1.1. Growth

The growth model is structured so that individual growth increments (between successive ages) can be estimated as free parameters. These growth increments can be constrained to be similar to a specific growth curve (perhaps taken from the literature) or fixed so that the growth curve can be treated as something that is known with certainty. If the growth increments are estimated as free parameters they are constrained so that the mean length is a monotonically increasing function of age. The modified growth model is also designed so that the size and age at which fish are first recruited to the fishery must be specified. For the current assessment, it is assumed that bigeye are recruited to the discard fisheries (Fisheries 10-13) when they are 30 cm long and two quarters old.

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

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

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

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

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

3.1.2. Recruitment and reproduction

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

A-SCALA allows a Beverton-Holt (1957) stock-recruitment relationship to be specified. The Beverton-Holt curve is parameterized so that the relationship between spawning biomass and recruitment is determined by estimating the average recruitment produced by an unexploited population (virgin recruitment), a parameter named steepness, and the initial age structure of the population. Steepness controls how quickly recruitment decreases when the spawning biomass is reduced. It is defined as the fraction of virgin recruitment that is produced if the spawning biomass is reduced to 20% of its unexploited level. Steepness can vary between 0.2 (in which case recruitment is a linear function of spawning biomass) and 1.0 (in which case recruitment is independent of spawning biomass). In practice, it is often difficult to estimate steepness because of a lack of contrast in spawning biomass and because there are other factors (*e.g.* environmental influences) that cause recruitment to be extremely variable. Thus, to estimate steepness it is often necessary to specify how this parameter might be distributed statistically. (This is known as specifying a prior distribution.)

For the current assessment, recruitment is assumed to be independent of stock size (steepness = 1). There is no evidence that recruitment is related to spawning stock size for bigeye in the EPO and, if steepness is estimated as a free parameter, steepness is estimated to be close to 1. We also present a sensitivity analysis with steepness = 0.75. In addition to the assumptions required for the stock-recruitment relationship, it is further assumed that recruitment should not be less than 25% of its average level and not greater than four times its average level more often than about 1% of the time. These constraints imply that, on a quarterly time step, such extremely small or large recruitments should not occur more than about once every 25 years.

Reproductive inputs have been revised for this assessment from those assumed by Maunder and Harley (2002). Recent biological studies undertaken by the IATTC indicate the size-at-maturity in much later than previously assumed. Also, we corrected inconsistencies in the way that fecundity-at-age and age-specific proportions of females were calculated.

Age at which 50% of females are assumed to be mature is about 5 years of age (20 quarters) compared to knife-edge maturity at 3.5 years assumed by Maunder and Harley (2002) (Figure 3.2). We examined a number of studies presenting age- or length-specific proportions of females. In this assessment we use estimates based on the analysis of a data set comprising historical estimates from Kume and Joseph (1966) and recent estimates reported in the IATTC Quarterly Report (Quarter 4 – 2002) (Figure 3.3 and Table 3.1). These estimates are similar to those from samples from the Japanese longline fleet for the EPO (Dr N Miyabe, *pers. comm.*) The fecundity index at age is assumed to be equal to the mean weight at age estimated by inserting mean lengths from the growth curve provided by Suda and Kume (1967) into the weight-length relationship provided by Nakamura and Uchiyama (1966) (see Section 3.1.1). The age-specific proportions of female bigeye and fecundity indices used in the current assessment are provided in Table 3.1.

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

3.1.3. Movement

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

3.1.4. Natural mortality

Age-specific vectors of natural mortality (*M*) used in the previous assessment of bigeye tuna (Watters and Maunder 2002, Maunder and Harley 2002) were based on fitting to age-specific proportions of females, maturity-at-age, and natural mortality estimates of Hampton (2000). As first two of these quantities have been revised in this assessment, new age-specific vectors of natural mortality were estimated outside of the assessment model (Harley and Maunder, unpublished analysis). These new estimates are slightly lower than previous estimates and increase at older ages due to the later maturity assumed. The previous observation that different levels of natural mortality had a large influence on the absolute population size and the population size relative to that which would produce AMSY (Watters and Maunder 2001) remains. In this assessment results are presented only from the basecase age-specific vector of natural mortality.

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 there is no net movement between these areas. The IATTC staff is currently collaborating with scientists of the SPC, Oceanic Fisheries Programme, and of the National Research Institute of Far Seas Fisheries of Japan to conduct a Pacific-wide assessment of bigeye. This work may help indicate how the assumption of a single stock in the EPO is likely to affect interpretation of the results obtained from the A-SCALA method.

3.2. Environmental influences

It is assumed that 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 current assessment, a modification was made to A-SCALA to allow for missing values in the environmental index thought to be related to recruitment. This allows us to start the population model in 1975, five years before the start of the time series for the environmental index. As in previous assessments (Watters and Maunder 2002, Maunder and Harley 2002), zonal-velocity anomalies (velocity anomalies in the east-west direction) at 240 m depth and in an area from 8°N-15°S and 100°-150°W are used as the candidate environmental variable for affecting recruitment. The zonal-velocity anomalies were calculated as the quarterly averages of anomalies from the long-term (January 1980-December 2002) monthly climatology. These data were included in the stock assessment model after they had been offset by two quarters because it was assumed that recruitment of bigeye in any quarter of the year might be dependent on environmental conditions in the quarter during which the fish were hatched. The zonal-velocity anomalies were estimated from the hind cast results of a general circulation model. The hindcast results are posted on the Internet by the US National Oceanic and Atmospheric Administration, National Centers for Environmental Prediction, and made available through the Lamont-Doherty Earth Observatory/International Research Institute for Climate Prediction Data Library. The hindcast results can be obtained at http://ingrid.ldeo.columbia.edu. Modifications to the assessment model allowed missing data in the environmental covariates thought to be related to recruitment. This allowed the model to be extended back to 1975 while still allowing for the environmental influence on recruitment.

In previous assessments (Watters and Maunder 2001, Maunder and Harley 2002) it was assumed that oceanographic conditions might influence the efficiency of the fisheries that catch bigeye associated with floating objects (Fisheries 1-5). In the last assessment an environmental influence on catchability was only assumed for Fishery 3. We found that including this effect did not greatly improve the results so we have not included environmental effects on purse seine catchability in this assessment. This also allowed the model to be extended back to 1975, as environmental data assumed to be related to changes in catchability were not available before 1980, and the current model can not accommodate missing values for environmental indices thought to be related to catchability.

4. STOCK ASSESSMENT

The A-SCALA method (Maunder and Watters 2003) is currently used to assess the status of the bigeye tuna stock in the EPO. This method was also used to conduct the previous three assessments of bigeye (Watters and Maunder 2001, 2002, Maunder and Harley 2002). A general description of the A-SCALA method is included in the previously-cited assessment documents, and technical details are provided in Maunder and Watters (2003). The version of A-SCALA used in this assessment is the same as described by Watters and Maunder (2002). 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 two quarters after hatching, and these discard fisheries (Fisheries 10-13) catch fish of only the first few age classes.
2. Bigeye tuna are recruited to the discard fisheries before they are recruited to the other fisheries of the EPO.
3. If a fishery can catch fish of a particular age, it should be able to catch fish that are somewhat younger and older (*i.e.* selectivity curves should be relatively smooth).
4. As bigeye tuna age, they become more vulnerable to longlining in the area south of 15°N, and the oldest fish are the most vulnerable to this gear (*i.e.* the selectivity curve for Fishery 9 is monotonically increasing).
5. There are random events that can cause the relationship between fishing effort and fishing mortality to change from quarter to quarter.
6. The data for fisheries that catch bigeye tuna from unassociated schools (Fisheries 6 and 7) and fisheries whose catch is composed of the discards from sorting (Fisheries 10-13) provide relatively little information about biomass levels. This constraint is based on the fact that these fisheries do not direct their effort at bigeye.
7. It is extremely difficult for fishermen to catch more than about 60% of the fish from any one cohort during a single quarter of the year.

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

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

1. recruitment in every quarter from the first quarter of 1975 through the first quarter of 2003 (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;

The weighting factors for the selectivity smoothness penalties (see Maunder and Watters 2003) in the previous assessment were 1, 0, 1, and -1, for the first, second, and third differences, and the length-based penalty, respectively. A weighting factor of 1000 was also applied to a monotonic penalty on the southern longline fishery selectivity. Cross validation (setting aside 20% of the length-frequency data as a test data set) using last years bigeye tuna assessment (Maunder and Harley 2002) indicated that weighting factors of 1 on the third difference was appropriate for domes shaped selectivities (Fisheries 1-8) and a weighting factor of 0.1 on the first difference with a length-based penalty of -1 and a monotonic penalty of 1000 are appropriate for asymptotic selectivity curves (Fishery 9).

In previous assessments two methods were used to determine what fishing mortality or effort was used in yield calculations and forward projections: 1) fishing mortality averaged over the most recent two years for yield calculations and effort averaged over the most recent two years multiplied by catchability averaged over the most recent two years for forward projections, and 2) effort mortality averaged over the last two years multiplied by average catchability over the whole time frame. These two methods produced substantially different results for the bigeye tuna assessment (Maunder and Harley 2002). The reason for the difference is that bigeye tuna catchability has been estimated to have increased for the floating object fisheries over the last few years. However, using the most recent catchability may not be the best choice because estimates of recent catchability are the most uncertain. We have used retrospective analysis to determine the most appropriate years to average catchability and effort. Retrospective analysis, where one year of catch and length-frequency data is removed in consecutive analyses, was carried out but while still including effort data for the full time frame of the stock assessment. The effort used for the periods where data was removed was generated using several different years to average the catchability and effort. The estimated catch for these periods was then compared to the actual catch. For bigeye tuna we estimated temporal trends in fishing mortality and catchability so there is a trade off between using older estimates of catchability and fishing mortality that may be better estimated but irrelevant (e.g. ignore recent trends) and estimates that are more recent but less certain. To accommodate this problem, for projections we used effort averaged over the last two years (2001 and 2002) and catchability averaged, not over the last year, but the two years prior (2000 and 2001). The equivalent for yield calculations is to average fishing mortality not over the last year but over the two years prior (2000 and 2001).

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 this assumption is not likely to be satisfied, these values may underestimate the amount of uncertainty in the results of the current assessment.

4.1. Indices of abundance

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

Comparing the CPUEs of the surface fisheries in 2002 to those achieved in 2001 illustrates that performance of these fisheries is quite variable. The CPUE from Fisheries 3 and 4 were higher than the very low levels observed in 2001. CPUE for Fisheries 2 and 7 are lower in 2002, and CPUE for Fishery 4 is similar (Table 4.1). CPUE for the discard fisheries (Fisheries 10 – 13) have generally been low for the last four years, consistent with weak recruitment (Section 4.2.2).

4.2. Assessment results

As there have been a number of important changes from the last assessment presented by Maunder and Harley (2002), we are presenting results for a number of versions of the assessment model in addition to the two sensitivity analyses presented by Maunder and Harley (2002). Below we describe the important aspects of the basecase assessment (1 below) and the change for each sensitivity analysis:

1. Basecase: steepness of the stock-recruitment relationship equals 1 (no relationship between stock and recruitment), species composition estimates of surface fishery catches, Korean longline catch based on data held by the IATTC, neural network standardized CPUE , and assumed sample sizes for the length-frequency data;
2. Sensitivity to the steepness of the stock-recruitment relationship. The base case included an assumption that recruitment was independent of stock size and a Beverton-Holt stock-recruitment relationship with steepness of 0.75 was used for the sensitivity analysis.
3. Sensitivity to estimates of purse seine catches. In the basecase, estimates of purse seine catches were based on species composition estimates for 2000 – 2002 and scaled estimates back to 1993. For sensitivity we compared this to cannery and unloading estimates of bigeye catches in the purse fisheries as used by Maunder and Harley (2002).
4. Sensitivity to estimates of Korean longline catch. In addition to the data held by the IATTC, which is used in the basecase analysis, a sensitivity analysis was conducted with the greater estimates of Korean longline catch estimated by the Secretariat for the Pacific Community (SPC).
5. Sensitivity to assumed CPUE for the longline fisheries. In the basecase longline CPUE was standardized using a neural network chosen for its improved performance in cross-validation trials. For sensitivity we used the same habitat standardized longline CPUE used by Maunder and Harley (2002).
6. Sensitivity to the sample sizes assumed for the length frequency samples. An iterative re-weighting procedure was used to determine the effective sample size in the sensitivity analysis.

Basecase results are described in the text and the sensitivity analyses are described in the text with figures and tables presented in Appendices B to F. We also undertook a number of sensitivity analyses that are not presented here. We examined models where the variation in length-at-age was estimated, same selectivity smoothness penalties assumed by Maunder and Harley (2002), no environmental recruitment relationship was included, and estimation of the equilibrium levels of fishing mortality prior to 1975. Most of these produced very similar results to the basecase. We have chosen to restrict our presentation to plausible sensitivity analyses that had an affect on management quantities. A more comprehensive presentation of sensitivity analysis, including investigation of growth estimation, environmental effects on recruitment and catchability, and natural mortality can be found in Watters and Maunder (2002).

The basecase 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 basecase 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 basecase assessment (Figure 4.2, Fisheries 2, 3, 5, 8, and 9).

Although the basecase 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 due to variation in the processes that describe the dynamics (e.g. variation in growth). The most recent size-composition data from Fisheries 4 and 7 are not informative (Figures 4.3a and 4.3b). In other cases, the basecase assessment tends to over-smooth and does not capture modes that move through the size-composition data. Recent length frequency data from Fisheries 2, 3, and 5 are generally in good agreement in relation to the position and transition modes so are well fitted by the model. There is strong agreement in the lack of strong cohorts during 1998 and 2000 and some evidence of moderate strength cohorts in the first quarter of 2001. The fit to these data is governed by complex tradeoffs between estimates of growth, selectivity, recruitment, and agreement among fisheries in the presence and absence of modes.

Of all the constraints used to fit the assessment model (see Sections 3 and 4), those on growth, catchability, and selectivity had the most influence. The penalties on recruitment are lower than presented by Maunder and Harley (2002) and the selectivity penalties are less due to the change in assumptions regarding which penalties to include. This following list indicates the major penalties (a large value indicates that the constraint was influential):

Total likelihood = -340428.2

Likelihood for catch data = 4.4

Likelihood for size-composition data = -340997.1

Constraints and priors on recruitment parameters = 5.9

Constraints and priors on growth parameters = 49.4

Constraints on fishing mortality rates = 0.0

Constraints and priors on catchability parameters = 462.5

Constraints on selectivity parameters = 20.5

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

The results presented in the following sections are likely to change in future assessments because (1) future data may provide evidence contrary to these results, and (2) the assumptions and constraints used in the assessment model may change. Future changes are most likely to affect absolute estimates of biomass, recruitment, and fishing mortality.

4.2.1. Fishing mortality

There have been important changes in the amount of fishing mortality on bigeye tuna in the EPO. On average, the fishing mortality on bigeye less than about 20 quarters old has increased since 1993, and that on fish more than about 24quarters old has decreased since then (Figure 4.4). The increase in average fishing mortality on younger fish can be attributed to the expansion of the fisheries that catch bigeye in association with floating objects. These fisheries (Fisheries 2-5) catch substantial amounts of bigeye (Figure 2.2), select fish that are less than 20 – 25 quarters old (Figure 4.5), and have expended a relatively large amount of fishing effort since 1993 (Figure 2.3). The decrease in average fishing mortality on older fish can be attributed to the contraction of the longline fishery that operates south of 15°N (Fishery 9). This fishery selects mostly fish that are more than 12 quarters old (Figure 4.5). (Note that the selectivity curve for this fishery is constrained to be monotonically increasing.) Both the amount of bigeye caught (Figure 2.2) and the amount of effort expended (Figure 2.3) by this fishery have decreased since 1993.

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

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

For the main surface fisheries (Fisheries 2, 3, and 5) there are strong increasing trends in catchability in recent years indicating that the effective effort (e.g. capacity) of the fleet is increasing. There has been almost no change in the catchability of bigeye tuna by the longline fleet (Figure 4.7b, Fisheries 8 and 9, bold lines). This result is to be expected, given the effort data for these fisheries were standardized before they were incorporated into the stock assessment model (Section 2.2.2).

4.2.2. Recruitment

The abundance of bigeye tuna being recruited to the fisheries in the EPO appears to be related to zonal-velocity anomalies at 240 m during the time that these fish are assumed to have hatched (Watters and Maunder 2002, Figure 4.8, upper panel). The mechanism that is responsible for this relationship has not been identified, and correlations between recruitment and environmental indices are often spurious. Given these latter two caveats, the relationship between zonal-velocity and bigeye recruitment should be viewed with some skepticism. Nevertheless, the relationship between zonal-velocity and bigeye recruitment 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 very similar estimates of recruitment to the basecase model. This suggests that there is sufficient information in the length frequency data to estimate most historical year class strengths.

Over the range of estimated spawning biomasses shown in Figure 4.10, the abundance of bigeye recruits appears to be unrelated to the spawning potential of adult females at the time of hatching (Figure 4.8). Previous assessments of bigeye in the EPO (*e.g.* Watters and Maunder 2001, 2002) also failed to show a relationship between adult biomass and recruitment over the estimated range of spawning biomasses. As noted in Section 3.1.2, the absence of an emergent relationship between stock and recruitment does not indicate that such a relationship is nonexistent because stock sizes may not have been sufficiently reduced, we may not have the correct measure of spawning biomass, or environmental variation may mask the relationship. In this assessment, there have be significant changes in assumptions regarding biological parameters and these may change again in the future as research continues. The basecase estimate of steepness is fixed at 1, which produces a model with a weak assumption that recruitment is independent of stock size. 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. Greater-than-average recruitments occurred in 1977, 1979, 1982-1983, 1992, 1994, and 1995-1997. However, that the lower confidence bounds of these estimates were only greater than the estimate of virgin recruitment for 1994 and 1997, so it is uncertain whether these recruitments were, in fact, greater than the virgin recruitment. The extended period of relatively large recruitments in 1995 to 1998 coincided with the expansion of the fisheries that catch bigeye in association with floating objects. An above average cohort is estimated for the first quarter of 2001 but this estimate is uncertain.

Recruitment has been much lower than average from the second quarter of 1998 to the end of 2000 and the upper confidence bounds of many of these recruitment estimates are below the virgin recruitment. Evidence for these low recruitments comes from the decreased CPUE achieved by some of the floating-object and discard fisheries (Table 4.1 and Figures 2.4 and 4.1), the length frequency data (Maunder and Harley 2002, Figures 4.3a, 4.3b, and 4.3c), and by poor environmental conditions for recruitment. The extended sequence of low recruitments is important because it is likely to produce a sequence of years in which the spawning biomass ratio will be below the level that would support the average maximum sustainable yield (AMSY) (see Section 5.1).

There is considerable uncertainty in the estimated levels of recruitment, particularly in the early years before the fishing on floating objects expanded. The average CV of the recruitment estimates is about 0.37. Most of the uncertainty in recruitment is a result of the fact that the observed data can be equally well fitted by a model with different estimates of the assessment parameters. Also, pre-1993 estimates are particularly uncertain as the floating object fisheries, which catch small bigeye, were not operating. Uncertainty in the most recent estimates of recruitment is, however, also caused by the fact that recently-recruited bigeye are represented in only a few length-frequency data sets.

4.2.3. Biomass

Trends in the biomass of 1+-year-old bigeye tuna in the EPO are shown in Figure 4.10 (upper panel), and estimates of the biomass at the start of each year are presented in Table 4.2. The biomass of 1+-year-old bigeye increased during 1981-1984, and reached its peak level of about 530,000 mt in 1986. After reaching this peak, the biomass of 1+-year-olds decreased to an historic low of about 185,000 mt at the start of 2003. There has been an accelerated decline in biomass since the small peak in 2000.

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

There is uncertainty in the estimated biomasses of both 1+-year-old bigeye and of spawners. The average CV of the biomass estimates of 1+-year-old bigeye is 0.16. The average CV of the spawning biomass estimates is 0.23.

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, in the EPO, trends in the biomass of bigeye have been influenced more by variation in fishing mortality or by variation in recruitment. Nevertheless, the assessment suggests two conclusions. First, it is apparent that fishing has reduced the total biomass of bigeye present in the EPO. This conclusion is drawn from the results of a simulation in which the biomass of bigeye tuna estimated to be present in the EPO at the start of the first quarter of 1975 was allowed to grow (using the time series of estimated recruitment anomalies, the estimated environmental effect, and the stock-recruitment curve illustrated in Figure 4.8) in the absence of fishing. The simulated biomass estimates are always greater than the biomass estimates from the basecase assessment (Figure 4.11). Second, the biomass of bigeye can be substantially increased by strong recruitment events. Both peaks in the biomass of 1+-year-old bigeye (1985 and 2000; Figure 4.10) were preceded by peak levels of recruitment (1982-1983 and 1995-1997, respectively; Figure 4.9).

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 4.12. 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 4.12, Fisheries 2-5). During the latter half of 2000, however, the average weight of the fish taken by Fisheries 2, 3, and 5 decreased (Figure 4.12). Fisheries 7 and 8 have captured bigeye that, on average, 30% less than the critical weight. The average weights of bigeye taken by Fishery 8 increased since 1999 (Figure 4.12). The average weight of bigeye taken by the longline fishery operating south of 15°N (Fishery 9) has always been around the critical weight. This indicates that Fishery 9 tends to maximize the yield per recruit (see Section 5.2). In general the average weight of bigeye taken by the all of the surface fisheries combined (excluding the discard fisheries) increased during 1998 and early 1999 and then decreased (Figure 4.12). The average weight of bigeye taken by both longline fisheries combined appears to have decreased during early 1997, 1998, and 1999, and then increased (Figure 4.12). These two trends, for the combined surface fisheries and the combined longline fisheries, were probably caused by the strong cohorts from 1995 – 1997 moving through the surface fisheries and into the longline fisheries and the subsequent weak recruitment from 1998 - 2000 (Figure 4.9).

4.3. Comparisons to external data sources

In the basecase assessment, the growth increments are estimated for the younger bigeye. The estimated mean length at age is less than given by Suda and Kume (1967: Table 4.3 and Figure 4.13). The most recent assessment of bigeye tuna in the western and central Pacific Ocean also estimated reduced growth rates for young bigeye (Hampton 2002), and this is also consitent with reduced growth found in both growth and tagging studies (Lehody et al. 1999)

4.4. Diagnostics

A mid-year technical meeting on diagnostics was held in La Jolla, October 2-4 2002. The outcome from this meeting was 1) a set of diagnostics that should be evaluated regularly, 2) a set of diagnostics that should be evaluated periodically, and 3) a list of specific research questions. Several of the recommendations have been included in this assessment. We present these in three sections; a) residual plots, b) parameter correlations, and c) retrospective analysis.

4.4.1. Residual plots

Residual plots show the difference between the observations and the model predictions. The residuals should show similar characteristics 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 around 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 smaller than the assumed standard deviation (Figures A.1 and A.3, i.e. the assumed sample size is too small; see Sections 4.5 and 5.6 and Appendix F for a sensitivity analysis to the length-frequency sample size), they have a negative bias (Figure A.1), are more variable for some lengths than others (Figure A.1), but tend to be consistent over time (Figure A.2). The negative bias is due to the large number of zero observations. The zero observation causes a negative residual, and also causes a small standard deviation which inflates the normalized residual.

The estimated quarterly effort deviations are shown versus time in Figure A.4. These residuals are assumed to be normally distributed (the residual is exponentiated before multiply 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 (sd = 0.2) the floating object and the northern longline fisheries have the least information (sd = 0.4), and the discard fisheries have no information (sd = 2). Therefore, a trend is less likely in the southern longline fishery (Fishery 9) than 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, however there is some consecutive residuals that are all above or all below the average. The standard deviation of the residuals is much higher than the 0.2 assumed for this fishery. For the other fisheries, the standard deviations of the residuals are all higher than those assumed, except for the discard fisheries. These results indicates that the assessment gives more weight to the CPUE information than it should (see below and section 4.5 for additional indication that less weight should be given to the CPUE information and more to the length-frequency data). The effort residuals for the floating object fisheries have a increasing trend over time. These trends may be related to true trends in catchability.

4.4.2. Parameter correlation

Often quantities such as recent estimates of recruitment deviates and fishing mortality can be highly correlated. This information indicates a flat solution surface that implies that a range of alternative states of nature have a similar likelihood. 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 2002 from yield calculations and projections (see Section 4).

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 (Figures A.5a, A.5b, and A.6). Less recent 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 (Figure A.7). This correlation is greater than for less recent spawning biomass estimates. Similar correlations are seen for recruitment and spawning biomass (Figure A.8).

4.4.3. Retrospective analysis

Retrospective analysis is a useful method to determine 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 stock assessment 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 more data improves the estimates, can be used to determine if there are consistent biases in the estimates.

We present two retrospective analyses, 1) removing the catch and length-frequency data for 2002, and 2) removing the catch and length-frequency data for 2002 and 2001. For both these analyses we continued to model the population to the start of 2003 using the same effort data but scaled by average effort deviates estimated for 2000 and 2001 to account for trends in catchability. We do not estimate recruitment or effort deviations for the years where the data has been excluded. This allows the prediction of abundance conditioned on "known" effort. Results show that the model is fairly robust but that there is some evidence that the earlier information on the cohorts from 1999 to 2001indicated that the cohorts were weaker than they actually were. These cohorts are still below average. Also, the strong cohorts in 1995 – 1997 were slightly stronger than ealier data suggested (Figures G.1 to G.3). The strength of the strong year classes prior to 1999 is shown in the trend in SBR.

4.5. Sensitivity analysis

Five sensitivity analyses are conducted in the current assessment: sensitivity to the stock–recruitment relationship (Appendix B), sensitivity to the method used to estimate catches in the surface fisheries (Appendix C), sensitivity to the SPC estimates of Korean longline catch data (Appendix D), sensitivity to the longline CPUE indices used in the previous assessment of Maunder and Harley (2002) (Appendix E), sensitivity to the assumed samples sizes for the length frequency data (Appendix F). Additional sensitivity analyses were conducted but are not presented and Watters and Maunder (2002) presented a number of sensitivity analyses. Here we describe difference in model fit and model prediction and delay our discussion of differences in yields and stock status to Section 5.6

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

When the cannery and unloading estimates of purse seine catches are used (as used by Maunder and Harley (2002), both biomass (Figure C.1) and recruitment (Figure C.2) are lower. The cannery and unloading estimates of catch are much lower, especially in 2001 and 2002 (Figure C.5).

The effect of changes in the longline catches is greater than that of changes in purse seine catches. When the larger SPC-estimated Korean longline catch is used, both the biomass (Figure D.1) and recruitment (Figure D.2) are increased. Biomass is 50% higher in 1975 and double in 2003. This is expected, since additional biomass is required to compensate for the increased removals if the same trend (as represented by the CPUE) is to be achieved, but the differences are greater than found by Maunder and Harley (2002). The SPC-estimated Korean longline catches are generally higher throughout the period but especially for 1985 – 1987 and 1990 – 1992 (Figure D.5).

The model is sensitive to longline CPUE as this is assumed to be proportional to abundance. When compared to the basecase, habitat-standardized CPUE has a greater decline for Fishery 8 but a greater increase in recent years for Fishery 9 (Figure E.5). Biomass trends are similar in the middle of the time series but higher at the start and end for the sensitivity analysis (Figure E.1). Recruitment patterns are generally similar (Figure E.2).

A sensitivity analysis was carried out to determine the influence of the length-frequency sample size. McAllister and Ianelli (1997) used an analytical method to determine the effective sample size for catch-at-age data based on the observed and predicted proportional catch-at-age. They used a method of iteratively modifying the sample size based on this calculation until the change in sample size was only small. Usually this took only three or four iterations. We use this method to determine new sample sizes for each set (fishery and time period) of length-frequency data. The original sample size used in the basecase was based on number of wells sample for the surface gears. For the longline gears we modified the sample size so that the average sample size for the southern longline fishery was equal to the average sample size for the surface fishery that had the maximum average sample size (Fishery 2). Table F.1 gives the average sample size by fishery for the basecase and for the iterative re-weighting sensitivity, Figures F.7a and F.7a show the frequency distributions for the scalar used to increase the sample sizes in the sensitivity analysis. The re-weighted sample sizes are much higher than the basecase for all fisheries (Table F.1 and Figures F.7a and F.7b). The sample size is increased on average between about 15 times for all surface fisheries and 229 and 107 times for the northern and southern longline fisheries respectively. This indicates that the purse seine effective sample size is still less than the number of fish measured (about 50 per well) and that the longline effective sample size is still substantially less than the number of fish measured, but the longline data sets have much higher effective sample sizes than the length frequency samples from the surface fisheries.

The results from the re-weighting sensitivity are quite different to the basecase in many aspects. The biomass trajectory is similar in the middle of the series (1985 – 1997) but it is less than half during the early part of the series (1975 – 1982), consistent until 1997 where it decreases sharply as observed in the basecase (Figure F.1). Recruitment is much more variable and generally more extreme (Figure F.2a) and the estimates are much more precise (Figure F.2b) with an average CV of 0.13 compared to 0.37 for the basecase. The model is no longer over-fitting the length frequency data from a residual standpoint (Figure F.5) which is not surprising as the method used to determine the effective sample sizes is based on these residuals. The change in the biomass trajectories illustrates the tradeoff between the length frequency and CPUE data. Figure F.6 indicates a strong trend in effort deviates (and therefore catchability) for Fishery 9. This is the largest longline fishery whose CPUE is standardized and thought to reflect abundance.

4.6. Comparison to previous assessments

Despite the large number of changes in important model assumptions and inputs, e.g., natural mortality, CPUE, and selectivity penalties, the last three assessments give a very similar picture to the basecase assessment for 2003. Biomass trajectories are very similar (Figure 4.14) and the previous assessment that started in 1975 (that for 2000) provides very similar results to this assessment but does suggest that the strong cohorts during 1995- 1997 were over-estimated in the 2000 assessment.

To make valid comparisons of changes in estimates of spawning biomass we used the values maturity and fecundity as assumed in this assessment and applied these to the estimated age-structure from the previous assessments. This is not completely satisfactory as the 2001 assessment (Watters and Maunder 2002) assumed a stock recruitment relationship assuming different spawning biomass. Patterns are similar but the differences are increased when compared to the biomass comparison (Figure 4.15). Again the results for the 2000 assessment are most similar to this assessment.

4.7. Summary of results from the assessment model

There have been important changes in the amount of fishing mortality caused by the fisheries that catch bigeye tuna in the EPO. On average, the fishing mortality on bigeye less than about 20 quarters old has increased substantially since 1993, and that on fish more than about 24 quarters old has decreased 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. The basecase assessment suggests that (1) the use of FADs has substantially increased the catchability of bigeye by fisheries that catch tunas associated with floating objects, and (2) that bigeye are substantially more catchable when they are associated with floating objects in offshore areas.

Recruitment of bigeye tuna to the fisheries in the EPO is variable, and the mechanisms that explain variation in recruitment have not been identified. Nevertheless, the abundance of bigeye tuna being recruited to the fisheries in the EPO appears to be related to zonal-velocity anomalies at 240 m during the time that these fish were assumed to have hatched. Over the range of spawning biomasses estimated by the base-case assessment, the abundance of bigeye recruits appears to be unrelated to the spawning potential of adult females at the time of hatching.

There are two important features in the estimated time series of bigeye. First, greater-than-average recruitments occurred in 1977, 1979, 1982-1983, 1992, 1994, and 1995-1997. However, that the lower confidence bounds of these estimates were only greater than the estimate of virgin recruitment for 1994 and 1997, so it is uncertain whether these recruitments were, in fact, greater than the virgin recruitment. An above average cohort is estimated for the first quarter of 2001 but this estimate is uncertain. Second, recruitment has been much lower than average for most of the recent period from the second quarter of 1998 to the end of 2000, and the upper confidence bounds of many of these recruitment estimates are below the virgin recruitment. Evidence for these low recruitments comes from the decreased CPUEs achieved by some of the floating-object and discard fisheries, the length frequency data, and by poor environmental conditions for recruitment. The extended sequence of low recruitments is important because it is likely to produce a sequence of years in which the spawning biomass ratio will be below the level that would support the average maximum sustainable yield (AMSY).

The biomass of 1+-year-old bigeye increased during 1980-1984, and reached its peak level of about 530,000 mt in 1986. After reaching this peak, the biomass of 1+-year-olds decreased to an historic low of about 185,000 mt at the start of 2003. Spawning biomass has generally followed a trend similar to that for the biomass of 1+-year-olds but lagged by 1-2 years. There is uncertainty in the estimated biomasses of both 1+-year-old bigeye and of spawners. Nevertheless, it is apparent that fishing has reduced the total biomass of bigeye present in the EPO both are predicted to be at their lowest levels by the end of 2003. There has been an accelerated decline in biomass since the small peak in 2000.

The estimates of recruitment and biomass are sensitive both to the way in which the assessment model is parameterized and to the data that are included in the assessment. Including the SPC-estimated Korean longline catch increased estimates of biomass and recruitment. However, including a stock-recruitment relationship did not change the estimates of biomass or recruitment. The re-weighting of the length frequency sample sizes produced the greatest differences in biomass trajectories. However, trends in effort deviates for the longline fisheries were inconsistent with CPUE data had been standardized. In general, the results of the sensitivity analysis and those presented by Watters and Maunder (2002) support the view that the basecase estimates of biomass are uncertain.

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} as a target reference point,
2. F_{MSY} as a limit reference point,
3. S_{min}, the minimum spawning biomass seen in the model time frame, as a limit reference point.

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

5.1. Assessment of stock status based on spawning biomass

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

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

where S_t is the spawning biomass at any time (t) during a period of exploitation, and $S_{F=0}$ is the spawning biomass that might be present if there were no fishing for a long period (*i.e.* the equilibrium spawning biomass if $F = 0$). The SBR has a lower bound of zero. If the SBR is near zero, the population has been severely depleted and is probably overexploited. If the SBR is one, or slightly less than that, the fishery has probably not reduced the spawning stock. If the SBR is greater than one, it is possible that the stock has entered a regime of increased production.

The SBR has been used to define reference points in many fisheries. Various studies (*e.g.* Clark 1991, Francis 1993, Thompson 1993, Mace 1994) suggest that some fish populations can produce the AMSY when the SBR is somewhere in the range 0.3 to 0.5, and that some fish populations are not able to produce the AMSY if the spawning biomass during a period of exploitation is less than about 0.2. Unfortunately, the types of population dynamics that characterize tuna populations have generally not been considered in these studies, and their conclusions are sensitive to assumptions about the relationship between adult biomass and recruitment, natural mortality, and growth rates. In the absence of simulation studies that are designed specifically to determine appropriate SBR-based reference points for tunas, estimates of SBR_t can be compared to an estimate of SBR for a population that is producing the AMSY ($\text{SBR}_{\text{AMSY}} = S_{\text{AMSY}}/S_{F=0}$). S_{AMSY} is the spawning biomass at AMSY (see Section 5.3 for details regarding calculation of AMSY and related quantities).

Estimates of SBR for bigeye in the EPO have been computed from the basecase assessment. Estimates of the spawning biomass during the period of harvest are presented in Section 4.2.2. The equilibrium spawning biomass of an unexploited population is estimated to be about 159,000 t, with lower and upper confidence limits (± 2 standard deviations) of about 137,000 t and 182,000 t. The SBR that would be expected if the stock were producing the AMSY (SBR_{AMSY}) is estimated to be about 0.18. This is much lower than the previous assessment due to changes in the assumptions regarding maturity, fecundity, and natural mortality. These changes also change our interpretation of trends in SBR from previous assessments.

At the beginning of January 2003, the spawning biomass of bigeye tuna in the EPO was slightly less than that in 1975 and higher than had been observed for several years. At this time the SBR was about 0.27, with lower and upper confidence limits (±2 standard deviations) of about 0.15 and 0.39. As the lower bound is only slightly less than 0.18, the spawning biomass of bigeye in the EPO was likely greater than the level required if the stock was to produce the AMSY.

A time series of SBR estimates for bigeye tuna in the EPO is shown in Figure 5.1. At the start of 1975, the SBR was about 0.35 (Figure 5.1). This is consistent with the fact that the stock of bigeye in the EPO was being utilized for a long period prior to 1975 and that the spawning biomass is made up of older individuals that may be more quickly removed from an exploited population. The SBR increased during 1983-1987 and by the beginning of the first quarter of 1987 was 0.45 (Figure 5.1). This increase can be attributed to the large cohorts that were recruited during 1982 and 1983 (Figure 4.9) and to the relatively small catches that were taken by the surface fisheries during this time (Figure 2.2, Fisheries 1 and 6). This peak in spawning biomass was soon followed by a peak in the longline catch (Figure 2.2, Fishery 9). After 1987 the SBR decreased to a level of about 0.20 by the first quarter of 1999 (Figure 5.1). This depletion can be attributed mostly to a long period (1984-1993) during which recruitment was low. Also it should be noted that the southern longline fishery took relatively large catches during 1985-1995 (Figure 2.2, Fishery 9). In 2000 the SBR increased to a level of about 0.31 by the first quarter of 2002 (Figure 5.1). This increase can be attributed to the relatively high levels of recruitment that are estimated to have occurred during 1997 (Figure 4.9). During the later part of 2002 the SBR decreased rapidly due to the weak year classes during 1998 – 2001 and the higher catches fromsurface fisheries.

The SBR estimates are reasonably precise; the average CV of these estimates is about 0.17. The relatively narrow confidence intervals (±2 standard deviations) around the SBR estimates suggest that for most quarters during January 1975 to January 1997 the spawning biomass of bigeye in the EPO was probably greater than the level that would be expected to occur if the population were producing the AMSY (Section 5.3). This level is shown as the dashed line drawn at 0.18 in Figure 5.1.

Estimates of the average SBR projected to occur during 2003-2007 are also presented in Figure 5.1 (see Section 6 for additional detail regarding the projections). The projection results indicate that the SBR is likely to reach an historic low level in 2006 and remain below the level that would be expected if the population were producing the AMSY until well after 2008. This decline is likely to occur regardless of environmental conditions and the amounts of fishing that occur in the near future because the projected estimates of SBR are driven by the small cohorts that were produced during 1999 to 2001 (Figure 4.9).

5.2. Assessment of stock status based on yield per recruit

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

Using the natural mortality and growth curves from the basecase assessment (Figures 3.1 and 4.13 respectively), the critical weight for bigeye tuna in the EPO is estimated to be about 54.7 kg. This is larger than previous estimates due to changes in natural mortality assumed in this assessment. The critical age of 18 quarters is less than the age at which 50% of females are assumed to be mature. This occurs because the critical age and yield-per-recruit calculations do no consider maturity, fecundity, or stock recruitment relationships.

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

5.3. Assessment of stock status based on AMSY

Maintaining tuna stocks at levels capable of producing the AMSY is the management objective specified by the IATTC Convention. One definition of the AMSY is the maximum long-term yield that can be achieved under average condition, 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 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 basecase 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 calculations were computed with the parameter estimates from the basecase assessment and estimated fishing mortality patterns averaged over 2000 and 2001. Therefore, while these AMSY-based results are currently presented as point estimates, there are uncertainties in these results. While analyses to present uncertainty in the basecase estimates were not undertaken as in the 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 2003, the biomass of bigeye tuna in the EPO appears to have been about 25% less than the level that would be expected to produce the AMSY (Table 5.1). However, the recent catches are estimated to have been about 40% above the AMSY level.

If fishing mortality is proportional to fishing effort, and the current patterns of age-specific selectivity (Figure 4.5) are maintained, the level of fishing effort that is estimated to produce AMSY is about 79% of the current level of effort (F multiplier in the list above). Decreasing effort by 21% of its present level would only increase the long-term average yield by about 2%, but would increase the spawning potential of the stock by about 50% (Figure 5.3). The results of the sensitivity analysis (section 5.4) give the results of an assessment with a stock-recruitment relationship.

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

Estimates of the AMSY, and its associated quantities, are sensitive to the age-specific pattern of selectivity that is used in the calculations. The AMSY-based quantities described previously were based on an average selectivity pattern for all fisheries combined (calculated from the current allocation of effort among fisheries). Different allocations of fishing effort among fisheries would change this combined selectivity pattern. To illustrate how the AMSY might change if the effort is reallocated among the various fisheries that catch bigeye in the EPO, the previously-described calculations were repeated using the age-specific selectivity pattern estimated for each fishery. If an additional management objective is to maximize the AMSY, the southern longline fishery (Fishery 9) would perform the best, and the floating-object fisheries (Fisheries 2-5) would perform the worst (Table 5.3). If the management objective is to maximize S_{AMSY}, the fishery that has recently been catching bigeye from unassociated schools of tuna (Fishery 7) would perform the best, followed by the southern longline fishery (Fishery 9) (Table 5.3). However, Fishery 7 catches very few bigeye, and would require an unrealistically high increase in effort (97 times) to remove AMSY; therefore the results of Fishery 7 will be ignored. The surface fisheries that catch bigeye by making purse-seine sets on floating objects (Fisheries 2-5) also perform the worst at maximizing S_{AMSY}.

The southern longline fishery (Fishery 9) is closest to simultaneously satisfying the objectives of maximizing the AMSY and S_{AMSY}. Changing the current allocation of fishing effort so that only one type of fishery would continue to operate in the EPO is unrealistic, given the diverse nature of the fleet and the commercial importance of the other tuna species.

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 detrimentally 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 calculating the lifetime reproductive potential for each age class. If a fish of a given age is not caught it has an expected (average over many fish of the same age) lifetime reproductive potential (*i.e.* the expected number of eggs that a fish will produce over its remaining lifetime). This value is a function of the fecundity of the fish at the different stages of its remaining life and the natural and fishing mortality it is subjected to. The higher the mortality, the less likely the individual is to survive and continue reproducing. Younger individuals may appear to have more time in which to reproduce, and therefore greater lifetime reproductive potential; however, because younger individuals have a greater rate of natural mortality their remaining expected lifespan is less. An older individual, which has survived through the ages for which mortality is high, has a higher expected lifespan, and thus may have a higher lifetime reproductive potential. Mortality rates may be greater at the oldest ages and reduce the expected lifespan of these ages, thus reducing lifetime reproductive potential. Therefore, the age of maximum lifetime reproductive potential may be at an intermediate age. Calculations are made for each quarterly age-class to calculate the lifetime reproductive potential. Because current fishing mortality is included, the calculations are based on marginal changes (*i.e.* the change in egg production if one individual or one unit of weight is removed from the population), and any large changes in catch would produce somewhat different results because of changes in the future fishing mortality rates. In the calculations the average fishing mortality at age over 2000 and 2001 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 25 quarters (Figure 5.4, upper panel). These calculations suggests that restricting catch from fisheries that capture old bigeye would provide the most benefit to the spawning biomass. However, this is not a fair comparison because an individual of age 25 quarters is considerably heavier than an individual recruiting to the fishery at age 2 quarters. The calculations were repeated based on avoiding capturing one unit of weight. If fishing avoids catching a single unit of weight, the most benefit to the spawning biomass would be achieved by avoiding catching fish recruiting to the fishery at age 2 quarters (Figure 5.4, lower panel). These calculations suggest that restricting catch from fisheries that capture young bigeye would provide the most benefit to the spawning biomass. The results also suggest that reducing catch by one ton of young bigeye will protect approximately the same amount of spawning biomass as reducing the catch of old bigeye by about two tons.

5.5 MSYref and SBRref

Section 5.3 discusses how MSY and the SBR at MSY are dependent on the selectivity of the different fisheries and the effort distribution among these fisheries. MSY can be increased or deceased applying more effort to one fishery or another. If the selectivity of the fisheries could be modified at will, there is an optimum yield that can be obtained (Global MSY Beddington and Taylor 1973; Getz 1980; Reed 1980). Maunder (2002b) showed that the optimal yield can be approximated (usually exactly) by applying a full or partial harvest at a single age. Maunder (2002b) termed this harvest MSY_{ref} and suggested that two thirds of MSY_{ref} may be an appropriate limit reference point (e.g. effort allocation and selectivity patterns should produce MSY that is at or above $\frac{2}{3} MSY_{ref}$). The two thirds suggestion was based on analyses in the literature 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 higher 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 where 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 in 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 calculated 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 143,967 metric tons and SBR_{ref} is estimated to be 0.04 (Figure 5.5). The low SBR_{ref} is a function of the lack of inclusion of a stock recruitment relationship in the basecase model. This is also consistent with the critical age (18 quarters) being less than the age at which 50% of the females are assumed to be mature. MSY at the current effort allocation is only 47% of MSY_{ref}. If the fishery was only exploited assuming the same selectivity pattern as Fishery 9 (southern longline fishery) MSY would be 85% of MSY_{ref}. More research is needed to determine if reference points based on MSY_{ref} and SBR_{ref} are appropriate. MSY_{ref} assuming a stock recruitment relationship is compared in Section 5.6.

5.6. Sensitivity to alternative parameterizations and data

Yields and reference points are moderately sensitive to alternative model assumptions, input data, and the periods assumed for fishing mortality. The basecase used average fishing mortality for 2000 and 2001.

Including a stock recruitment model with a steepness of 0.75, the SBR required if the population was produceg AMSY is estimated to be at 0.29 compared to 0.18 for the basecase and 0.36 for the previous assessment (Maunder and Harley 2002) (Table 5.1). This value does not change much for any of the other sensitivity analyses. The sensitivity analyses for steepness and the re-weighting estimate *F* multipliers less than the basecase (0.53 and 0.54 respectively) while others are higher but only the Korean longline sensitivity estimates a values greater than 1 (1.08) (Table 5.1 and Figures B.4, C.4, D.4, E.4, and F.4). This analysis also estimates a MSY 16% higher than the basecase.

The *F* multiplier is much more sensitive than other management quantities to the periods for fishing mortality assumed in the calculations (Tables 5.2, H.1, and H.2, and Figures H.1 and H.2). Assuming recent (2001 and 2002) fishing mortality estimates gives much lower *F* multipliers (basecase = 0.57), and using the 1999 and 2000 estimated fishing mortalities gives *F* multipliers slightly above 1. Under recent fishing mortalities, all sensitivity analyses estimate *F* multipliers much less than one – the most optimistic sensitivity analysis predicts that fishing effort should be reduced by 17%. If effort for the longline fisheries is assumed to remain constant and the *F* multiplier only estimated for the purse seine fisheries the estimate is 0.03, suggesting that effort should be reduced by 97% for these fisheries.

5.7. Summary of stock status

At the beginning of January 2003, the spawning biomass of bigeye tuna in the EPO was beginning to decline from a recent high level. At that time the SBR was about 0.27, about 49% greater than the level that would be expected to produce the AMSY, with lower and upper confidence limits (± 2 standard deviations) of about 0.15 and 0.39. The estimate of the lower confidence bound is only slightly less than the estimate of SBR_{AMSY} (0.18), suggesting that, at the start of January 2003, the spawning biomass of bigeye in the EPO was greater than the level that is required to produce the AMSY.

The relatively narrow confidence intervals (±2 standard deviations) around the SBR estimates suggest that for most quarters during January 1975 to January 1997 the spawning biomass of bigeye in the EPO was probably greater than the level that would be expected to occur if the population were producing the AMSY. This level is shown as the dashed line drawn at 0.18 in Figure 5.1.

Estimates of the average SBR projected to occur during 2003-2007 (Figure 5.1) indicate that the SBR is likely to reach an historic low level in 2006 and remain below the level required if the population were to produce the AMSY until 2007 and probably after that. This decline is likely to occur regardless of environmental conditions and the amounts of fishing that occur in the near future because the projected estimates of SBR are driven by the small cohorts that were produced during 1998 to 2000.

The average weight of fish in the catch of all fisheries combined has been below the critical weight (about 54.7 kg) since 1993, suggesting that the recent age-specific pattern of fishing mortality is not satisfactory from a yield-per-recruit perspective.

The distribution of effort among fishing methods affects both the equilibrium yield per recruit and the equilibrium yield. When floating-object fisheries take a large proportion of the total catch, the maximum possible yield per recruit is less than that when longline catches are dominant. Also, if longline catches are dominant, the maximum yield per recruit (or a value close to it) can be obtained over a wide range of *F* multipliers. When floating-object fisheries take a large proportion of the total catch, a more narrow range of *F* multipliers provides a yield per recruit that is close to the maximum. When floating-object fisheries take a large proportion of the total catch and a stock-recruitment relationship exists, extremely large amounts of fishing effort would cause the population to crash. When longline catches are dominant, the population can sustain substantially greater fishing mortality rates. These conclusions are valid only if the age-specific selectivity pattern of each fishery is maintained.

Recent catches are estimated to have been about 40% above the AMSY level. If fishing mortality is proportional to fishing effort, and the current patterns of age-specific selectivity are maintained, the level of fishing effort that is estimated to produce AMSY is about 79% of the current level of effort. Decreasing the effort to 79% of its present level would only increase the long-term average yield by 2%, but such an action would increase the spawning potential of the stock by about 50%. The catch of bigeye by the surface fleet may be determined largely by the strength of recruiting cohorts. Thus, the catches of bigeye taken by the surface fleet will probably decline when the large cohorts recruited during 1995-1998 are no longer vulnerable to the surface fisheries. 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.

With the exception of the steepness sensitivity, analyses suggest that at the start of 2003 the spawning biomass was above the level that would be present if the stock were producing the AMSY. MSY and the *F* multiplier are sensitive to how the assessment model is parameterized, the data that are included in the assessment, and the periods assumed to represent average fishing mortality.

Estimates of the average SBR projected to occur during 2003-2007 are also presented in Figure 5.1. The projection results indicate that the SBR is likely to reach an historic low level in 2006 and remain below the level that would be expected if the population were producing the AMSY until well after 2008. This decline is likely to occur regardless of environmental conditions and the amounts of fishing that occur in the near future because the projected estimates of SBR are driven by the small cohorts that were produced during 1999 to 2001

6. SIMULATED EFFECTS OF FUTURE FISHING OPERATIONS

A simulation study was conducted to gain further understanding of 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 hypothetical 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. One hundred and one simulations were conducted for each of the scenarios outlined in Sections 6.1 and 6.2. The simulations discussed throughout the following subsections were conducted for a time span of five years, covering the period of 2003 through 2007 (with quarterly time steps). These types of simulations were also conducted in previous assessment of bigeye by Watters and Maunder (2001, 2002). This method is used for the basecase assessment and some sensitivity analyses.

In addition to the basecase assessment, a sensitivity analysis to the assumptions used in the calculation of the catchability used in the projections is included. The difference between the analyses is the period over which the effort deviates are taken. In the basecase assessment, the future catability is calculated as the average catchability multiplied by the average effort deviates by quarter for 2000 and 2001. In the sensitivity analysis, two alternatives were considered, (1) assuming average catchability with effort deviates for 1999 and 2000, and (2) average catchability with effort deviates from 2001 and 2002.

In addition to the method used in previous assessment, a new method has been applied based on the normal approximation to the likelihood profile. The previously used method does not take parameter uncertainty into consideration. It only considers 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 in the estimates of the current status. This uncertainty should be considered in any forward projections. Unfortunately, the appropriate methods are often not applicable to models as large and computationally intense as the bigeye stock assessment model. Therefore, we have used a normal approximation to the likelihood profile which allows for the inclusion of both parameter uncertainty and uncertainty about future recruitment. This method is implemented by extending the assessment model an additional 5 years with effort data based on the average over 2001 and 2002, by quarter, and catchability and effort deviates for 2000 and 2001 (again by quarter). These are the same assumption as used in the standard method for projections. No catch or length-frequency data is included for these years and the projections are based on the average catchability estimated (within the projection model) over the period 1975-2002. The recruitment 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. The descriptions below only refer to the method used in previous assessments.

6.1. Assumptions about fishing operations

6.1.1. Fishing effort

The following scenarios have been specified to describe the hypothetical amount of fishing effort that might be exerted by the surface fleet during 2003-2007.

1. The surface fleet will exert an amount of effort that is equal to 75% of the average amount of effort it exerted during 2001-2002.
2. The surface fleet will exert an amount of effort that is equal to the average amount of effort it exerted during 2001-2002.
3. The surface fleet will exert an amount of effort that is equal to 125% of the average amount of effort it exerted during 2001-2002.
4. The surface fishery will not discard small bigeye tuna, i.e. Fisheries 10 – 13 will have zero effort.

These scenarios are based on quarterly levels of fishing effort. For example, in the first scenario, the effort during the fourth quarters of 2003, 2004, 2005, 2006, and 2007 is equal to 75% of the average effort exerted during the fourth quarters of 2001 and 2002.

All of the simulations were conducted under the assumption that, from 2003 through 2007, the longline fleet will exert an amount of effort equal to the amount of effort it exerted during 2000 and 2001 (again by quarter).

6.1.2. Selectivity and catchability

Two assumptions were made about selectivity (the age-specific component of fishing mortality). First, it was assumed that the selectivity curve for each fishery included in the simulation study does not change during the course of the simulation. Second, it was assumed that the selectivity curve for each fishery included in the simulation is same as that estimated by the stock assessment model (*i.e.* the selectivity curves are the same as those shown in Figure 4.5).

It was further assumed that, for each fishery included in the simulation, the catchability of bigeye tuna does not change during the course of the simulation. Determination of future levels of catchability for are described in Section 6.

6.1.3. Discards

Two scenarios have been specified to describe the future status of discarded bigeye. In the first scenario, it is assumed that all discarded bigeye will die. In the second scenario, it is assumed either that there are no discards because the fish that are usually discarded will not be caught or, equivalently, that all discarded bigeye survive. The assumption of no discards is not intended to represent a scenario in which small fish are retained in the catch, as this has not been explicitly modeled in this simulation study. In most instances, assuming that small fish will be retained is equivalent to assuming that discarded fish will die. Therefore, readers interested in the results of retaining fish that would normally be discarded should consider the simulations conducted under the first scenario for describing the status of discards. It should also be noted, however, that future retention of small fish would cause the simulated catches taken by the primary surface fleet (Fisheries 2-5 and 7) to be underestimated.

6.2. Assumptions about population dynamics

The simulation study was conducted under the assumption that, in the future, the biological and demographic parameters that govern the population dynamics of bigeye tuna in the EPO will be similar to those that governed the dynamics of the stock during January 1975-January 2003. In particular, the stock-recruitment relationship, growth function, weight-length relationship, fecundity schedule, and natural mortality curve were assumed to be the same as those estimated by or used in the basecase stock assessment (Sections 3 and 4). As for the basecase assessment, it was also assumed that bigeye move around the EPO rapidly enough to ensure that the population is randomly mixed at the beginning of each quarter (Section 3.1.3), and that there is a single stock of bigeye in the EPO (see Section 3.1.5).

Stochasticity is added to each simulation by randomly sampling from a distribution of recruitment anomalies. These anomalies are assumed to come from the same distribution as those in the basecase assessment. It should be noted that the estimates of recruitment from the stock assessment model appear to be autocorrelated (Figure 4.7), but, in the simulation study, recruitment was not autocorrelated. Adding autocorrelation to the simulated time series of recruitment would cause the simulation results to be more variable.

6.3. Simulation results

The simulations were used to predict future levels of the SBR, the average weight of bigeye tuna in the catch of all fisheries combined, 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 6.1-6.4 and Table 6.1. The amount of uncertainty is probably underestimated because the simulations were conducted under the assumption that the parameters estimated by and used in the stock assessment model correctly describe the dynamics of the system. As mentioned in Section 4, this assumption is not likely to be fulfilled.

Unless stated otherwise, all comparisons will be based on comparing the 50% quartile for a sensitivity analysis to the corresponding 50% quartile for the average effort projections.

6.3.1. Predicted SBRs

Within the range of scenarios specified for the simulation study, future changes in the amount of fishing effort exerted by the surface fleet are predicted to have moderate effects on the SBR (Figure 6.1a and Table 6.1). Increasing the surface effort to 125% of its recent, average level is predicted to cause the median estimate of the SBR to decrease by about 28% by the end of 2007 (Table 6.1). Decreasing the surface effort to 75% of its recent average is predicted to increase the median estimate of the SBR by about 57% (Table 6.1).

As noted in Section 5.1, the SBR is projected to decrease throughout 2003, and is likely to be less than SBR_{AMSY} (0.18) through 2004 and continue to decline through 2005 (Figures 6.1a and 6.1b). This trend is due to the series of small cohorts that are estimated to have been recruited during 1998-2000 and the high fishing mortality of these cohorts (Figure 4.9). This decline will occur regardless of environmental conditions and the amount of fishing effort that is exerted during the next two years. The rate at which the spawning biomass subsequently increases after 2006 is projected to depend on future levels of surface-fishing effort, and increased levels of effort will cause any increase to occur more slowly (Figure 6.1a). It should be noted that average environmental conditions are assumed to occur throughout the period of the projection. If environmental conditions affect recruitment (as suggested by the results presented in Section 4.2.2), conditions during the next two years will only affect the degree to which the SBR increases after the end of the projection period.

If the surface fleet continues to exert an average amount of fishing effort, the SBR is predicted to be moderately sensitive to assumptions about the status of discarded bigeye tuna (Figure 6.1a and Table 6.1). If the small bigeye that are usually discarded are not captured, or if the discarded fish survive, the SBR is predicted to be about 14% greater than that predicted when the discarded bigeye are assumed to die (Table 6.1a). This suggests that preventing discards of small bigeye tuna from the catches taken around floating objects would increase the spawning biomass.

If parameter estimation uncertainty, plus uncertainty about future recruitment, is included in the analysis (see Section 6.5), the results for the projected SBR are substantially more uncertain (Figure 6.1b) but the 95% confidence intervals for SBR in 2005 – 2007 still do not encompass SBR_{AMSY}.

6.3.2. Predicted average weights of bigeye tuna in the combined catch

Within the range of scenarios specified for the simulation study, it is predicted that future changes in the amount of fishing effort exerted by the surface fleet will have moderate effects on the average weight of bigeye tuna caught by the fisheries operating in the EPO (Figure 6.2 and Table 6.1). Increasing the surface effort to 125% of its recent average is, after five years, predicted to cause the average weight of fish in the combined catch to decrease by about 14% (Table 6.1). Decreasing the surface effort to 75% of its recent average is predicted to increase the average weight of bigeye in the catch by about 23% (Table 6.1). Under all of the simulated effort scenarios, the average weight of fish in the combined catch taken during 2006 is predicted to be less than the critical weight (compare the estimated critical weight of about 54.7 kg to the 80% quantiles in Table 6.1). These results suggest that it will be difficult to maximize the yield per recruit without reducing the amount of effort exerted by the surface fisheries to levels less than 75% of the recent average.

If the fisheries that catch bigeye tuna in association with floating objects continue to expend an average amount of effort, preventing discards (or ensuring that discarded fish survive) will increase the average weight of fish in the combined catch by about 18% at the end of 2006 (Figure 6.2 and Table 6.1). This result is to be expected because the discard fisheries (Fisheries 10-13) catch a large number of small fish, and this influences the estimate of average weight. The important point, however, is that preventing discards will substantially increase the yield per recruit. It was previously concluded that a substantial reduction in the amount of surface fishing effort would be needed to maximize the yield per recruit, but this reduction can be more moderate if discards are prevented.

6.3.3. Predicted catches taken by the primary surface fisheries

If the future level of effort increases by 25%, the quarterly catches taken by the surface fleet during 2006 are predicted to decrease by 3% (Table 6.1). Similarly, if the future levels of fishing effort decrease by 25%, the quarterly catches taken by the surface fleet during 2006 are predicted to be only 7% less than those predicted under average levels of effort (Table 6.1). This decline with increased effort is consistent with the F multiplier being less than 1.

If the fisheries that catch bigeye tuna in association with floating objects continue to exert an average amount of effort, preventing discards (or ensuring that discarded fish survive) may increase the future catches of the surface fleet (Figure 6.3 and Table 6.1). Preventing discards would increase the quarterly surface catch during 2006 by about 5% (Table 6.1). Preventing discards can increase the catch taken by the surface fleet because an increased number of small fish would survive, and the total biomass of recruiting cohorts would increase from gains due to growth (Section 5.2).

6.3.4. Predicted catches taken by the longline fleet

The results from the simulation study suggest that future changes in the amount of effort exerted by the surface fleet can affect the catches by the longline fleet (Figure 6.4 and Table 6.1). The quarterly longline catch during 2006 is predicted to increase by about 18% if surface fishing effort is reduced to 75% of its recent average for the next 5 years (Table 6.1). Similarly, the quarterly longline catch during 2006 is predicted to decrease by about 27% if the surface fishing effort is increased to 125% of its recent average (Table 6.1).

The future catch taken by longline vessels is predicted to be moderately sensitive to whether the surface fleet continues to discard small bigeye while sorting the catches taken around floating objects (Figure 6.4 and Table 6.1). Preventing discards would not substantially affect the longline catch during 2006 (Table 6.1).

6.4. Sensitivity to the method used to calculate fishing mortality rates

The results of the projections are sensitive to the period averaged to calculate future catchability. The basecase assumes catchability (including effort deviates) for 2000 and 2001 – we have compared this to projections based on catchabilities in 1999 and 2000, and 2001 and 2002 (Tables H.3 and H.4 and Figures H.3 to H.6). Using catchabilities for 1999 and 2000 provides generally similar results but predicts slightly lower future catches and marginally higher SBR. Catchabilities for 2001 and 2002 predict much higher catches for the purse seine fisheries and lower longline catches. The SBR is reduced to almost half of that from the basecase projections. Using catchability for 2001 and 2002 with a steepness of 0.75 essentially sent to population to extinction.

6.5. Results using the normal approximation to the likelihood profile

In general the estimates from the normal approximation to the likelihood profile are the same as the estimates using the previous method as both use the same effort and catchability assumptions. The difference occurs in the confidence intervals which are much larger for the likelihood profile method. These estimates of the confidence intervals are more realistic because they include parameter uncertainty.

6.6. Summary of the simulation results

The small cohorts of bigeye tuna that were apparently recruited to the fisheries in the EPO during 1998-2000 should cause the SBR to decrease throughout 2003 and to be substantially less than SBR_{AMSY}. During 2003, the spawning biomass of bigeye in the EPO should decline to historically low levels and continue to decline further. This decline is predicted to occur regardless of the amount of fishing effort and environmental conditions that occur in the near future. The SBR is projected to further decrease during 2004-2006.

Future changes in the level of surface fishing effort are predicted to affect the SBR, the average weight of fish in the catch from all fisheries combined, and the total catch of the longline fleet. Increasing the level of surface fishing effort to 125% of its recent average is predicted to decrease the SBR, decrease the average weight of fish in the combined catch, increase the total catch taken by the surface fleet, and decrease the total catch taken by the longline fleet. Reducing the level of surface fishing effort to 75% of its recent average is predicted to have the opposite effects.

Preventing the discards of small bigeye tuna from catches taken around floating objects (or ensuring that discarded fish survive) would increase the SBR, the yield per recruit, the catch taken by the surface fleet, and the catch taken by the longline fleet. Thus, any measure that effectively reduces the kill of bigeye that are about 2-5 quarters old may help to achieve a variety of management objectives.

The sensitivity analysis indicates that if fishing mortality rates continue at their recent (2001 and 2002) levels, longline catches and SBR will decrease dramatically to extremely low levels. As the basecase does not include a stock recruitment model, recruitment will not decline so purse seine catches are predicted to stay at moderate levels.

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. New data collected during 2003 and updated data for 2002 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. Particularly we will attempt to obtain data for recently developed and growing fisheries.

The collection and analysis of bigeye otolith data from the EPO will help determine mean length at age and variation in length at age.

7.2. Refinements to the assessment model and methods

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

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

The likelihood profile method for performing projections will be further developed in an effort to replace the method used in previous assessments.

The IATTC staff will continue analyses of tagging data to examine hypotheses regarding rates of mixing and for integrating recapture data into the model to assist in estimation of fishing mortality rates.

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

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

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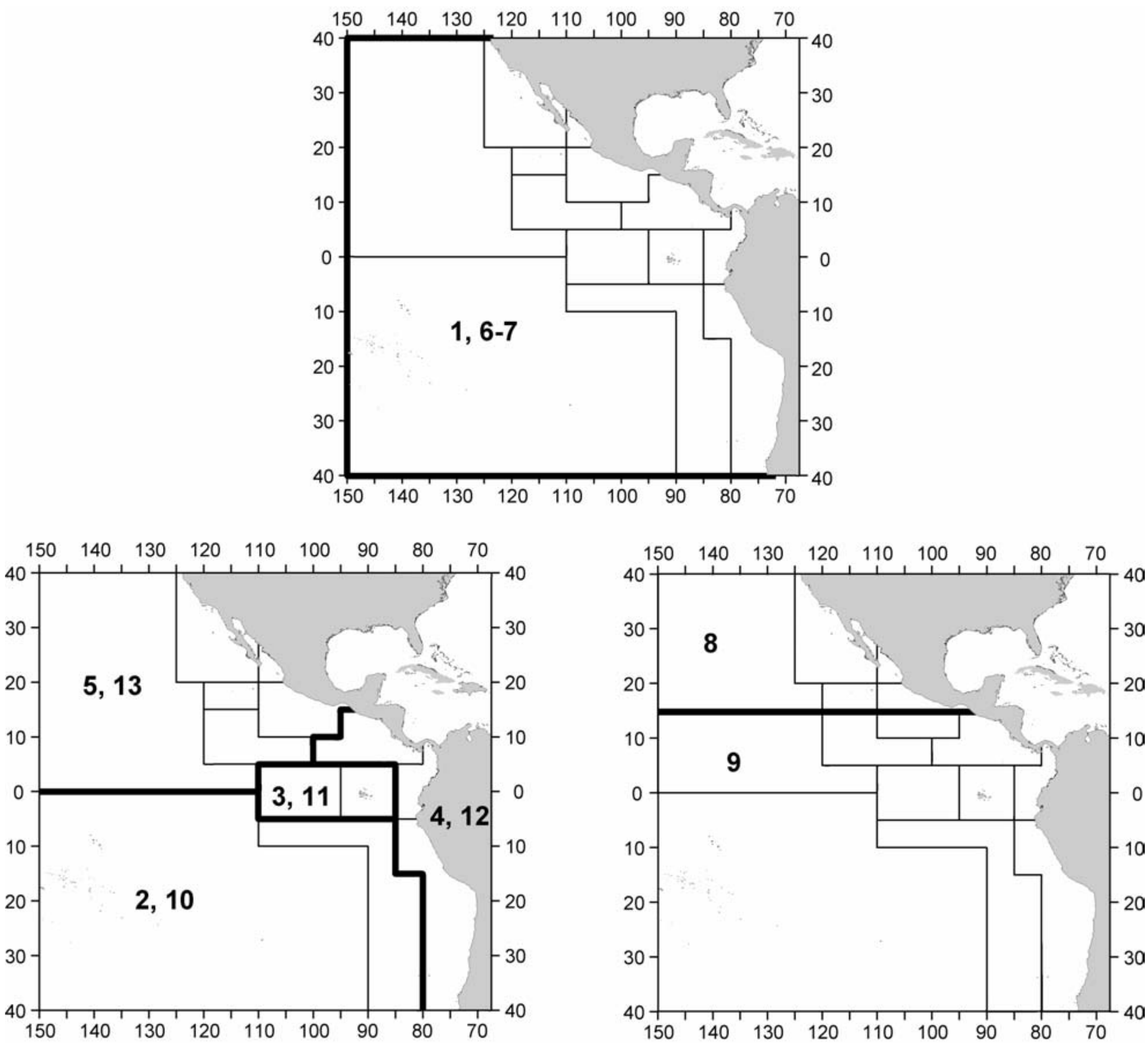

FIGURE 2.1. Spatial extents of the fisheries defined for the stock assessment of bigeye tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the bold numbers the fisheries to 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 del 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 del stock, y los números en negritas las pesquerías correspondientes a estos últimos límites. En la Tabla 2.1 se describen las pesquerías.

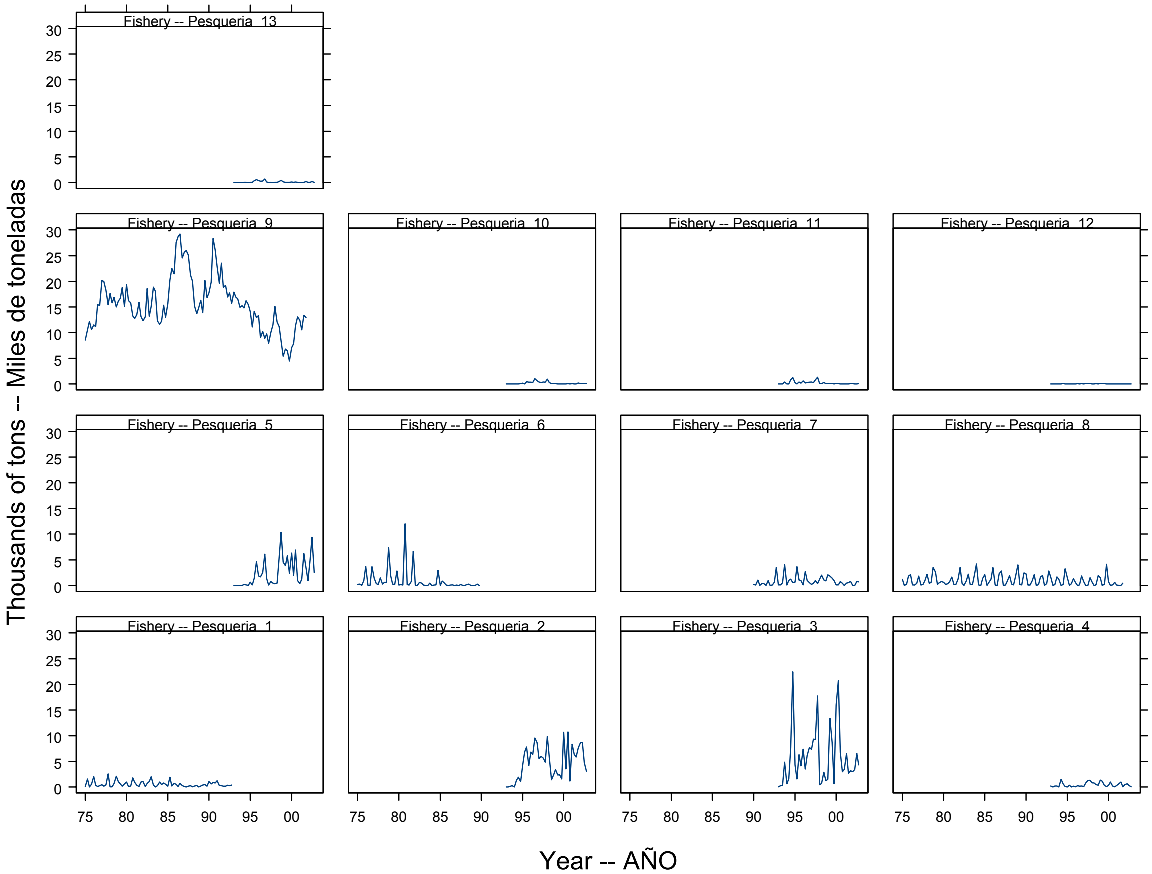

FIGURE 2.2. Catches taken by the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). Since the data were analyzed on a quarterly basis, there are four observations of catch for each year. Although all the catches are displayed as weights, the stock assessment model uses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

FIGURA 2.2. Capturas realizadas por las pesquerías definidas para la evaluación del stock de atún patudo en el OPO (Tabla 2.1). Ya que los datos fueron analizados por trimestre, hay cuatro observaciones de captura para cada año. Aunque se presentan todas las capturas como pesos, el modelo la evaluación usa capturas en número para las Pesquerías 8 y 9. Se estimaron las capturas en peso para las Pesquerías 8 y 9 multiplicando las capturas en número de peces por estimaciones del peso medio.

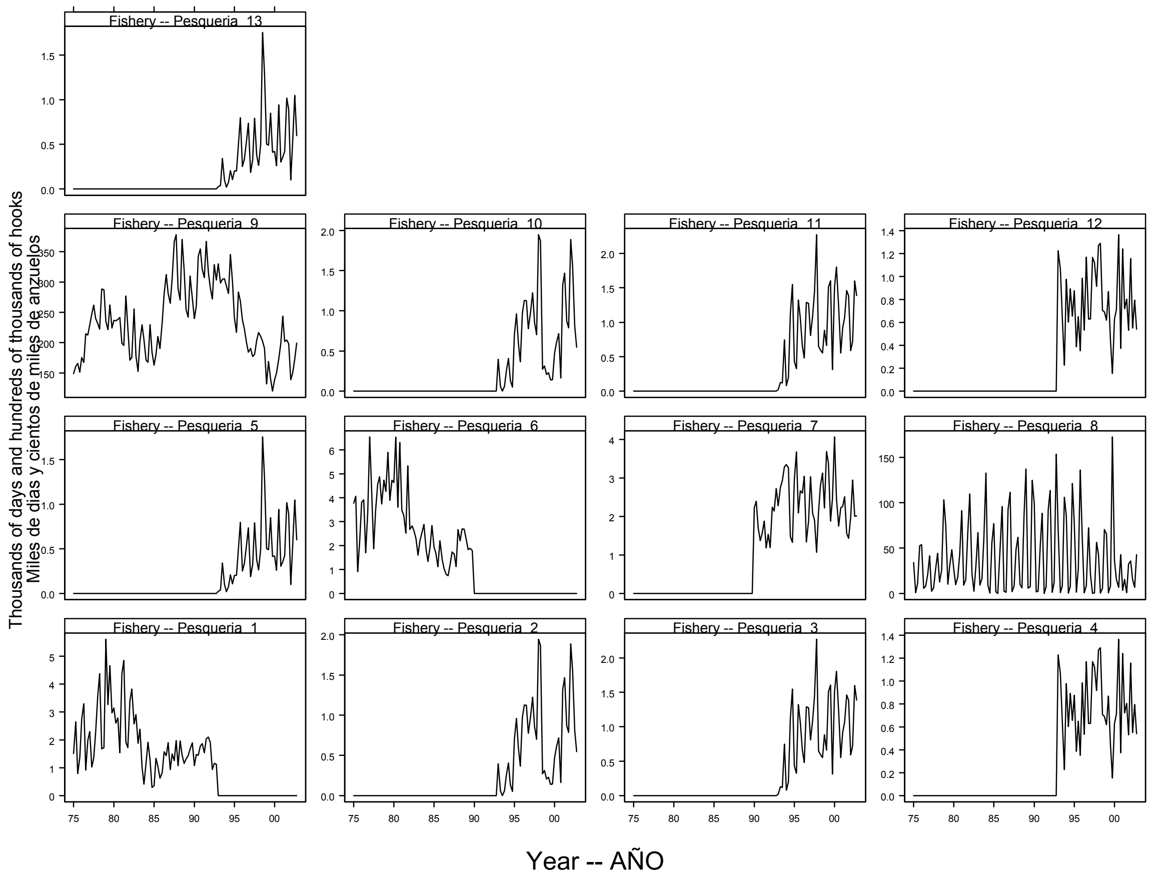

FIGURE 2.3. Fishing effort exerted by the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of effort for each year. The effort for Fisheries 1-7 and 10-13 is in days fished, and that for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

FIGURA 2.3. Esfuerzo de pesca ejercido por las pesquerías definidas para la evaluación del stock 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.

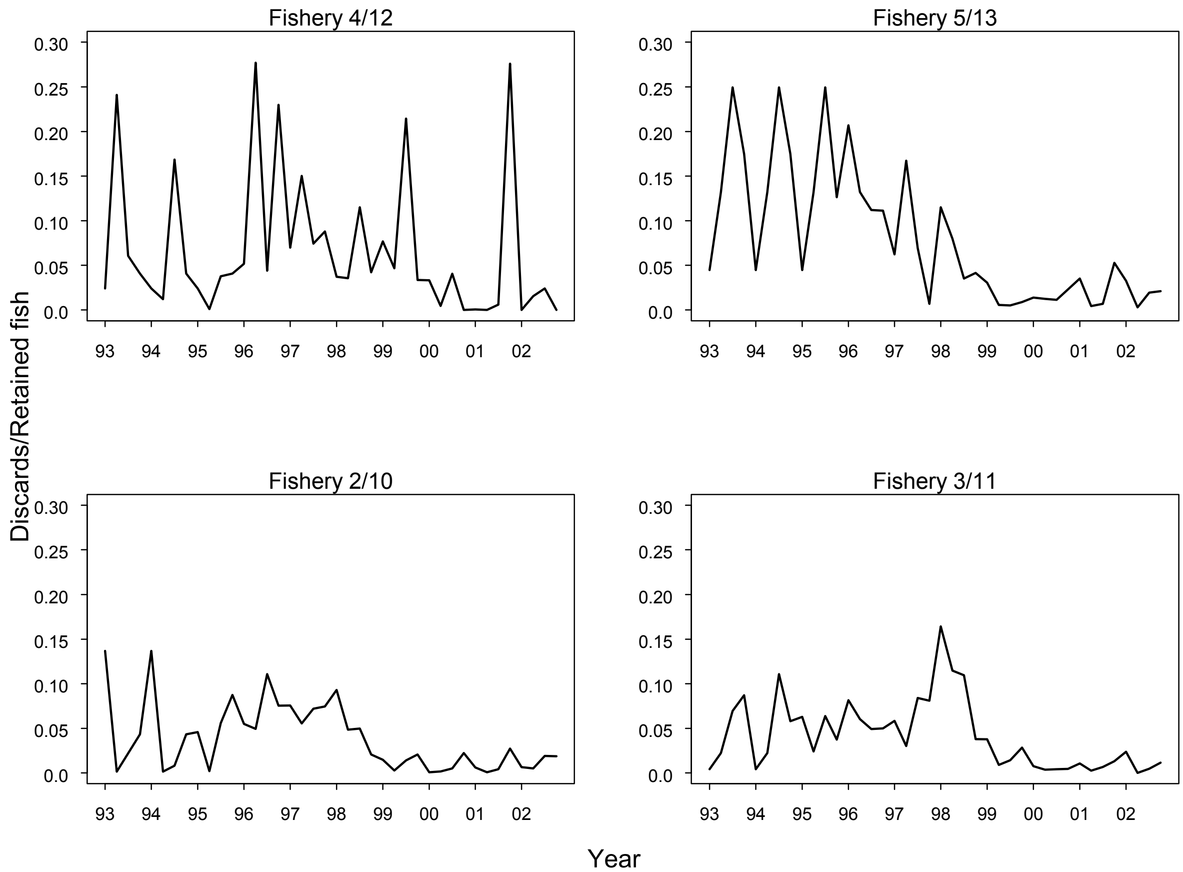

FIGURE 2.4 Weight of small discarded fish as a proportion of the retained match by quarter for the four floating object fisheries. The “real” and corresponding discard fisheries are noted.

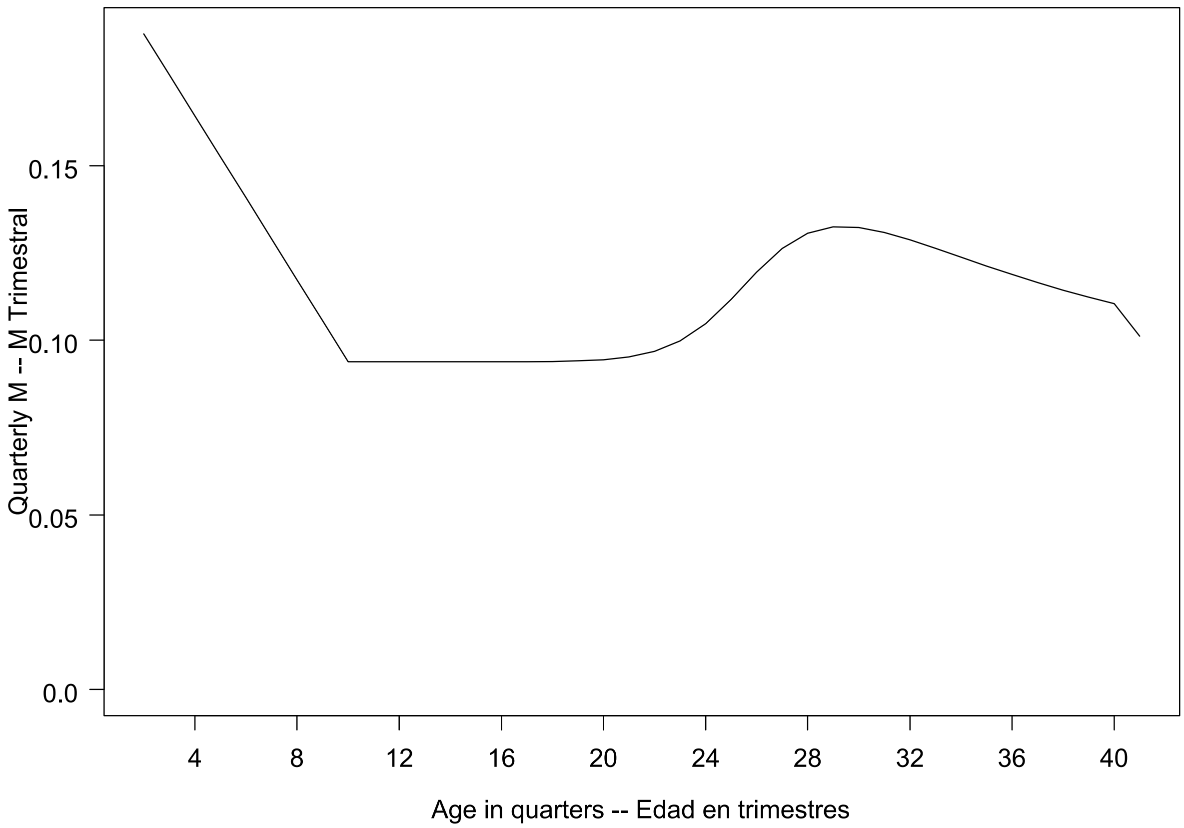

FIGURE 3.1. Quarterly natural mortality (*M*) rates used for the basecase assessment of bigeye tuna in the EPO.
FIGURA 3.1. Tasas de mortalidad natural (*M*) trimestral usadas para la evaluación del caso base de atún patudo en el OPO.

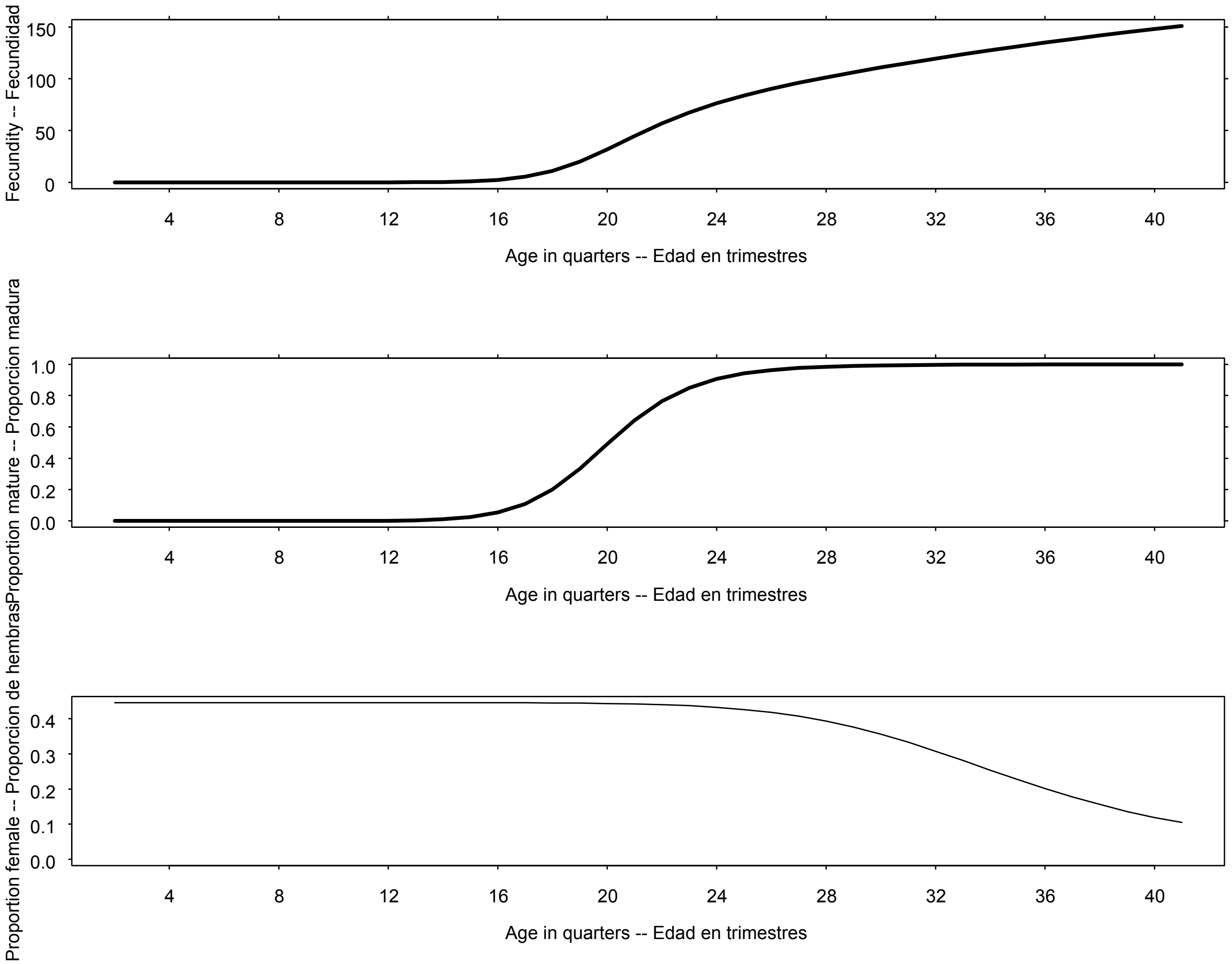

FIGURE 3.3. Age-specific fecundity (top panel), age-specific proportion of mature females (middle panel), and age-specific proportion of females in the population (bottom panel) as assumed in the bases-case model and estimation of natural mortality.

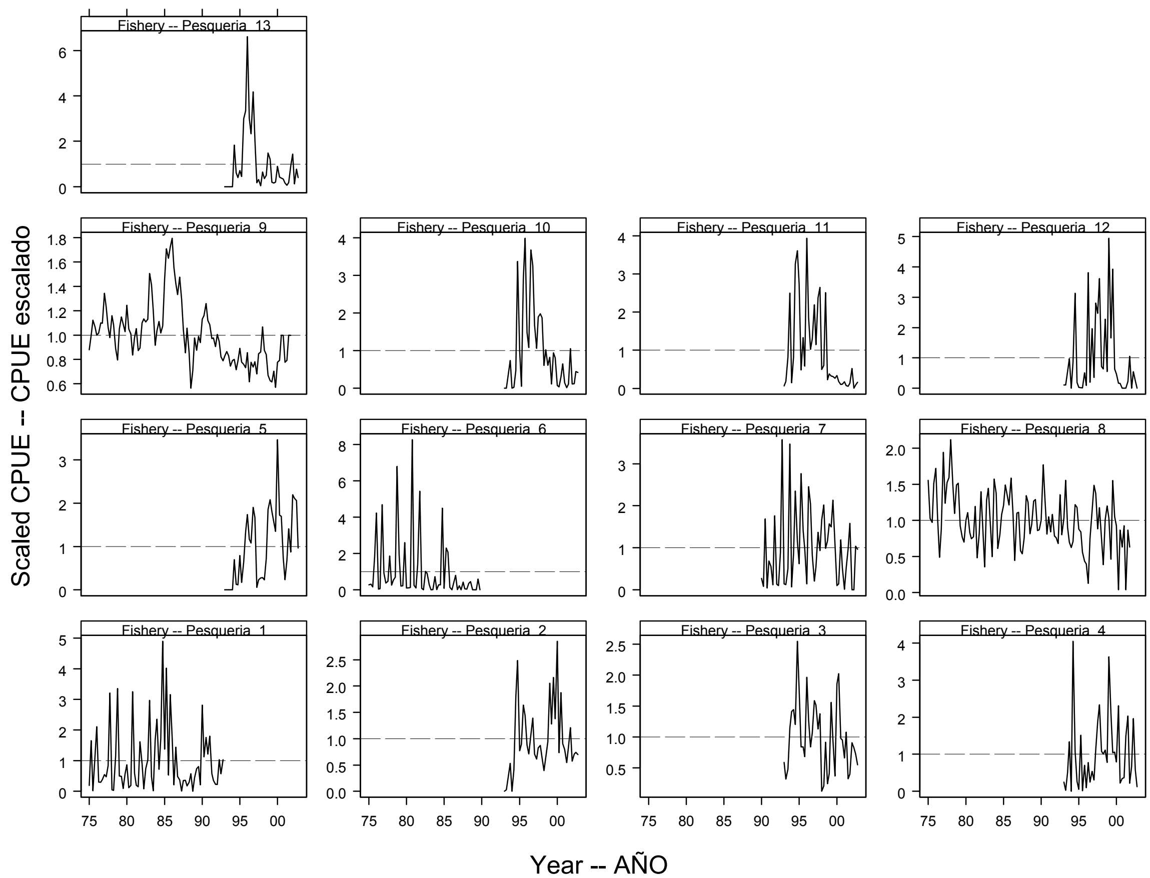

FIGURE 4.1. CPUEs of the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of CPUE for each year. The CPUEs for Fisheries 1-7 and 10-13 are in kilograms per day fished, and those for Fisheries 8 and 9 are in numbers of fish caught per standardized number of hooks. The data are adjusted so that the mean of each time series is equal to 1.0. Note that the vertical scales of the panels are different.

FIGURA 4.1. CPUE logradas por las pesquerías definidas para la evaluación del stock 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.

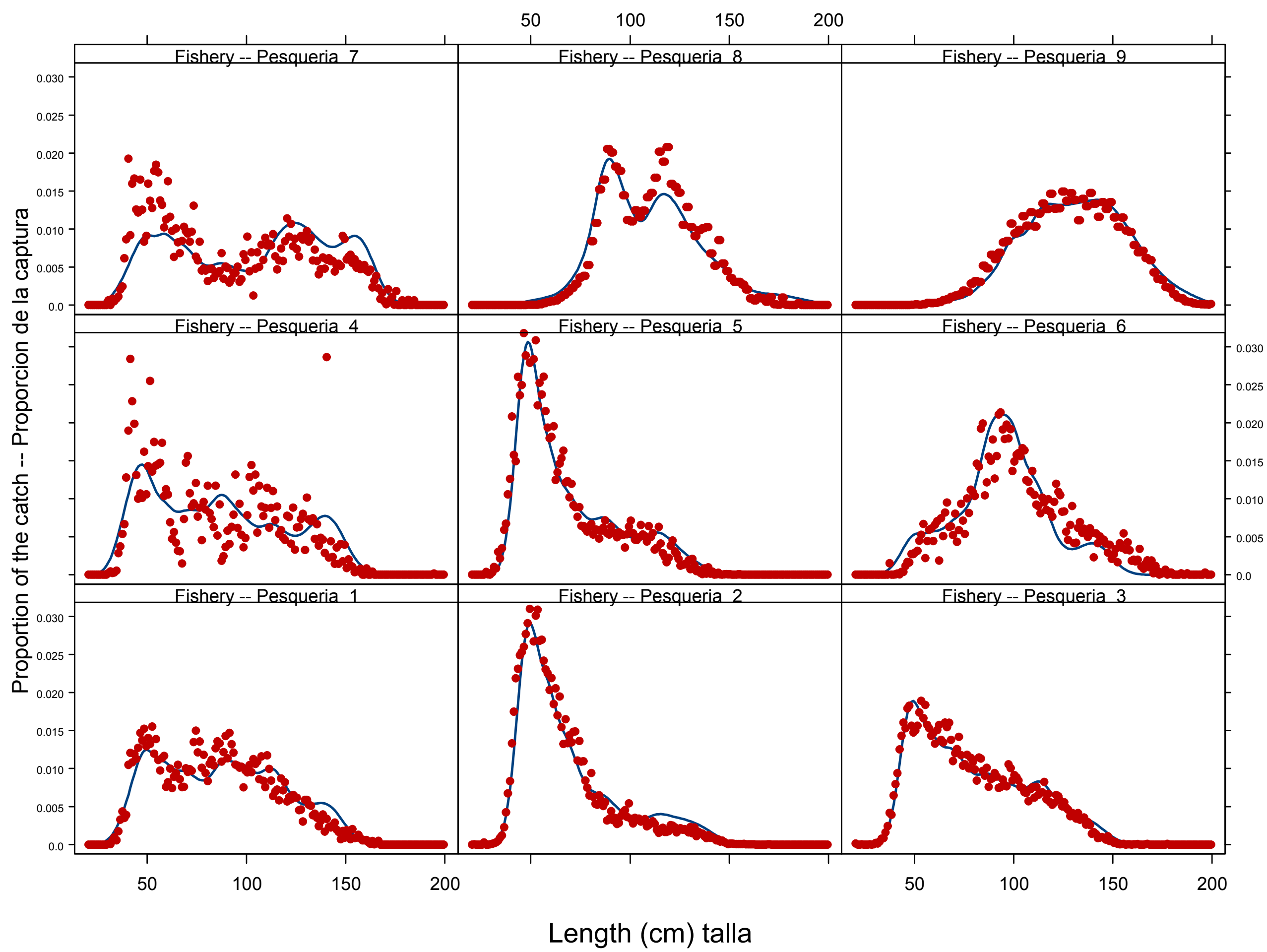

FIGURE 4.2. Average observed (solid circles) and predicted (curves) size compositions of the catches taken by the fisheries defined for the stock assessment of bigeye tuna in the EPO.

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

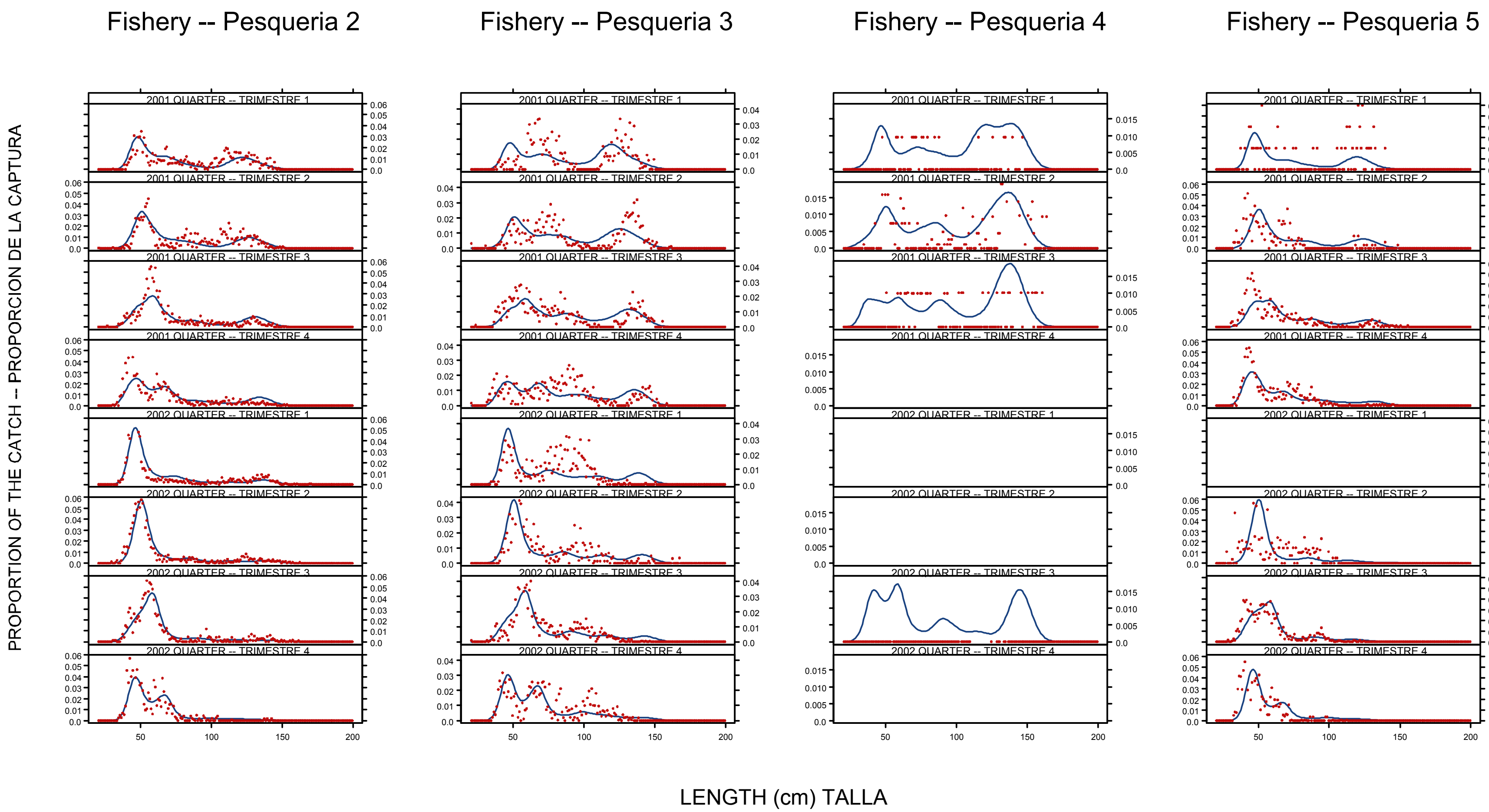

FIGURE 4.3a. Recent size compositions of the catches of bigeye tuna taken by the fisheries that operate in the EPO. The solid circles are observations and the curves are predictions from the basecase assessment.

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

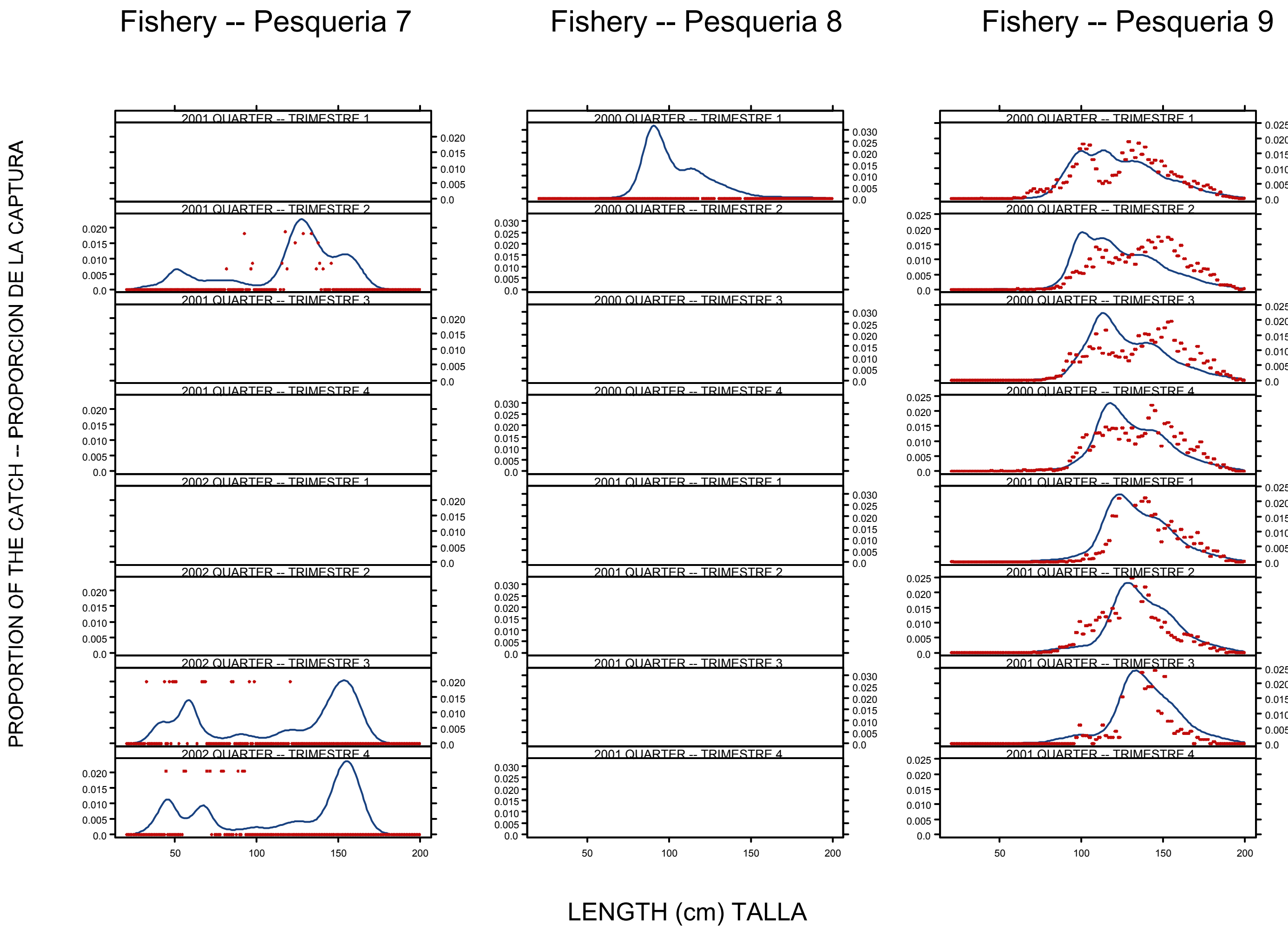

FIGURE 4.3b. Recent size compositions of the catches of bigeye tuna taken by the fisheries that operate in the EPO. The solid circles are observations and the curves are predictions from the basecase assessment.

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

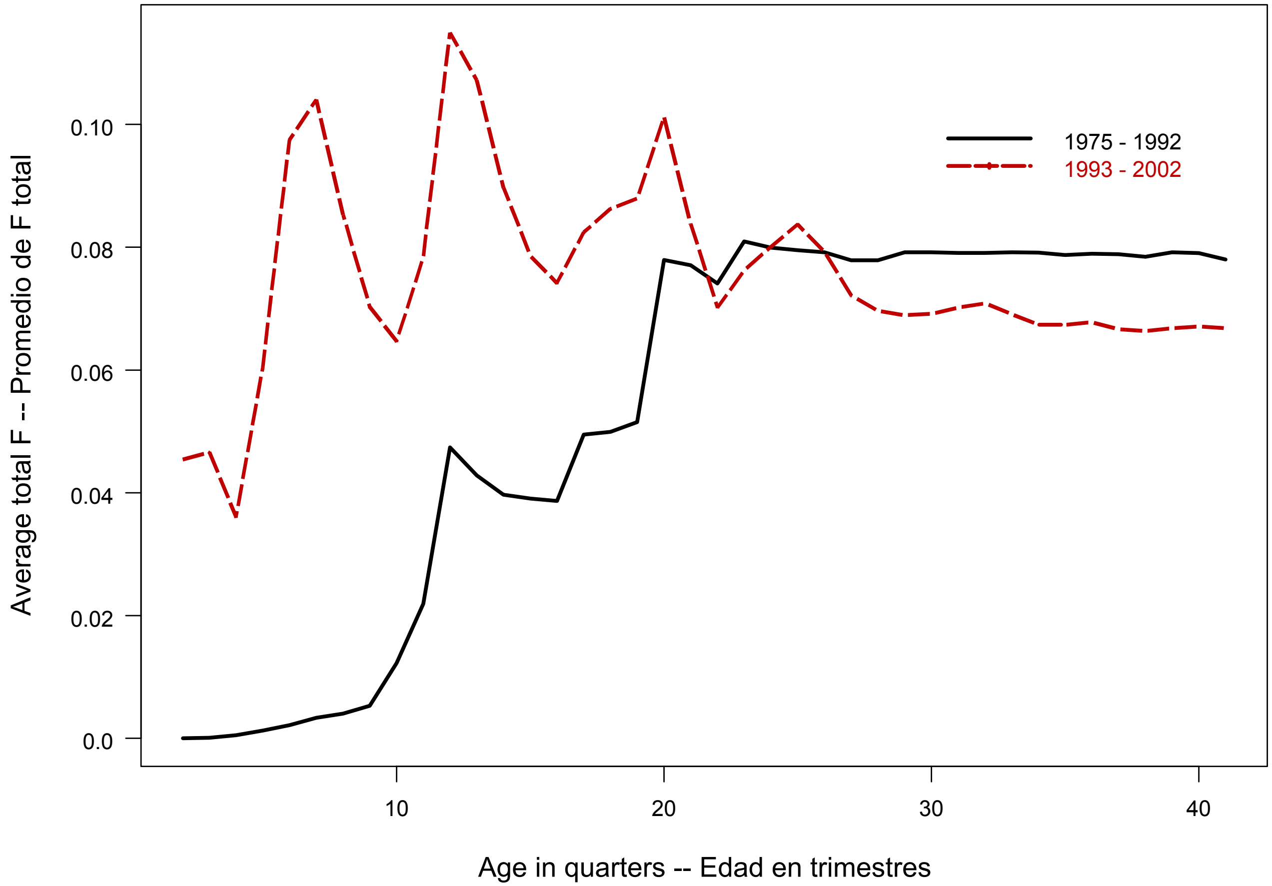

FIGURE 4.4. Average total quarterly fishing mortality at age on bigeye tuna in the EPO. The curve for 1975-1992 displays averages for the period prior to the expansion of the floating-object fisheries. The curve for 1993-2002 displays averages for the period since this expansion.
FIGURA 4.4. Mortalidad por pesca trimestral total media a edad sobre atún patudo en el OPO. La curva para 1975-1992 muestra los promedios para el período previo a la expansión de la pesquería sobre objetos flotantes. La curva para 1993-2002 indica los promedios para el periodo desde esta expansión.

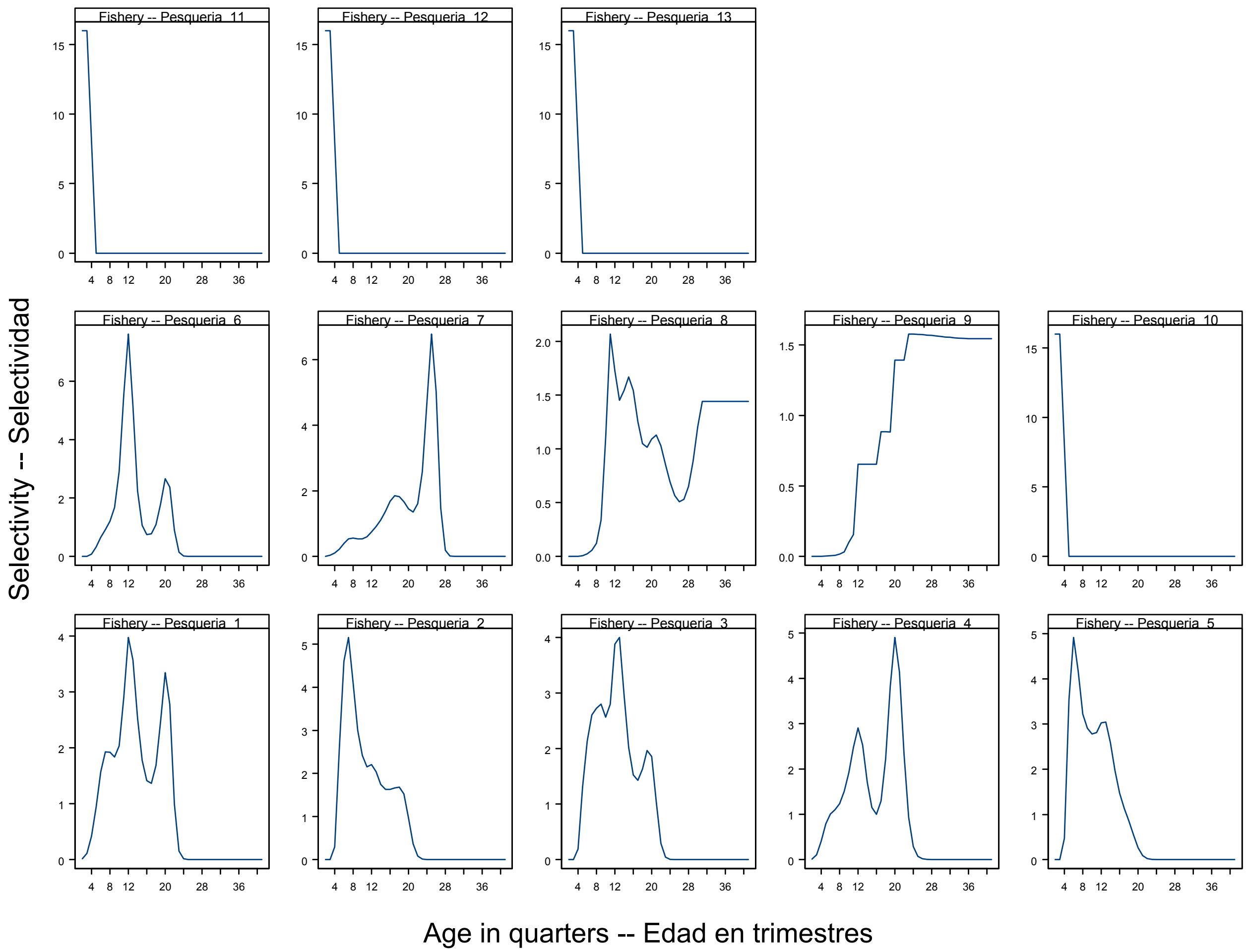

FIGURE 4.5. Selectivity curves for the 13 fisheries that take bigeye tuna in the EPO. The selectivity curves for Fisheries 1 through 9 were estimated with the A-SCALA method. The curves for Fisheries 10-13 are based on assumptions.
FIGURA 4.5. Curvas de selectividad para las 13 pesquerías que capturan atún patudo en el OPO. Se estimaron las curvas de selectividad de las Pesquerías 1 a 9 con el método A-SCALA; las de las Pesquerías 10-13 se basan en supuestos.

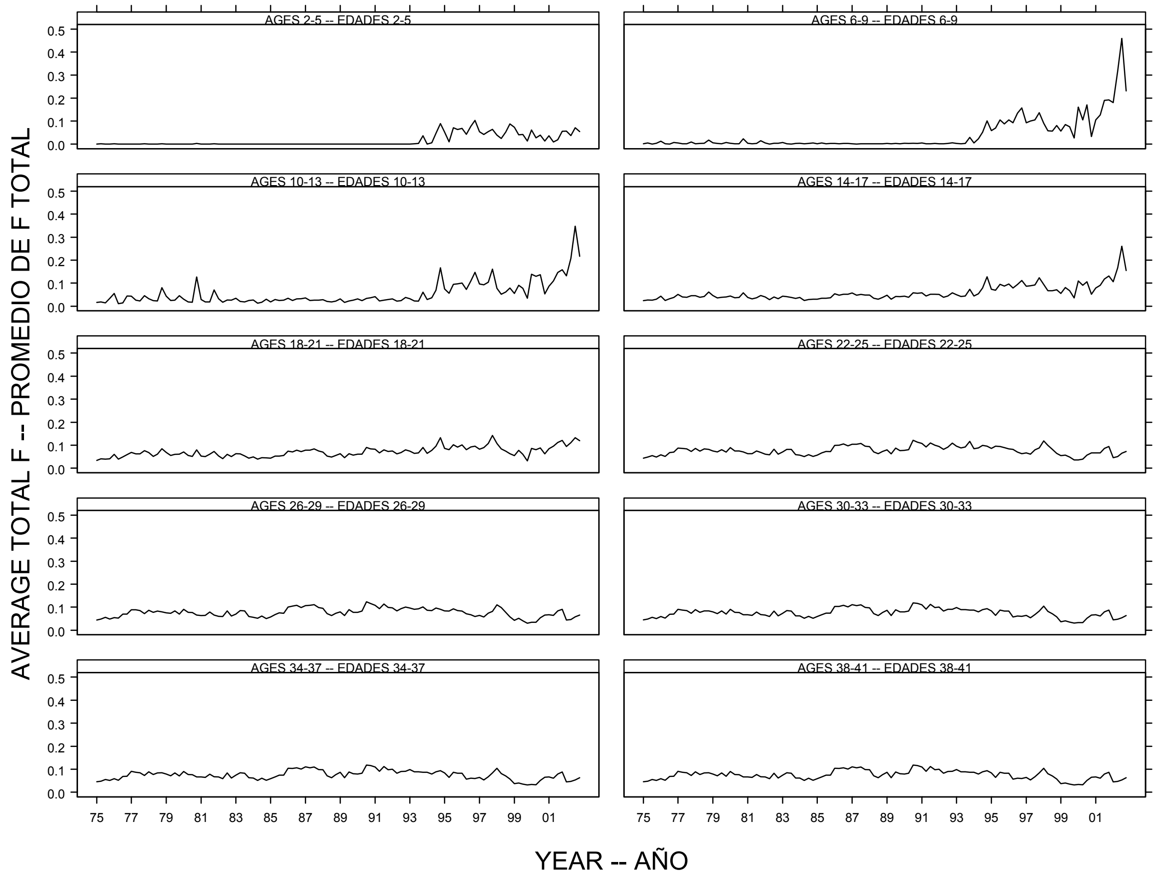

FIGURE 4.6a. Time series of average total quarterly fishing mortality on bigeye tuna that have been recruited to the fisheries of the EPO. Each panel illustrates an average of four quarterly fishing mortality vectors that affected the fish that were as old as the range of ages indicated in the title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

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

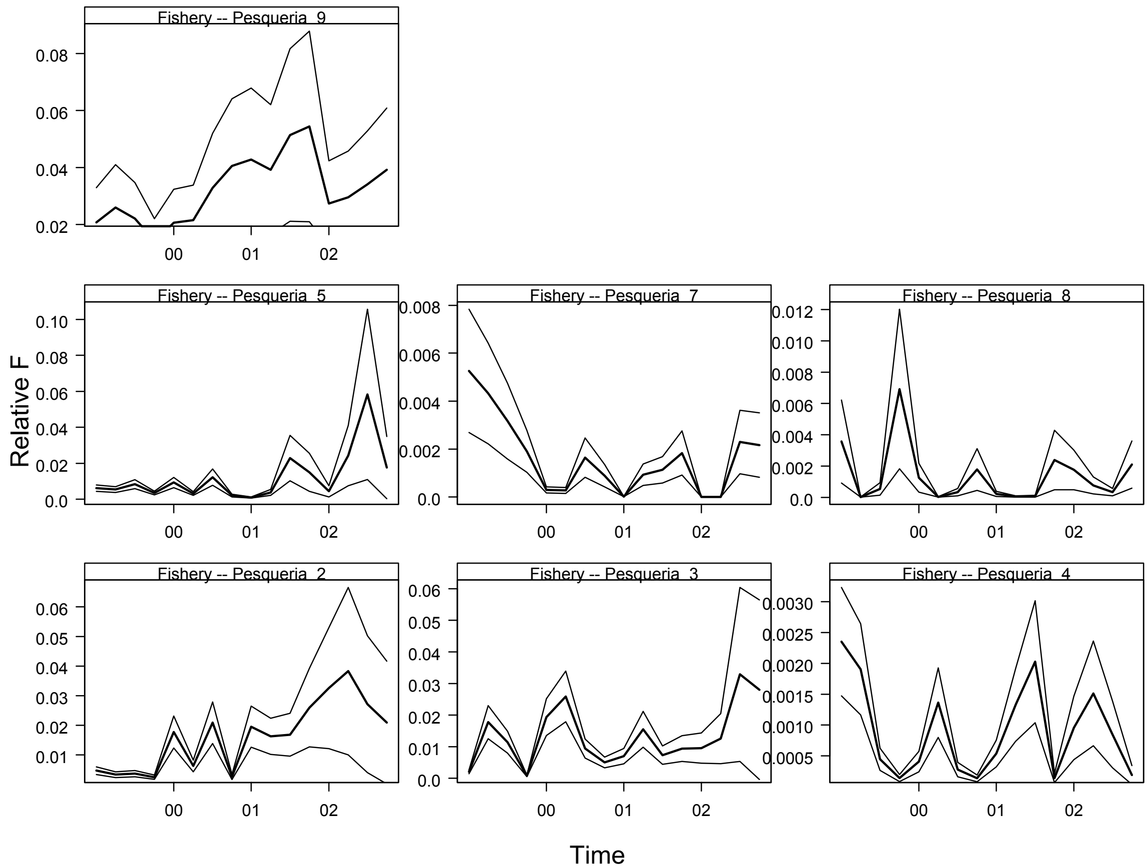

FIGURE 4.6b. Gear and year-specific fishing mortality scalars for the most recent 16 quarters for fisheries currently operating in the EPO. Upper and lower 95% confidence intervals are presented.

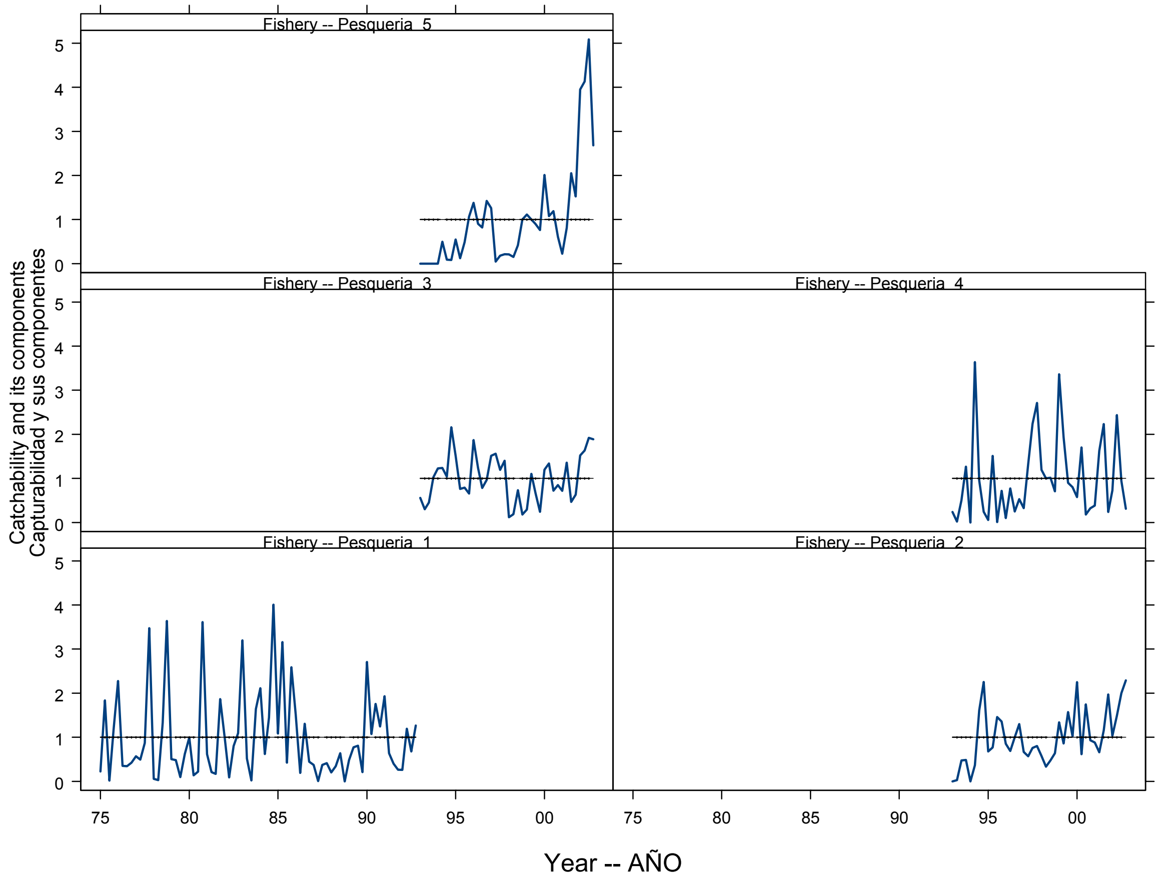

FIGURE 4.7a. Trends in catchability (q) for the 13 fisheries that take bigeye tuna in the EPO. The estimates are scaled to the first estimate of q for each fishery (dashed line). The bold lines include random effects, and illustrate the overall trends in catchability.

FIGURA 4.7a. Tendencias en capturabilidad (q) para las 13 pesquerías que capturan atún patudo en el OPO. Se escalan las estimaciones a la primera estimación de q para cada pesquería (línea de trazos). La línea delgada (Pesquería 3 solamente) ilustra el índice ambiental para q. Las líneas gruesas incluyen efectos aleatorios e ilustran las tendencias generales en capturabilidad.

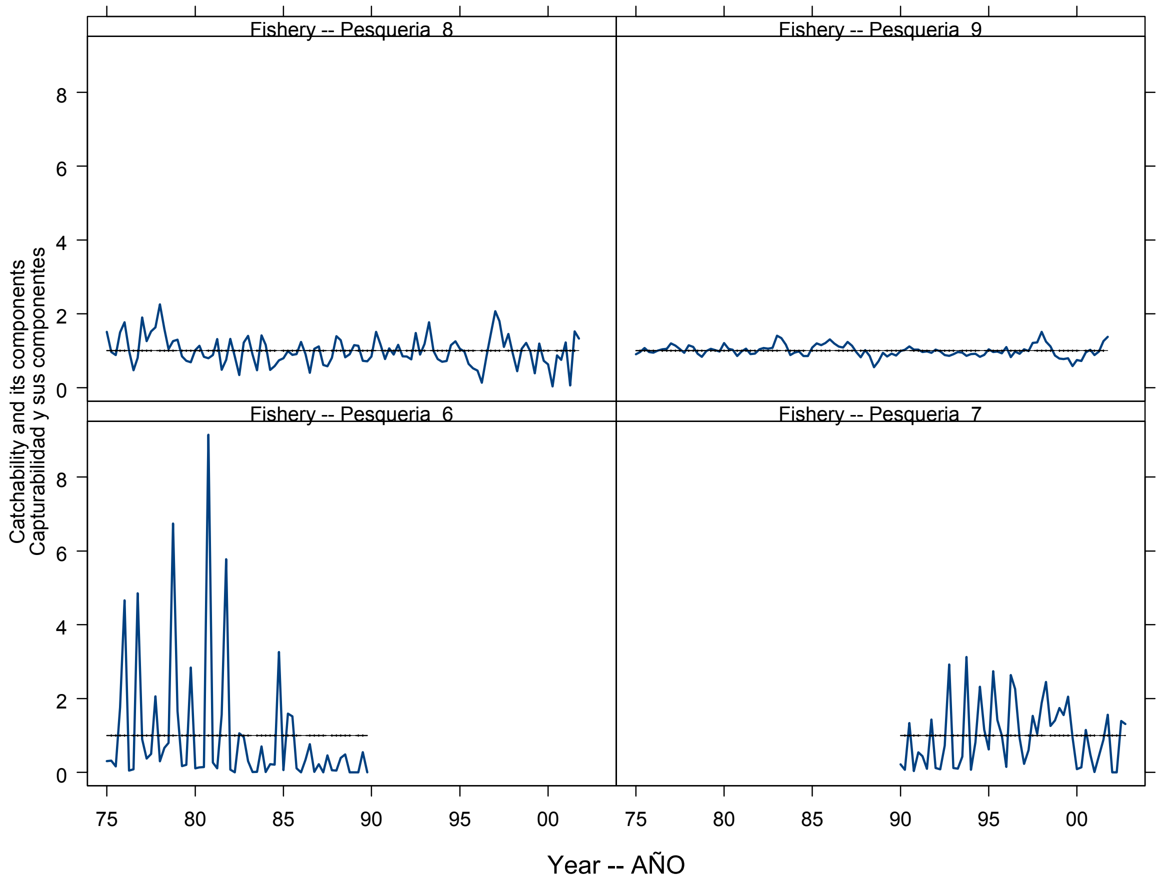

FIGURE 4.7b. Trends in catchability (q) for the 13 fisheries that take bigeye tuna in the EPO. See Figure 4.7a for additional details.
FIGURA 4.7b. Tendencias en capturabilidad (q) para las 13 pesquerías que capturan atún patudo en el OPO. Ver Figura 4.7a para mayor detalle.

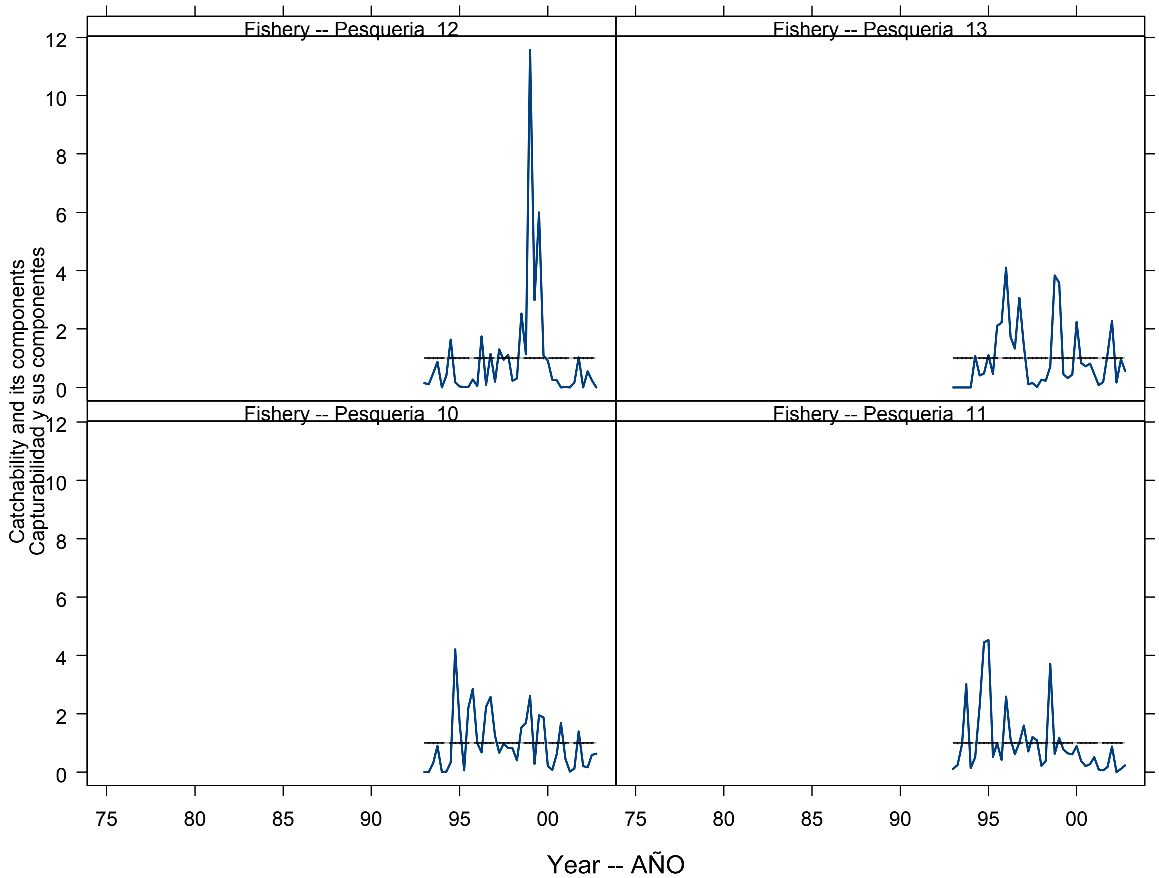

FIGURE 4.7c. Trends in catchability (*q*) for the 13 fisheries that take bigeye tuna in the EPO. See Figure 4.7a for additional details.

FIGURA 4.7c. Tendencias en capturabilidad (*q*) para las 13 pesquerías que capturan atún patudo en el OPO. Ver Figura 4.7a. para mayor detalle.

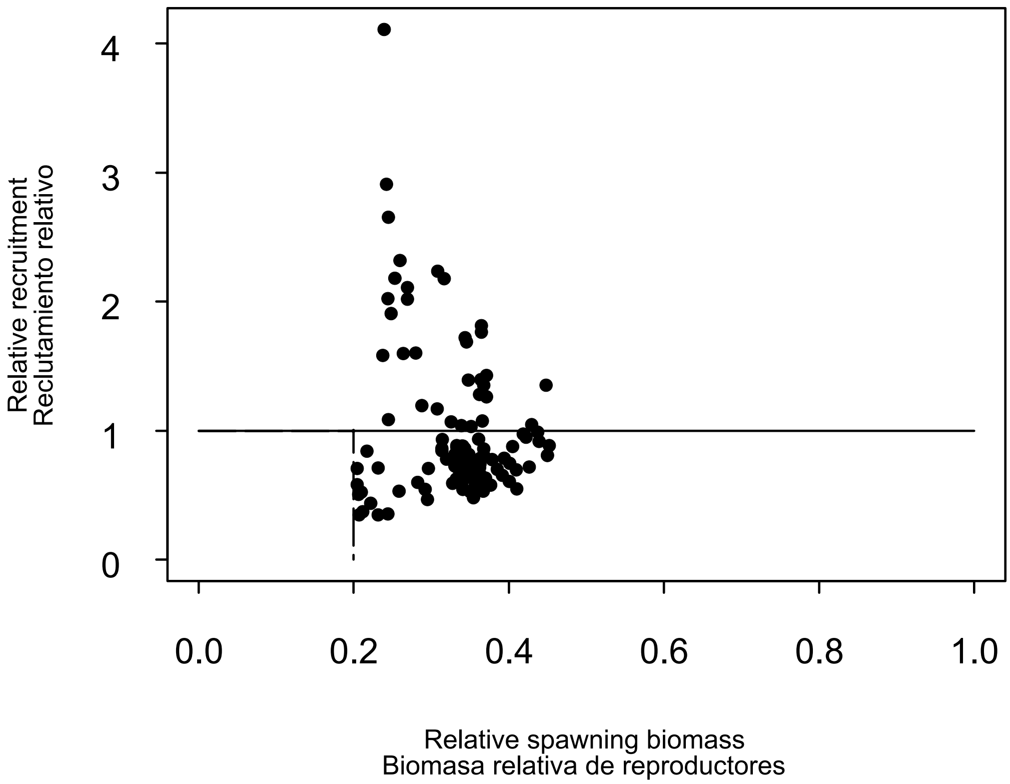

FIGURE 4.8. Estimated relationship between the recruitment of bigeye tuna and spawning biomass. The recruitment is scaled so that the estimate of virgin recruitment is equal to 1.0. The spawning biomass is scaled so that the estimate of virgin spawning biomass is equal to 1.0. The curve displayed is the estimated (or assumed) stock-recruitment relationship, and the dashed horizontal line in this panel indicates the estimate of steepness.

FIGURA 4.8. Relaciones estimadas entre el reclutamiento de atún patudo y anomalías de velocidad zonal en el momento supuesto de cría (recuadro superior) y entre el reclutamiento y la biomasa reproductora (recuadro inferior). Se escala el reclutamiento para que la estimación de reclutamiento virgen equivalga a 1,0. Se escala la biomasa reproductora (hembras de la menos 3 años de edad) para que la estimación de biomasa reproductora virgen equivalga a 1,0. La curva en el recuadro inferior es la relación stock-reclutamiento estimada, y la línea de trazos horizontal indica la uestimación de inclinación.

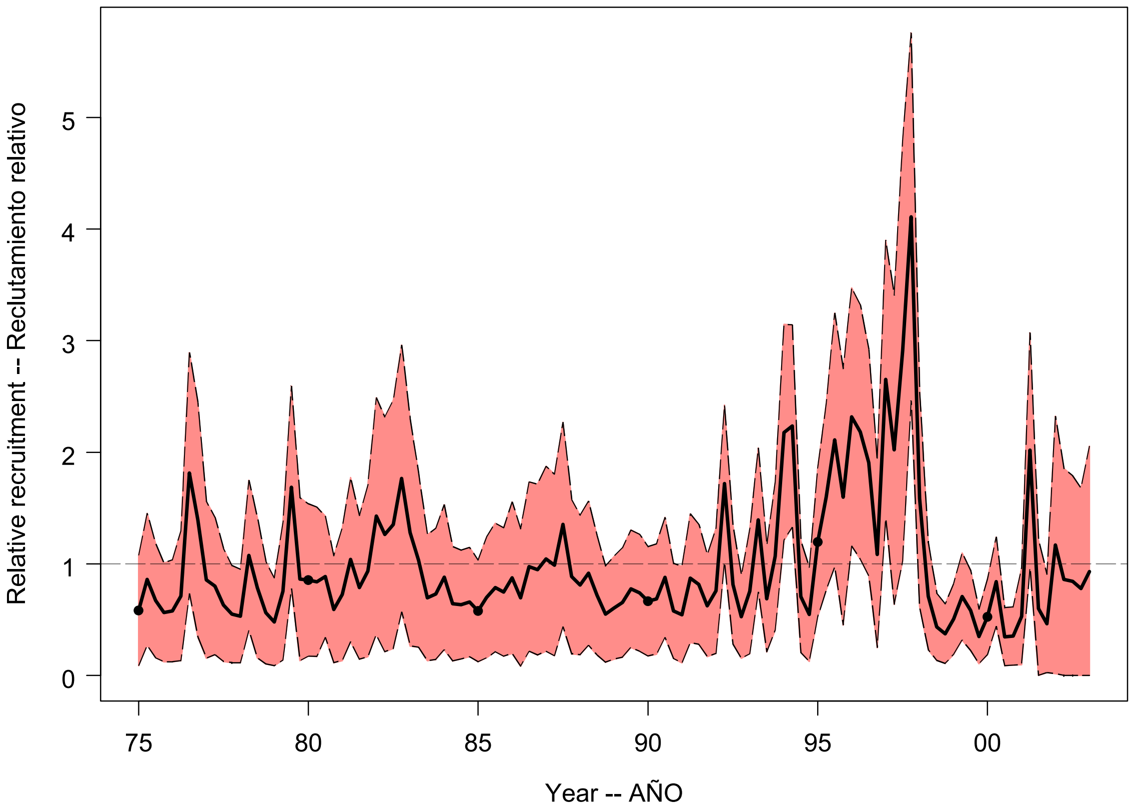

FIGURE 4.9. Estimated recruitment of bigeye tuna to the fisheries of the EPO. The estimates are scaled so that the estimate of virgin recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the thin lines are confidence intervals (±2 standard errors) 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 representan los intervalos de confianza (±2 errores 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.

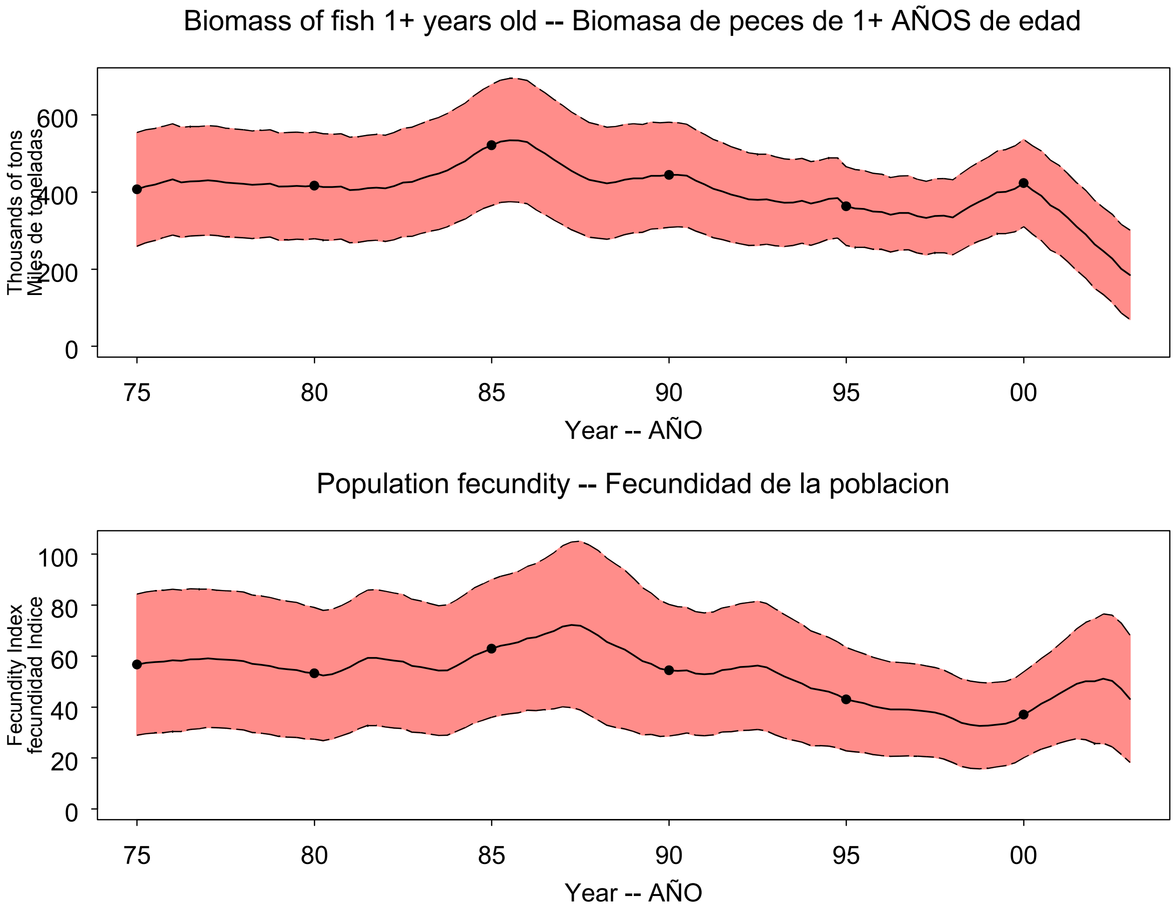

FIGURE 4.10. Estimated biomass and fecundity index (see Section 3.1.2) of bigeye tuna in the EPO. The bold lines illustrate the maximum likelihood estimates of the biomass, and the thin lines are confidence intervals (±2 standard errors) around those estimates. Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year.

FIGURA 4.10. Biomasa estimada e índice de fecundidad (ver Sección 3.12) de atún patudo en el OPO. Las líneas gruesas ilustran las estimaciones de verosimilitud máxima de la biomasa, y las líneas delgadas son los intervalos de confianza (±2 errores estándar) alrededor de estas estimaciones. Ya que el modelo de evaluación representa el tiempo por trimestre, hay cuatro estimaciones de biomasa para cada año.

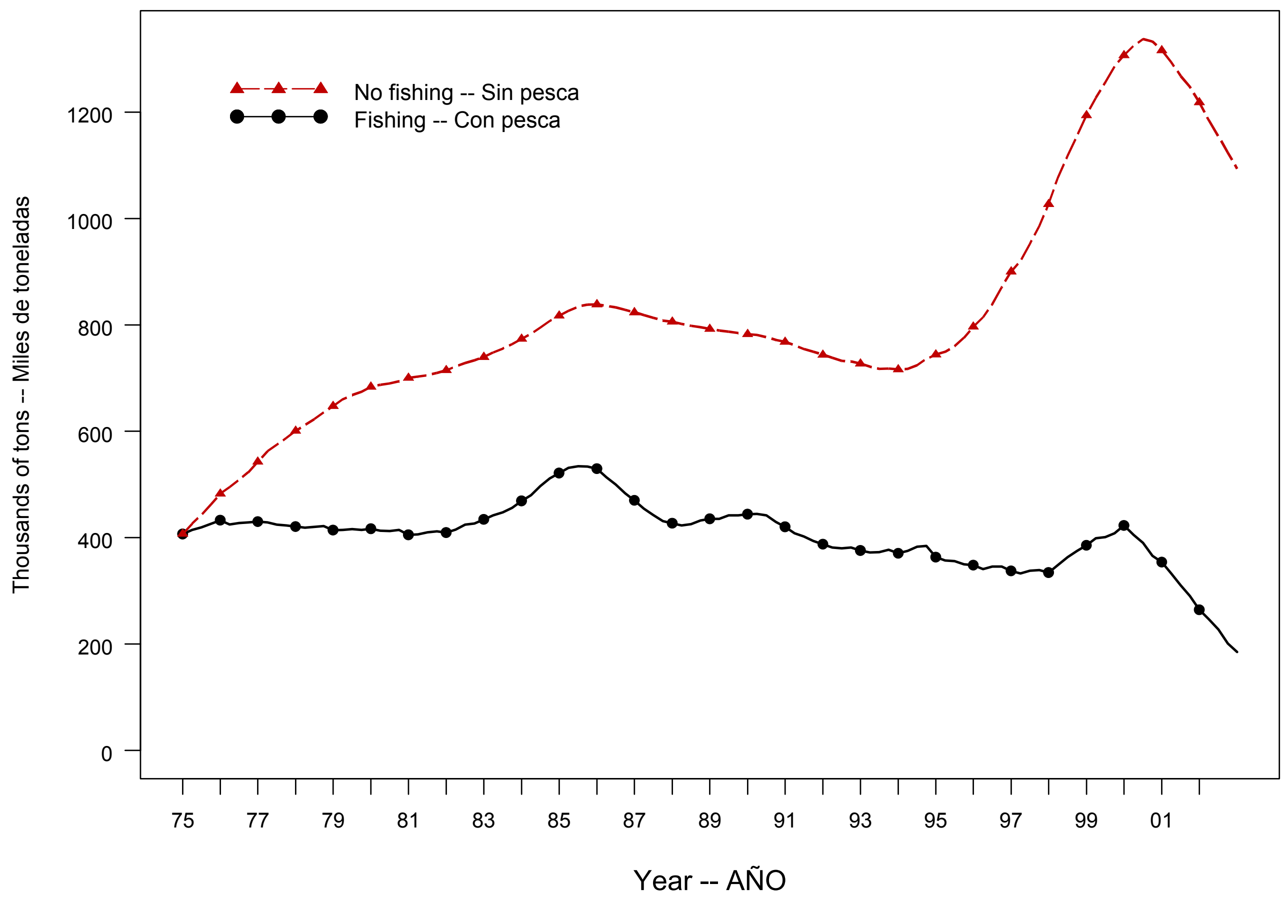

FIGURE 4.11. Biomass trajectory of a simulated population of bigeye tuna that was not exploited during January 1975 through December 2002 ("no fishing") and that predicted by the stock assessment model ("fishing").
FIGURA 4.11. Trayectoria de biomasa de una población simulada de atún patudo no explotada durante enero de 1975 a diciembre de 2002 ("sin pesca") y la predicha por el modelo de evaluación del stock ("con pesca").

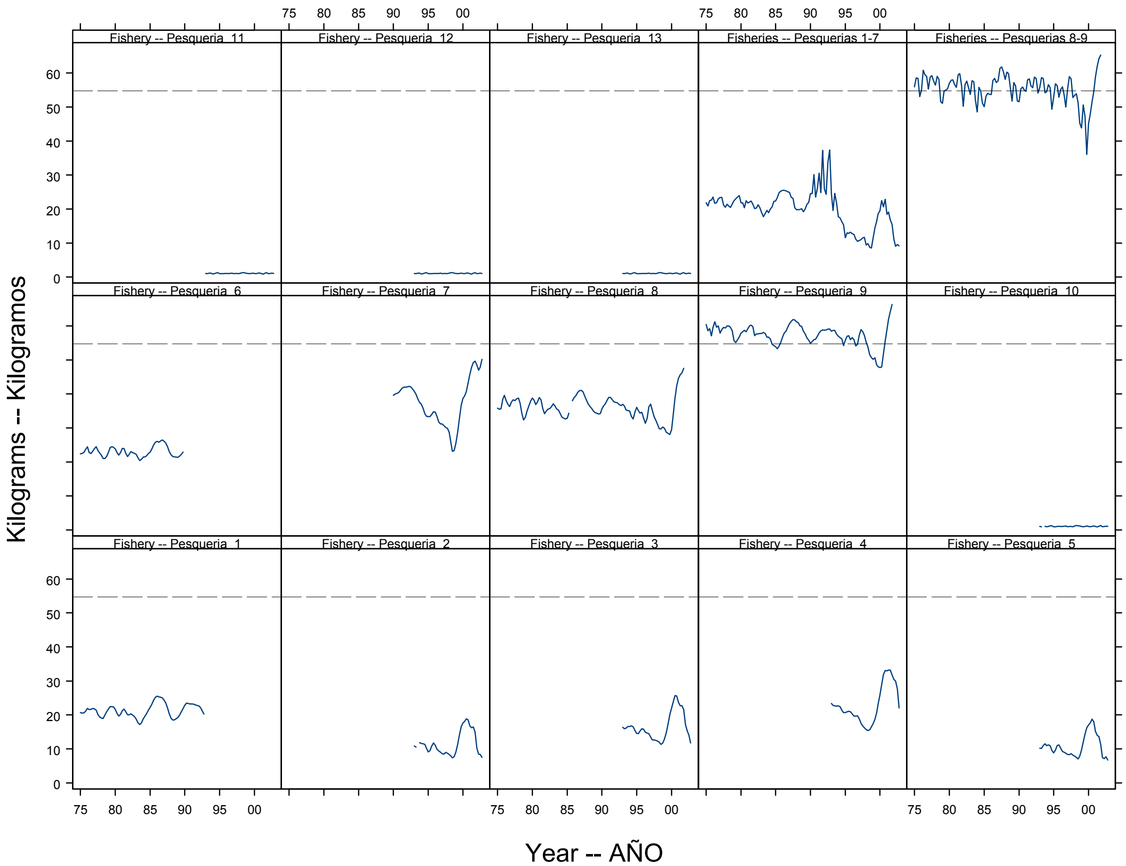

FIGURE 4.12. Estimated average weights of bigeye tuna caught by the fisheries of the EPO. The time series for "Fisheries 1-7" is an average of Fisheries 1 through 7, and the time series for "Fisheries 8-9" is an average of Fisheries 8 and 9. The dashed horizontal line (at about 54.7 kg) identifies the critical weight.

FIGURA 4.12. 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 54,7 kg) identifica el peso crítico.

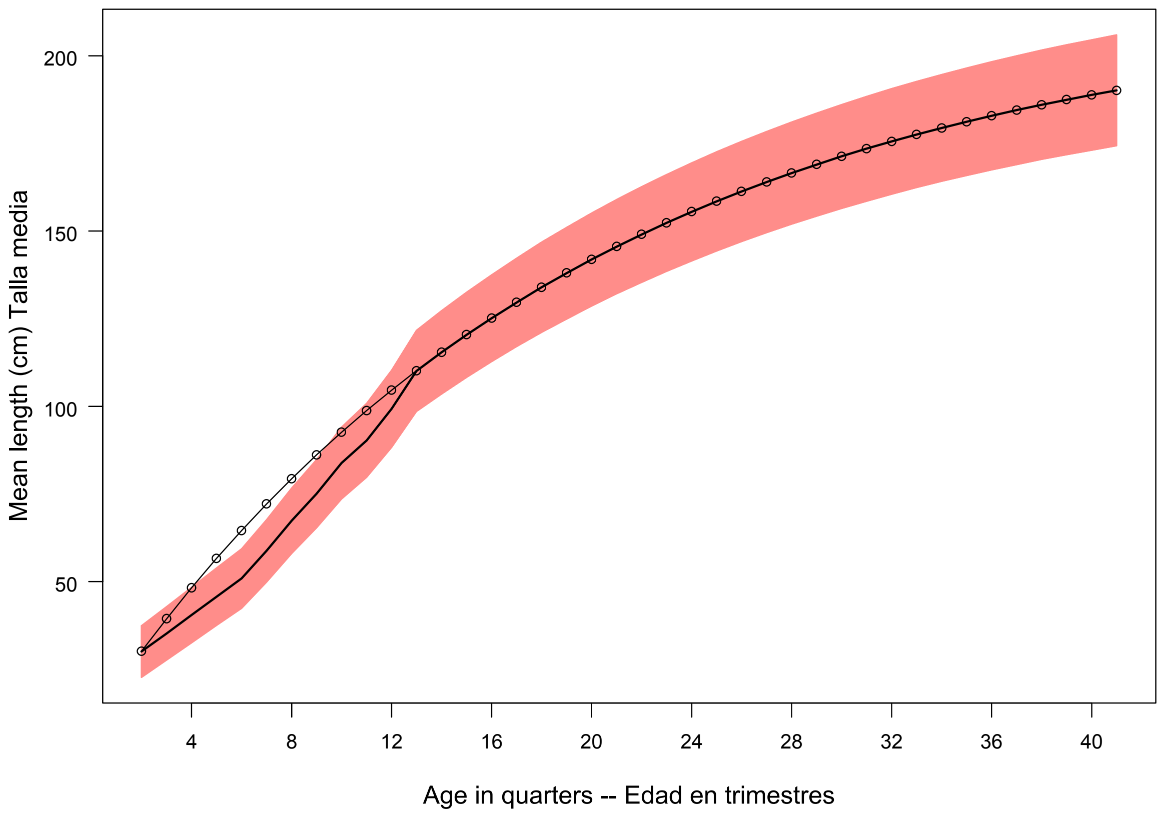

FIGURE 4.13. Estimated average lengths at age for bigeye tuna in the EPO. The filled area indicates the range of lengths estimated to be covered by two standard deviations of the length at age. The line with circles represent the growth curve from Suda and Kume (1967), which is used as a prior.

FIGURA 4.13. Talla a edad media estimada para el atún patudo en el OPO. El área sombreada indica el rango de tallas que se estima ser abarcado por dos desviaciones estándar de la talla a edad. . La línea con círculos representa la curva de crecimiento de Suda y Kume (1967), usada como distribución previa.

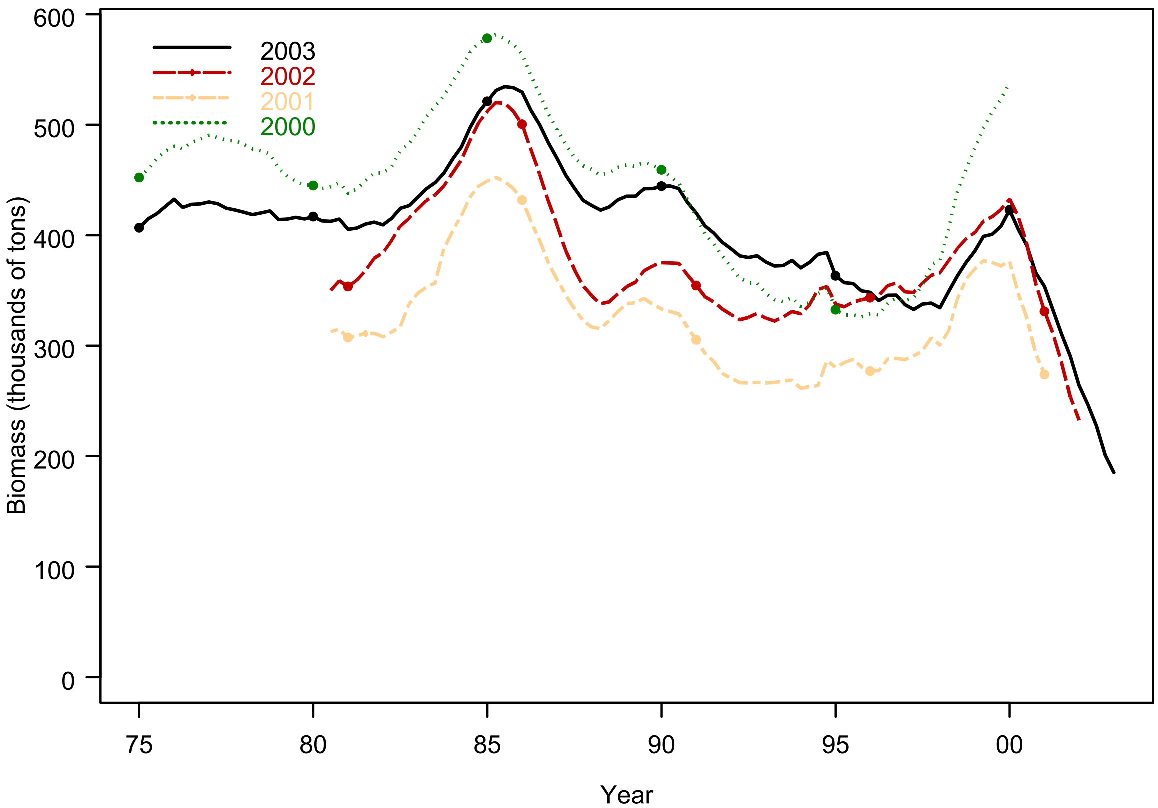

FIGURE 4.14. Comparison of biomass (ages 1 year and older) from previous assessments and the current assessment.
FIGURA 4.14. Comparación de biomasa (edad 3 años y mayores) de evaluaciones previas y la evaluación actual.

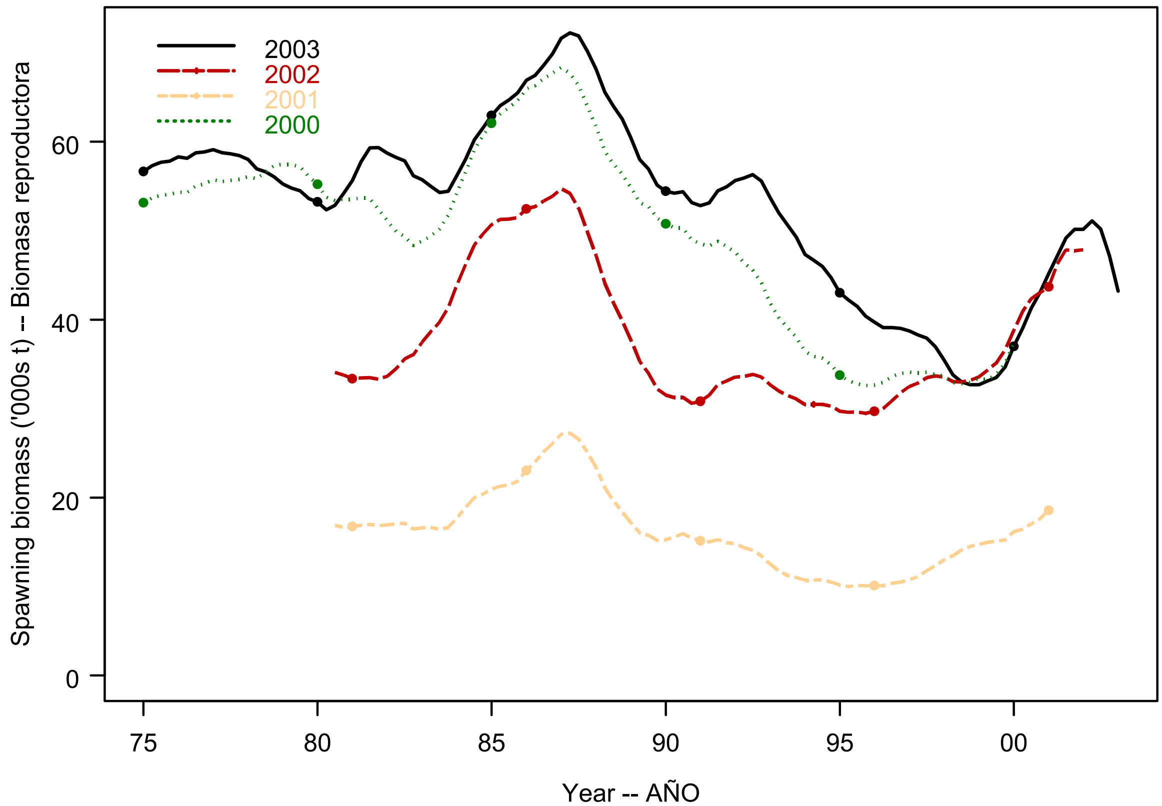

FIGURE 4.15. Comparison of spawning biomass from previous assessments based on current assumptions regarding maturity, fecundity, and proportion of females in each age class.

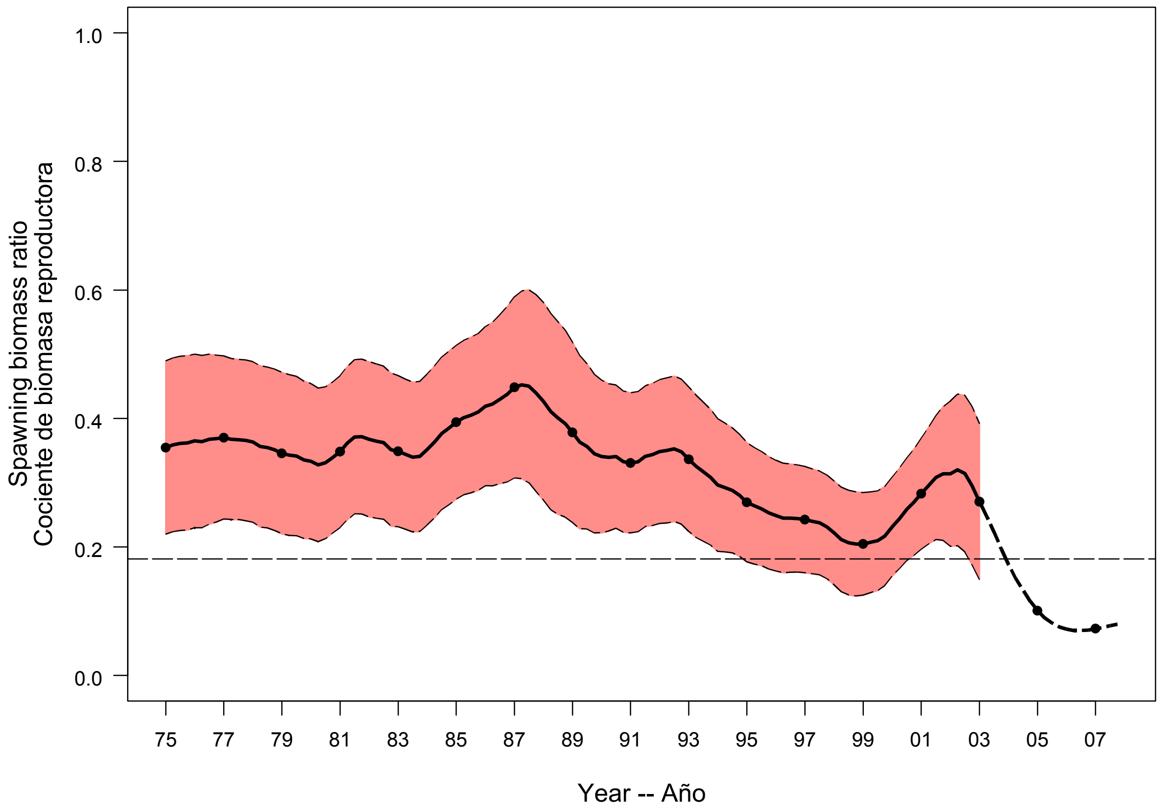

FIGURE 5.1. Estimated time series of spawning biomass ratios (SBRs) for bigeye tuna in the EPO. The dashed horizontal line (at about 0.18) identifies the SBR at AMSY. The solid lines illustrate the maximum likelihood estimates, and the dashed lines are confidence intervals (±2 standard errors) around those estimates. The dashed line continuing the SBR trend indicates the SBR predicted to occur if, effort continues at the average of that observed in 2001 and 2002, catchability (with effort deviates) continues as the average for 2000 and 2001, average environmental conditions occur during the next five years (see Section 6).

FIGURA 5.1. Serie de tiempo estimada de los cocientes de biomasa reproductora (SBR) para el atún patudo en el OPO. La línea de trazos horizontal (en aproximadamente 0,18) identifica el SBR en RMSP. Las líneas sólidas ilustran las estimaciones de verosimilitud máxima, y las líneas de trazos representan los intervalos de confianza (±2 errores estándar) alrededor de esas estimaciones. La línea de trazos que extiende la tendencia del SBR indica el SBR medio predicho si ocurren niveles de mortalidad por pesca y condiciones ambientales medias durante los próximos cinco años (ver Sección 6).

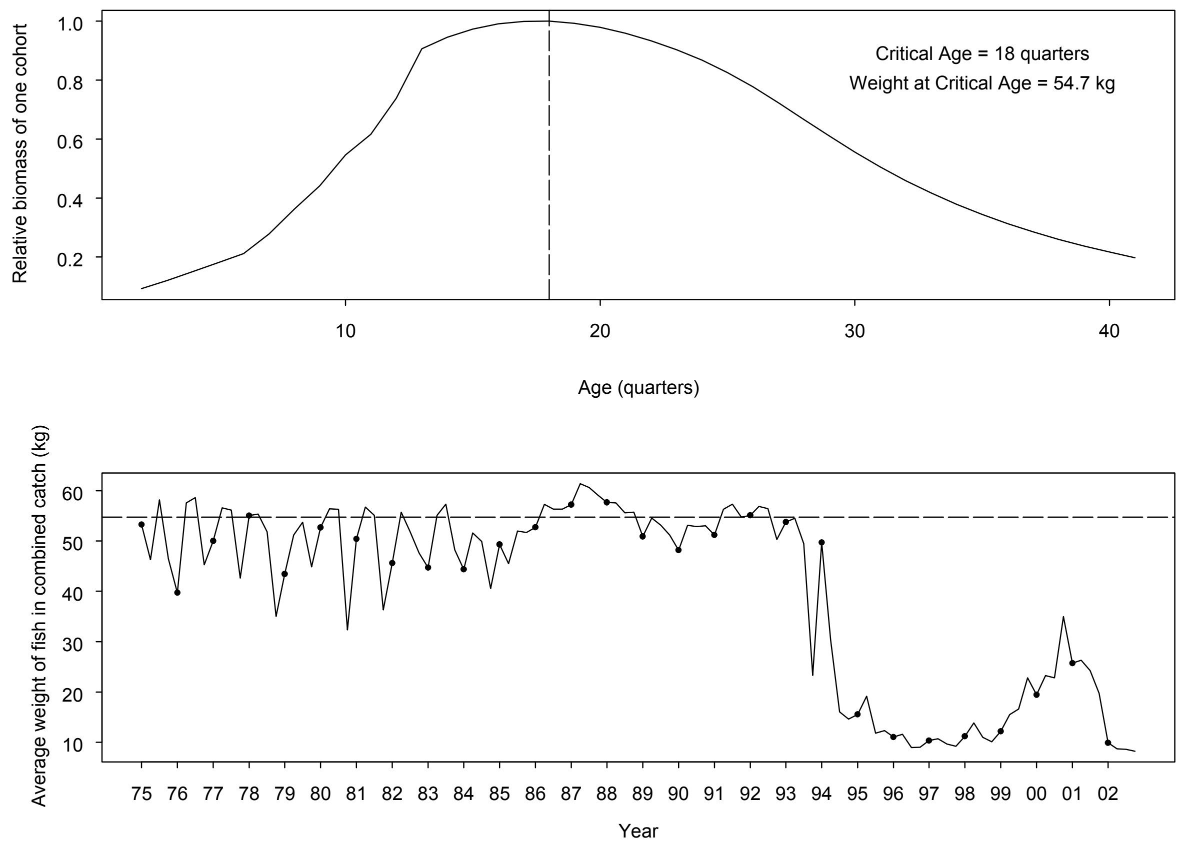

FIGURE 5.2. Combined performance of all fisheries that take bigeye tuna in the EPO at achieving the maximum yield per recruit. The upper panel illustrates the growth (in weight) of a single cohort of bigeye, and identifies the critical age and critical weight (Section 5). The critical weight is drawn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

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

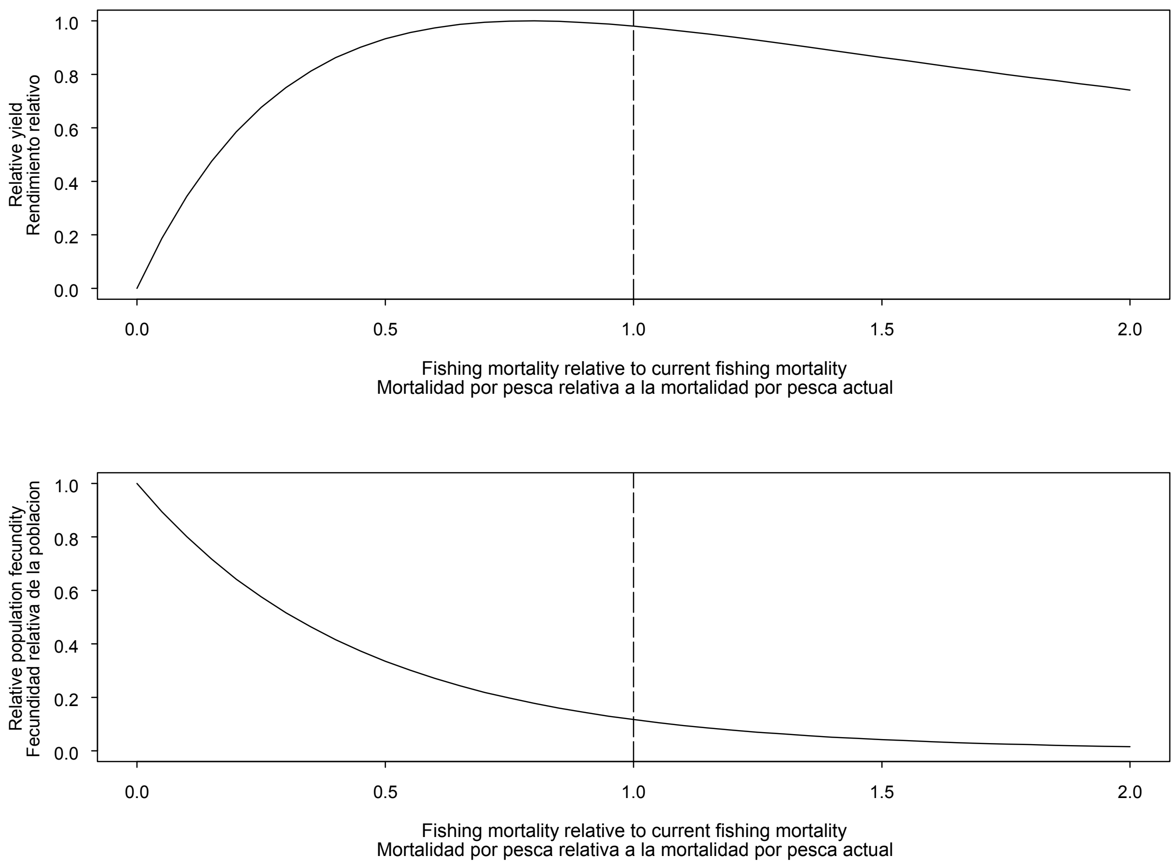

FIGURE 5.3. Predicted effects of long-term changes in fishing effort on the yield (upper panel) and spawning biomass (lower panel) of bigeye tuna under equilibrium conditions with average fishing mortality patterns from 2000 and 2001. The yield estimates are scaled so that the AMSY is at 1.0, and the 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 el patrón actual de selectividad por edad de todas las pesquerías combinadas. 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.

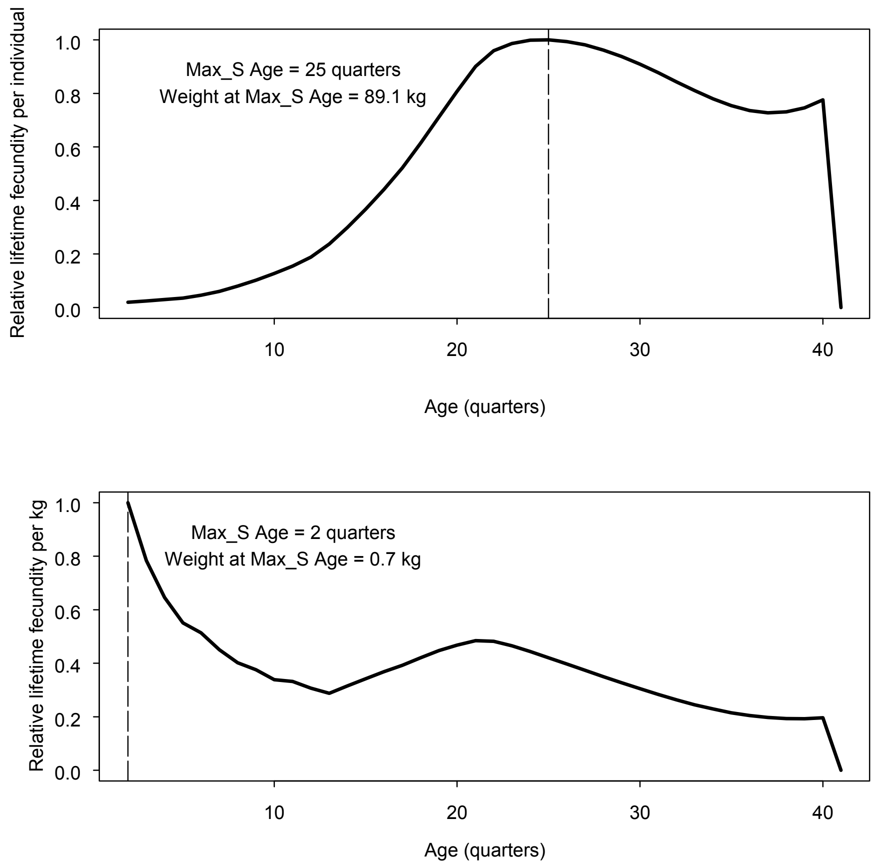

FIGURE 5.4. Marginal relative lifetime reproductive potential at age, based on individuals (upper panel) and weight (lower panel) assuming quarterly fishing averaged over 2000 and 2001. The vertical lines represent the ages at which marginal relative lifetime reproductive potential is maximized.
FIGURA 5.4. Potencial de reproducción de vida entera relativo marginal a edad basado en individuos (recuadro superior) y peso (recuadro inferior). Las líneas verticales representan la edad a la cual se logra el potencial de reproducción relativo marginal máximo.

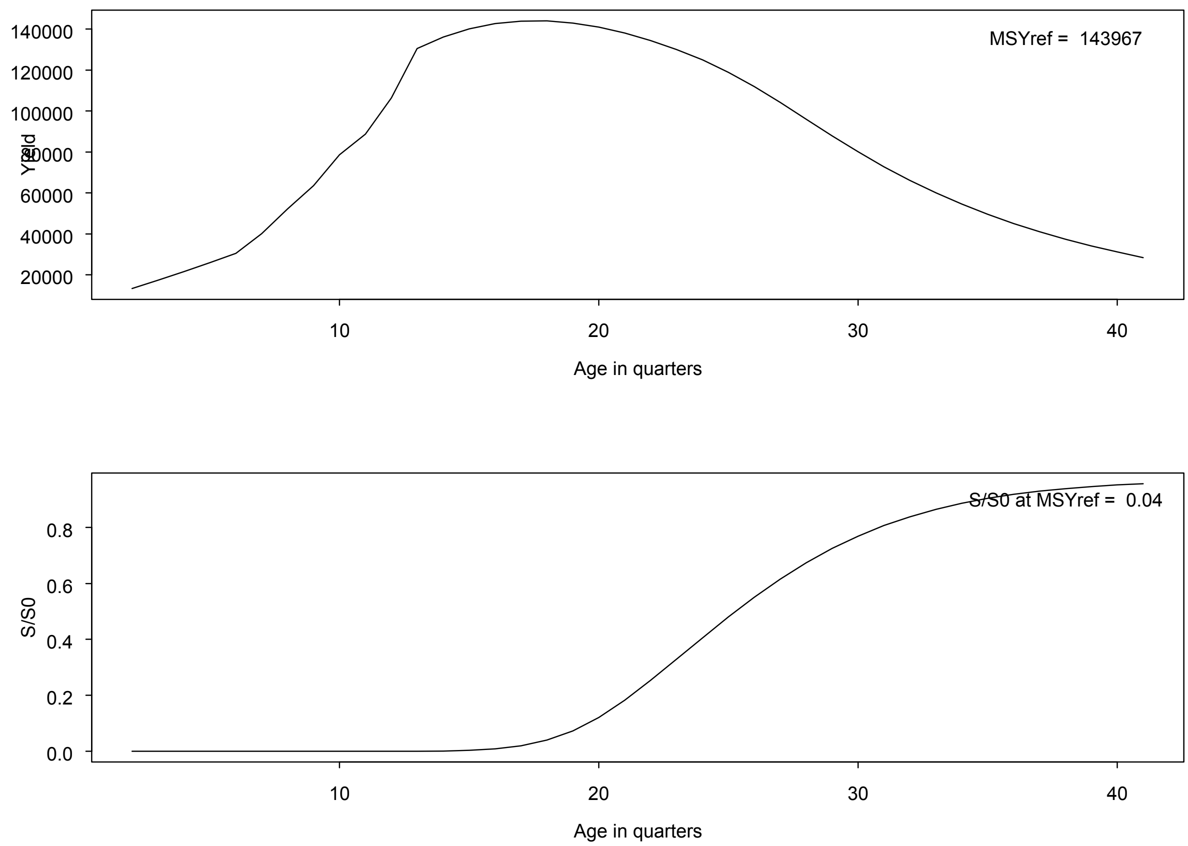

FIGURE 5.5. Yield calculated when only catching individuals at a single age (top panel) and the associated SBR (lower panel).

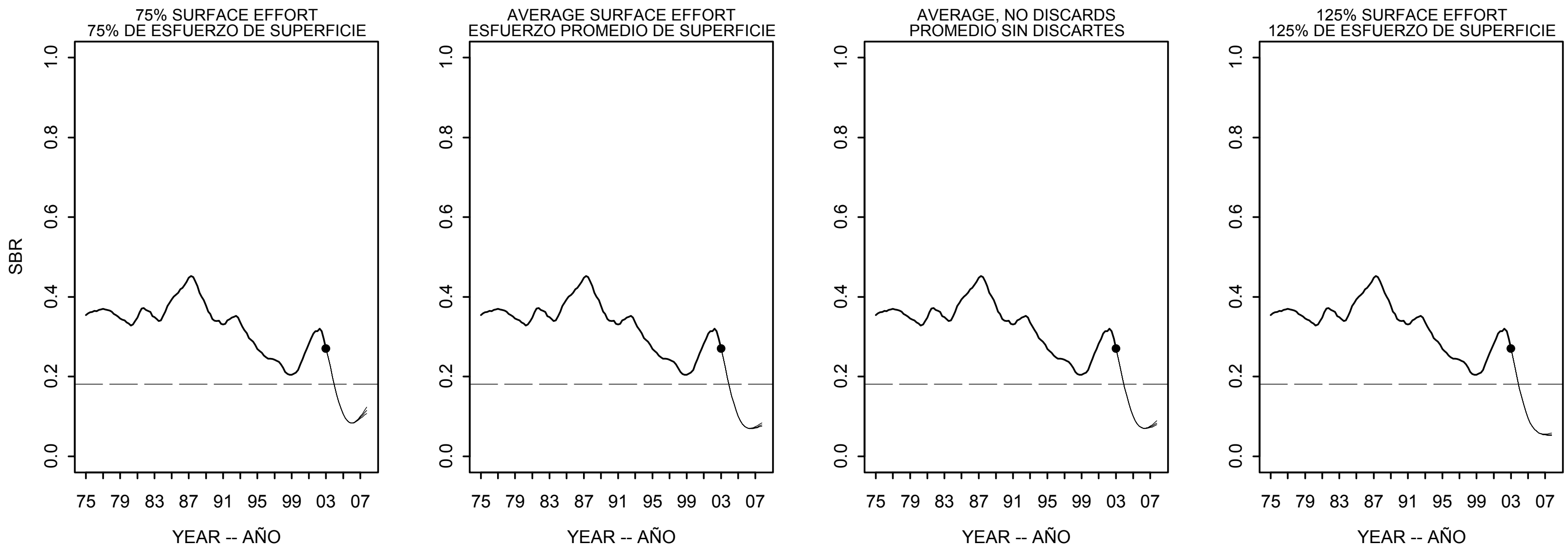

FIGURE 6.1a. Simulated SBRs during 2003-2007 for bigeye tuna in the EPO. Each panel illustrates the results of 101 simulations using the different scenarios described in Sections 6.1 and 6.2. The median estimates of the simulated SBRs are indicated by the solid lines to the right of each solid dot. The shaded areas indicate the regions bounded by the 20% and 80% quantiles of the simulated SBRs. The dashed horizontal lines indicate the SBR_{AMSY} (0.18).

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

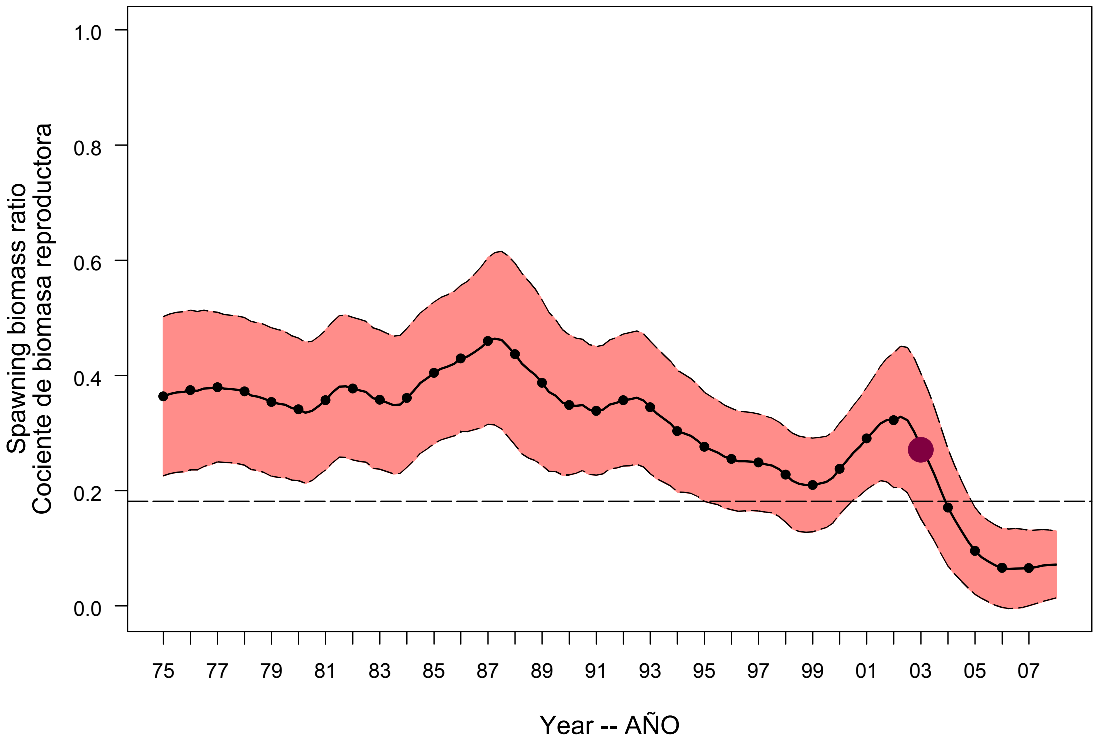

FIGURE 6.1b. SBRs, including projections for 2003-2007 under average effort for 2001 and 2002 and average catchability for 2000 and 2001 for bigeye tuna in the EPO. These calculations include parameter estimation uncertainty and uncertainty about future recruitment. The shaded areas indicate the 95% confidence intervals and the large dot indicates the estimate for the first quarter of 2003. The dashed line indicates the SBR_{AMSY} (0.18).

FIGURE 6.1b. SBR, incluyendo proyecciones para 2002-2006 con niveles actuales de esfuerzo de atún patudo en el OPO. Los cálculos incluyen incertidumbre en la estimación de parámetros y sobre reclutamiento futuro. Las zonas sombreadas señalan los intervalos de confianza de 95%. La línea de trazos señala el SBR_{RMSP} (0,38).

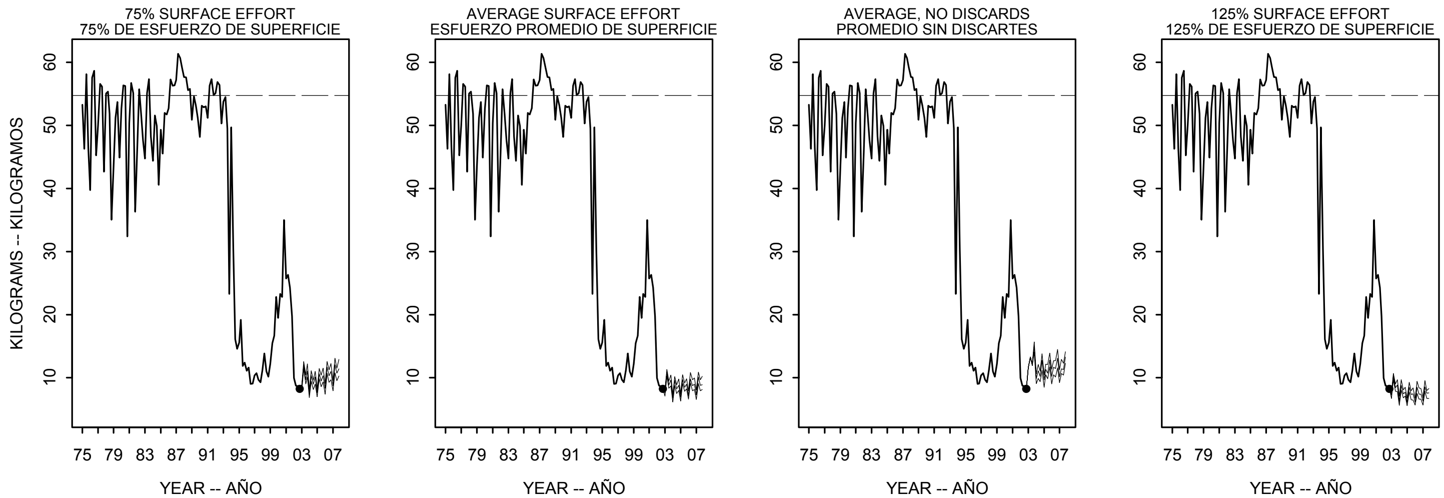

FIGURE 6.2. Simulated estimates of the average weight of bigeye tuna in the combined catch during 2003-2007 under average effort for 2001 and 2002 and average catchability for 2000 and 2001 for bigeye tuna in the EPO. Each panel illustrates the results of 101 simulations using the different scenarios described in Sections 6.1 and 6.2. The median estimates of the simulated average weights are indicated by the solid lines to the right of each solid dot. The shaded areas indicate the regions bounded by the 20% and 80% quantiles of the simulated average weights. The dashed horizontal lines indicate the critical weight (54.7 kg).

FIGURA 6.2. Estimaciones simuladas del peso medio de atún patudo en la captura combinada durante 2003-2007. Cada recuadro ilustra los resultados de 101 simulaciones usando los diferentes escenarios descritos en las Secciones 6.1 y 6.2. Las estimaciones medianas del peso medio simulado son indicadas por las líneas sólidas a la derecha de cada punto sólido. Las zonas sombreadas indican las regiones delimitadas por los cuantiles de 20% y 80% del peso medio simulado. Las líneas de trazos horizontales señalan el peso crítico (54,7 kg).

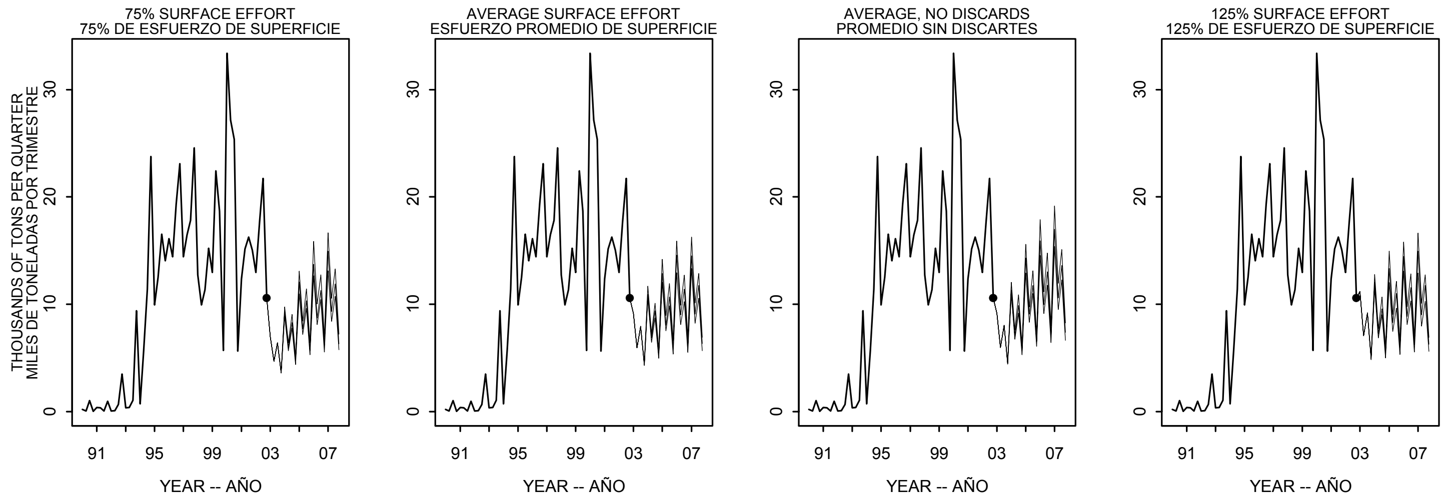

FIGURE 6.3. Simulated catches of bigeye tuna taken by the primary surface fleet (Fisheries 2-5 and 7) during 2003-2007 under average effort for 2001 and 2002 and average catchability for 2000 and 2001 for bigeye tuna in the EPO. Each panel illustrates the results of 101 simulations using the different scenarios described in Sections 6.1 and 6.2. The median estimates of the simulated catches taken by these fisheries are indicated by the solid lines that are drawn to the right of each solid dot. The shaded areas indicate the regions bounded by the 20% and 80% quantiles of the simulated catches.

FIGURA 6.3. Capturas simuladas de atún patudo logradas por la flota primaria de superficie (Pesquerías 2-5 y 7) durante 2003-2007. Cada recuadro ilustra los resultados de 101 simulaciones usando los diferentes escenarios descritos en las Secciones 6.1 y 6.2. Las estimaciones medianas de las capturas simuladas de estas pesquerías son indicadas por las líneas sólidas a la derecha de cada punto sólido. Las zonas sombreadas indican las regiones delimitadas por los cuantiles de 20% y 80% de las capturas simuladas.

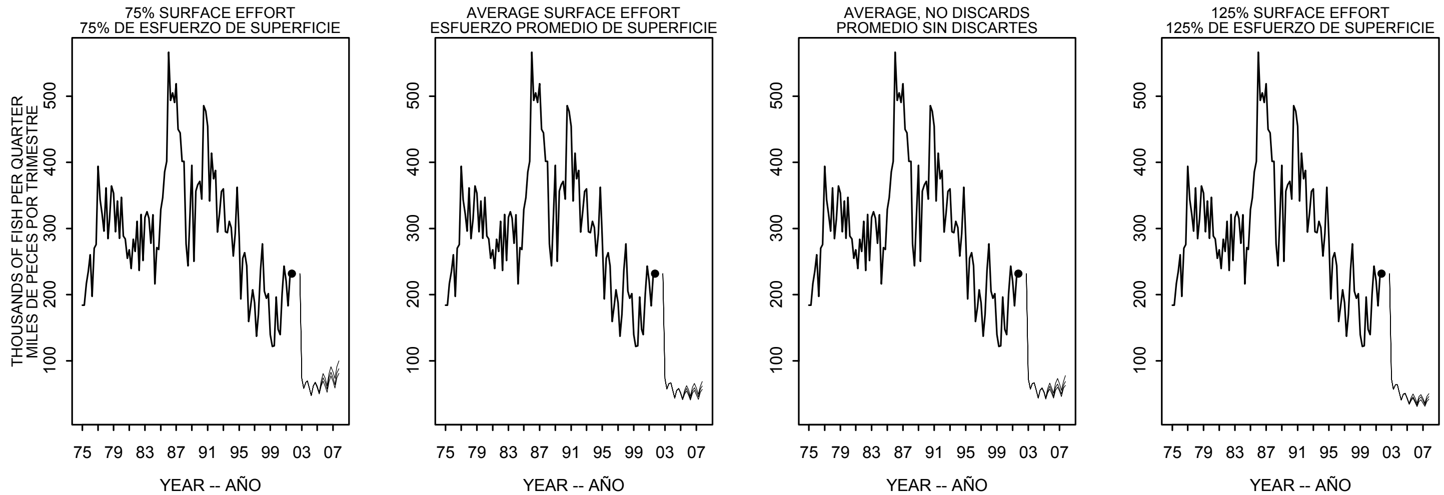

FIGURE 6.4. Simulated catches of bigeye tuna taken by the longline fleet (Fisheries 8 and 9) during 2003-2007 under average effort for 2001 and 2002 and average catchability for 2000 and 2001 for bigeye tuna in the EPO. Each panel illustrates the results of 101 simulations using the different scenarios described in Sections 6.1 and 6.2. The median estimates of the simulated catches taken by these fisheries are indicated by the solid lines to the right of each solid dot. The shaded areas indicate the regions bounded by the 20% and 80% quantiles of the simulated catches.

FIGURA 6.4. Capturas simuladas de atún patudo logradas por la flota palangrera (Pesquerías 8 y 9) durante 2003-2007. Cada recuadro ilustra los resultados de 101 simulaciones usando los diferentes escenarios descritos en las Secciones 6.1 y 6.2. Las estimaciones medianas de las capturas simuladas de estas pesquerías son indicadas por las líneas sólidas a la derecha de cada punto sólido. Las zonas sombreadas indican las regiones delimitadas por los cuantiles de 20% y 80% de las capturas simuladas.

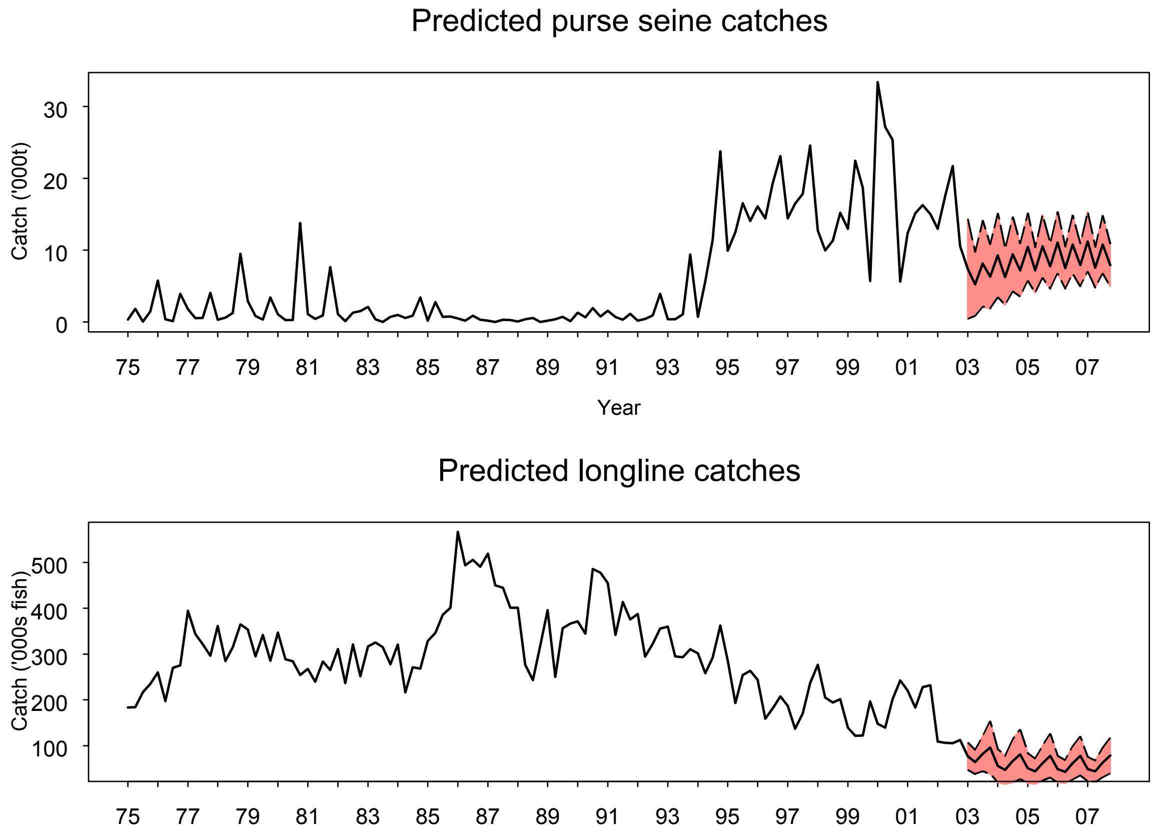

FIGURE 6.5. Predicted catches for the surface (Fisheries 2, 3, 4, 5, and 7) and longline (Fisheries 8 and 9) fisheries based on average effort for 2002 and 2001 and average catchability for 2000 and 2001. Prediction were undertaken using the likelihood profile method described in Section 6. The shaded areas represent 95% confidence intervals for the predictions of future catches.

TABLE 2.1. Fishery definitions used for the stock assessment of bigeye tuna in the EPO. PS = purse seine; PL = 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 3.1, 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; BB = carnada; LL = palangre; FLT = lances sobre objeto flotante; UNA = lances sobre atunes no asociados; DOL = lances sobre delfines. En la Figura 3.1 se ilustran las zonas de muestreo, y en la Sección 2.2.2 se describen los descartes.

Fishery	Gear	Set type	Years	Sampling areas	Catch data
Pesquería	**Arte**	**Tipo de lance**	**Año**	**Zonas de muestreo**	**Datos de captura**
1	PS	FLT	1980-1992	1-13	retained catch only–descargas solamente
2	PS	FLT	1993-2001	11-12	retained catch + discards from inefficiencies in fishing process–descargas + descartes de ineficacias en el proceso de pesca
3	PS	FLT	1993-2001	7, 9	
4	PS	FLT	1993-2001	5-6, 13	
5	PS	FLT	1993-2001	1-4, 8, 10	
6	PS PL	UNA DOL	1980-1989	1-13	retained catch only–escargas solamente
7	PS PL	UNA DOL	1990-2001	1-13	retained catch + discards from inefficiencies in fishing process–descargas + descartes de ineficacias en el proceso de pesca
8	LL		1980-2001	N of–de 15°N	retained catch only–descargas solamente
9	LL		1980-2001	S of–de 15°N	
10	PS	FLT	1993-2001	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	1993-2001	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	1993-2001	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	1993-2001	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 and fecundity indices used to define the spawning biomass.
TABLA 3.1. Proporciones de patudo hembra por edad e índices de fecundidad usados para definir la biomasa reproductora.

Age in quarters Edad en trimestres	Proportion female Proporción hembra	Index of fecundity Indice de fecundidad
2	0.44	0.00
3	0.44	0.00
4	0.44	0.00
5	0.44	0.00
6	0.44	0.00
7	0.44	0.00
8	0.44	0.00
9	0.44	0.00
10	0.44	0.00
11	0.44	0.00
12	0.44	0.02
13	0.44	0.14
14	0.44	0.38
15	0.44	0.99
16	0.44	2.41
17	0.44	5.40
18	0.44	10.99
19	0.44	19.91
20	0.44	31.74
21	0.44	44.69
22	0.44	56.97
23	0.44	67.56
24	0.43	76.41
25	0.43	83.86
26	0.42	90.30
27	0.41	96.04
28	0.39	101.30
29	0.38	106.20
30	0.36	110.83
31	0.33	115.24
32	0.31	119.46
33	0.28	123.51
34	0.25	127.42
35	0.23	131.18
36	0.20	134.80
37	0.18	138.30
38	0.16	141.66
39	0.14	144.90
40	0.12	148.02
41	0.10	151.02

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

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

Quarter	Fishery 2	Fishery 3	Fishery 4	Fishery 5	Fishery 7
Trimestre	**Pesquería 2**	**Pesquería 3**	**Pesquería 4**	**Pesquería 5**	**Pesquería 7**
1	-28%	38%	80%	846%	-100%
2	30%	-23%	32%	209%	-100%
3	-12%	123%	-71%	46%	6%
4	-42%	37%	-42%	11%	-39%

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-1+ fish**	**Spawning biomass**
Año	**Reclutamiento total**	**Biomasa de peces de edad 1+**	**Biomasa de peces reproductores**
1975	12,067	406,721	56,646
1976	20,273	432,545	58,303
1977	12,799	430,055	59,121
1978	13,321	420,934	58,035
1979	17,042	413,994	55,246
1980	14,278	416,801	53,227
1981	15,715	405,319	55,655
1982	26,175	409,286	58,729
1983	16,848	434,509	55,739
1984	12,685	468,837	56,202
1985	12,677	521,106	62,957
1986	15,756	529,438	66,924
1987	19,257	469,829	71,622
1988	13,484	427,040	68,146
1989	12,506	435,318	60,431
1990	12,641	444,358	54,435
1991	12,871	420,191	52,829
1992	17,199	387,650	55,656
1993	17,590	375,739	53,726
1994	25,531	370,345	47,344
1995	29,309	363,116	43,036
1996	33,760	348,208	39,725
1997	52,703	337,141	38,737
1998	13,981	334,359	35,450
1999	9,661	385,459	32,697
2000	9,313	422,961	37,019
2001	16,290	353,724	45,166
2002	16,453	264,178	50,155

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. Edad en trimestres desde la cría.

Age (quarters)	Average length (cm)	Average weight (kg)	Age (quarters)	Average length (cm)	Average weight (kg)
Edad (trimestres)	**Talla media (cm)**	**Peso medio (kg)**	**Edad (trimestres)**	**Talla media (cm)**	**Peso medio (kg)**
2	30.00	0.74	22	149.02	74.56
3	35.22	1.16	23	152.33	79.46
4	40.44	1.73	24	155.48	84.30
5	45.66	2.45	25	158.46	89.08
6	50.88	3.34	26	161.30	93.78
7	58.75	5.06	27	163.99	98.39
8	67.35	7.50	28	166.55	102.90
9	75.06	10.25	29	168.98	107.31
10	83.80	14.09	30	171.28	111.61
11	90.27	17.47	31	173.48	115.79
12	99.27	23.00	32	175.56	119.86
13	110.08	31.02	33	177.53	123.81
14	115.37	35.53	34	179.41	127.64
15	120.38	40.18	35	181.19	131.35
16	125.13	44.94	36	182.88	134.94
17	129.64	49.80	37	184.49	138.40
18	133.93	54.72	38	186.01	141.75
19	138.00	59.68	39	187.46	144.97
20	141.87	64.66	40	188.84	148.08
21	145.54	69.62	41	190.14	151.06

TABLE 5.1. Estimates of the AMSY and its associated quantities for the basecase and sensitivity analyses. All analyses are based on average fishing mortality for 2000 and 2001. B_{recent} and B_{AMSY} are defined as the biomass of bigeye 1+ years old at the start of 2003 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 2002.
TABLA 5.1. Estimaciones del RMSP y sus valores asociados. Se definen B_{recent} y B_{RMSP} como la biomasa de patuda de edad 1+ años al principio de 2001 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 2001.

	Basecase **Caso base**	**Steepness = 0.75**	**Standard catches**
AMSY (mt)—RMSP (tm)	67,948	65,882	63,256
B_{AMSY} (mt)—B_{RMSP} (tm)	246,841	411,885	229,092
S_{AMSY}—S_{RMSP}	28,989	59,414	26,728
B_{AMSY}/B_0—B_{RMSP}/B_0	0.28	0.36	0.29
S_{AMSY}/S_0—S_{RMSP}/S_0	0.18	0.29	0.19
C_{recent}/AMSY—C_{recent}/RMSP	1.40	1.45	1.14
$B_{\text{recent}}/B_{\text{AMSY}}$—$B_{\text{recent}}/B_{\text{RMSP}}$	0.75	0.56	0.93
$S_{\text{recent}}/S_{\text{AMSY}}$—$S_{\text{recent}}/S_{\text{RMSP}}$	1.49	0.86	1.66
F multiplier—Multiplicador de F	0.79	0.53	0.88

	SPC Korean LL	**HBS cpue**	**Iterative reweighting**
AMSY (mt)—RMSP (tm)	78,895	68,246	65,393
B_{AMSY} (mt)—B_{RMSP} (tm)	296,586	254,007	244,640
S_{AMSY}—S_{RMSP}	35,902	30,531	28,628
B_{AMSY}/B_0—B_{RMSP}/B_0	0.27	0.27	0.31
S_{AMSY}/S_0—S_{RMSP}/S_0	0.18	0.18	0.20
C_{recent}/AMSY—C_{recent}/RMSP	1.32	1.41	1.46
$B_{\text{recent}}/B_{\text{AMSY}}$—$B_{\text{recent}}/B_{\text{RMSP}}$	1.21	1.04	0.45
$S_{\text{recent}}/S_{\text{AMSY}}$—$S_{\text{recent}}/S_{\text{RMSP}}$	2.45	2.11	0.66
F multiplier—Multiplicador de F	1.08	0.94	0.54

TABLE 5.2. Estimates of the AMSY and its associated quantities based on alternative assumptions about current fishing mortality. B_{recent} and B_{AMSY} are defined as the biomass of bigeye 1+ years old at the start of 2003 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 2002.
TABLA 5.1. Estimaciones del RMSP y sus valores asociados. Se definen B_{recent} y B_{RMSP} como la biomasa de patuda de edad 1+ años al principio de 2001 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 2001.

	F 2000 and 2001 – Basecase	*F* 1999 and 2000	*F* 2001 and 2002
	Caso base		
AMSY (mt)—RMSP (tm)	67,948	66,950	63,764
B_{AMSY} (mt)—B_{RMSP} (tm)	246,841	248,737	234,093
S_{AMSY}—S_{RMSP}	28,989	29,472	28,003
B_{AMSY}/B_0—B_{RMSP}/B_0	0.28	0.28	0.26
S_{AMSY}/S_0—S_{RMSP}/S_0	0.18	0.18	0.18
C_{recent}/AMSY—C_{recent}/RMSP	1.40	1.42	1.49
$B_{\text{recent}}/B_{\text{AMSY}}$—$B_{\text{recent}}/B_{\text{RMSP}}$	0.75	0.74	0.79
$S_{\text{recent}}/S_{\text{AMSY}}$—$S_{\text{recent}}/S_{\text{RMSP}}$	1.49	1.47	1.54
F multiplier—Multiplicador de *F*	0.79	1.05	0.57

TABLE 5.3. Estimates of the AMSY, and its associated quantities, obtained by assuming that each fishery maintains its current pattern of age-specific selectivity (Figure 4.5) and that each fishery is the only fishery operating in the EPO. The estimates of the AMSY and B_{AMSY} are in metric tons. The F multiplier indicates how many times effort would have to be effectively increased to achieve the AMSY based on the average fishing mortality over 2000 and 2001.
TABLA 5.3. Estimaciones del RMSP y sus cantidades asociadas, obtenidas suponiendo que cada pesquería mantiene su patrón actual de selectividad por edad (Figura 4.5) y que cada pesquería es la única que opera en el OPO. Se expresan RMSP, B_{RMSP}, y S_{RMSP} en toneladas métricas. Los valores en paréntesis indican el tonelaje que se descartaría si se extrajeran los peces pequeños de la captura durante la clasificación. Si no se clasifica la captura, se suman los valores en paréntesis a los valores superiores para obtener estimaciones del RMSP. El multiplicador de F indica cuántas veces se tendría que aumentar efectivamente el esfuerzo para lograr el RMSP basado en la mortalidad por pesca media en los dos últimos años.

Fishery Pesquería	AMSY RMSP	B_{AMSY} B_{RMSP}	S_{AMSY} S_{RMSP}	$B_{\text{AMSY}}/B_{F=0}$ $B_{\text{RMSP}}/B_{F=0}$	$S_{\text{AMSY}}/S_{F=0}$ $S_{\text{RMSP}}/S_{F=0}$	F multiplier Multiplicador de F
1	Not currently operating in the EPO–No opera actualmente en el OPO					
2	49,032	49,032	188,660	0.21	0.15	3.10
3	63,882	63,882	194,055	0.22	0.13	4.29
4	80,483	80,483	227,787	0.26	0.12	76.48
5	47,586	47,586	182,405	0.21	0.15	5.64
6	Not currently operating in the EPO–No opera actualmente en el OPO					
7	103,759	103,759	285,970	0.32	0.13	96.89
8	101,819	101,819	232,677	0.26	0.10	153.79
9	122,632	122,632	284,994	0.32	0.09	5.79

TABLE 6.1. Summary of the outcomes from 101 simulations using the scenarios described in Sections 6.1 and 6.2. "Quantiles" identify the levels at which 20%, 50%, and 80% of the predicted outcomes are less than or equal to the value provided in the table. The 50% quantile is equal to the median.
TABLA 6.1. Resumen de los resultados de 101 simulaciones usando los escenarios descritos en las Secciones 6.1 y 6.2. Los "cuantiles" identifican los niveles en los cuales el 20%, 50%, y 80% de los resultados predichos inferiores o iguales al valor en la tabla. El cuantil de 50% es igual a la mediana.

Quantile	75% surface effort	Average surface effort	Average surface effort, no discards	125% surface effort
Cuantil	**75% del esfuerzo de superficie**	**Esfuerzo de superficie medio**	**Esfuerzo de superficie medio, sin descartes**	**125% del esfuerzo de superficie**
SBR for fourth quarter of 2007–SBR para el cuarto trimestre de 2007				
20%	0.10	0.07	0.07	0.05
50%	0.11	0.07	0.08	0.05
80%	0.11	0.08	0.08	0.05
Average weight (kg) of fish in the combined catch during 2007–Peso medio (kg) de los peces en la captura combinada durante 2007				
20%	10.9	9.0	10.4	7.5
50%	12.1	9.8	11.6	8.4
80%	13.7	10.9	13.2	9.4
Median of quarterly catches (mt) by the primary surface fleet (Fisheries 2-5 and 7) during 2007–Mediana de las capturas trimestrales (tm) por la flota primaria de superficie (Pesquerías 2-5 y 7) durante 2007				
20%	8,750	9,191	9,595	8,900
50%	10,739	11,490	12,012	11,093
80%	12,893	13,977	14,566	13,343
Median of quarterly catches, in thousands of fish, by the longline fleet (Fisheries 8 and 9) during 2007–Mediana de las capturas trimestrales, en miles de peces, por la flota palangrera (Pesquerías 8 y 9) durante 2007				
20%	71	51	53	37
50%	87	65	68	47
80%	119	87	91	62

APPENDIX A: DIAGNOSTICS

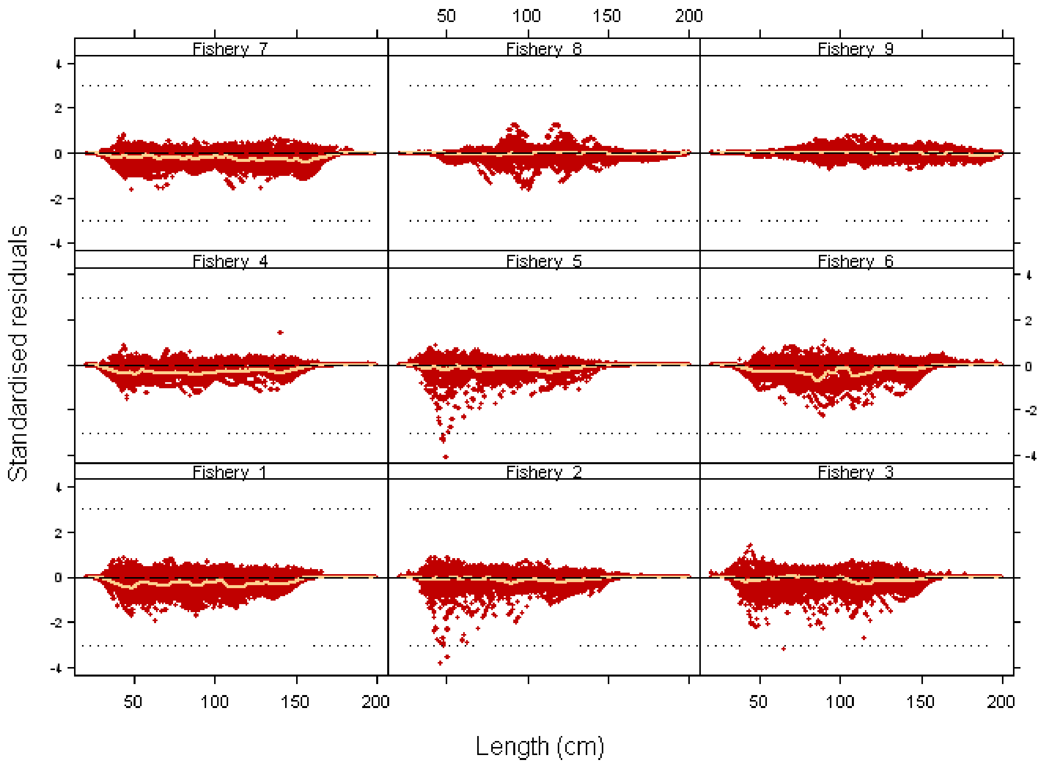

FIGURE A.1. Standardized residuals for the fit to the length frequency data by fishery and length class. The fitted line is a loess smoother.

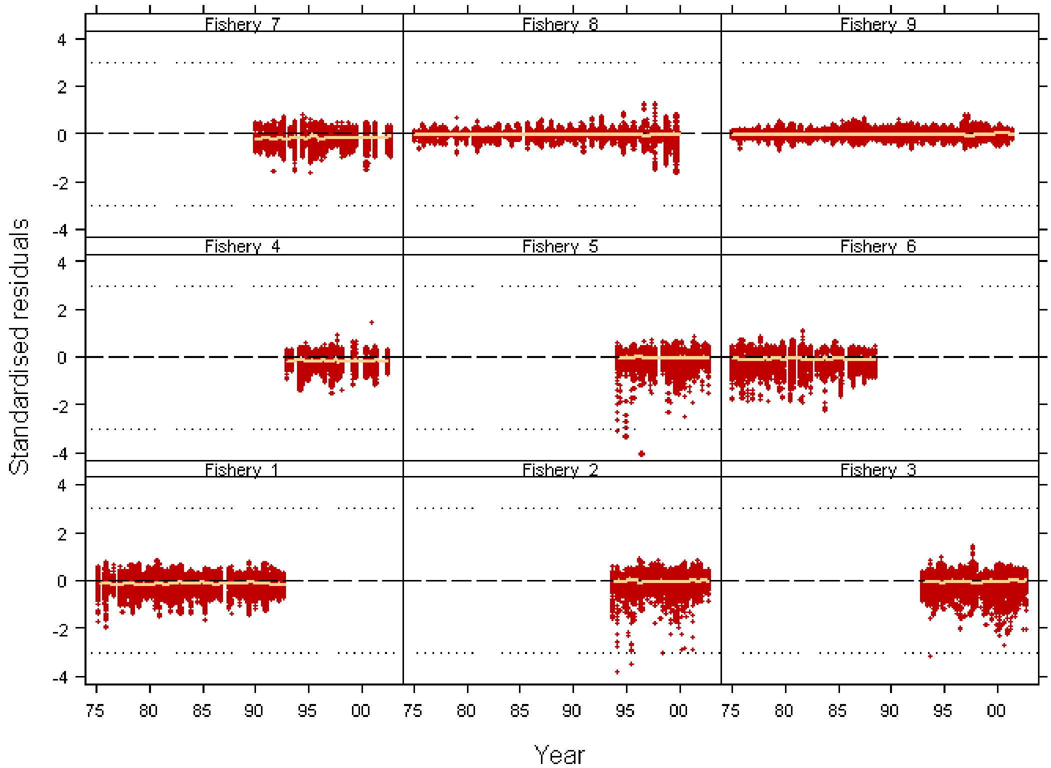

FIGURE A.2. Standardized residuals for the fit to the length frequency data by fishery and year. The fitted line is a loess smoother.

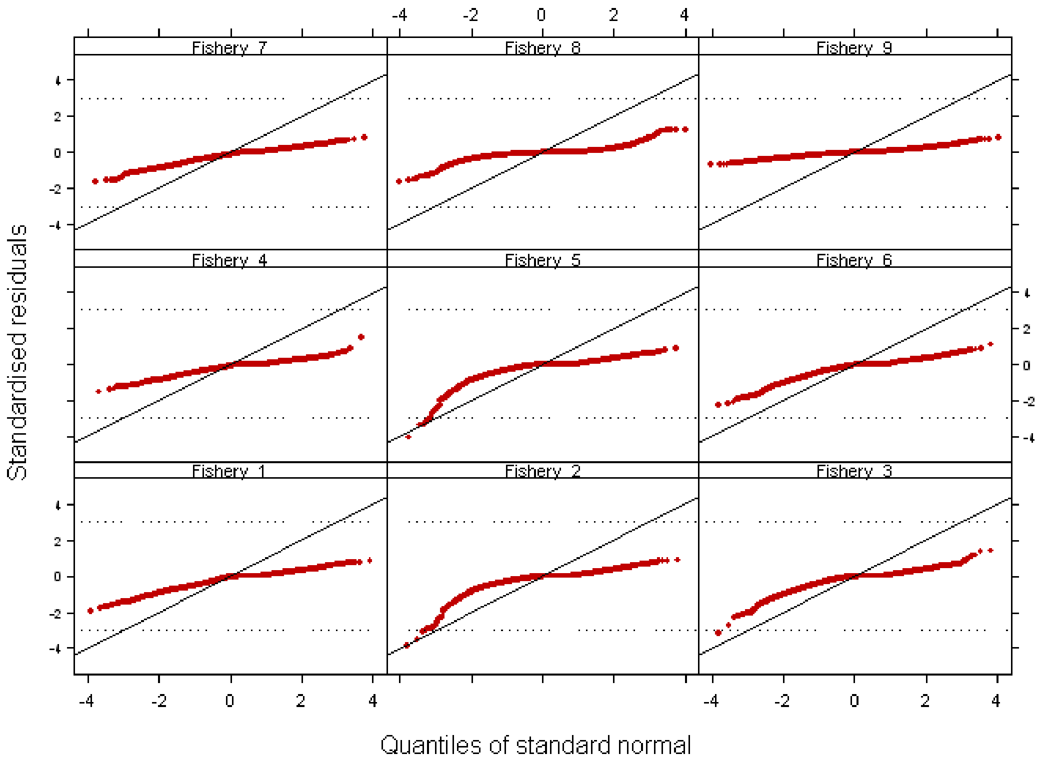

FIGURE A.3. A Q-Q plot for the residuals of the fit to the length frequency data by fishery. The solid line indicates the expectation for residuals following a normal distribution.

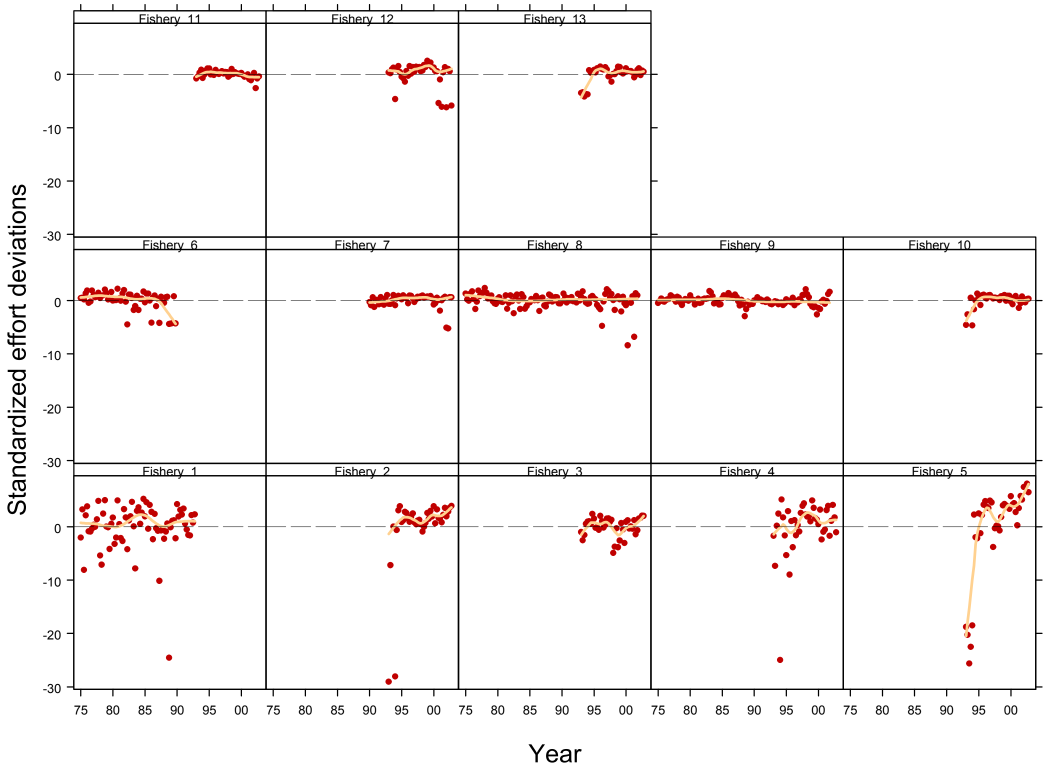

FIGURE A.4. Standardized effort deviates by fishery and time quarter. The fitted line is a loess smoother.

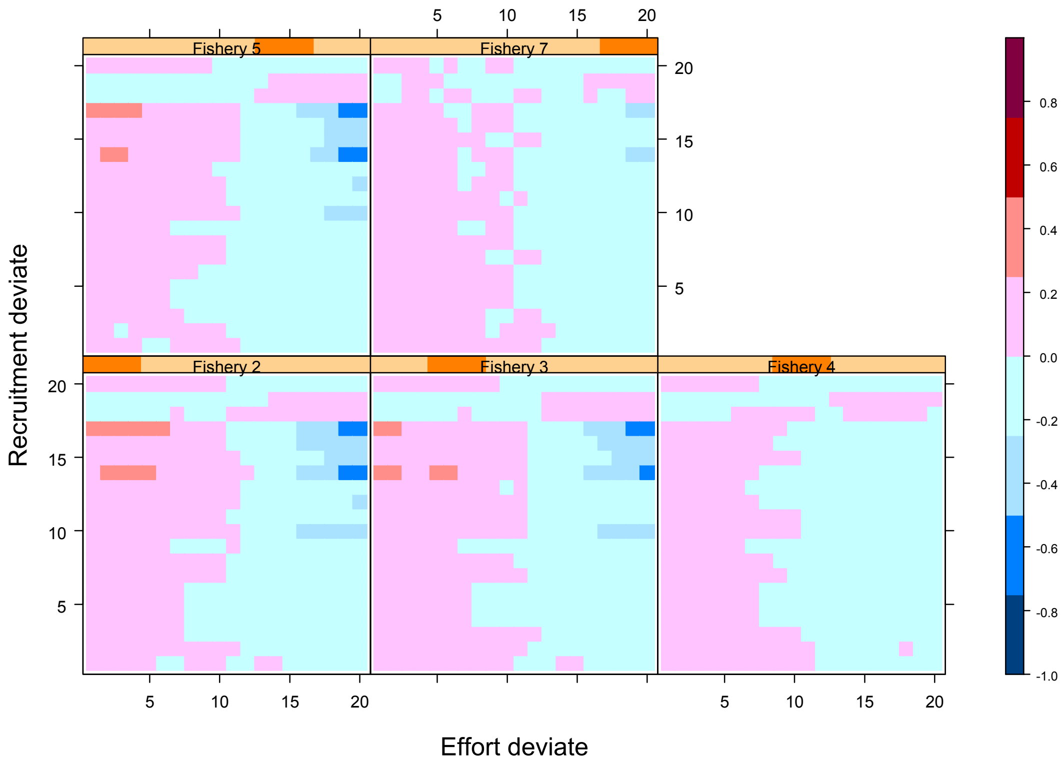

FIGURE A.5a. Correlation between the estimated effort deviates and recruitment deviates for the most recent 20 quarters for the surface fisheries.

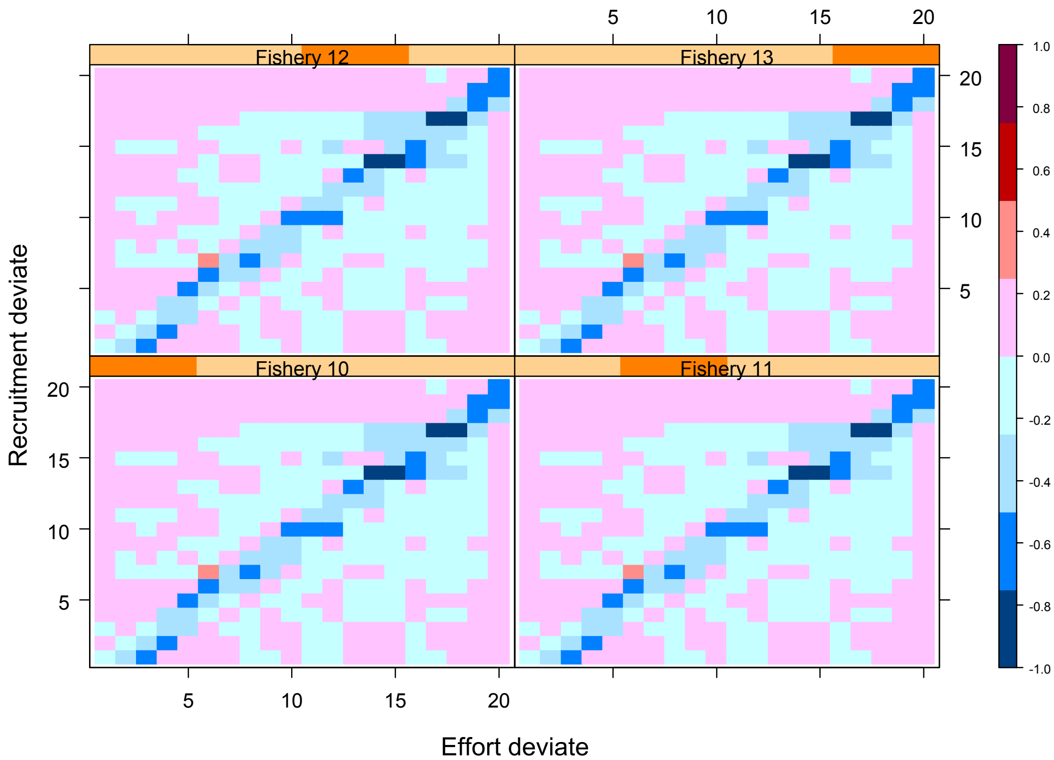

FIGURE A.5b. Correlation between the estimated effort deviates and recruitment deviates for the most recent 20 quarters for the discard fisheries.

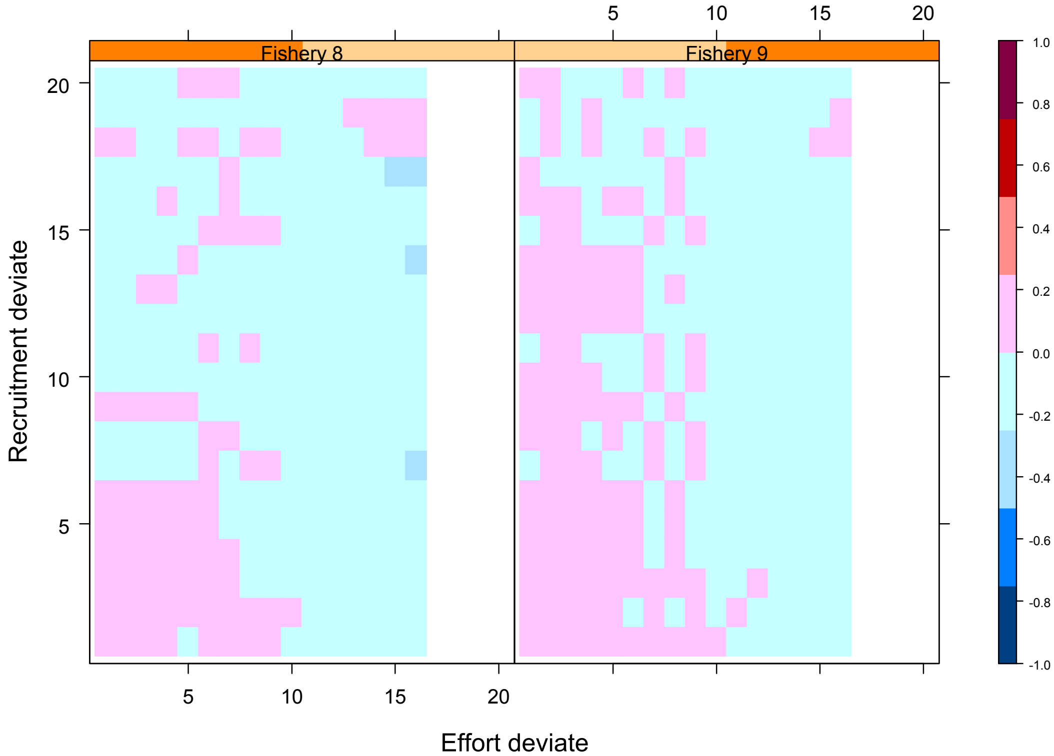

FIGURE A.6. Correlation between the estimated effort deviates and recruitment deviates for the most recent 20 quarters for the longline fisheries.

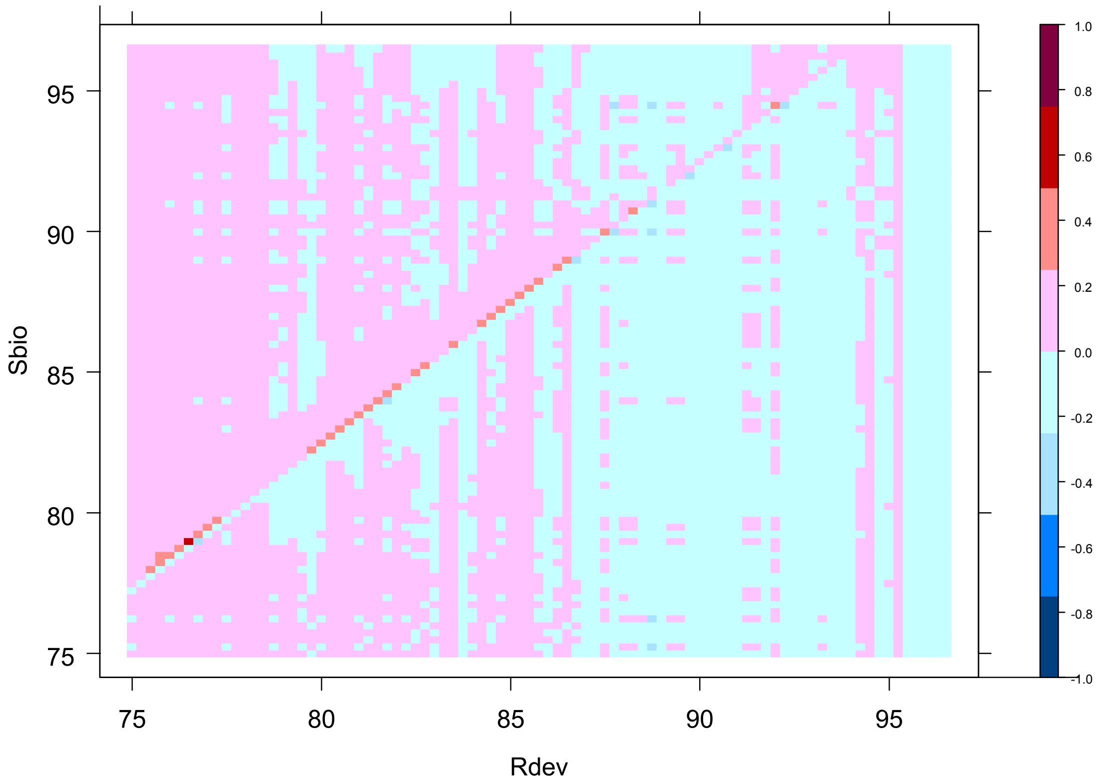

FIGURE A.7. Correlation between the estimated spawning biomass and recruitment deviates.
FIGURA A.7. .

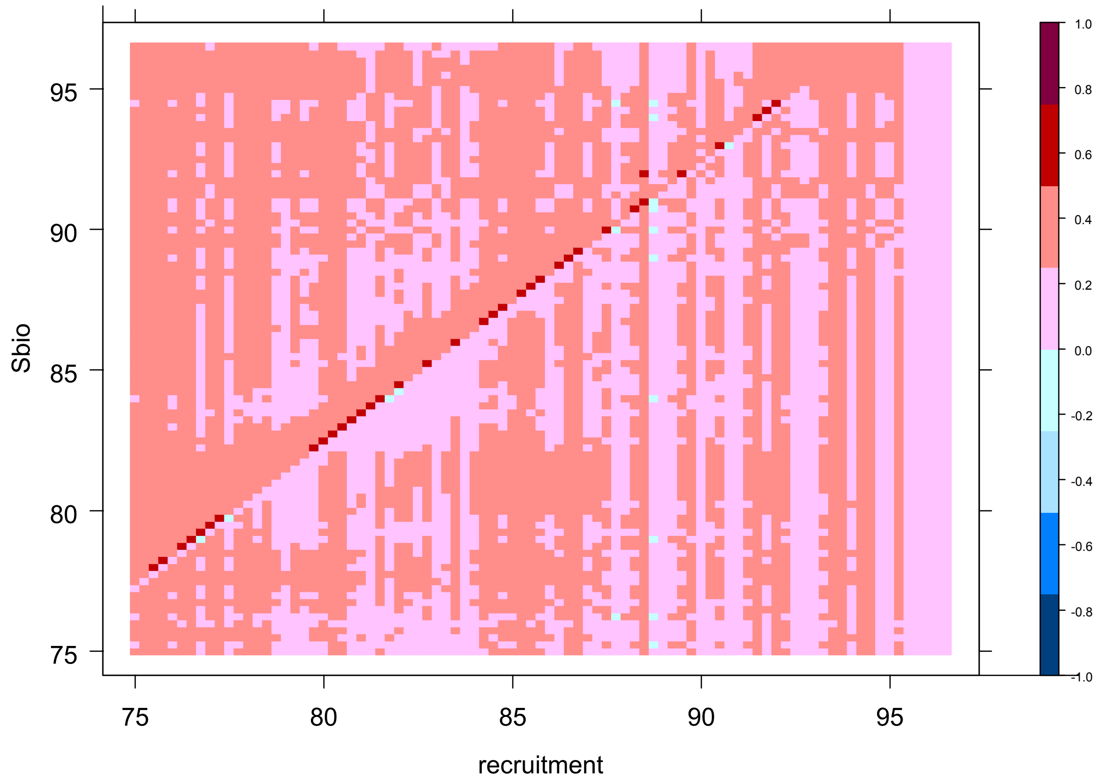

FIGURE A.8. Correlation between the estimated spawning biomass and recruitment.
FIGURA A.8. .

APPENDIX B: STEEPNESS SENSITIVITY ANALYSIS

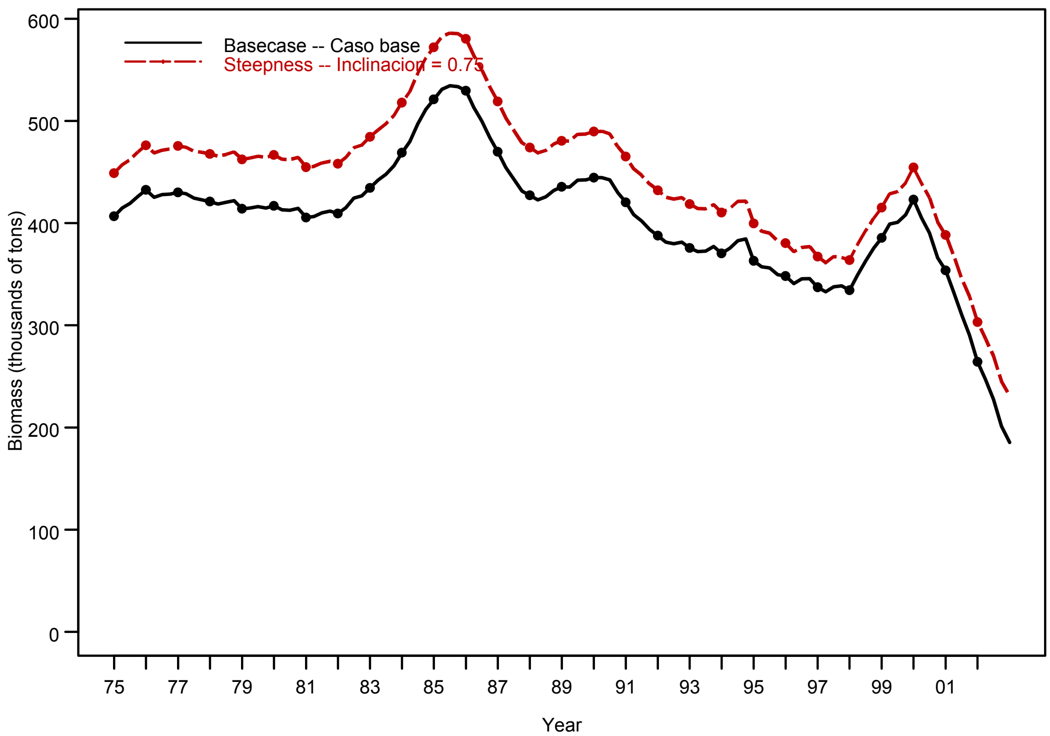

FIGURE B.1. Comparison of estimates of biomass from the analysis without a stock recruitment relationship (base case) and with a stock recruitment relationship (steepness = 0.75).
FIGURA B1. Comparación de las estimaciones de biomasa del análisis sin relación de reclutamiento de stock (caso base) y con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

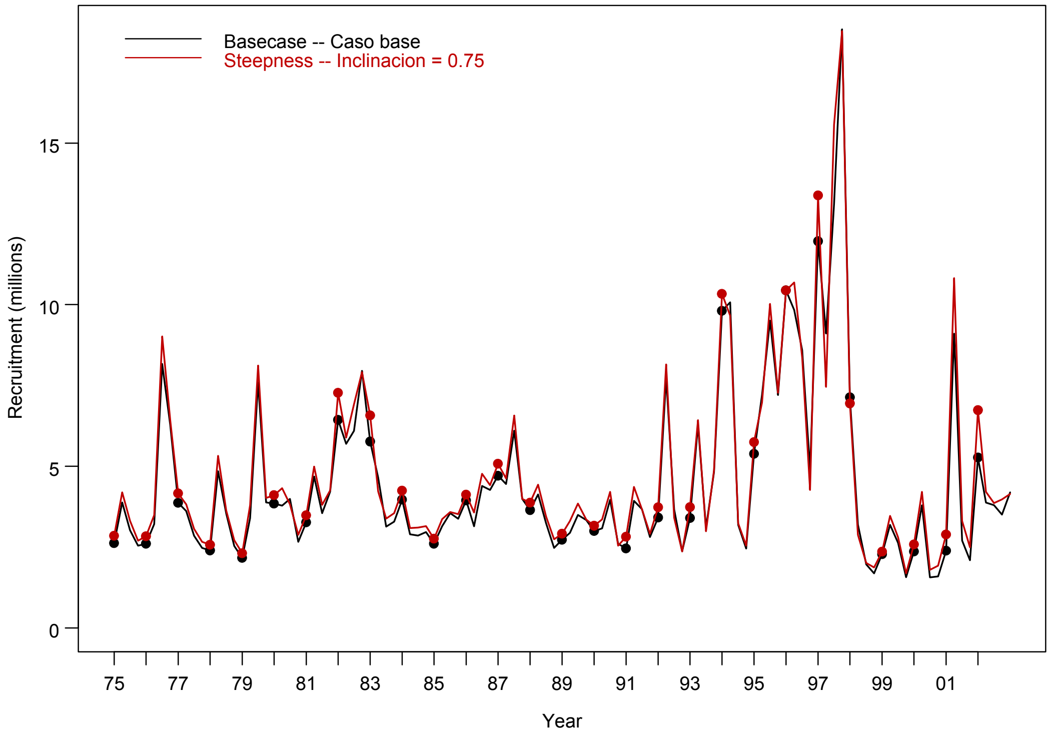

FIGURE B.2. Comparison of estimates of recruitment from the analysis without a stock recruitment relationship (base case) and with a stock recruitment relationship (steepness = 0.75).
FIGURA B.2. Comparación de las estimaciones de reclutamiento del análisis sin relación de reclutamiento de stock (caso base) y con (inclinación = 0,75).

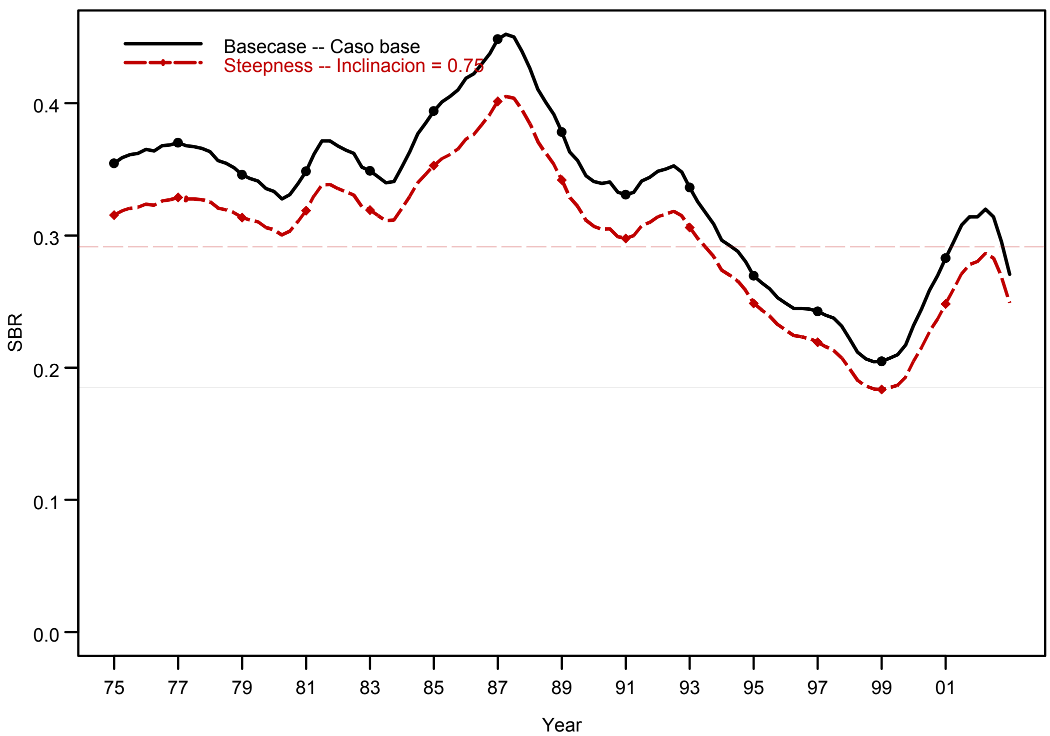

FIGURE B.3. Comparison of estimates of the spawning biomass ratio (SBR) from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). The horizontal lines represent the SBR associated with AMSY.

FIGURA B.3. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) del análisis sin relación de reclutamiento de stock (caso base) y con relación de reclutamiento de stock (inclinación = 0,75). Las líneas horizontales representan el SBR asociado con el RMSP.

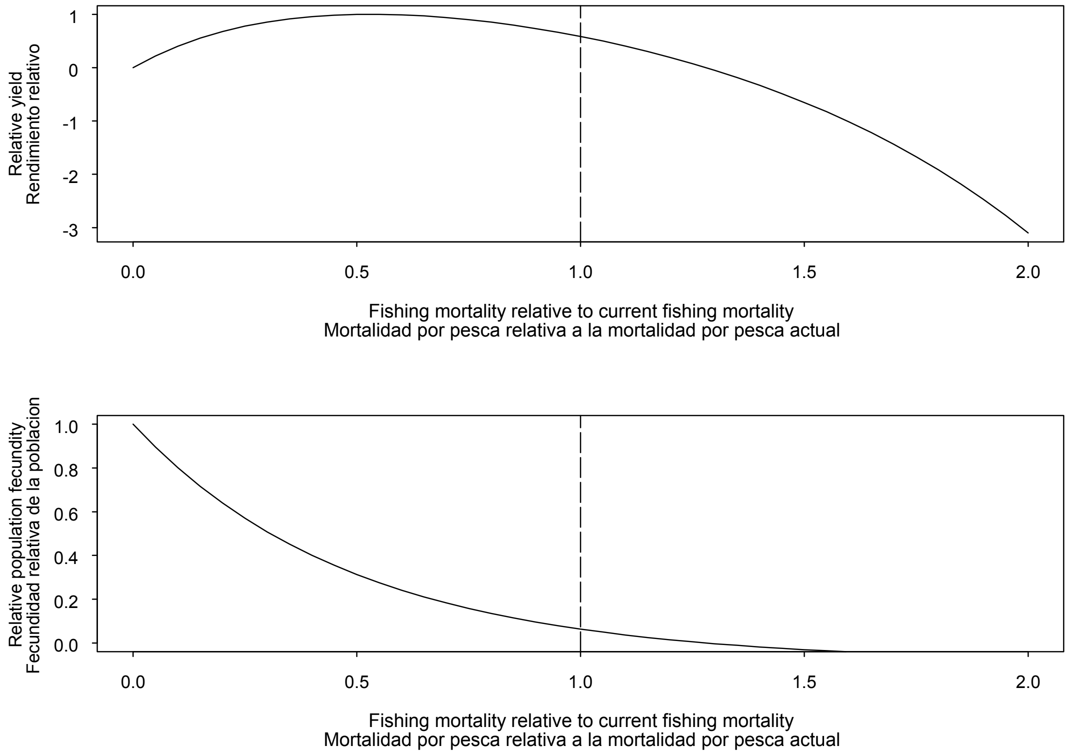

FIGURE B.4. Comparison of the relative yield (top panel solid line) with the relative yield per recruit (top panel, dashed line) when the stock assessment model has a stock recruitment relationship (steepness = 0.75).

FIGURA B.4. Comparación del rendimiento relativo con el rendimiento por recluta relativo (recuadro superior, línea de trazos) cuando el modelo de evaluación del stock tiene una relación de reclutamiento de stock (inclinación = 0.75).

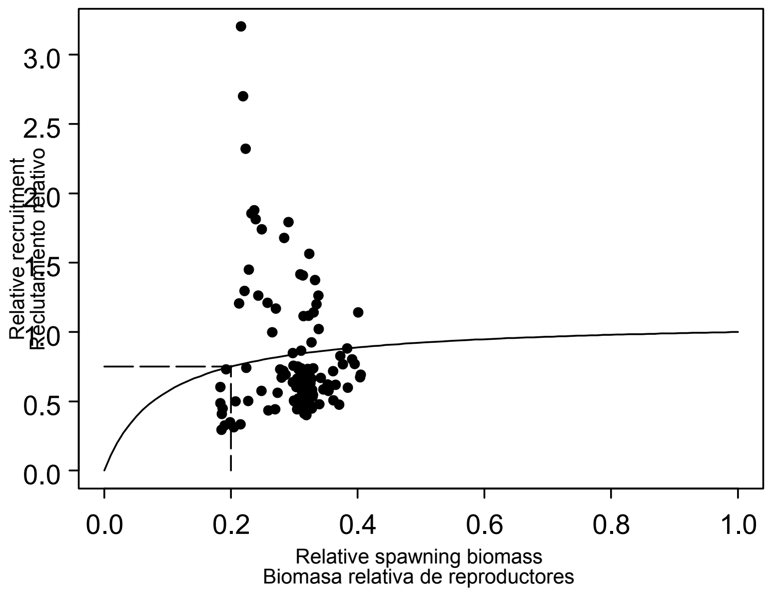

FIGURE B.5. Recruitment plotted against spawning biomass when the analysis has a stock-recruitment relationship (steepness = 0.75).
FIGURA B.5. Reclutamiento graficado contra biomasa reproductora cuando el análisis tiene una relación de reclutamiento de stock (inclinación = 0,75).

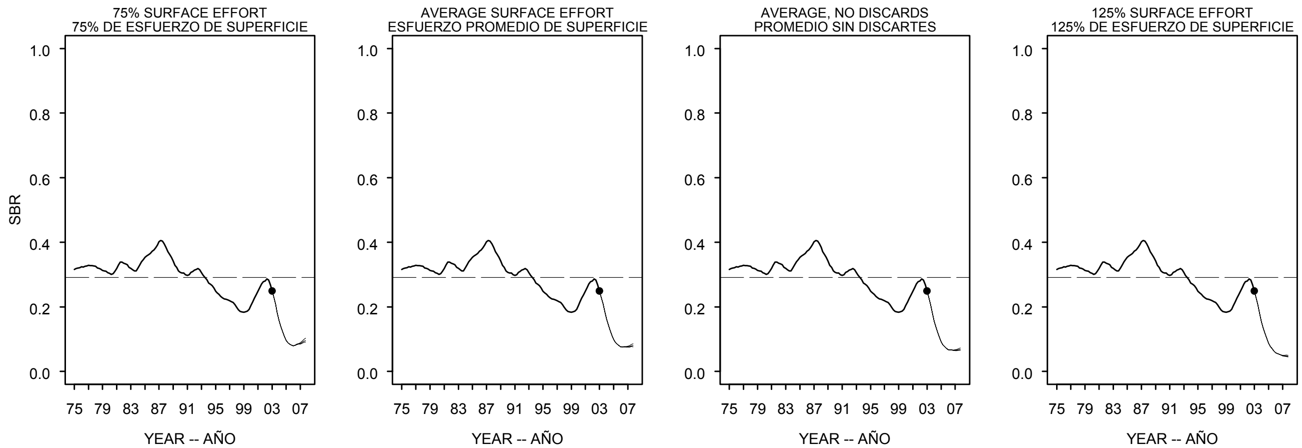

FIGURE B.6. Simulated SBRs during 2003-2007 for bigeye tuna in the EPO when a stock recruitment relationship is assumed (steepness = 0.75). Each panel illustrates the results of 101 simulations using the different scenarios described in Sections 6.1 and 6.2. The median estimates of the simulated SBRs are indicated by the solid lines to the right of each solid dot. The shaded areas indicate the regions bounded by the 20% and 80% quantiles of the simulated SBRs. The dashed horizontal lines indicate the SBR_{AMSY} (0.29).

FIGURA B.6. SBR simulados durante 2003-2007 para el atún patudo en el OPO. Cada recuadro ilustra los resultados de 101 simulaciones usando los diferentes escenarios descritos en las Secciones 6.1 y 6.2. Las estimaciones medianas de los SBR simulados son indicadas por las líneas sólidas a la derecha de cada punto sólido. Las zonas sombreadas indican las regiones delimitadas por los cuantiles de 20% y 80% de los SBR simulados. Las líneas de trazos horizontales señalan el SBR_{RMSP} (0,29).

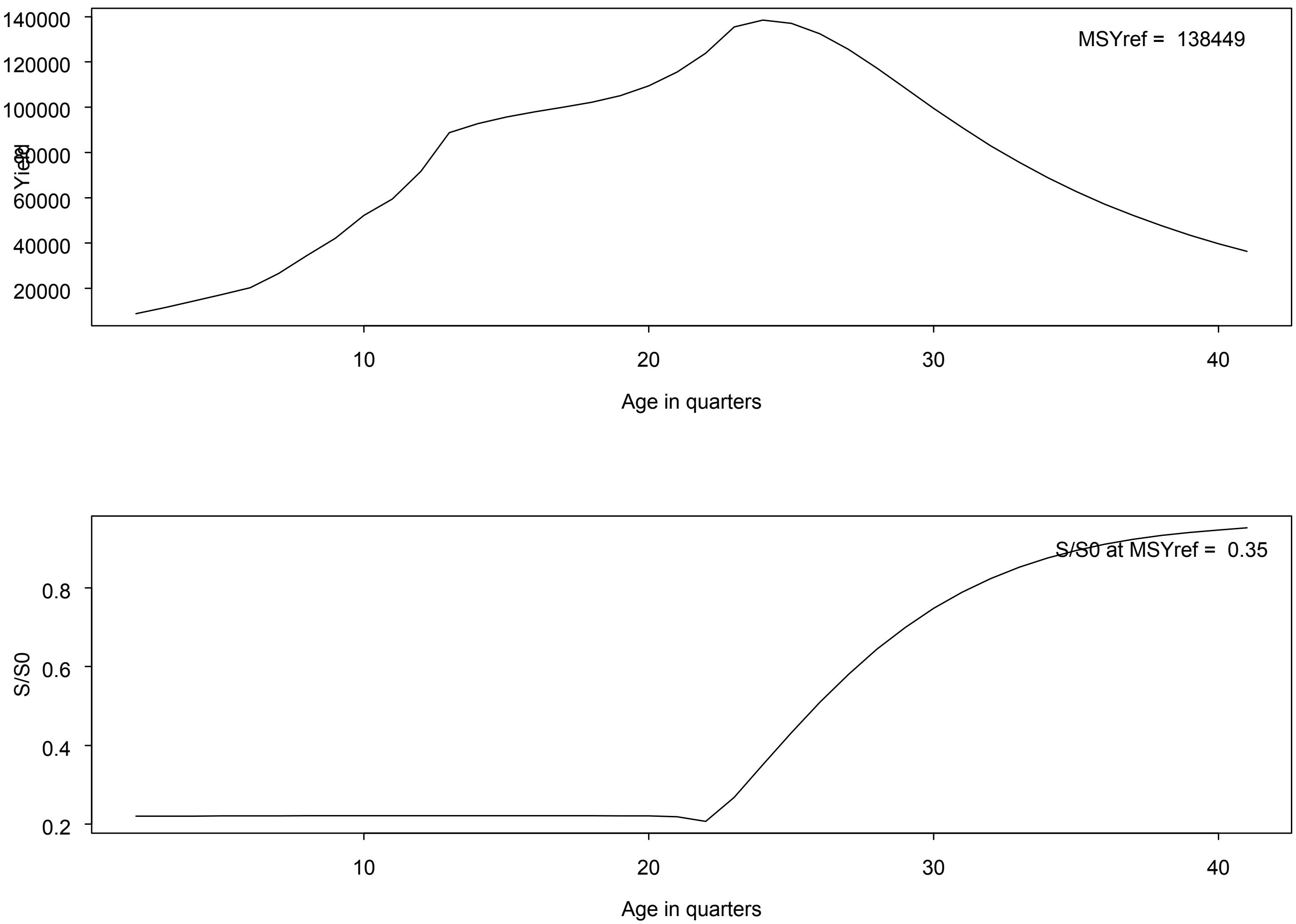

FIGURE B.7. Yield calculated when only catching individuals at a single age (top panel) and the associated SBR (lower panel).

APPENDIX C: PURSE SEINE CATCH SENSITIVITY ANALYSIS

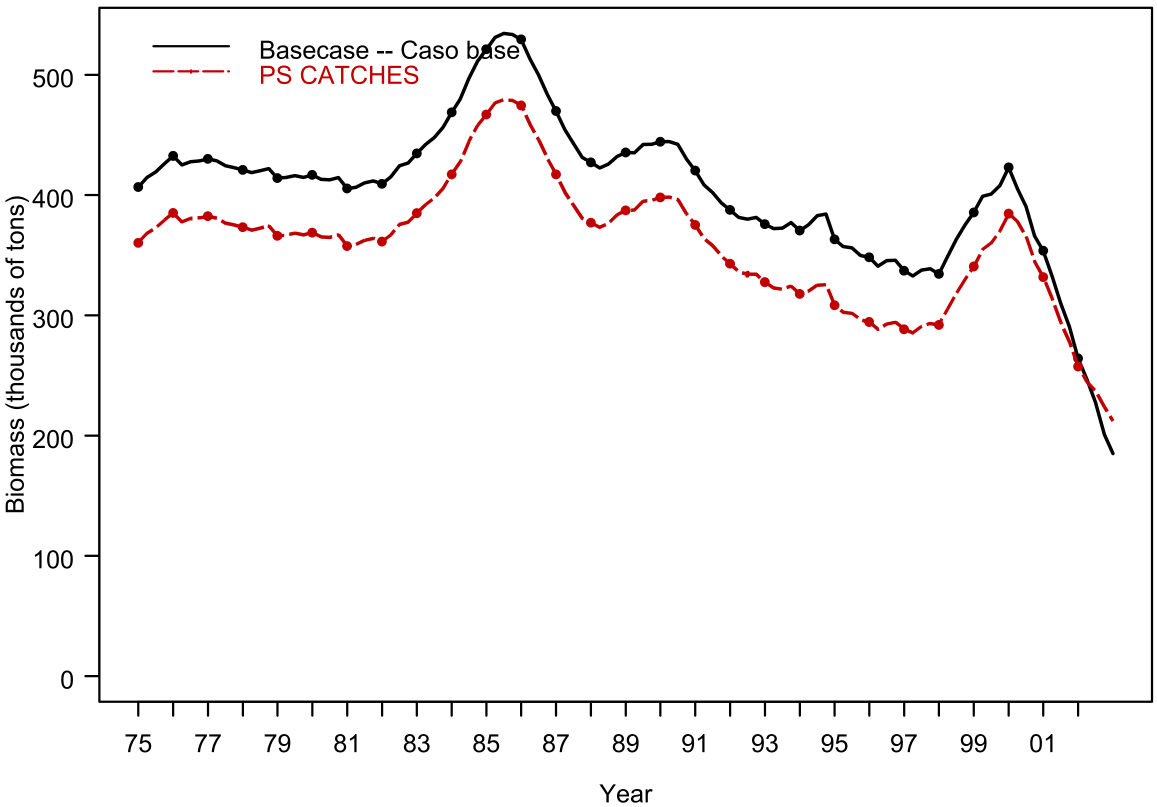

FIGURE C.1. Comparison of estimates of biomass from the base case and with the cannery estimates of purse seine catch.

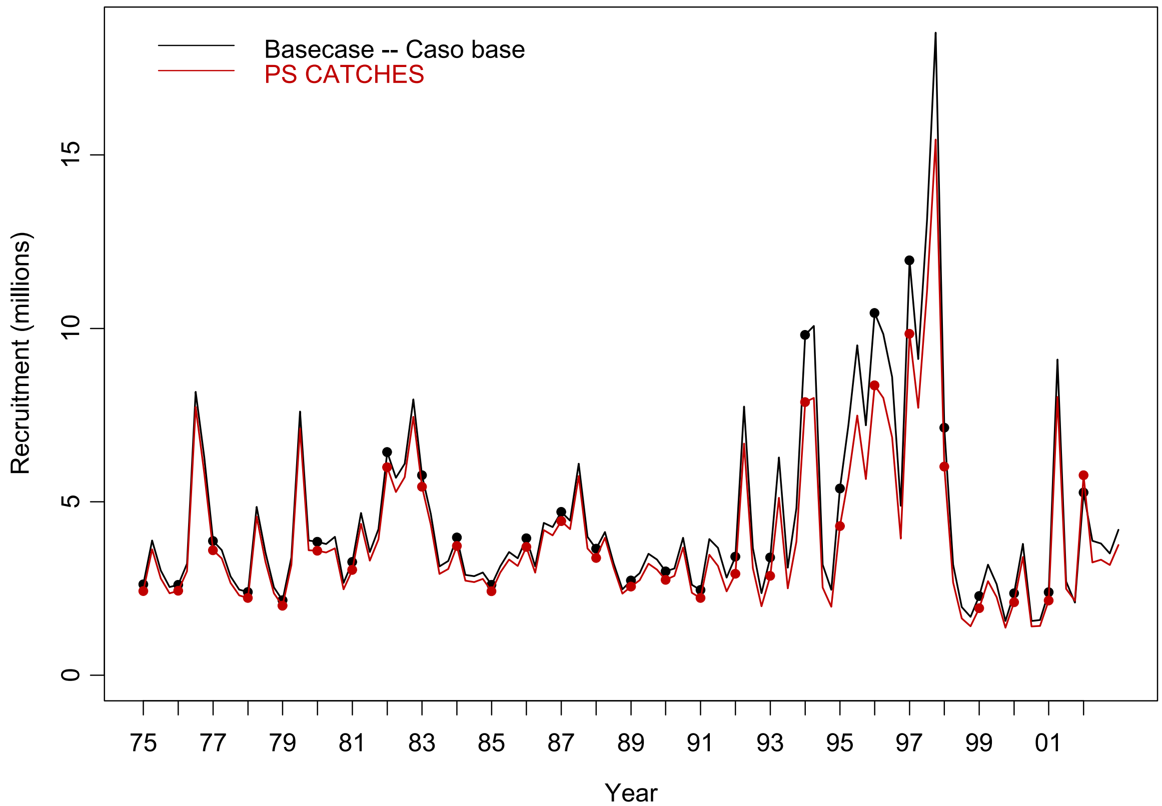

FIGURE C2. Comparison of estimates of recruitment from the base case and with the cannery estimates of purse seine catch.

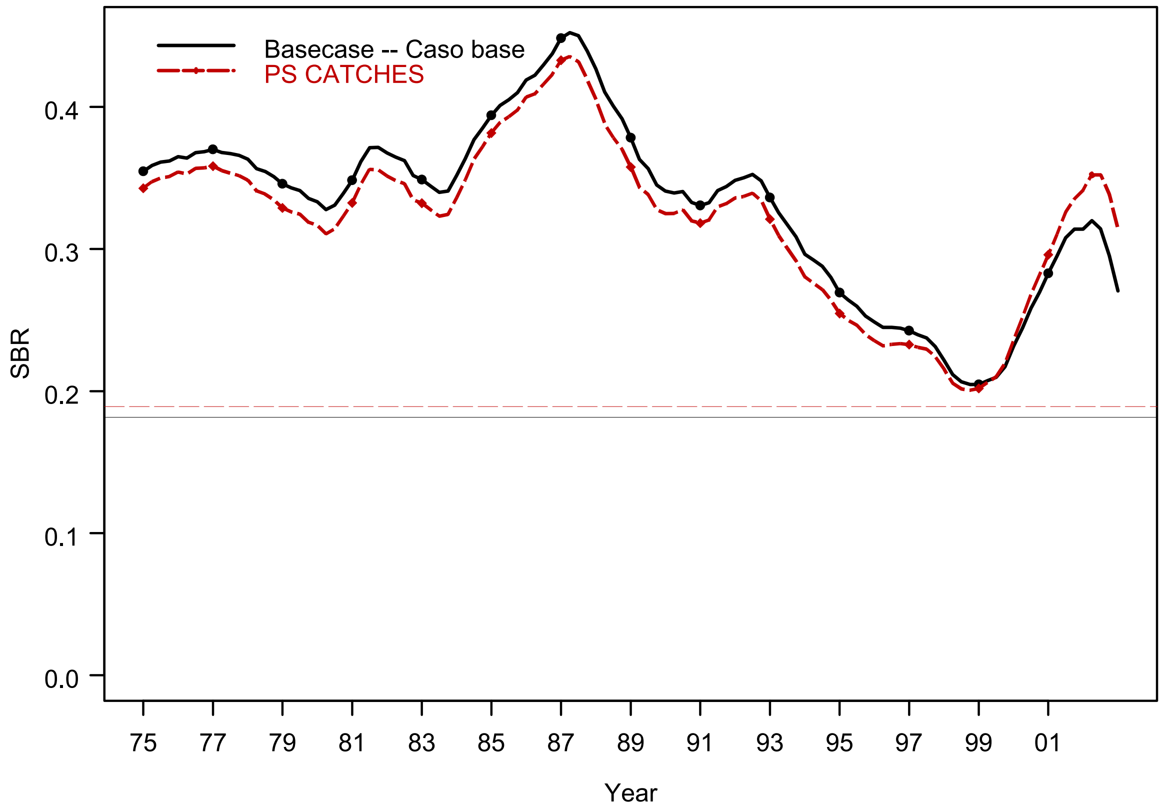

FIGURE C.3. Comparison of estimates of the spawning biomass ratio (SBR) from the base case and with the cannery estimates of purse seine catch. The horizontal lines represent the SBR associated with AMSY.

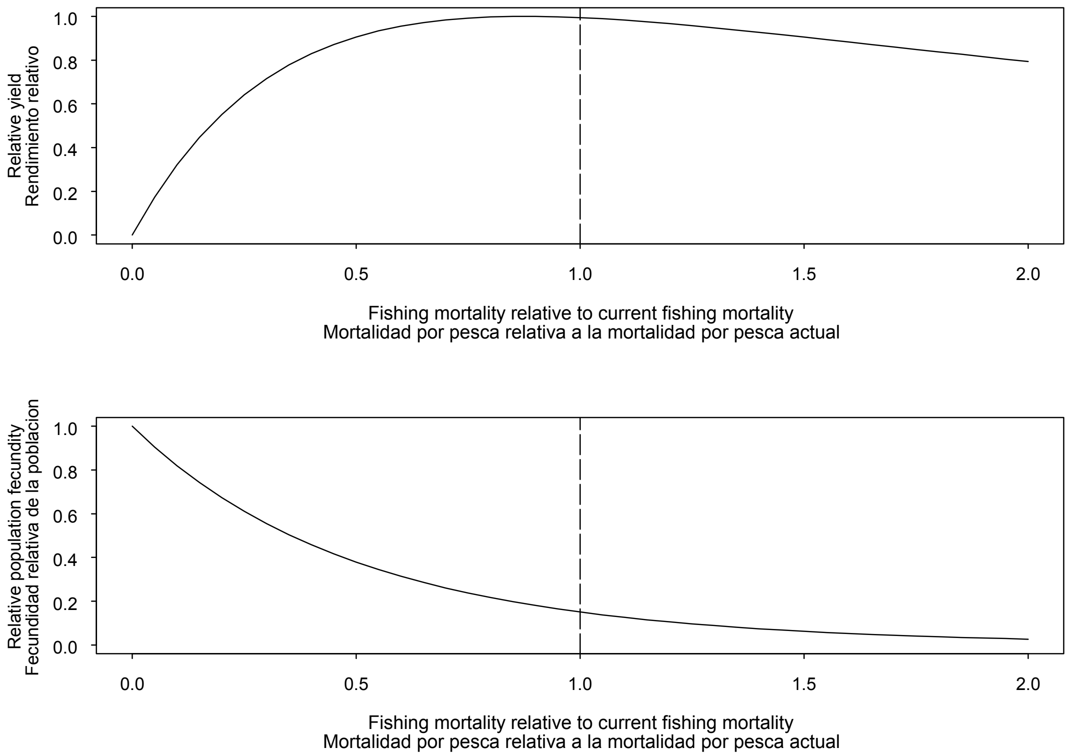

FIGURE C.4. Comparison of the relative yield (top panel solid line) with the relative yield per recruit (top panel, dashed line) when the stock assessment model includes the cannery estimates of purse seine catch.

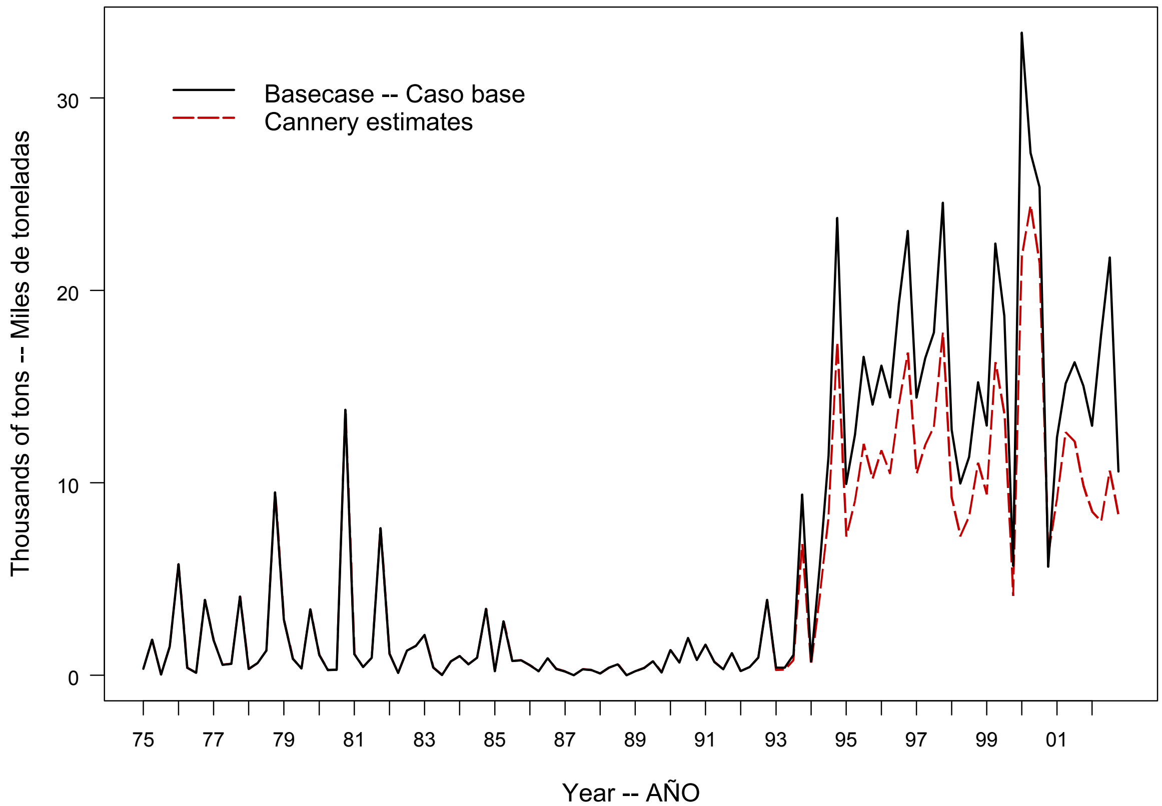

FIGURE C.5. Total purse seine catch used in the basecase (solid line) and the sensitivity analysis based on the cannery estimates of purse seine catch (dashed line).

APPENDIX D: SPC KOREAN CATCH SENSITIVITY ANALYSIS

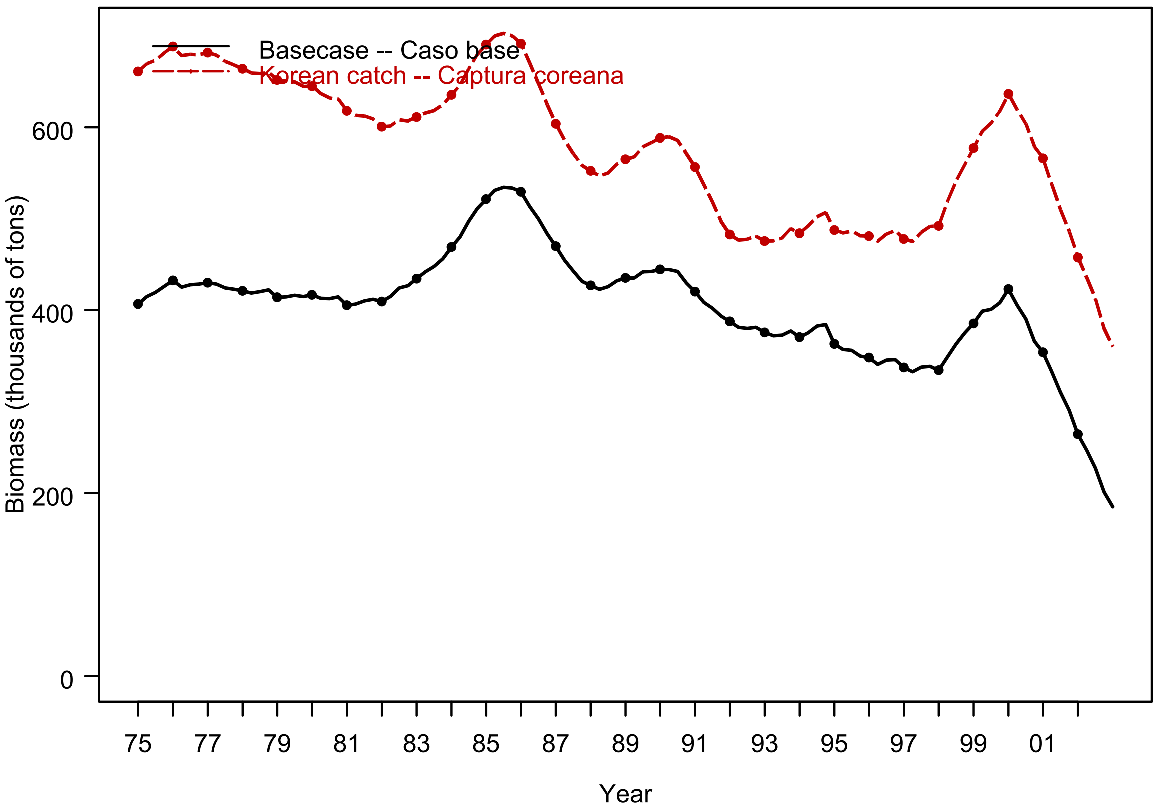

FIGURE D.1. Comparison of estimates of biomass from the base case and with the SPC-estimated Korean longline catch.
FIGURA D.1. Comparación de las estimaciones de biomasa del caso base y con la captura coreana estimada por SPC.

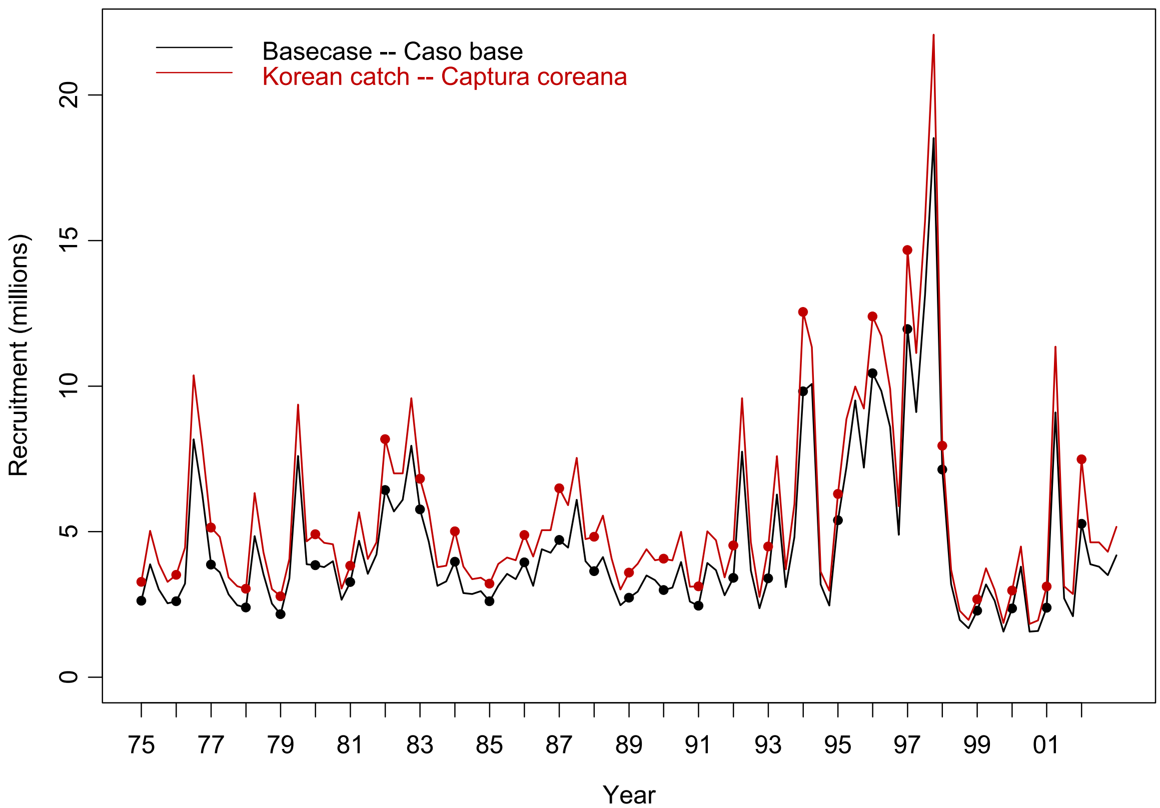

FIGURE D.2. Comparison of estimates of recruitment from the base case and with the SPC-estimated Korean longline catch.
FIGURA D.2. Comparación de las estimaciones de reclutamiento del caso base y con la captura coreana estimada por SPC.

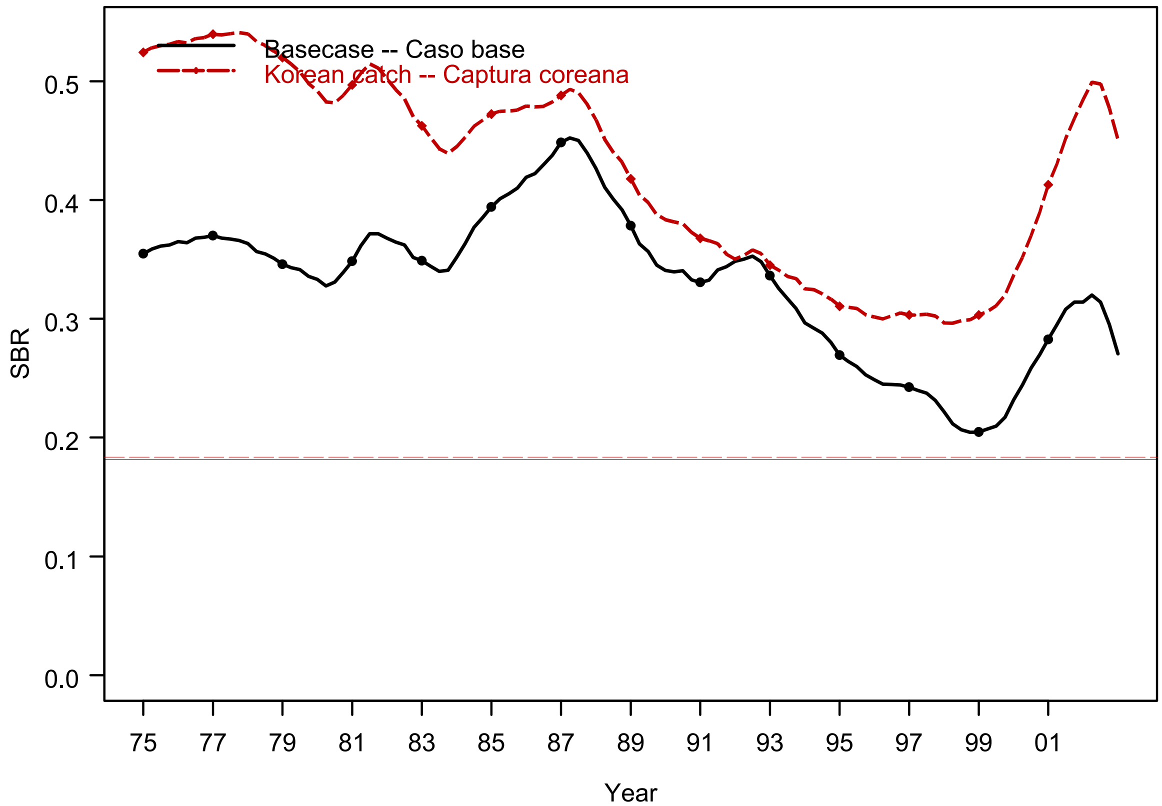

FIGURE D.3. Comparison of estimates of the spawning biomass ratio (SBR) from the base case and with the SPC-estimated Korean longline catch. The horizontal lines represent the SBR associated with AMSY.

FIGURA D.3. Comparación de las estimaciones del cociente de biomasa reproductora (SBR) del caso base y con la captura coreana estimada por SPC.

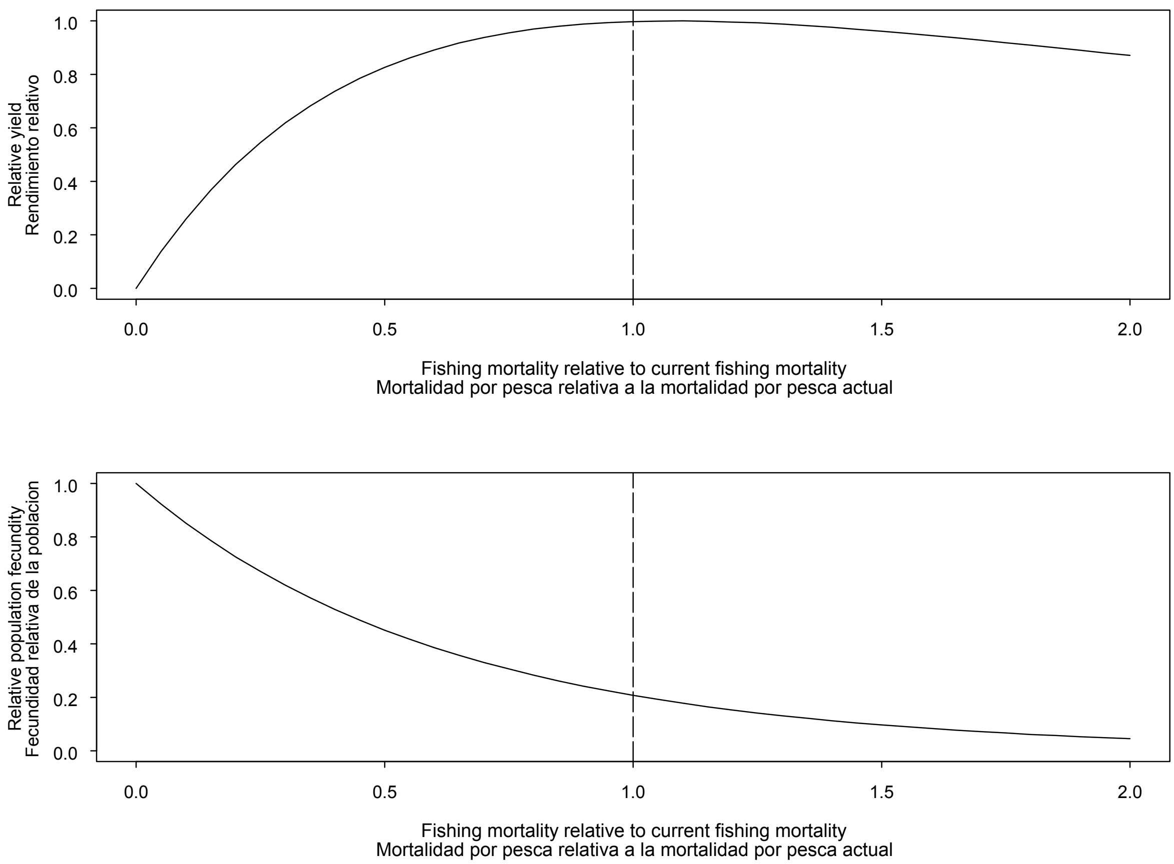

FIGURE D.4. Comparison of the relative yield (top panel solid line) with the relative yield per recruit (top panel, dashed line) when the stock assessment model has the SPC-estimated Korean longline catch.

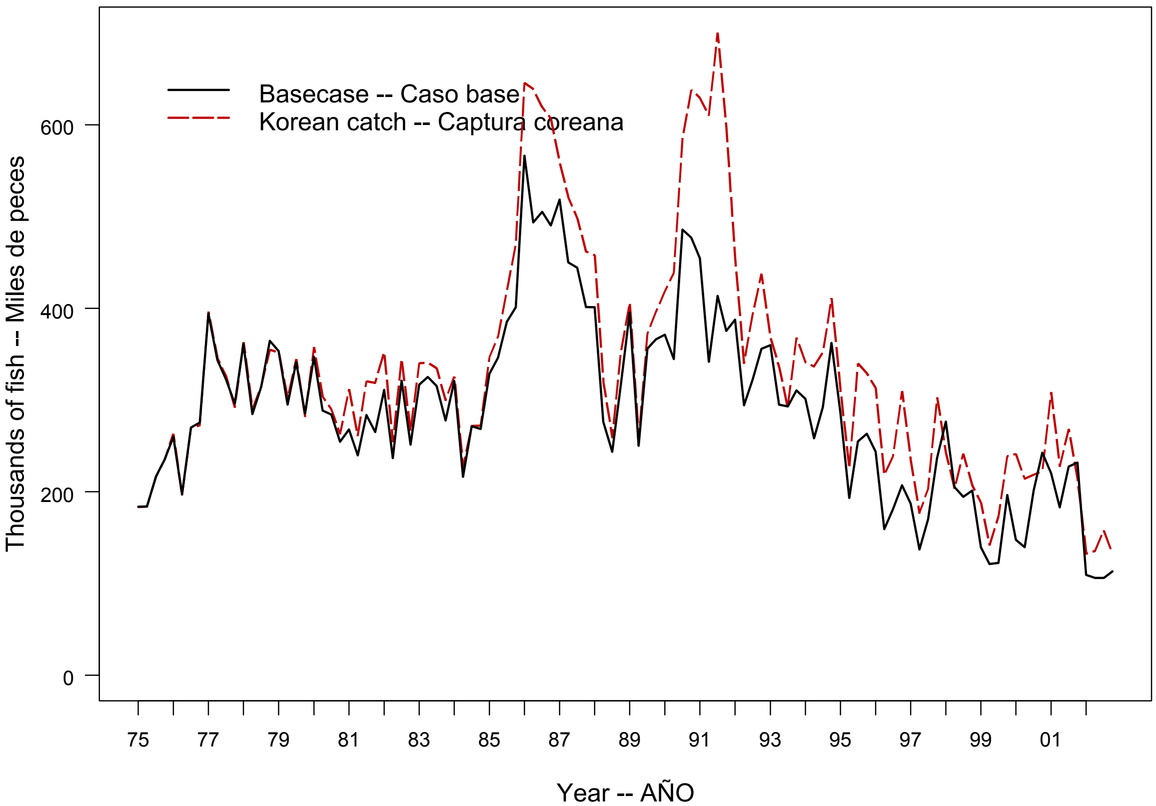

FIGURE D.5. Total longline catch used in the basecase (solid line) and the sensitivity analysis based on the SPC estimates of Korean catch (dashed line).

FIGURA D.5. Captura palangrera total usada en el caso base (línea de trazos) y el análisis de sensibilidad basado en las estimaciones de SPC de la captura coreana (línea sólida).

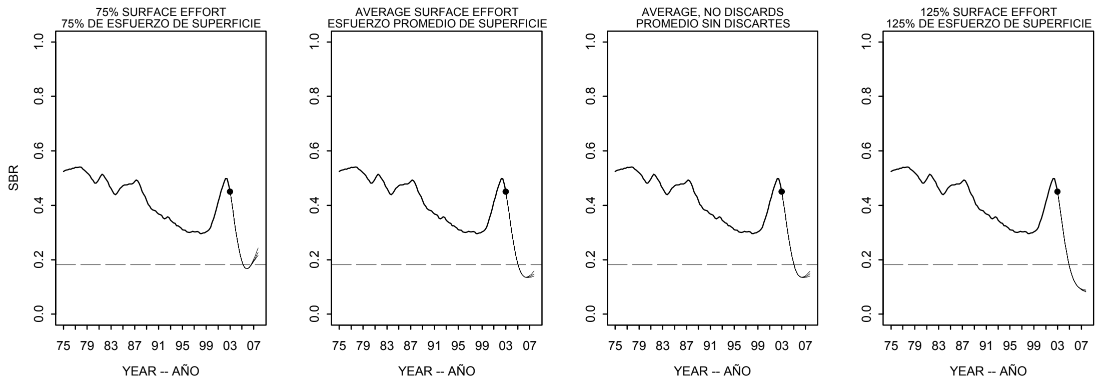

FIGURE D6. Simulated SBRs during 2003-2007 for bigeye tuna in the EPO when the SPC-scaled Korean estimates of catch are used. Each panel illustrates the results of 101 simulations using the different scenarios described in Sections 6.1 and 6.2. The median estimates of the simulated SBRs are indicated by the solid lines to the right of each solid dot. The shaded areas indicate the regions bounded by the 20% and 80% quantiles of the simulated SBRs. The dashed horizontal lines indicate the SBR_{AMSY} (0.29).

APPENDIX E: HABITAT STANDARDIZED LONGLINE CPUE

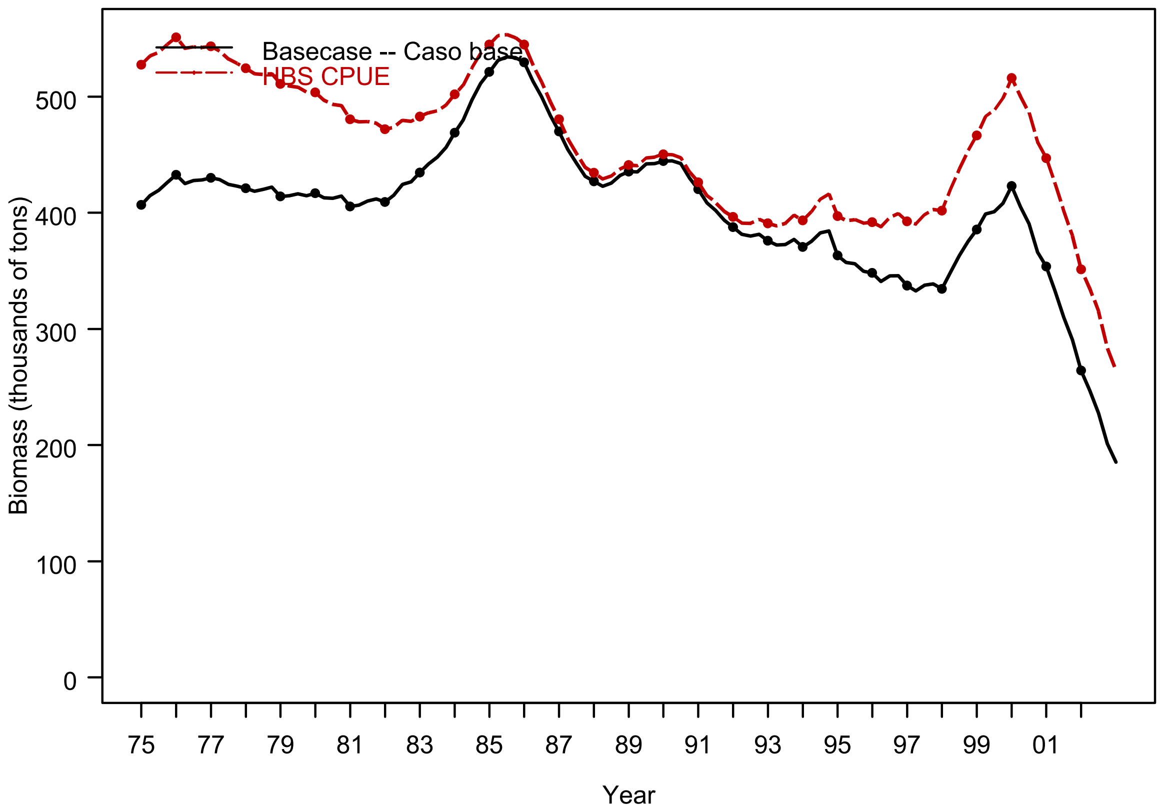

FIGURE E.1. Comparison of estimates of biomass from the base case and with the habitat standardized CPUE as used in the last assessment (Maunder and Harley 2002).

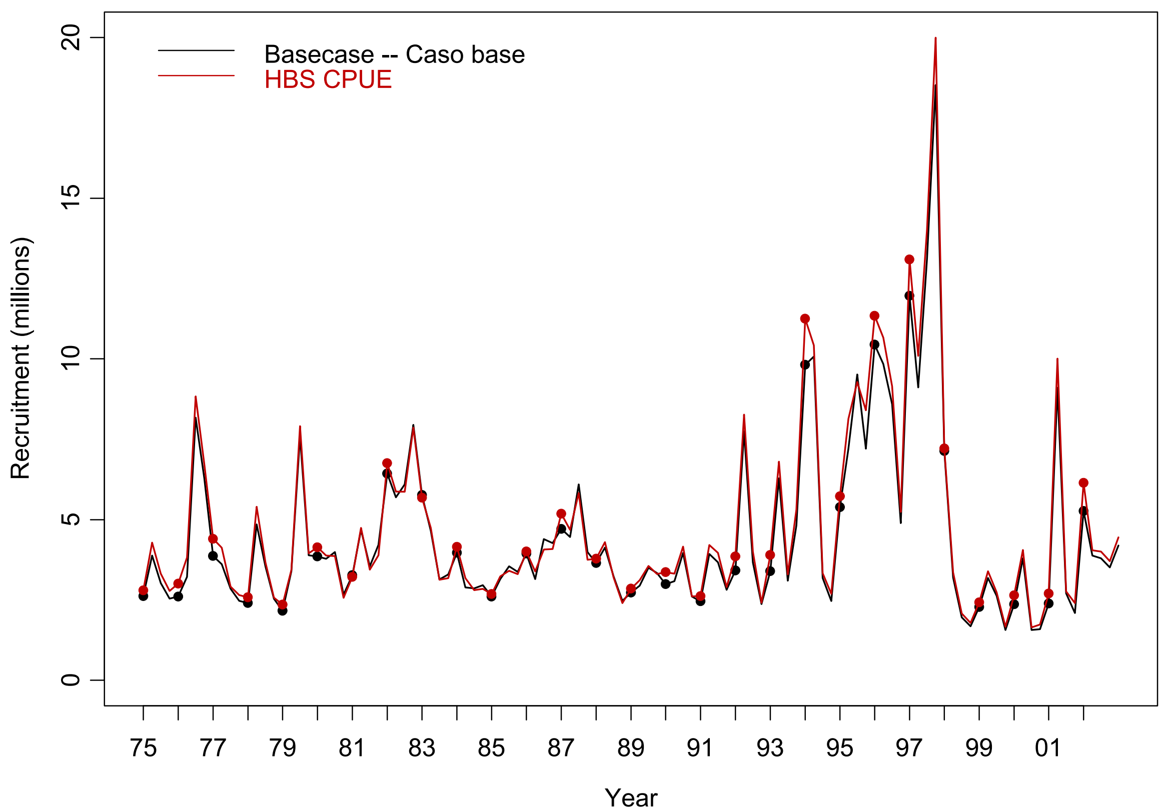

FIGURE E.2. Comparison of estimates of recruitment from the base case and with the habitat standardized CPUE as used in the last assessment (Maunder and Harley 2002).

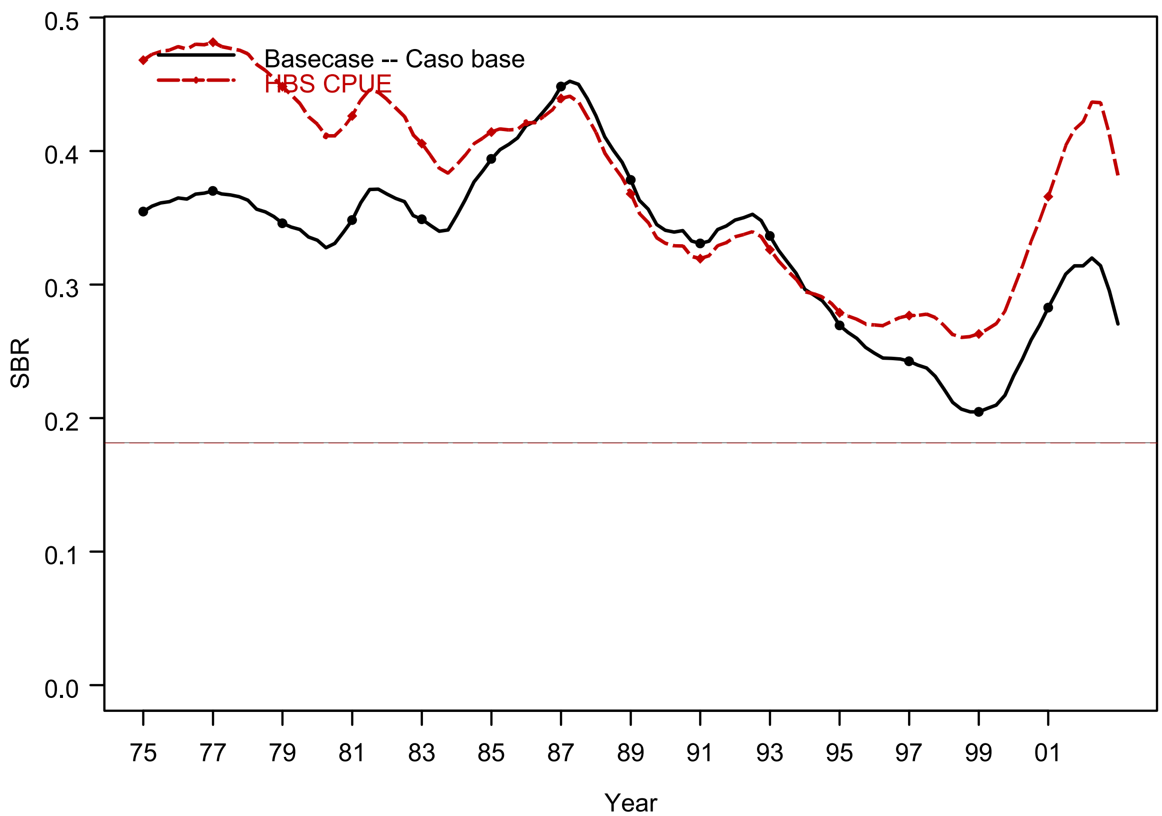

FIGURE E.3. Comparison of estimates of the spawning biomass ratio (SBR) from the base case and with the habitat standardized CPUE as used in the last assessment (Maunder and Harley 2002). The horizontal lines represent the SBR associated with AMSY.

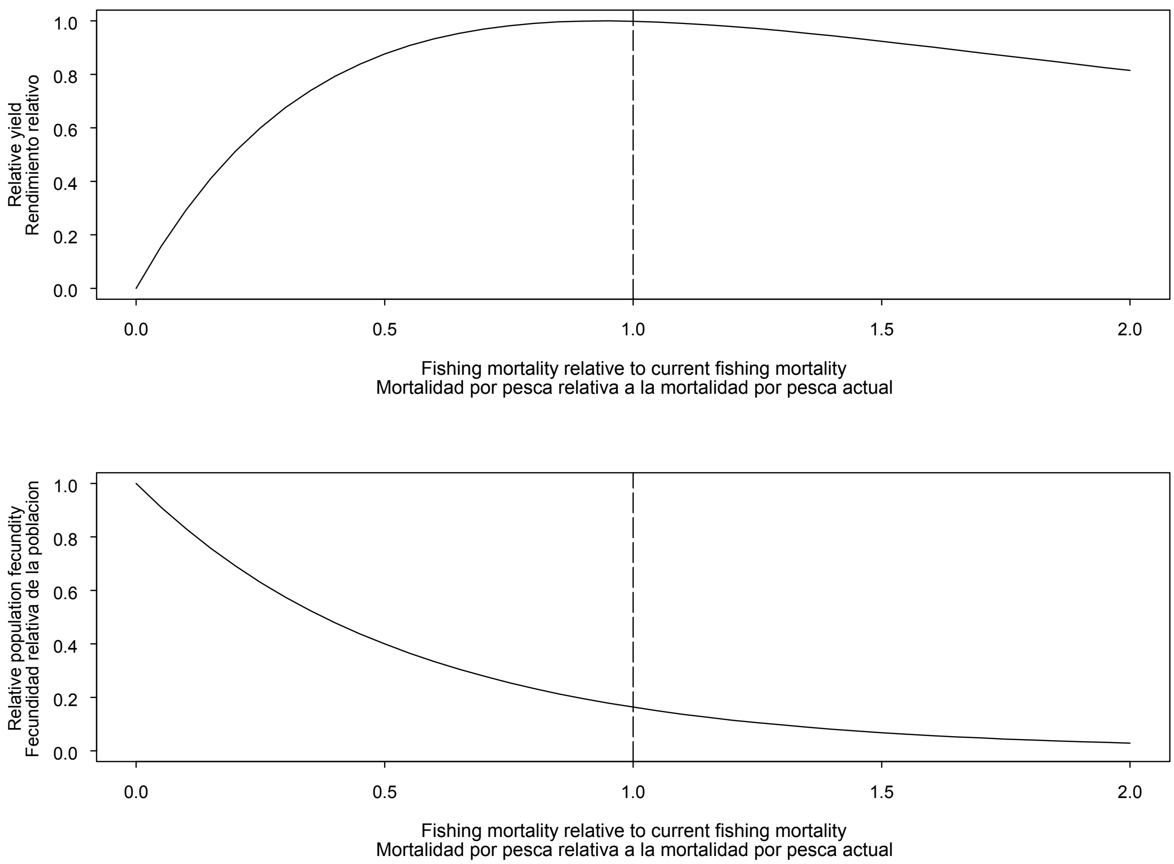

FIGURE E.4. Comparison of the relative yield (top panel solid line) with the relative yield per recruit (top panel, dashed line) when the stock assessment model has the habitat standardized CPUE as used in the last assessment (Maunder and Harley 2002).

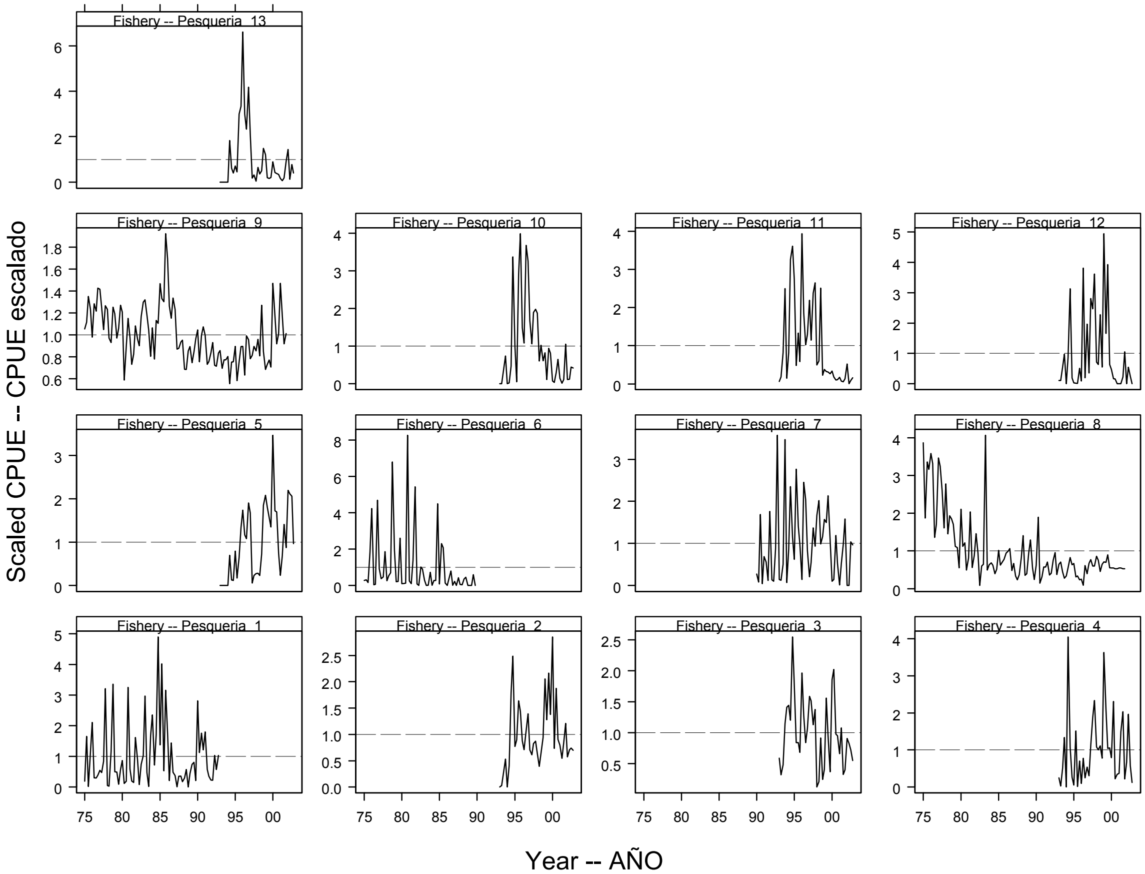

FIGURE E.5. CPUEs of the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). The CPUE for the longline fisheries (8 and 9) are based on those estimated using the habitat standardized method used in the previous assessment (Maunder and Harley 2002). The CPUE for all other fisheries is the same as that in Figure 4.1.

APPENDIX F: ITERATIVE REWEIGHTING OF LONGLINE SAMPLE SIZE

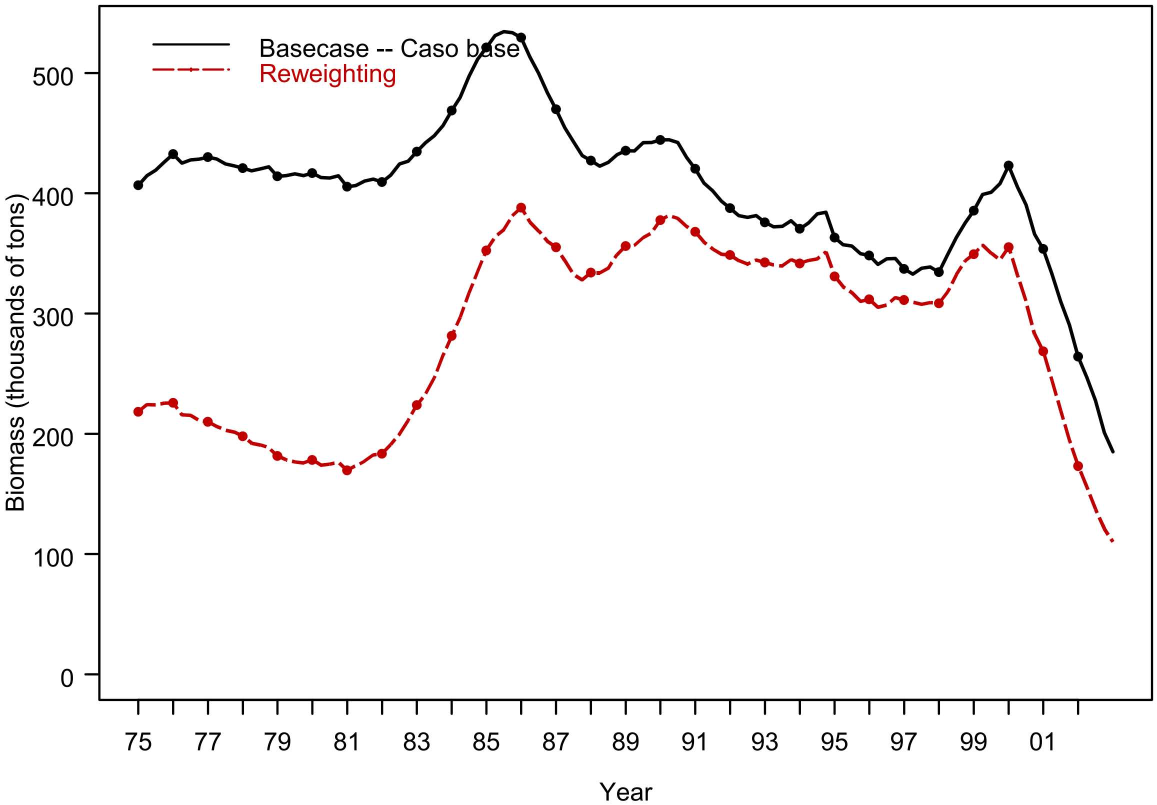

FIGURE F.1. Comparison of estimates of biomass from the base case and with the length frequency sample sizes based on the iterative re-weighting procedure.

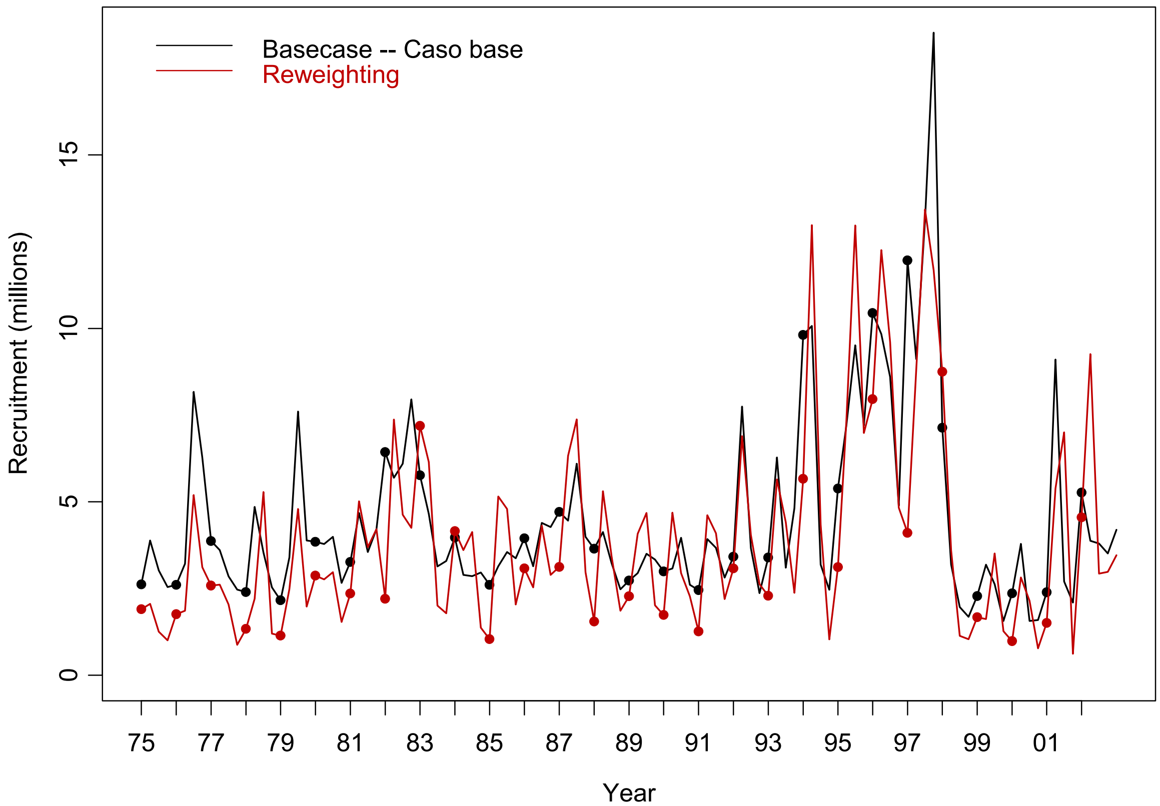

FIGURE F.2a. Comparison of estimates of recruitment from the base case and with the length frequency sample sizes based on the iterative re-weighting procedure.

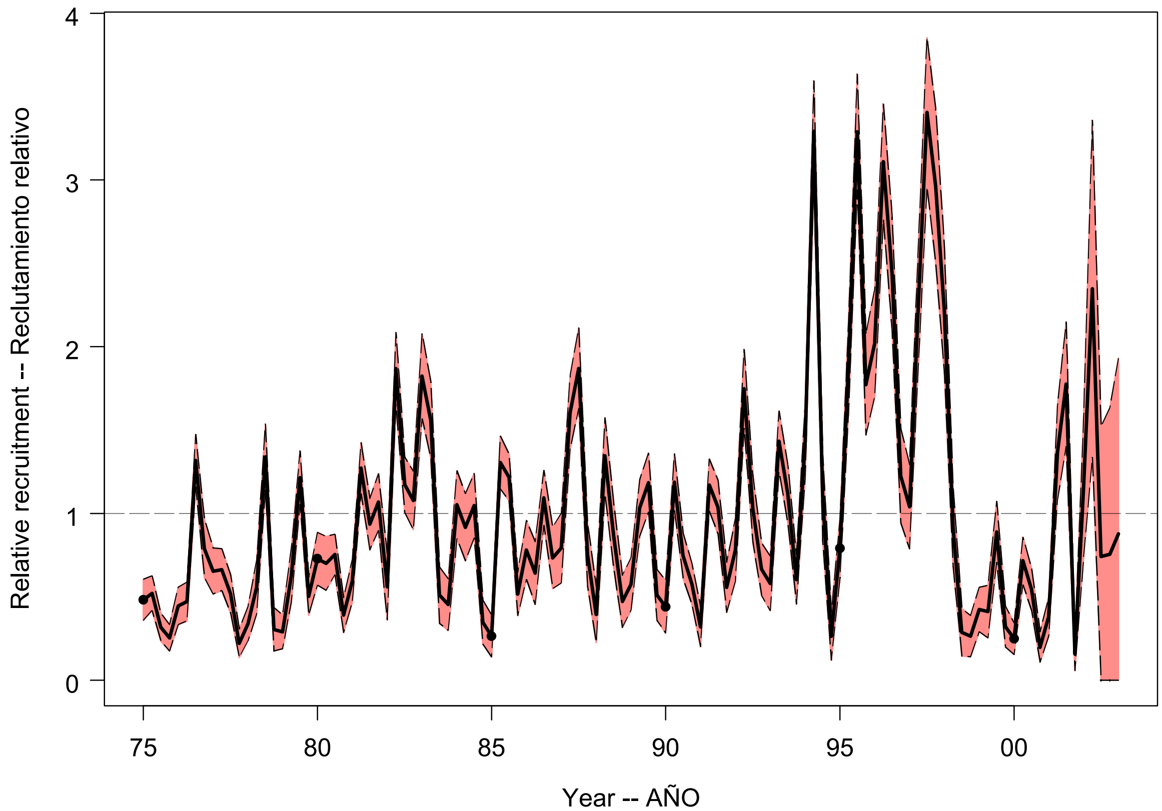

FIGURE F.2b. Estimates of recruitment from sensitivity with the length frequency sample sizes based on the iterative re-weighting procedure.The shaded region represent the 95% confidence intervals for the estimates

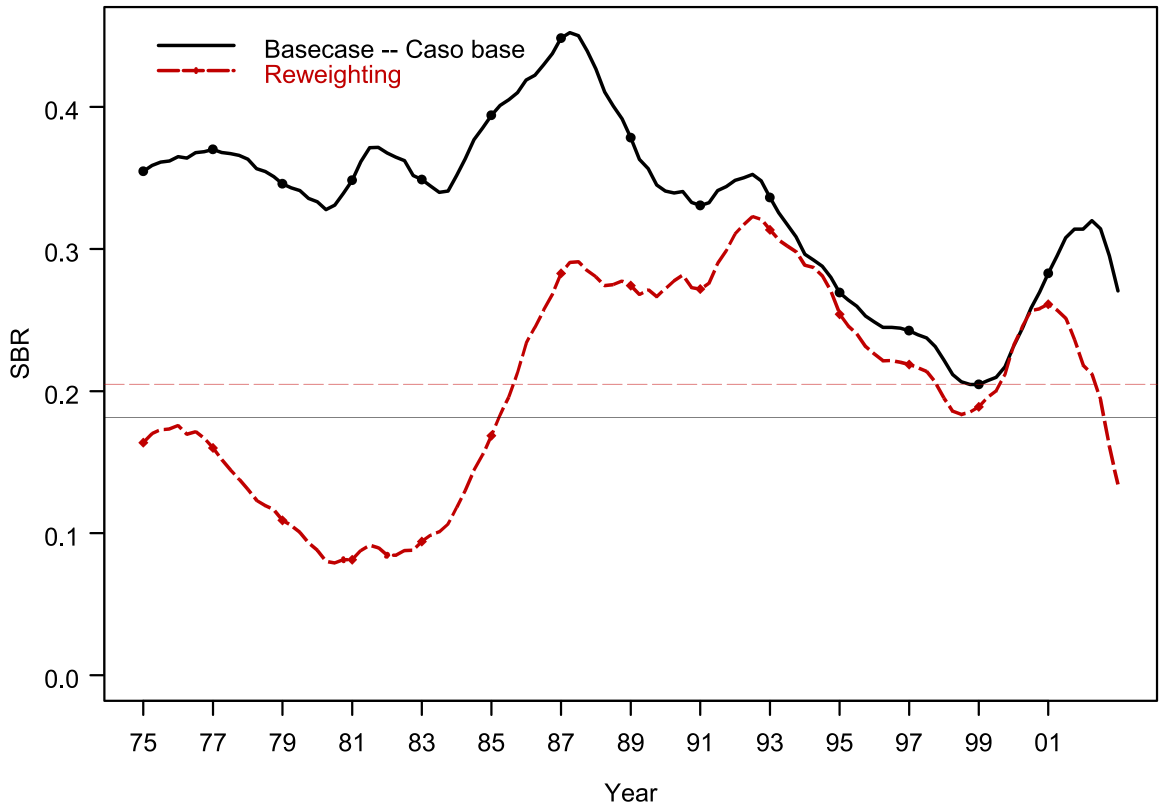

FIGURE F.3. Comparison of estimates of the spawning biomass ratio (SBR) from the base case and with the length frequency sample sizes based on the iterative re-weighting procedure. The horizontal lines represent the SBR associated with AMSY.

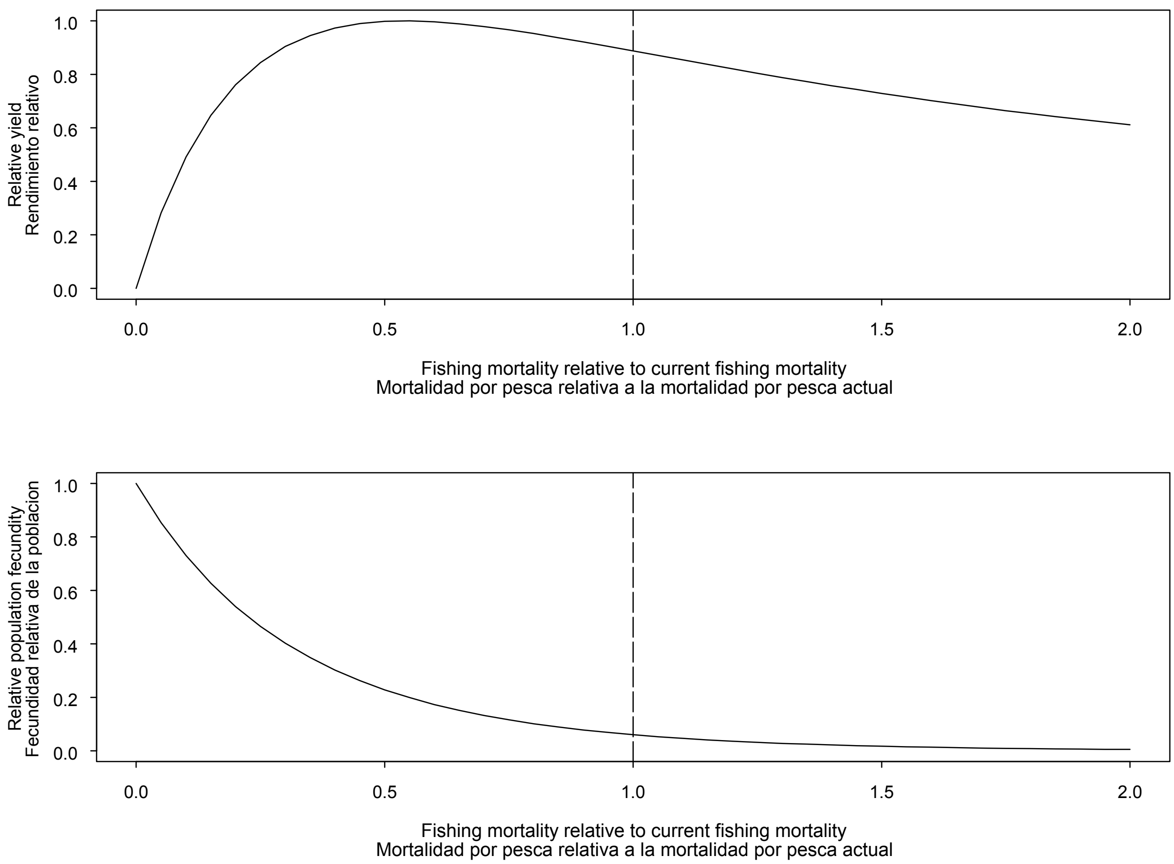

FIGURE F.4. Comparison of the relative yield (top panel solid line) with the relative yield per recruit (top panel, dashed line) when the stock assessment model has length frequency sample sizes based on the iterative re-weighting procedure.

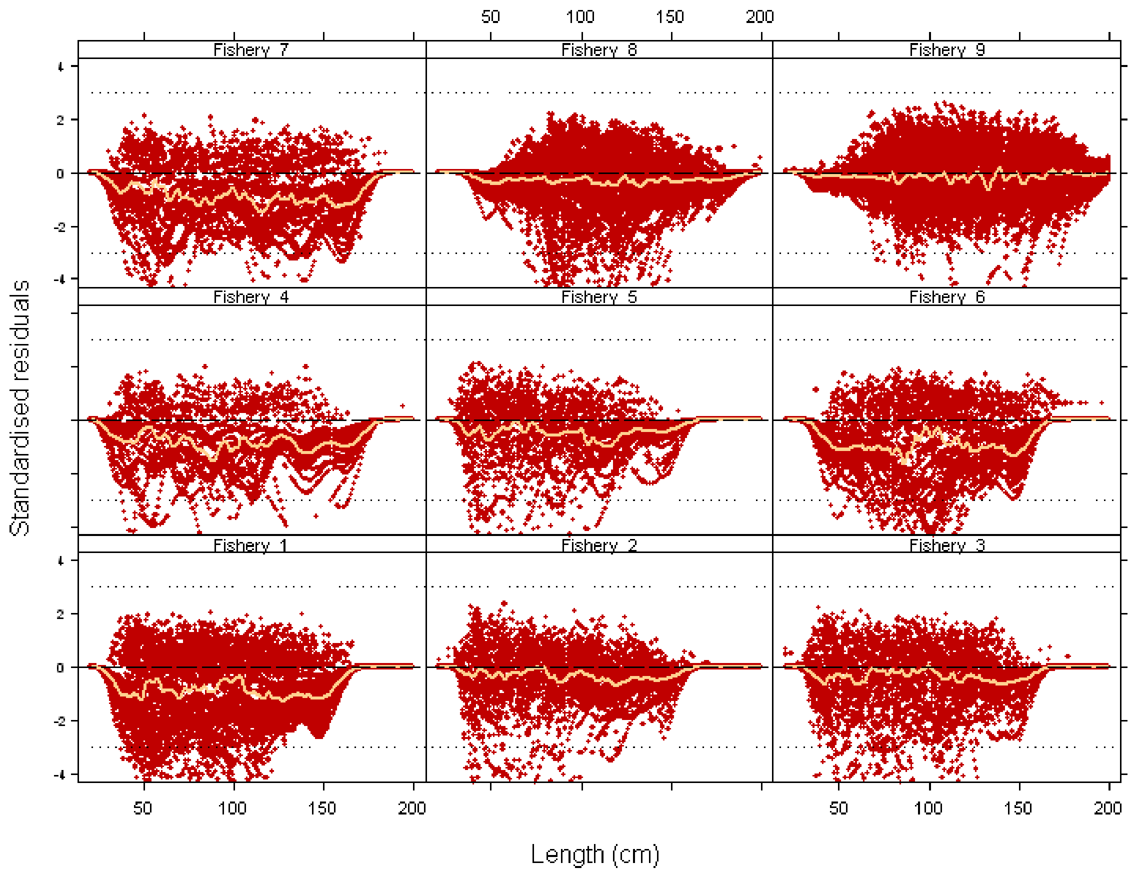

FIGURE F.5. Standardized residuals for the fit to the length frequency data by fishery and length class when the length frequency sample sizes are based on the iterative re-weighting procedure. The fitted line is a loess smoother.

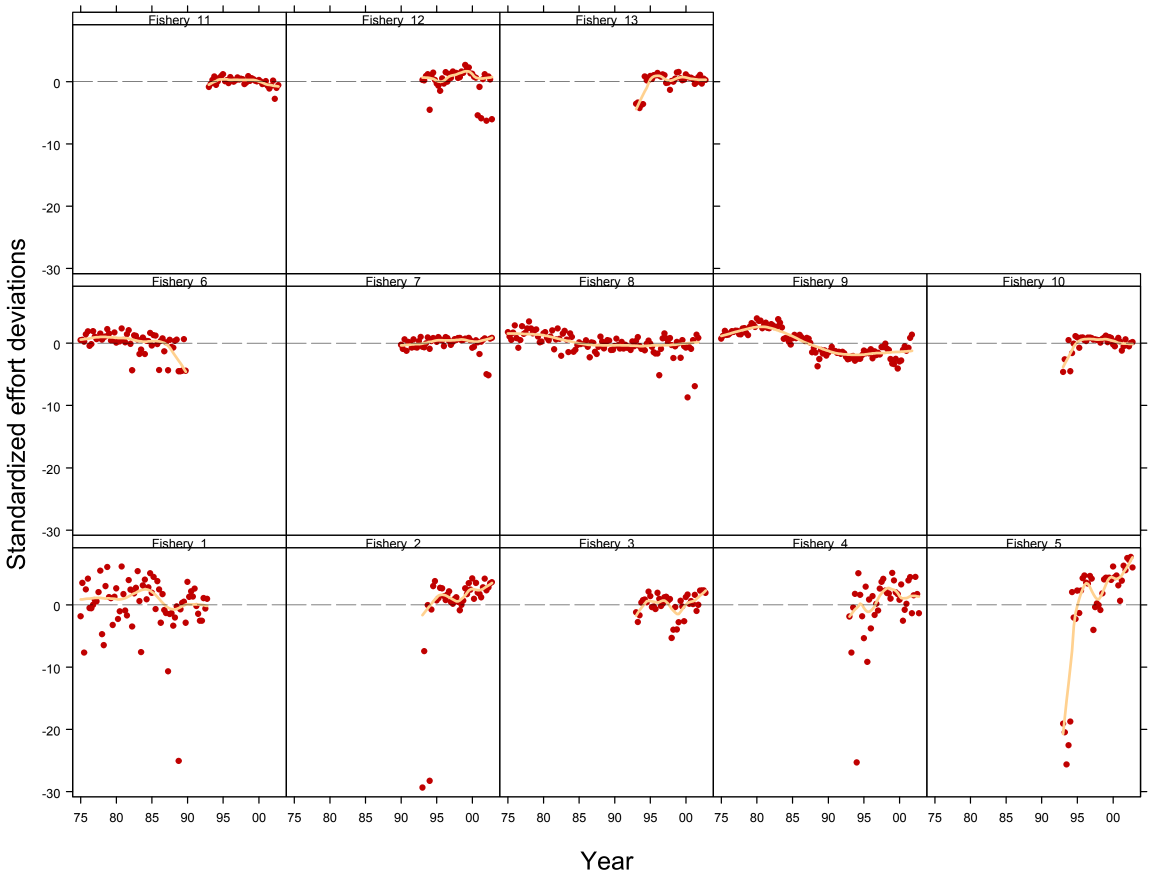

FIGURE F.6. Standardized effort deviates by fishery and time quarter when the length frequency sample sizes are based on the iterative re-weighting procedure. The fitted line is a loess smoother.

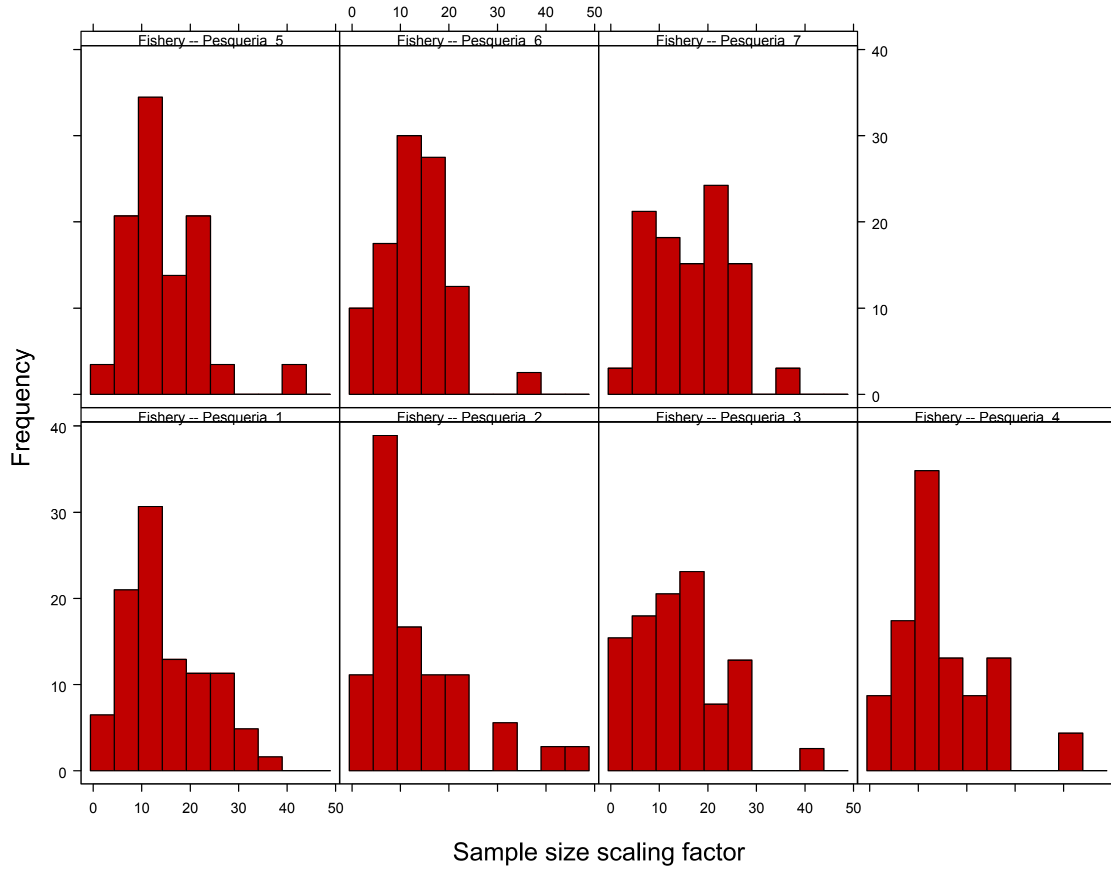

FIGURE F.7a. Amount that the length-frequency sample size is scaled in the iterative reweighting sensitivity for the surface fisheries.

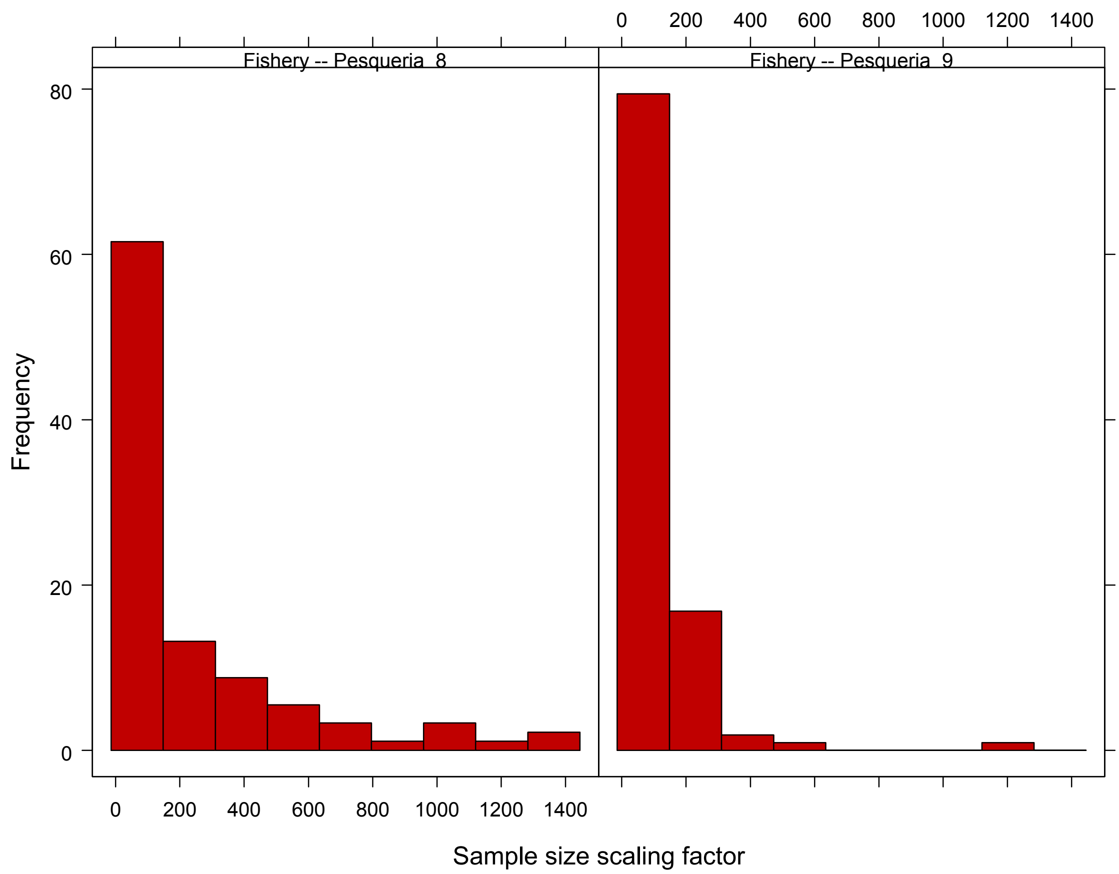

FIGURE F.7b. Amount that the length-frequency sample size is scaled in the iterative reweighting sensitivity for the longline fisheries.

TABLE F.1. The average length-frequency sample size for each fishery for the basecase assessment and the sensitivity using the iterative reweighting. The average scaling factor for the iterative reweighting is also given.

Fishery	Basecase	Reweighted	Scaling factor
1	3.8	46.3	15.8
2	13.8	162.8	14.4
3	12.4	132.3	14.8
4	2.0	29.1	16.0
5	7.3	99.4	15.5
6	6.5	58.2	14.0
7	3.1	41.0	17.6
8	5.8	190.6	229.9
9	13.8	870.7	106.9

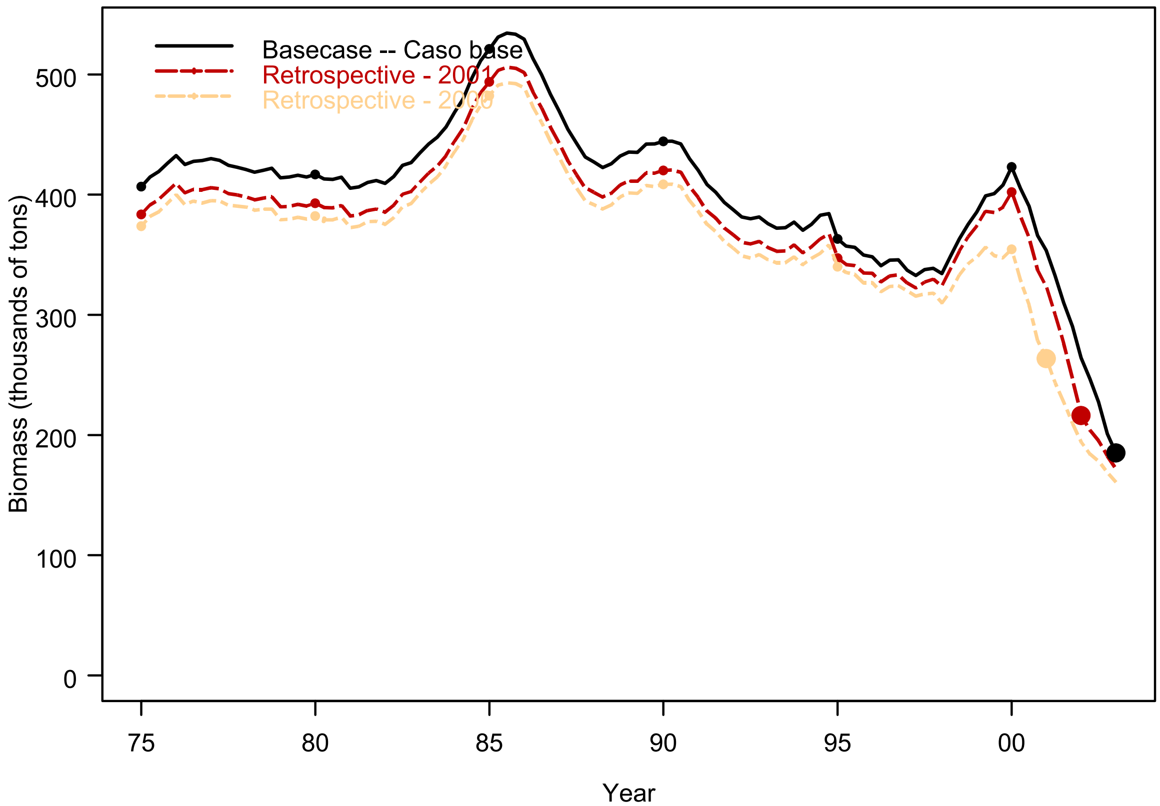

FIGURE G.1. Biomass (of 1+ fish) estimated by the retrospective analyses compared to the basecase. Retro 2001 uses data only up to 2001 and retro 2000 uses data only up to 2000. The large solid circles indicate the last time period estimated by the model without projecting the biomass.

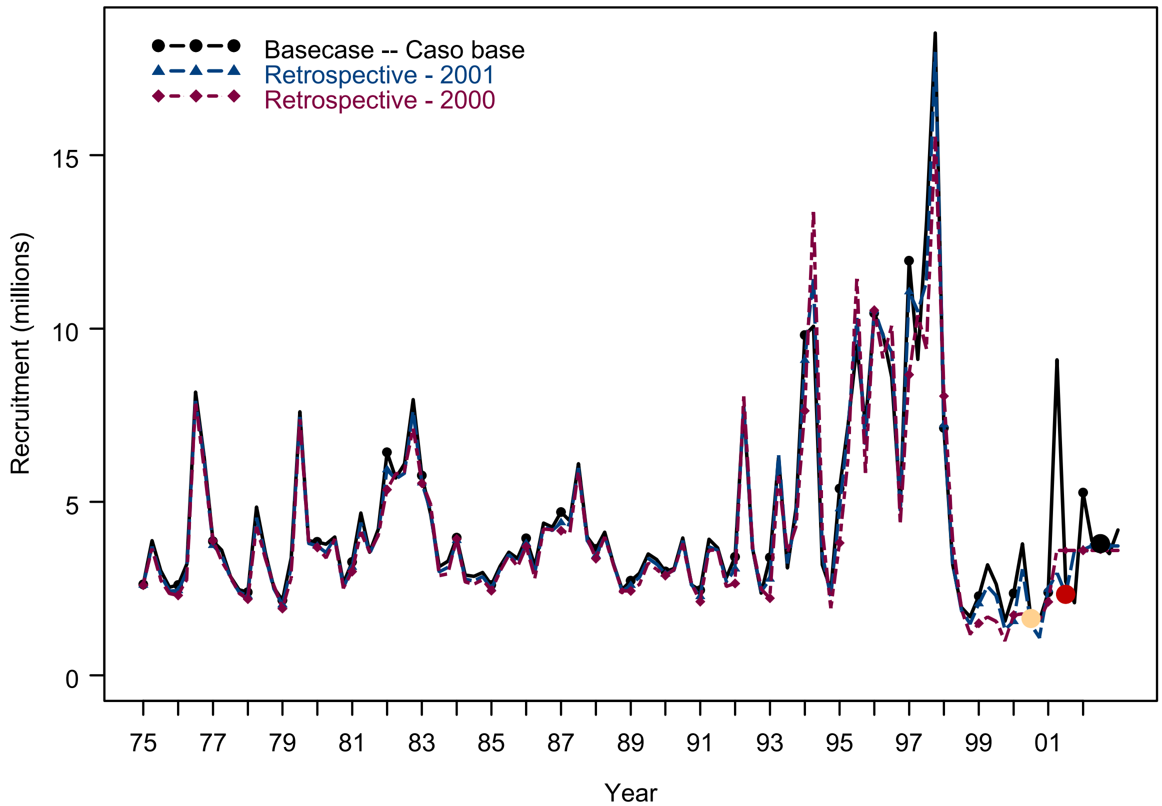

FIGURE G.2. Recruitment estimated by the retrospective analyses compared to the basecase. Retro 2001 uses data only up to 2001 and retro 2000 uses data only up to 2000. The large solid circles indicate the first recruitment estimated by the model with information from the length-frequency data.

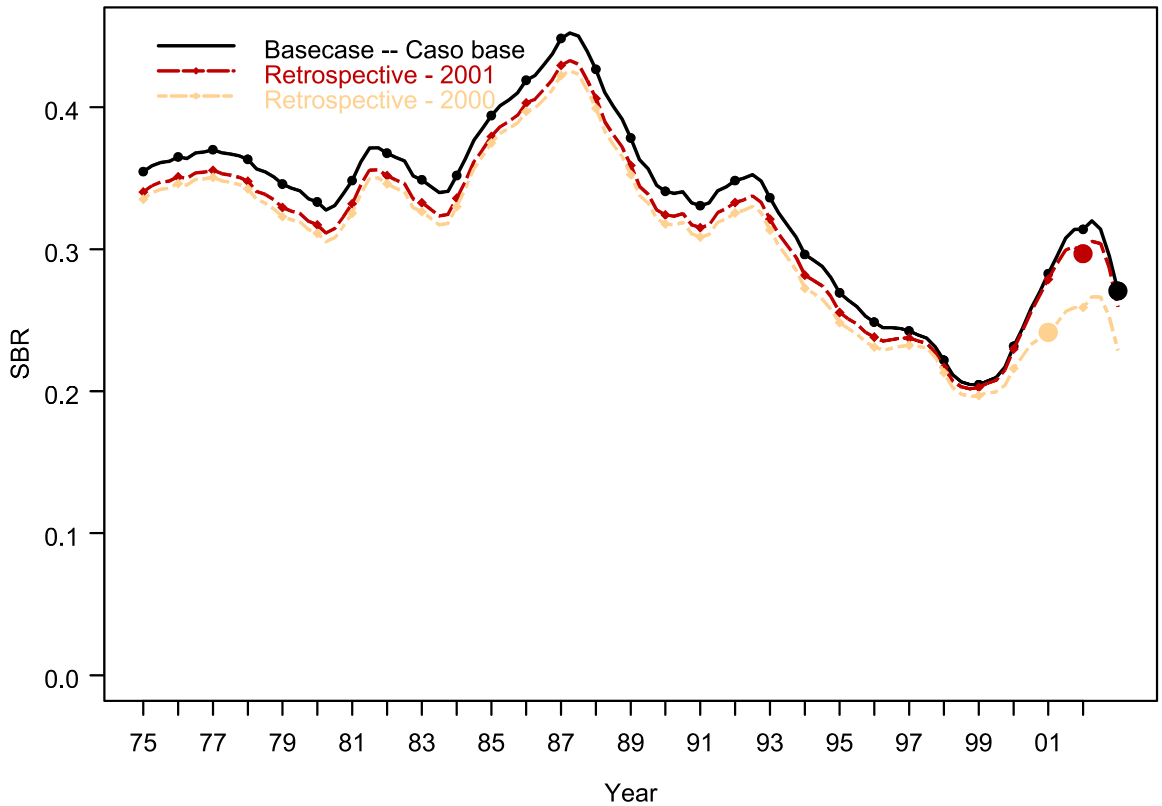

FIGURE G.3. SBR estimated by the retrospective analyses compared to the basecase. Retro 2001 uses data only up to 2001 and retro 2000 uses data only up to 2000. The large solid circles indicate the last time period estimated by the model without projecting the biomass.

APPENDIX H: ANALYSIS OF THE SENSITIVITY OF YIELD AND PROJECTIONS TO THE METHOD USED TO CALCULATE FISHING MORTALITY RATES

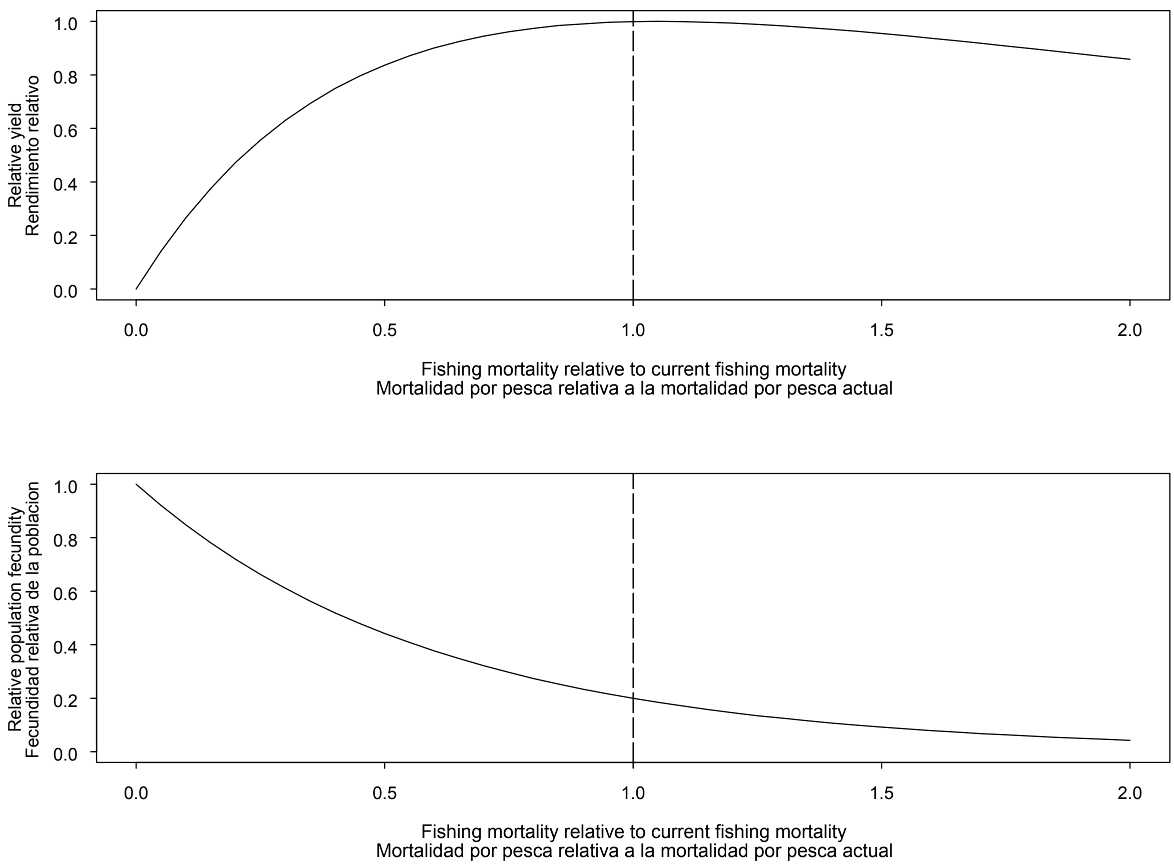

FIGURE H.1. Comparison of the relative yield (top panel solid line) with the relative yield per recruit (top panel, dashed line) when fishing mortality is based on average estimates for 1999 and 2000.

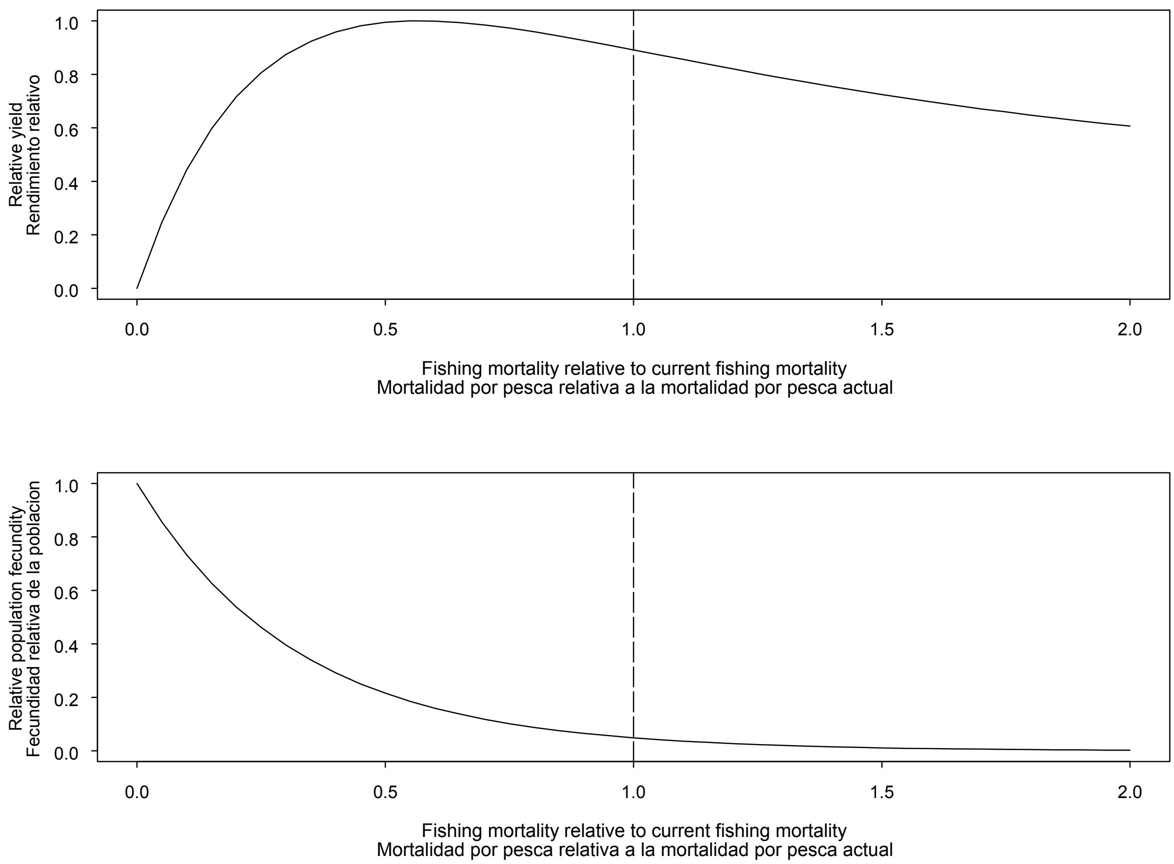

FIGURE H.2. Comparison of the relative yield (top panel solid line) with the relative yield per recruit (top panel, dashed line) when fishing mortality is based on average estimates for 2001 and 2002.

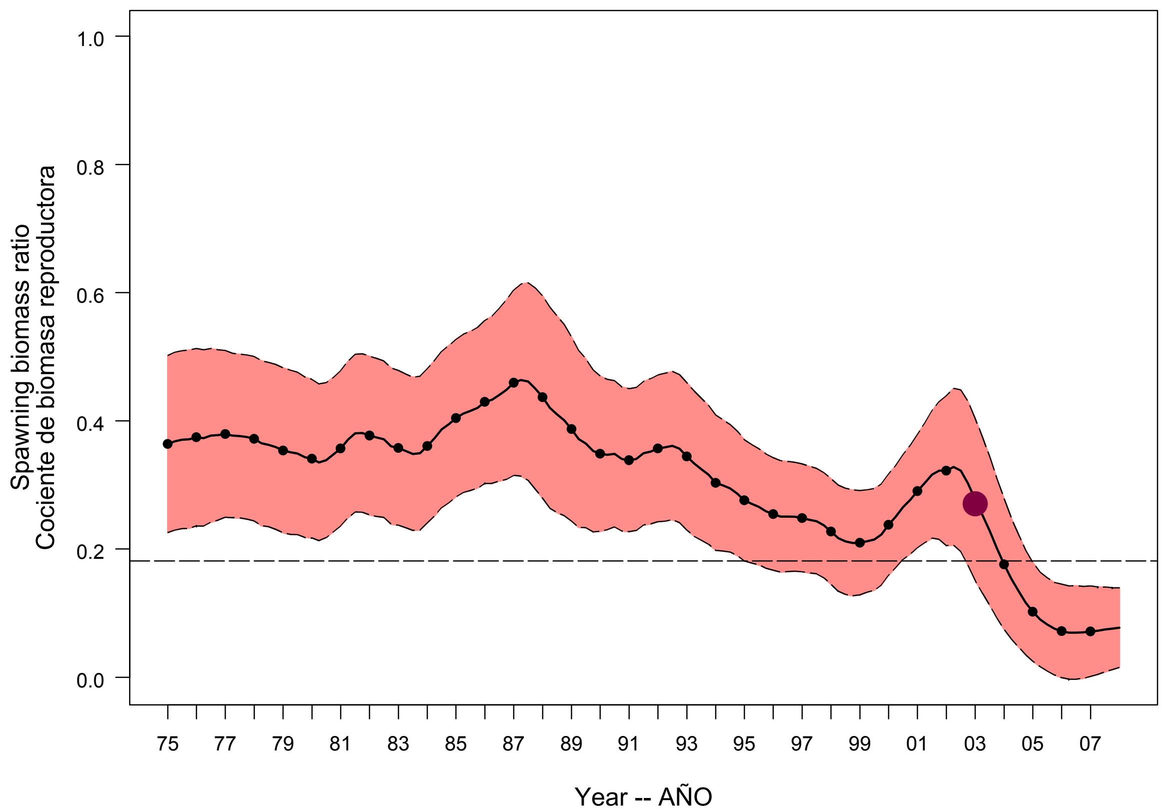

FIGURE H.3. SBRs, including projections for 2003-2007 under current effort levels and average catchability for 1999 and 2000 for bigeye tuna in the EPO. These calculations include parameter estimation uncertainty and uncertainty about future recruitment. The shaded areas indicate the 95% confidence intervals and the large dot indicates the estimate for the first quarter of 2003. The dashed line indicates the SBR_{AMSY} (0.18).

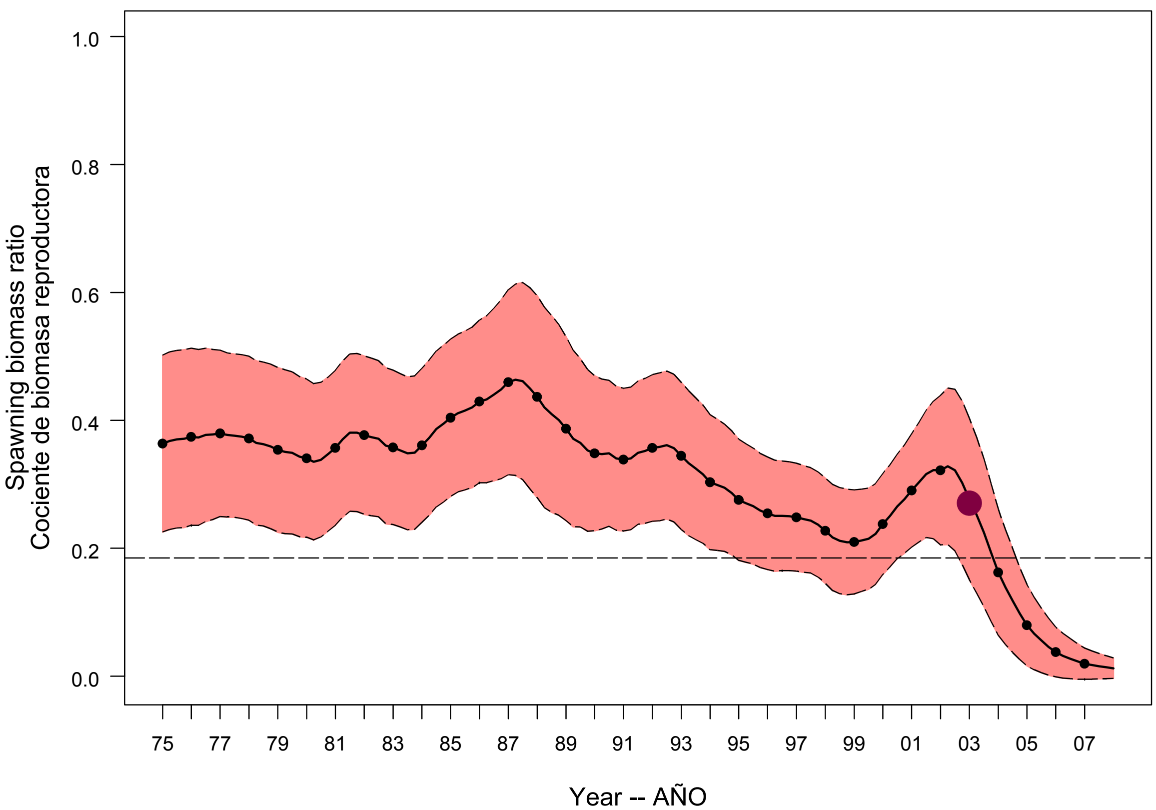

FIGURE H.4. SBRs, including projections for 2003-2007 under current effort levels and average catchability for 2001 and 2002 for bigeye tuna in the EPO. These calculations include parameter estimation uncertainty and uncertainty about future recruitment. The shaded areas indicate the 95% confidence intervals and the large dot indicates the estimate for the first quarter of 2003. The dashed line indicates the SBR_{AMSY} (0.18).

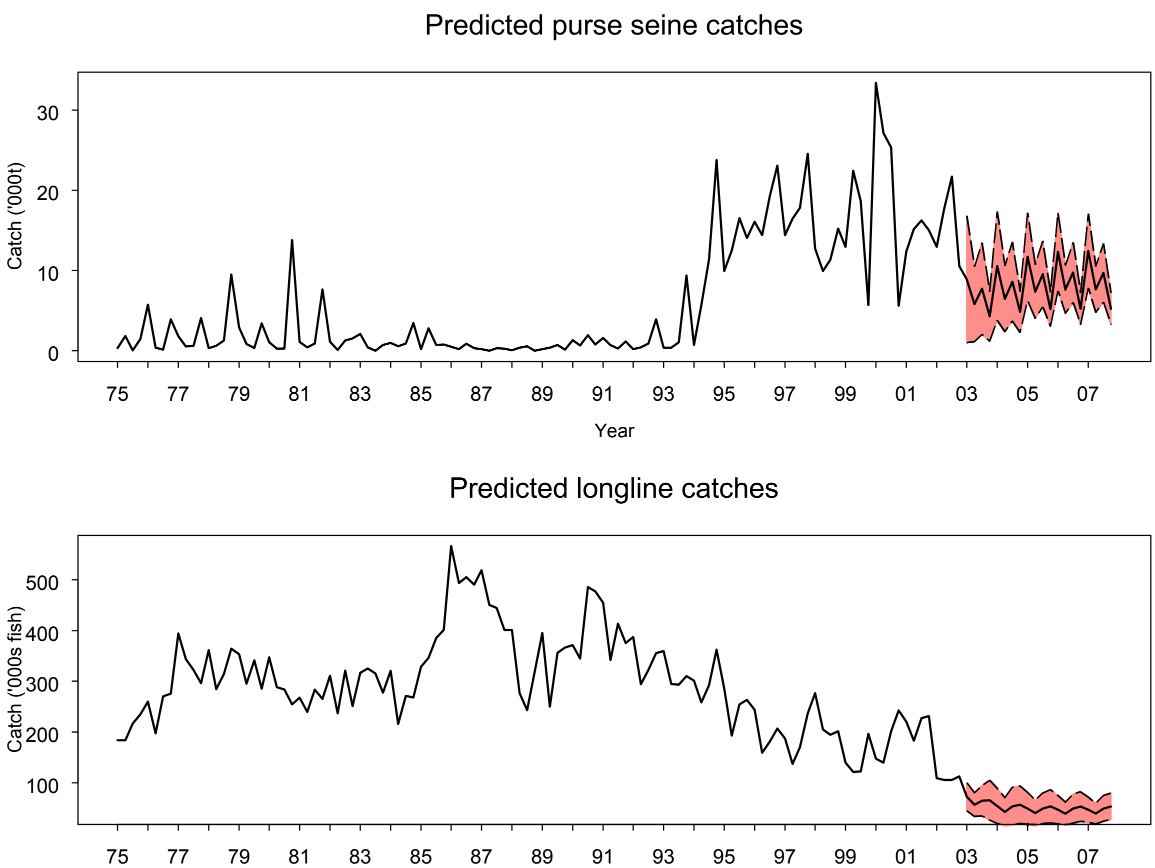

FIGURE H.5. Predicted catches for the surface (Fisheries 2, 3, 4, 5, and 7) and longline (Fisheries 8 and 9) fisheries based on average effort for 2001 and 2002 and average catchability for 1999 and 2000. Prediction were undertaken using the likelihood profile method described in Section x.x. The shaded areas represent 95% confidence intervals for the predictions of future catches.

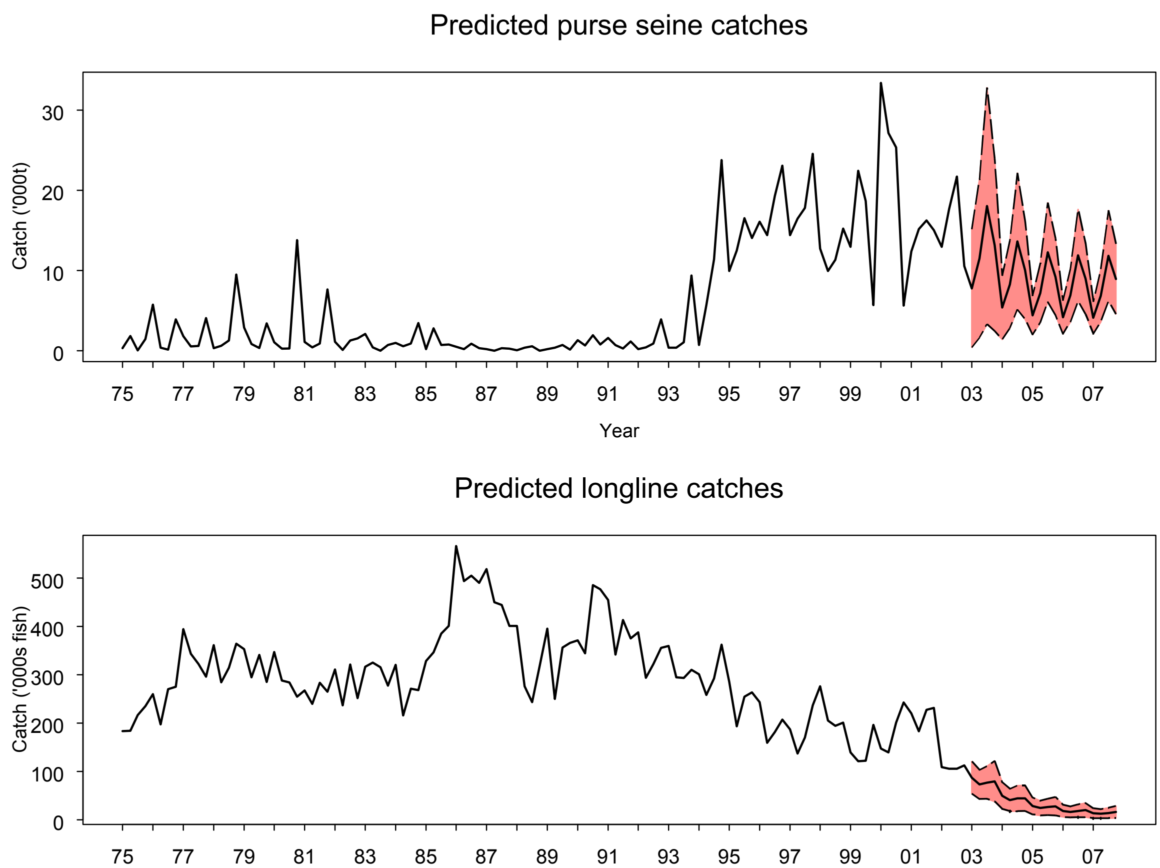

FIGURE H.6. Predicted catches for the surface (Fisheries 2, 3, 4, 5, and 7) and longline (Fisheries 8 and 9) fisheries based on average effort for 2001 and 2002 and average catchability for 2001 and 2002. Prediction were undertaken using the likelihood profile method described in Section x.x. The shaded areas represent 95% confidence intervals for the predictions of future catches.

TABLE H.1. Estimates of the AMSY and its associated quantities based on average fishing mortality for 1999 and 2000. B_{recent} and B_{AMSY} are defined as the biomass of bigeye 1+ years old at the start of 2001 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 2001.

	Basecase Caso base	Steepness = 0.75	Cannery PS catches
AMSY (mt)—RMSP (tm)	66,950	64,695	62,132
B_{AMSY} (mt)—B_{RMSP} (tm)	248,737	411,603	229,590
S_{AMSY}—S_{RMSP}	29,472	59,511	27,082
B_{AMSY}/B_0—B_{RMSP}/B_0	0.28	0.36	0.29
S_{AMSY}/S_0—S_{RMSP}/S_0	0.18	0.29	0.19
C_{recent}/AMSY—C_{recent}/RMSP	1.42	1.47	1.16
$B_{\text{recent}}/B_{\text{AMSY}}$—$B_{\text{recent}}/B_{\text{RMSP}}$	0.74	0.56	0.92
$S_{\text{recent}}/S_{\text{AMSY}}$—$S_{\text{recent}}/S_{\text{RMSP}}$	1.47	0.85	1.64
F multiplier—Multiplicador de F	1.05	0.70	1.14

	SPC Korean LL	HBS cpue	Iterative reweighting
AMSY (mt)—RMSP (tm)	78,581	67,373	62,863
B_{AMSY} (mt)—B_{RMSP} (tm)	302,280	257,320	243,734
S_{AMSY}—S_{RMSP}	36,843	31,220	29,202
B_{AMSY}/B_0—B_{RMSP}/B_0	0.28	0.28	0.31
S_{AMSY}/S_0—S_{RMSP}/S_0	0.19	0.19	0.21
C_{recent}/AMSY—C_{recent}/RMSP	1.32	1.43	1.51
$B_{\text{recent}}/B_{\text{AMSY}}$—$B_{\text{recent}}/B_{\text{RMSP}}$	1.19	1.02	0.45
$S_{\text{recent}}/S_{\text{AMSY}}$—$S_{\text{recent}}/S_{\text{RMSP}}$	2.39	2.06	0.64
F multiplier—Multiplicador de F	1.40	1.24	0.76

TABLE H.2. Estimates of the AMSY and its associated quantities on average fishing mortality for 2001 and 2002. Estimates could not be obtained for the steepness or iterative re-weighting scenarios. See Table H.1 for further description of the table.

	Basecase	**Steepness = 0.75**	**Cannery PS catches**
	Caso base		
AMSY (mt)—RMSP (tm)	63,764		62,441
B_{AMSY} (mt)—B_{RMSP} (tm)	234,093		226,767
S_{AMSY}—S_{RMSP}	28,003		26,645
B_{AMSY}/B_0—B_{RMSP}/B_0	0.26		0.29
S_{AMSY}/S_0—S_{RMSP}/S_0	0.18		0.19
C_{recent}/AMSY—C_{recent}/RMSP	1.49		1.15
$B_{\mathrm{recent}}/B_{\mathrm{AMSY}}$—$B_{\mathrm{recent}}/B_{\mathrm{RMSP}}$	0.79		0.93
$S_{\mathrm{recent}}/S_{\mathrm{AMSY}}$—$S_{\mathrm{recent}}/S_{\mathrm{RMSP}}$	1.54		1.67
F multiplier—Multiplicador de *F*	0.57		0.80

	SPC Korean LL	**HBS cpue**	**Iterative reweighting**
			Relación stock-reclutamiento
AMSY (mt)—RMSP (tm)	74,348	64,222	
B_{AMSY} (mt)—B_{RMSP} (tm)	282,750	241,313	
S_{AMSY}—S_{RMSP}	34,821	29,476	
B_{AMSY}/B_0—B_{RMSP}/B_0	0.26	0.26	
S_{AMSY}/S_0—S_{RMSP}/S_0	0.18	0.18	
C_{recent}/AMSY—C_{recent}/RMSP	1.40	1.50	
$B_{\mathrm{recent}}/B_{\mathrm{AMSY}}$—$B_{\mathrm{recent}}/B_{\mathrm{RMSP}}$	1.27	1.09	
$S_{\mathrm{recent}}/S_{\mathrm{AMSY}}$—$S_{\mathrm{recent}}/S_{\mathrm{RMSP}}$	2.53	2.18	
F multiplier—Multiplicador de *F*	0.83	0.70	

TABLE H.3. Summary of the outcomes from 101 simulations using the scenarios described in Sections 6.1 and 6.2, but where future catchability is the average of that in 1999 and 2000. "Quantiles" identify the levels at which 20%, 50%, and 80% of the predicted outcomes are less than or equal to the value provided in the table. The 50% quantile is equal to the median.

Quantile	75% surface effort	Average surface effort	Average surface effort, no discards	125% surface effort
Cuantil	**75% del esfuerzo de superficie**	**Esfuerzo de superficie medio**	**Esfuerzo de superficie medio, sin descartes**	**125% del esfuerzo de superficie**
SBR for fourth quarter of 2007–SBR para el cuarto trimestre de 2007				
20%	0.11	0.08	0.08	0.05
50%	0.12	0.08	0.08	0.05
80%	0.12	0.08	0.09	0.06
Average weight (kg) of fish in the combined catch during 2007–Peso medio (kg) de los peces en la captura combinada durante 2007				
20%	9.0	7.5	10.2	6.4
50%	10.7	8.8	11.5	7.5
80%	12.4	10.1	13.2	8.5
Median of quarterly catches (mt) by the primary surface fleet (Fisheries 2-5 and 7) during 2007–Mediana de las capturas trimestrales (tm) por la flota primaria de superficie (Pesquerías 2-5 y 7) durante 2007				
20%	7,278	6,916	8,172	6,890
50%	10,621	10,383	12,050	10,094
80%	13,887	13,698	15,962	13,724
Median of quarterly catches, in thousands of fish, by the longline fleet (Fisheries 8 and 9) during 2007–Mediana de las capturas trimestrales, en miles de peces, por la flota palangrera (Pesquerías 8 y 9) durante 2007				
20%	67	47	52	35
50%	77	55	60	40
80%	89	62	69	46

TABLE H.4. Summary of the outcomes from 101 simulations using the scenarios described in Sections 6.1 and 6.2, but where future catchability is the average of that in 2001 and 2002. "Quantiles" identify the levels at which 20%, 50%, and 80% of the predicted outcomes are less than or equal to the value provided in the table. The 50% quantile is equal to the median.

Quantile	75% surface effort	Average surface effort	Average surface effort, no discards	125% surface effort
Cuantil	**75% del esfuerzo de superficie**	**Esfuerzo de superficie medio**	**Esfuerzo de superficie medio, sin descartes**	**125% del esfuerzo de superficie**
SBR for fourth quarter of 2007–SBR para el cuarto trimestre de 2007				
20%	0.07	0.04	0.04	0.03
50%	0.07	0.04	0.04	0.03
80%	0.07	0.05	0.05	0.03
Average weight (kg) of fish in the combined catch during 2007–Peso medio (kg) de los peces en la captura combinada durante 2007				
20%	9.2	7.4	8.0	6.3
50%	10.3	8.2	9.1	7.1
80%	11.2	9.3	10.1	7.8
Median of quarterly catches (mt) by the primary surface fleet (Fisheries 2-5 and 7) during 2007–Mediana de las capturas trimestrales (tm) por la flota primaria de superficie (Pesquerías 2-5 y 7) durante 2007				
20%	8,356	8,297	8,943	7,940
50%	11,267	10,994	11,803	10,344
80%	15,356	14,478	15,586	14,002
Median of quarterly catches, in thousands of fish, by the longline fleet (Fisheries 8 and 9) during 2007–Mediana de las capturas trimestrales, en miles de peces, por la flota palangrera (Pesquerías 8 y 9) durante 2007				
20%	59	39	40	27
50%	67	45	46	31
80%	83	54	56	36

APPENDIX I: ADDITIONAL RESULTS FROM THE BASECASE ASSESSMENT

This appendix contains additional results from the basecase 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.

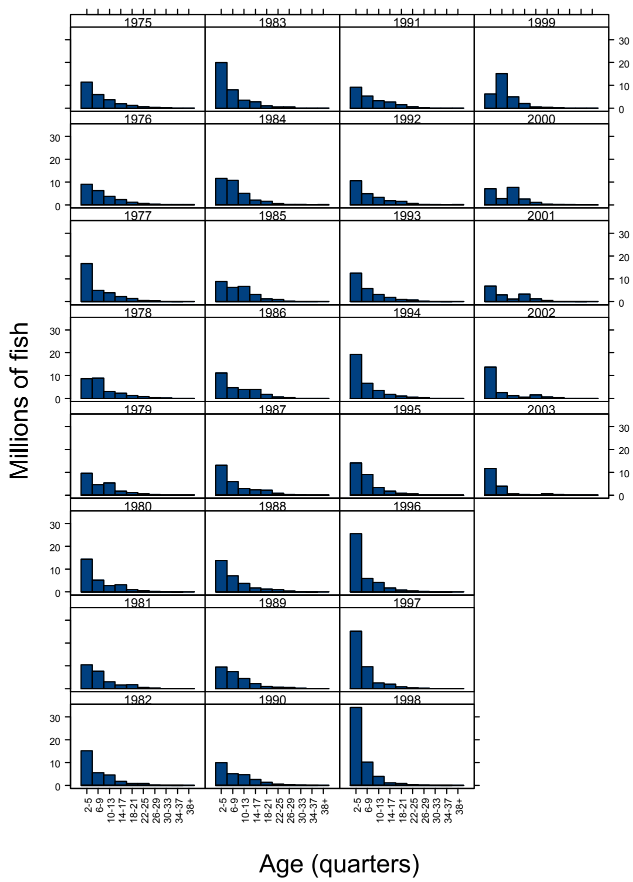

FIGURE I.1. Numbers of bigeye tuna present in the EPO on 1 January of each year.
FIGURA I.1. Número de atunes aleta amarilla presentes en el OPO el 1 de enero de cada año.

TABLE I.1. Average annual fishing mortality rates on bigeye tuna in the EPO.

Year	age 2-5	age 6-9	age 10-13	age 14-17	age 18-21	age 22-25	age 26-29	age 30-33	age 34-37	age 38+
1975	0.00	0.03	0.09	0.12	0.18	0.19	0.20	0.20	0.20	0.20
1976	0.01	0.05	0.15	0.16	0.24	0.25	0.24	0.25	0.25	0.25
1977	0.01	0.04	0.16	0.20	0.29	0.34	0.34	0.34	0.34	0.34
1978	0.01	0.07	0.17	0.20	0.30	0.33	0.33	0.34	0.34	0.34
1979	0.01	0.05	0.15	0.18	0.28	0.30	0.30	0.31	0.31	0.31
1980	0.02	0.11	0.16	0.19	0.28	0.32	0.32	0.32	0.32	0.32
1981	0.01	0.06	0.14	0.17	0.25	0.27	0.27	0.28	0.27	0.27
1982	0.00	0.03	0.13	0.16	0.24	0.26	0.26	0.27	0.27	0.27
1983	0.00	0.03	0.13	0.17	0.27	0.30	0.30	0.31	0.31	0.31
1984	0.00	0.03	0.11	0.14	0.20	0.22	0.22	0.23	0.23	0.23
1985	0.00	0.03	0.12	0.15	0.24	0.27	0.27	0.27	0.27	0.27
1986	0.00	0.03	0.16	0.23	0.34	0.41	0.41	0.42	0.42	0.42
1987	0.00	0.02	0.16	0.23	0.35	0.42	0.43	0.43	0.43	0.43
1988	0.00	0.02	0.12	0.17	0.26	0.31	0.31	0.32	0.32	0.32
1989	0.00	0.03	0.13	0.18	0.27	0.31	0.31	0.32	0.32	0.32
1990	0.00	0.04	0.17	0.22	0.34	0.39	0.38	0.38	0.38	0.38
1991	0.00	0.03	0.17	0.23	0.35	0.42	0.41	0.41	0.41	0.41
1992	0.01	0.04	0.15	0.21	0.32	0.38	0.36	0.37	0.37	0.37
1993	0.02	0.05	0.17	0.22	0.33	0.39	0.37	0.37	0.37	0.37
1994	0.10	0.20	0.29	0.29	0.34	0.37	0.35	0.35	0.35	0.35
1995	0.24	0.29	0.33	0.33	0.35	0.38	0.32	0.32	0.32	0.32
1996	0.32	0.42	0.42	0.36	0.33	0.32	0.27	0.27	0.27	0.27
1997	0.26	0.42	0.45	0.38	0.35	0.28	0.26	0.26	0.26	0.26
1998	0.18	0.27	0.29	0.30	0.35	0.39	0.34	0.33	0.33	0.33
1999	0.22	0.25	0.28	0.22	0.22	0.20	0.15	0.15	0.15	0.15
2000	0.26	0.48	0.48	0.35	0.31	0.19	0.18	0.17	0.17	0.18
2001	0.34	0.50	0.48	0.39	0.37	0.31	0.29	0.29	0.29	0.29
2002	0.59	0.97	0.82	0.56	0.37	0.22	0.20	0.20	0.20	0.20