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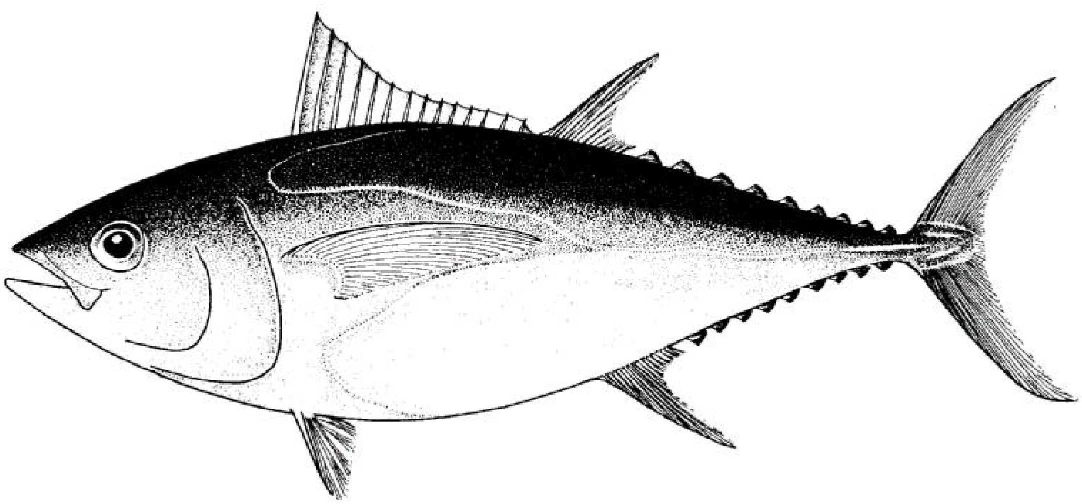
Status of bigeye tuna in the eastern Pacific Ocean in 2001 and outlook for 2002



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STATUS OF BIGEYE TUNA IN THE EASTERN PACIFIC OCEAN IN 2001 AND OUTL00K FOR 2002

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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 same as that used for the previous assessment with modifications to some of the assumptions. The modifications include fixing variation of length at age based on otolith data from the western Pacific bigeye stock, down-weighting the influence of the floating-object catch and effort data on abundance, using habitat-based standardised effort for the longline fisheries, and basing future projections on average observed fishing mortality rather than on effort multiplied by average catchability and selectivity. New and updated catch, effort, and environmental data have been included in the assessment. Purse-seine and baitboat catch, effort, and length-frequency data were updated for 1980 to 2000 and new data were included for 2001. New Taiwanese longline catch data were included for 1998. Japanese catch data were updated for 1998 and 1999, and new data included for 2000.

Three sensitivity analyses were carried out this year:

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 was used for the sensitivity analysis.
2. 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).
3. Sensitivity to the method used to estimate the fishing mortality rate used in yield calculations and forward projects. In the basecase analyses fishing mortality is calculated on average catchability over the whole modeling time frame. The sensitivity analysis included the assumption that future catchability remained at the levels of 2000 and 2001.

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 since 1993, and that on fish more than about 20 quarters old has decreased since then. The increase in average fishing mortality on the younger fish can be attributed to 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 time series of recruitment estimates. First, greater-than-average recruitments occurred in 1982-83, 1987, 1992, 1994, and 1995-1997. Second, recruitment has been much less than average for most of the 1998 to 2001 period, and the upper confidence bounds of almost of these recruitment estimates are below the virgin recruitment. This extended sequence of low recruitments is important because it is likely to produce a series of years in which the spawning biomass ratio (the ratio of spawning biomass during a period of exploitation to that which might accumulate in the absence of fishing, SBR) will be below the level that would be expected to occur if the stock were producing the average maximum sustainable yield. There is, however, considerable uncertainty in the estimated levels of recruitment for bigeye tuna in the EPO.

The biomass of 1+-year-old bigeye increased during 1980-1984 and reached its peak level of about 520,000 mt in 1985. After reaching this peak, the biomass of 1+-year-olds decreased to an historic low of about 232,000 mt at the start of 2002. Spawning biomass has generally followed a trend similar to that for the biomass of 1+-year-olds. 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.

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. In general, the results of the sensitivity analysis and those presented by Watters and Maunder (2002) support the view that the basecase estimates of recruitment and biomass are uncertain.

At the beginning of January 2002, the spawning biomass of bigeye tuna in the EPO was at a low level. At that time the SBR was about 0.28, with lower and upper confidence limits (± 2 standard deviation) of about 0.15 and 0.41. This estimate is the lowest seen in the modeling time period and is less than the estimate of SBR_{AMSY} (the spawning biomass ratio required to produce the average maximum sustanable yield; 0.38), suggesting that, at the start of January 2002, the spawning biomass of bigeye in the EPO was probably less than the level that is required to produce the AMSY. However, the spawning biomass appears to have been above this level throughout most of the July 1980-January 2001 period. The stochastic projections indicate that the SBR is likely to reach an historic low level, below the level that would be expected if the population were producing the AMSY, within the next three years. This decline is likely to occur regardless of the environmental conditions and the amount of fishing that occurs in the near future because the projected estimates of SBR are driven by the small cohorts that were produced during 1999 and 2001. The projected SBR may increase during 2003-2006, but the timing and rate of this increase would be dependent on future levels of recruitment (which may be driven by future environmental conditions) and fishing mortality.

The average weight of fish in the catch of all fisheries combined has been below the critical weight (about 35.5 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 (and therefore the yield) 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.

At the beginning of January 2002, the spawning biomass of bigeye tuna in the EPO appears to have been about 26% less than the level that would be expected to produce the AMSY. However, the recent catches are estimated to have been about 11% 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 185% of the current level of effort. Increasing the effort to 185% of its present level would increase the long-term average yield about 11%, but such an action would decrease the spawning potential of the stock by about 42%. 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 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.

The sensitivity analyses support the view that, at the start of 2002, the spawning biomass was below the level that would be present if the stock were producing the AMSY. However, the sensitivity analyses presented in this report and in previous assessments, and the stochastic analyses confirm the fact that there is uncertainty in the estimate of the AMSY and the amount of fishing mortality that is required to achieve this yield. Both of these quantities are sensitive to how the assessment model is parameterized and to the data that are included in the assessment. It is important to understand that the status of the stock is highly dependent on the method used to calculate the fishing mortalities used in the yield calculations. If the catchabilities remain as high as in the most recent years, as opposed to moving back to their average levels, and effort levels continue at their recent levels, the bigeye population is estimated to be in an over-exploited state with respect to producing AMSY.

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 shows that if fishing mortality rates continue at their recent levels due to the recent increase in catchability being sustained, the fishery is predicted under average recruitment to recover from the low levels predicted in 2003, and the SBR will be about the level required to produce AMSY.

Work continued this year on the Pacific-wide bigeye assessment method which was described at the second meeting of the Scientific Working Group. The method has undergone some important improvements during the year, but new results for the EPO are not yet available. Initial results show that the MULTIFAN-CL method, which is used for the Pacific-wide bigeye assessment, gives essentially identical results to A-SCALA when using the same assumptions and data.

2. DATA

Catch, effort, and size-composition data for July 1980 through December 2001 were used to conduct the stock assessment of bigeye tuna, *Thunnus obesus*, in the eastern Pacific Ocean (EPO). The data for 2001, which are preliminary, include records that had been entered into the IATTC databases as of early 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, baitboat, 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 two previous assessments of bigeye in the EPO (Watters and Maunder 2001, 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 baitboats 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.

In previous assessments (*e.g.* Watters and Maunder 2001) the IATTC staff defined, for the purposes of stock assessment, three types of catch data: landings, discards, and catch. The previous definitions of these terms are applied throughout this report.

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 landings. Removals by Fisheries 2-5 and 7 are landings, 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. The data for 1980 through 2000 are updated (compared to those presented by Watters and Maunder (2002) in previous assessments of bigeye in the EPO). The data for 2001 are new. 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 (2000) and Taiwan (1998). Catch data for Japan were also updated for 1998 and 1999. Two sets of Korean longline catch data are investigated. The first set is based on data in the IATTC database. The second set is 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. 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), estimates of standardized CPUE were obtained with regression trees (Watters and Deriso 2000). In this assessment we use CPUE standardised by the habitat-based method (Hinton and Nakano 1996). The indices were supplied by SPC.

The following is a brief description of the habitat-based effort standardization method. A detailed description can be found in Bigelow *et al*. (in press) and the references therein. The effectiveness of longline effort with respect to bigeye tuna is strongly affected by the fishing depth of the gear. This is due to the preference of bigeye for habitat characteristics (*e.g*. temperature and oxygen levels). Since the mid-1970s, longlines have been modified so as to fish at greater depths to increase catch rates 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. This preference, in terms of ambient temperature, is calculated by coupling archival tag and acoustic-tracking information with temperature data for the associated area. Different values were used for day and night, due to differences in bigeye behavior during these periods. Preferred oxygen levels were calculated from physiological experiments and tracking studies. The depth of the longlines are calculated, using the approximate length of mainline between buoys and applying a catenary curve to represent the shape of the longline. The depth is modified by a shoaling effect of ocean currents, which reduces the fishing depth of the longline. The relative habitat preference associated with each hook, which are distributed uniformly along the line between bouys, is calculated using a time series of temperature at depth (with pre-1980 data represented by a monthly climatology) and average (1934-1994) dissolved oxygen at depth for each 5-degree area-month stratum. The effective effort is then calculated as the sum of the habitat preference for the hooks. For longline, only Japanese effort data are used in the model, because these data include information on the number of hooks per basket, provide the only consistent large area coverage of the distribution of bigeye, and represent the majority of the effort.

2.2.1. Catch

Trends in the catches of bigeye tuna taken from the EPO during each quarter from July 1980 through December 2001 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 July 1, 1980, and substantial amounts of bigeye were already being removed from the EPO by that time.

For this assessment, the Japanese longline data are available through 2000. In the previous assessment (Watters and Maunder 2002), Japanese longline data were available only through 1999. It is assumed that the total longline effort expended in 2001 is equal to the amount expended in 2000. Thus, in the assessment, the estimated longline catch in 2001 is a function of the fishing effort in 2000, the estimated abundance in 2001, and the estimated selectivities and catchabilities for the longline fisheries (Fisheries 8 and 9).

The catches taken by Fisheries 2 and 4 during 2001 were greater than those taken during 2000. As percentages of the catches taken in 2000, these increases were, respectively, about 24%, and 40%, Fisheries 3, 5, and 7 were less than that in 2000. The catch decreased by about 67%, 42%, and 53%, for these fisheries, respectively. The longline catch was 80% lower, and 64% greater in 2000 compared to 1999, for Fisheries 8 and 9, respectively.

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 2000, the total amount of fishing effort expended by Fisheries 2, 4, and 5 increased during 2001. As percentages of the effort expended in 2000, these increases were, respectively, about 121%, 2%, and 35%. The total amount of fishing effort expended by Fisheries 3 (-12%) and 7 (-26%) decreased from 2000 to 2001. These results indicate that the floating-object fishery in the southern offshore area (Fishery 2) expanded the most during 2001, as was also the case in 2000. 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). The effective longline fishing effort decreased in the north (Fisheries 8, 77%) and increased in the south (Fishery 9, 12%) from 1999 to 2000.

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 2001. It is assumed, therefore, that the total amount of longlining effort exerted during each quarter of 2001 was equal to that exerted during the corresponding quarter of 2000.

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 (submitted). 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.

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 2001. Data for years prior to 2001 have also been updated. No new longline length-frequency data are available for this assessment.

The fisheries of the EPO catch bigeye tuna of various sizes. The average size compositions of the catches from each fishery defined in Table 2.1 have been described in 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 (2001) size-compositions for the fisheries that catch bigeye in association with floating objects contain more large-sized bigeye than what has been caught by these fisheries on average (compare Figure 4.3a to Figure 4.2 for Fisheries 2-5). This is due to a strong cohort that can be identified moving through the length-frequency data.

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 the 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 in press; see Background Paper A2).

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 the spawning biomass may not have been reduced to less than 20% of its unexploited level 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.

Spawners are defined as 3+-year-old females, and an age-specific fecundity schedule is used to provide an index of spawning potential. 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.

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

Three age-specific vectors of natural mortality (M) were used in the previous assessment of bigeye tuna (Watters and Maunder 2002). For the basecase assessment, the M at age was assumed to be the same as that used in the previous two assessments (Anonymous 2000, Watters and Maunder 2001). This mortality schedule was derived by assuming that M is relatively high for young (small) bigeye and that observed changes in size-specific sex ratios indicate increased M for older females. The basecase natural mortality curve was estimated by fitting to some of the natural mortality estimates of Hampton (2000) and the sex-ratio data provided by Hampton *et al.* (1998). The basecase vector of M is illustrated in Figure 3.1. Two other vectors of M were used in sensitivity analyses described in Watters and Maunder (2002) . These two vectors were obtained by subtracting/adding 0.05 from/to all of the age-specific estimates in the base-case vector. The 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. 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 that movement of fish between these areas is in equilibrium (*i.e.* immigration balances emigration). 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, 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 2001) 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 hindcast 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.

It is also assumed that oceanographic conditions might influence the efficiency of the five fisheries that catch bigeye associated with floating objects (Fisheries 1-5). Whether environmental conditions affect fishery performance is determined by incorporating an environmental effect into the stock assessment and determining whether that effect explains a significant amount of the variation in the estimates of catchability (q). For the current assessment, fishery-specific indices of vertical shear were considered as candidate environmental variables affecting q. These shear indices were calculated by taking the absolute difference of hindcasted velocities at 25 and 240 m. The differences were based on zonal velocities for Fisheries 2, 3, and 5, and meridional velocities (velocities in the north-south direction) for Fisheries 1 and 4. The vertical shear indices were calculated, for each quarter, as fishery-specific spatial averages over the following areas:

Fishery 1: 5°N-15°S, 70-85°W

Fishery 2: 0°-10°S, 110-150°W

Fishery 3: 5°N-5°S, 85-110°W

Fishery 4: 5°N-15°S, 70-85°W

Fishery 5: 8°N-0°, 110-150°W

The data that were used to develop the vertical shear indices were obtained from the same source as those used for modeling an environmental effect on recruitment.

4. STOCK ASSESSMENT

The A-SCALA method (Maunder and Watters submitted) is currently used to assess the status of the bigeye tuna stock in the EPO. This method was also used to conduct the previous two assessments of bigeye (Watters and Maunder 2001, 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 (submitted). 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 third quarter of 1980 through the first quarter of 2002 (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 initial catchability for each fishery, environmental effects, 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. parameters of a linear model relating the standard deviations in length at age to the mean lengths at age;
6. initial population size and age-structure.

The parameters in the following list are assumed to be known for the current stock assessment of bigeye in the EPO:

1. age-specific natural mortality rates (Figure 3.1);
2. age-specific sex ratios (Table 3.1);
3. age-specific maturity schedule (Section 3.1.2);
4. age-specific fecundity indices (Table 3.1);
5. selectivity curves for the discard fisheries (Figure 4.5, Fisheries 10-13);
6. the steepness of the stock-recruitment relationship.

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 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 CPUEs of both longline fisheries decreased markedly between 1985 and 2000 (Figure 4.1, Fisheries 8 and 9). Catch and effort data were not available for 2001 for any of the longline fisheries, so the CPUEs for 2001 are only estimates. The longline CPUE in the area north of 15°N is estimated to have decreased and that in the area south of 15°N is estimated to have increased (Figure 4.1, Fisheries 8 and 9).

Comparing the CPUEs of the surface fisheries in 2001 to those achieved in 2000 illustrates that performance of these fisheries is quite variable. The performance of the fisheries that catch the majority of bigeye associated with floating objects (Fisheries 2, 3, and 5) was substantially worse in 2001 than it was in 2000 (Table 4.1). In contrast, the performances of Fisheries 4 and 7 were substantially increased in 2001 (Table 4.1).

4.2. Assessment results

Three versions of the assessment model are presented:

1. steepness of the stock-recruitment relationship equals 1 (no relationship between stock and recruitment);
2. steepness of the stock-recruitment relationship equals 0.75 (moderate relationship between stock and recruitment);
3. steepness of the stock-recruitment relationship equals 1 and Korean longline catch data as estimated by SPC.

Version 1 is used as the basecase assessment, and the other two are provided as sensitivity analyses. A more comprehensive 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). There are, however, two peaks in the average size composition for the northern longline fishery (Fishery 8) are not well described by the basecase assessment.

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. For example, 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 oversmooth and does not capture modes that move through the size-composition data. For example, there is good evidence for a strong mode moving through the most recent size compositions from Fisheries 3 and 8 (Figures 4.3a and 4.3b). In the former case, the basecase assessment attempts to describe the movement of this mode, but both the rate at which the mode progresses and the height of the mode appear to be underestimated (Figure 4.3a). In the latter case, there are multiple modes in the observed size compositions, but the predicted size composition is unable to adequately represent these modes (Figure 4.3b). The fit to these data is governed by complex tradeoffs between estimates of growth, selectivity, and recruitment. The reduction in the variation of length at age and the estimation of mean length at age in the current assessment has improved the fit to the length-frequency data compared to the previous assessment (Watters and Maunder 2002).

Of all the constraints used to fit the assessment model (see Sections 3 and 4), those on recruitment, growth, catchability, and selectivity had the most influence. This result is supported from the results in the following list (a large value indicates that the constraint was influential):

Total likelihood = -239452.2

Likelihood for catch data = 5.6

Likelihood for size-composition data = -240037.2

Constraints and priors on recruitment parameters = 22.7

Constraints and priors on growth parameters = 50.2

Constraints on fishing mortality rates = 0.0

Constraints and priors on catchability parameters = 409.4

Constraints on selectivity parameters = 97.0

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 20 quarters 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 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 4.6. 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. An annual summary of the estimates of total fishing mortality is presented in Appendix D (Table D.1).

In two previous assessments of bigeye from the EPO (Watters and Maunder 2001, 2002) 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 assessment (Watters and Maunder 2002) does not include the first component, and an environmental effect was estimated only for Fishery 3. The random effects on q are retained in the basecase assessment, and these effects have dominated the temporal trends in q for all fisheries except Fishery 3 (Figures 4.7a, 4.7b, and 4.7c). For Fishery 3 (the floating-object fishery that operates around the Galapagos Islands), temporal trends in q are strongly influenced by vertical shear. Strong vertical shear reduces the catchability for this fishery. In general, vertical shear in the area defined for Fishery 3 tends to be weak during El Niño episodes and strong during La Niña episodes.

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) bigeye are more catchable near floating objects in offshore areas than in coastal areas. The average catchabilities of Fisheries 2, 3, and 5 (recent floating-object fisheries in offshore areas) are substantially greater than the average catchability for Fishery 1 (early floating-object fishery in the coastal area). These results support the first suggestion. The average catchabilities of Fisheries 2, 3, and 5 are substantially greater than the average catchability for Fishery 4 (recent floating-object fishery in the coastal area), which supports the second suggestion.

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.

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, lower panel). 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, or environmental variation may mask the relationship. The basecase estimate of steepness is fixed at 1, which produces a model for which recruitment has an assumption that recruitment is independent of stock size. A sensitivity analysis is presented in Appendix A 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. The estimate of virgin recruitment is about 5.6 million bigeye per quarter, with lower and upper confidence limits (±2 standard deviations) of about 4.4 million and 7.1 million, respectively. Greater-than-average recruitments occurred in 1982-1983, 1987, 1992, 1994, and 1995-1997. Note, 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.

Recruitment has been much lower than average for most of the recent period from 1998 to 2001, and the upper confidence bounds of all these recruitment estimates are below the virgin recruitment. These low recruitments are predicted from some of the decreased CPUEs achieved by the floating-object fisheries (Table 4.1) 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 be expected to occur if the stock produces the average maximum sustainable yield (AMSY) (see Section 5.1). It should be noted that despite the low recruitments during 2000, small bigeye continued to be caught in association with floating objects (Figure 4.3a).

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 0.44. 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 model parameters. 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 520,000 mt in 1985. After reaching this peak, the biomass of 1+-year-olds decreased to an historic low of about 232,000 mt at the start of 2002. There has been an accelerated decline in biomass since 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. As noted in Section 4.2.2, the spawning biomass is estimated from a fecundity index, so the values presented in the figures and tables should not be interpreted as actual tonnages. The spawning biomass has generally followed a trend similar to that for the biomass of 1+-year-olds (see previous paragraph). A summary of the age-specific estimates of the abundance of bigeye in the EPO at the beginning of each calendar year is presented in Appendix C (Figure C.1).

There is uncertainty in the estimated biomasses of both 1+-year-old bigeye and of spawners. The average CV of the biomass estimates of 1+-year-old bigeye is 0.24. The average CV of the spawning biomass estimates is 0.21.

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 third quarter of 1980 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 consistently captured bigeye that, on average, had average weights that are close to the critical weight. However, Fishery 7 has very low catches. Fishery 8 comes relatively close to maximizing the yield per recruit (see Section 5.2). The average weights of bigeye taken by Fishery 8 increased during 1999 (Figure 4.12). The average weight of bigeye taken by the longline fishery operating south of 15°N (Fishery 9) has always been greater than the critical weight. This indicates that Fishery 9 does not tend 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 growth of the large cohorts produced during 1995-1998 (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).

4.4. Sensitivity analysis

Two sensitivity analyses are conducted in the current assessment: sensitivity to the stock–recruitment relationship (Appendix A) and sensitivity to the SPC estimates of Korean longline catch data (Appendix B). Additional sensitivity analyses were conducted in the previous assessment (Watters and Maunder 2002). These analyses included alternative surface-fishery catches during 2000, different levels of natural mortality, estimation of growth, and influences of environmental variables on recruitment and catchability. A sensitivity analysis that investigated the influence of the method used to determine the species composition of the catches for 2000 and 2001 was also conducted this year (results not reported), and this had only a small effect on the results.

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 base case. This probably occurs for two reasons: (1) there is sufficient information in the catch-at-length data for all years and (2) the biomass does not get to low levels at which the stock-recruitment model has a large effect. Therefore, the stock-recruitment relationship does not provide additional information to the stock assessment.

When the larger SPC-estimated Korean longline catch is used, both the biomass (Figure B.1) and recruitment (Figure B.2) are increased. 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.

4.5. Comparison to previous assessments

The assessment results are very similar to those from the previous assessments of Watters and Maunder (2001, 2002) and the results using cohort analysis (Figure 4.14). The previous assessment indicated that the biomass increased in 2000, whereas the current assessment indicates a slight increase, then a decline to a value similar to that at the start of 2000.

4.6. Summary of results from the assessment model

There have been important changes in the amount of fishing mortality caused by the fisheries that catch bigeye tuna in the EPO. On average, the fishing mortality on bigeye less than about 20 quarters old has increased since 1993, and that on fish more than about 20 quarters old has decreased since then. The increase in average fishing mortality on the younger fish can be attributed to 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 cannot currently be 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 time series of recruitment estimates. First, greater-than-average recruitments occurred in 1982-83, 1987, 1992, 1994, and 1995-1997. Second, recruitment has been much less than average for most of the recent period from 1998 to 2001, and the upper confidence bounds of almost of these recruitment estimates are below the virgin recruitment. This extended sequence of low recruitments is important because it is likely to produce a series of years in which the SBR will be below the level that would be expected to occur if the stock were producing the AMSY. There is, however, considerable uncertainty in the estimated levels of recruitment for bigeye tuna in the EPO.

The biomass of 1+-year-old bigeye increased during 1980-1984, and reached its peak level of about 520,000 mt in 1985. After reaching this peak, the biomass of 1+-year-olds decreased to an historic low of about 232,000 mt at the start of 2002. Spawning biomass has generally followed a trend similar to that for the biomass of 1+-year-olds. 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.

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. In general, the results of the sensitivity analysis and those presented by Watters and Maunder (2002) support the view that the basecase estimates of recruitment and 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 three 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, but the most recent year is the lowest spawning biomass level and the only year below S_{AMSY}. Development of reference points that are consistent with the precautionary approach to fisheries management will continue.

In addition to the basecase assessment a sensitivity to the assumptions used in the calculation of the fishing mortalities used in the projections was included. In the basecase assessment the fishing mortality is calculated as the average catchability over the whole time period of the fishery multiplied by the selectivity and the average effort, by quarter, over 2000 and 20001. In the sensitivity analysis, fishing mortality was calculated as the average estimated fishing mortality, by quarter, over 2000 and 20001. This fishing mortality includes effort, average catchability, selectivity, and the effort deviations. The difference between the two assessments is in the inclusion of the effort deviations. Because the assessment model assumes that the observed fishing effort is randomly distributed around the fishing effort-natural mortality relationship, it appears appropriate to leave the effort deviates out of the calculations. However, because there has been an increasing trend in catchability for the floating-object fisheries, this assumption may underestimate the fishing mortality rate in the projections. There are two methods to overcome this problem. The first is to model trends in catchability, as done by Watters and Maunder (2001), and the second is to include the effort deviations in the calculations of average fishing mortality. The second approach for the sensitivity analysis has been chosen, as the first approach requires the addition of a large number of parameters that greatly increase the estimation time of the model. In addition, previous analyses have shown that including trends in catchability for the floating-object fisheries do not change the estimates of biomass if the standard deviations for the effort deviations are high. The standard deviations for the floating-object effort deviations are increased in this assessment, compared to that used by Watters and Maunder (2002).

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

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

where S_t is the spawning biomass at any time (t) during a period of exploitation, and $S_{F=0}$ is the spawning biomass that 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 zero, or slightly greater than that, 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 (SBR_{AMSY} =

$S_{AMSY}/S_{F=0}$). 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 444,000 (this is an index of spawning potential, and the units are not metric tons), with lower and upper confidence limits (± 2 standard deviations) of about 341,000 and 547,000. The SBR that would be expected if the stock were producing the AMSY (SBR_{AMSY}) is estimated to be about 0.38.

At the beginning of January 2002, the spawning biomass of bigeye tuna in the EPO was at a low level. At this time the SBR was about 0.28, with lower and upper confidence limits (±2 standard deviations) of about 0.15 and 0.41. A time series of SBR estimates for bigeye tuna in the EPO is shown in Figure 5.1. At the start of 1981, the SBR was about 0.68 (Figure 5.1, bold line). This is consistent with the fact that the stock of bigeye in the EPO was being utilized for a long period prior to 1981. The SBR increased during 1981-1985, and, by the beginning of the fourth quarter of 1984, it was greater than 1.0 (Figure 5.1, bold line). 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 1985 the SBR decreased to a level of about 0.50 by the second quarter of 1988 (Figure 5.1, bold line). The SBR increased rapidly during late 1988 and 1989 due to the peak in recruitment in 1987, and then declined steadily from 1990 to 1998. This depletion can be attributed mostly to a long period (1984-1993) during which recruitment was low. Also it should be noted that the southern longline fishery took relatively large catches during 1985-1995 (Figure 2.2, Fishery 9). In 1999 and early 2000 the SBR increased rapidly to a level of about 1.08 by the second quarter of 2000 (Figure 5.1, bold line). 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 2000 and 2001 the SBR decreased rapidly to below the level the level that would produce AMSY.

The SBR estimates are reasonably precise; the average CV of these estimates is about 0.12. The relatively narrow confidence intervals (±2 standard deviations) around the SBR estimates suggest that for most quarters during July 1980 to January 2001 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 0.38 in Figure 5.1. However, in 2002 the spawning biomass of bigeye in the EPO was probably less than the level that would be expected to occur if the population was producing the AMSY.

Estimates of the average SBR projected to occur during 2002-2006 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 2003 and remain below the level that would be expected if the population were producing the AMSY until 2005. 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 1999-2001 (Figure 4.9). Confidence intervals have not been estimated for the projected SBRs, but these intervals would be very wide. The projected SBR may increase during 2003-2006 (as shown in Figure 5.1), but the timing and rate of this increase would be dependent on future levels of recruitment (which may be driven by future environmental conditions) and fishing mortality.

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 35.5 kg.

Figure 5.2 shows that the fishery was catching, on average, bigeye above the critical weight during 1980-1993, 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 conditions, using the current, age-specific selectivity pattern of all fisheries combined. Watters and Maunder (2001) describe how the AMSY and its related quantities are calculated. These calculations have, however, been modified to include, where applicable, the Beverton-Holt stock-recruitment relationship (see Maunder and Watters (submitted) 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. Therefore, while these AMSY-based results are currently presented as point estimates, there are uncertainties in these results. Additional analyses were conducted to present the uncertainty in these quantities.

At the beginning of January 2002, the biomass of bigeye tuna in the EPO appears to have been about 26% 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 11% 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 185% of the current level of effort (F multiplier in Table 5.1). Increasing the effort by 85% of its present level would increase the long-term average yield by about 11%, but that would decrease the spawning potential of the stock by about 42% (Figure 5.3). The shape of the current yield curve is different from that estimated in the previous assessment (Watters and Maunder 2002) because the basecase assessment does not include a stock-recruitment relationship, whereas the previous assessments did. The results of the sensitivity analysis (section 5.4) give the results of an assessment with a stock-recruitment relationship.

Recent catches may have been greater than the AMSY because large cohorts were recruited to the fishery throughout most of the 1995-1998 period (Figure 4.9). 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.

Estimation of the AMSY, and its associated quantities, is 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. It should be noted that these estimates are based on the fishing mortality rates estimated by the method used to estimate fishing mortality rates in the sensitivity analysis. 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 5.2). 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 5.2). However, Fishery 7 catches very few bigeye, and would require an unrealistically high increase in effort (88 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) will 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 the most recent two years 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 12 quarters (Figure 5.4, upper panel). These calculations suggests that restricting catch from fisheries that capture intermediate-aged bigeye (ages 10-15) would provide the most benefit to the spawning biomass. However, this is not a fair comparison because an individual of age 12 quarters is much 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 middle-aged bigeye by about three tons.

5.5. Sensitivity to alternative parameterizations and data

The method used to calculate the fishing mortalities used in the yield calculations has a substantial effect on the results. The sensitivity analysis is based on a much higher fishing mortality rate for small bigeye. However there is considerable uncertainty in these estimates of fishing mortality (Figure C.1). This is caused by the positive effort deviations for the surface fisheries in 2000 and 2001 (Figure 4.7). The major differences are that the current effort is estimated to be about equal to the effort required to produce AMSY, the AMSY is lower (-15%), and the SBR, biomass, and spawning biomass required to produce AMSY are all lower (Table 5.1).

Perceptions about the status of the bigeye stock in the EPO are only somewhat sensitive both to the assumptions about the stock-recruitment relationship and the Korean longline catch data. Estimated SBRs are similar for the alternative assessments, but the difference between SBR and SBR_{AMSY} at any given time is marginally sensitive to the stock recruitment-relationship (Figure A.3).

Estimates of AMSY and the amount of fishing mortality required to achieve the AMSY are sensitive to the assumptions about the stock-recruitment relationship. Including a stock-recruitment relationship reduces both the AMSY (-12%) and effort levels (-48%) required to obtain AMSY (Table 5.1). In addition, the estimated equilibrium yield at the current effort level (61,757) is estimated to be smaller than that under the assumption of no stock recruitment relationship (63,061 mt). If there is no stock-recruitment relationship, because recruitment is constant (*i.e.* recruitment does not decline with stock size), the yield curve is equivalent to the yield-per-recruit (YPR) curve, but when a stock-recruitment curve is used, recruitment would be significantly reduced if current effort levels are continued for a long time (*i.e.* equilibrium conditions, Figure A.4). Therefore, the total yield will be reduced further if a stock-recruitment relationship exists.

When the larger SPC-estimated Korean longline catch data is included in the analysis, AMSY is increased (87,381 mt) and effort level required to produce AMSY is increased (12%).

Stochastic estimates of AMSY, the proportion of current effort that would produce AMSY, and the SBR that would produce AMSY were calculated by randomly sampling the model parameters based on the variance-covariance of the parameter estimates (Figure C.2). In this simple study we ignored any uncertainty in the estimated growth rates. The results show that there is substantial uncertainty in the estimates of these quantities. Future work needs to be conducted to get a fuller understanding of the uncertainty of management quantities for bigeye tuna in the EPO.

In general, the sensitivity analyses in this report, those conducted by Watters and Maunder (2002), and the stochastic analyses confirm the fact that there is uncertainty in the estimate of the AMSY and the amount of fishing effort that is required to achieve this yield.

5.6. Summary of stock status

At the beginning of January 2002, the spawning biomass of bigeye tuna in the EPO was at a low level. At that time the SBR was about 0.28, with lower and upper confidence limits (± 2 standard deviations) of about 0.15 and 0.41. However, the spawning biomass appears to have been above this level throughout most of the July 1980-January 2001 period. The stochastic projections indicate that the SBR is likely within the next three years to reach an historic low level below the level that would be expected if the population were producing the AMSY. This decline is likely to occur regardless of the environmental conditions and the amount 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 and 2001. The projected SBR may increase during 2003-2006, but the timing and rate of this increase would be dependent on future levels of recruitment (which may be driven by future environmental conditions) and fishing mortality.

The average weight of fish in the catch of all fisheries combined has been below the critical weight (about 35.5 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 between 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 (and therefore the yield) to crash. When longline catches are dominant, the population can sustain substantially higher fishing mortality rates. These conclusions are valid only if the age-specific selectivity pattern of each fishery is maintained.

At the beginning of January 2002, the spawning biomass of bigeye tuna in the EPO appears to have been about 26% less than the level that would be expected to produce the AMSY. However, the recent catches are estimated to have been about 11% 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 185% of the current level of effort. Increasing the effort to 185% of its present level would increase the long-term average yield about 11%, but such an action would decrease the spawning potential of the stock by about 42%. 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 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.

The sensitivity analyses support the view that, at the start of 2002, the spawning biomass was below the level that would be present if the stock were producing the AMSY. However, the sensitivity analyses in this report, those presented by Watters and Maunder (2002), and the stochastic analyses confirm the fact that there is uncertainty in the estimate of the AMSY and the amount of fishing mortality that is required to achieve this yield. Both of these quantities are sensitive to how the assessment model is parameterized and to the data that are included in the assessment. It is important to understand that the status of the stock is highly dependent on the method used to calculate the fishing mortalities used in the yield calculations. If the catchabilities remain as high as in the most recent years, as apposed to moving back to their average levels, and effort levels continue at their recent levels, the bigeye population is estimated, under average recruitment, to recover to the level that would produce the AMSY.

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 2002 through 2006 (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.

In addition to the basecase assessment, a sensitivity to the assumptions used in the calculation of the fishing mortalities used in the projections is included. This is the same sensitivity described in the stock status section. In the basecase assessment the fishing mortality is calculated as the average catchability over the whole time period of the fishery multiplied by the selectivity and the average effort, by quarter, over 2000 and 2001. In the sensitivity analysis, fishing mortality was calculated as the average estimated fishing mortality, by quarter, over 2000 and 2001. This fishing mortality includes effort, average catchability, selectivity, and the effort deviations. The difference between the two assessments is in the inclusion of the effort deviations.

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 2002-2006.

1. The surface fleet will exert an amount of effort that is equal to 75% of the average amount of effort it exerted during 2000-2001.
2. The surface fleet will exert an amount of effort that is equal to the average amount of effort it exerted during 2000-2001.
3. The surface fleet will exert an amount of effort that is equal to 125% of the average amount of effort it exerted during 2000-2001.

These scenarios are based on quarterly levels of fishing effort. For example, in the first scenario, the effort during the fourth quarters of 2002, 2003, 2004, 2005, and 2006 is equal to 75% of the average effort exerted during the fourth quarters of 2000 and 2001.

All of the simulations were conducted under the assumption that, from 2002 through 2006, the longline fleet will exert an amount of effort equal to the amount of effort it exerted during 2000 (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. Future levels of catchability for each fishery were assumed to be equal to the average catchability for that fishery during 2000 and 2001 (these averages were computed on a quarterly basis).

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 July 1980-January 2002. 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 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.

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 11% by the end of 2006 (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 10% (Table 6.1).

As noted in Section 5.1, the SBR is projected to decrease throughout 2002, and is likely to be substantially less than SBR_{AMSY} (0.38) through 2004 (Figure 6.1a). This trend is due to the series of small cohorts that are estimated to have been recruited during 1999-2001 (Figure 4.9). This trend 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 throughout 2003 and 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 also affect the degree to which the SBR increases during 2005-2006.

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 4% 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, the results for the projected SBR are substantially more uncertain (Figure 6.1b). In this case, the 95% confidence intervals 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 10% (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 13% (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 35.5 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 27% 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 increase by 14% (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 about 18% less than those predicted under average levels of effort (Table 6.1).

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 4% (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 12% 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 14% 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 sensitivity analysis are substantially different from the results of the basecase. The sensitivity analysis is based on a much higher fishing mortality rate for small bigeye; however there is large uncertainty in these estimates of fishing mortality (Figure C.1). This is caused by the positive effort deviations for the surface fisheries in 2000 and 2001 (Figure 4.7). The sensitivity analysis predicts that, like the basecase, the SBR will drop to a low level in 2003; however, unlike the basecase, it will stay at a low level at least until 2006, with only a small recovery (Figure C.4). The SBR will be substantially below the level required to produce AMSY for the whole period of the projection. Projected catches and average weights for the sensitivity analysis are presented in Figures C.5 – C.7

The results of the sensitivity analysis are also substantially more sensitive to changes in the surface fishery effort compared to the basecase assessment. Increasing the surface effort to 125% of its recent average level is predicted to cause SBR to decrease by about 23%, the average weight of fish in the combined catch to decrease by about 12%, the surface catch increases by 5%, and the longline catch to decrease by about 20% (Table C.1). Decreasing the surface effort to 75% of its recent average level is predicted to cause the median estimate of the SBR to increase by about 34%, the average weight of fish in the combined catch to increase by about 17%, the surface catch decreases by 8%, and the longline catch to increase by about 28% (Table C.2). Sensitivity to the discards is similar to that estimated for the basecase.

6.5. Summary of the simulation results

The small cohorts of bigeye tuna that were apparently recruited to the fisheries in the EPO during 1999-2001 may cause the SBR to decrease throughout 2002 and to be substantially less than SBR_{AMSY}. During the next year, the spawning biomass of bigeye in the EPO may decline to historically low levels. 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 increase during 2003-2006, but the rate at which this increase occurs will depend on future levels of fishing effort, and possibly on environmental conditions during 2002-2003.

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) is projected to 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 shows that if fishing mortality rates continue at their recent levels due to the recent increase in catchability being sustained, the fishery is unlikely to recover from the low levels predicted in 2003, and the SBR will remain below the level required to produce AMSY.

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 yellowfin tuna in the EPO. New data collected during 2002 and updated data for 2001 will be incorporated into the next stock assessment.

The IATTC staff also intends to screen other types of environmental data for use in the stock assessment model.

The collection an 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.

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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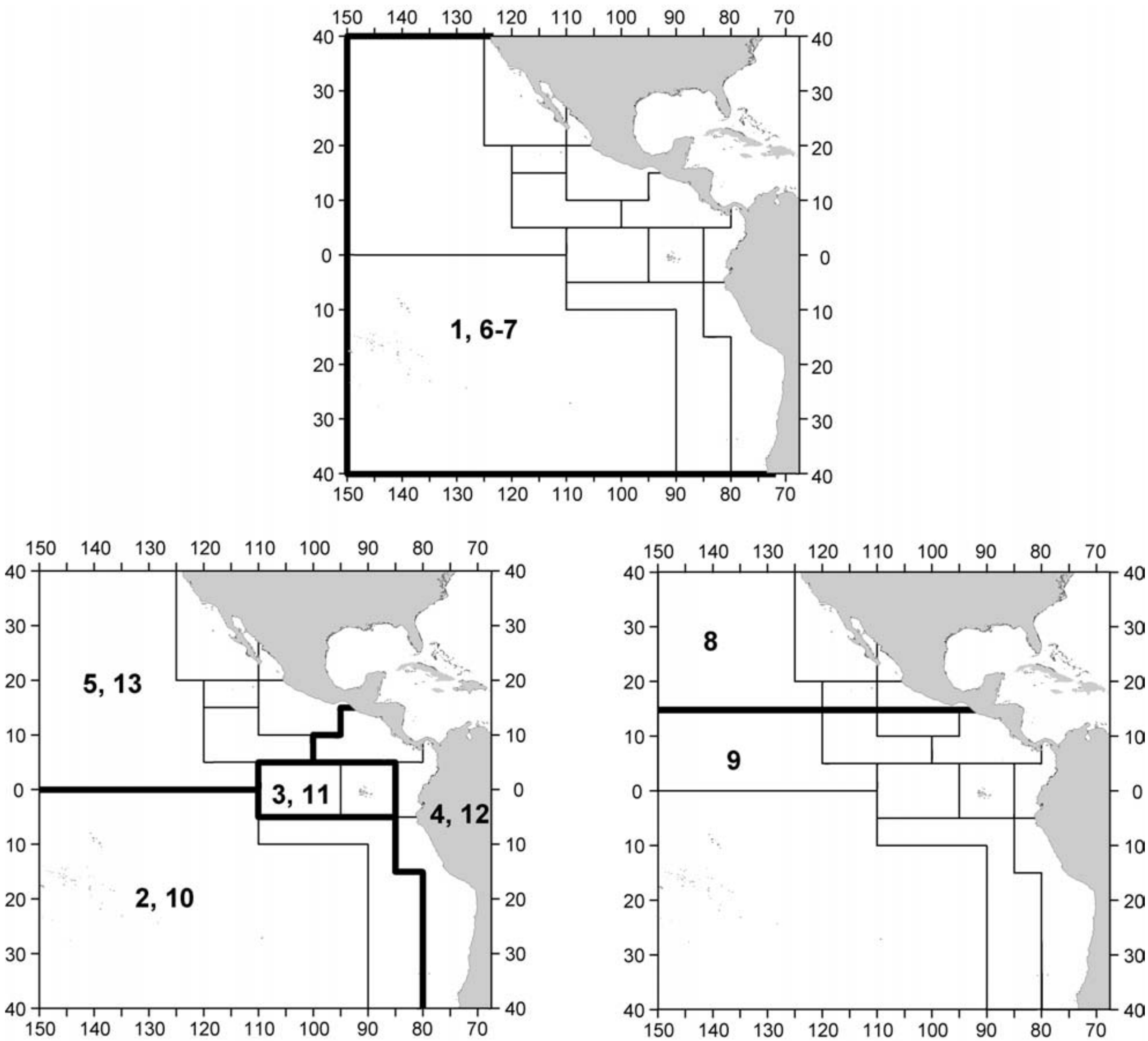


FIGURE 2.1. Spatial extents of the fisheries defined for the stock assessment of bigeye tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the bold numbers the fisheries to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

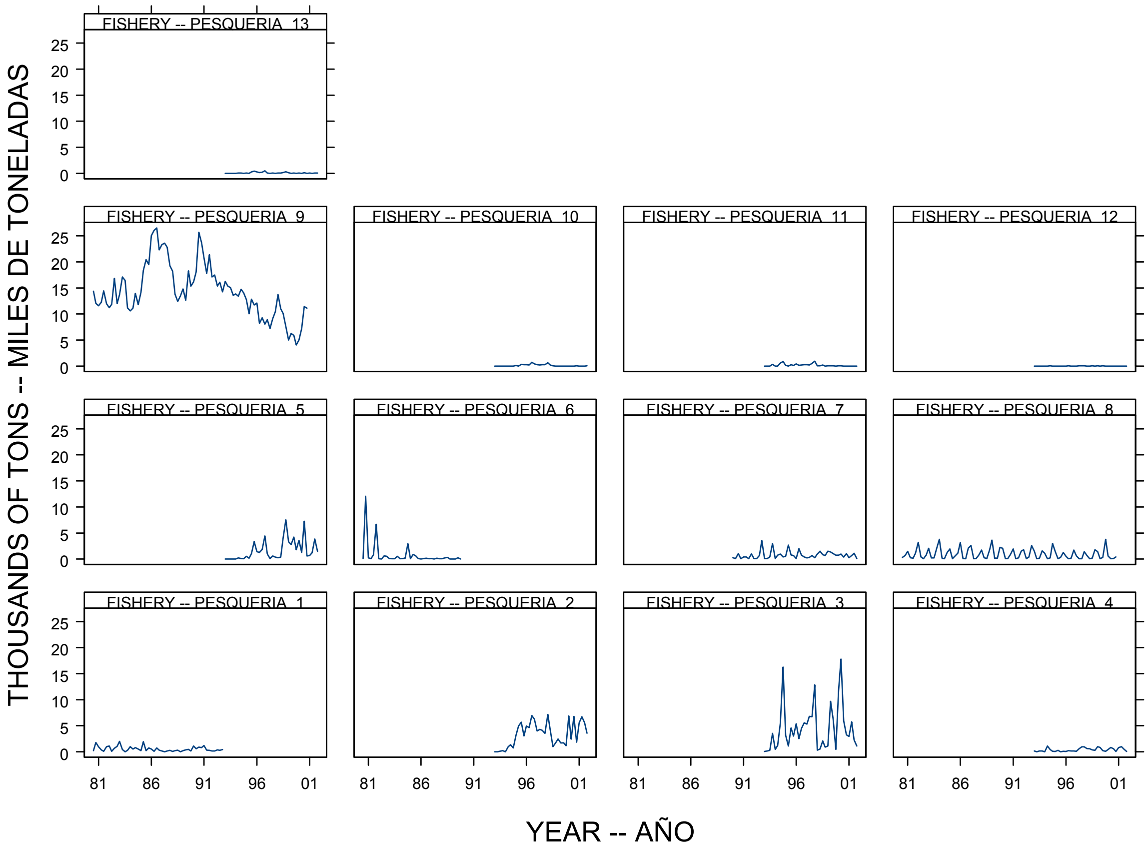


FIGURE 2.2. Catches taken by the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). Since the data were analyzed on a quarterly basis, there are four observations of catch for each year. Although all the catches are displayed as weights, the stock assessment model uses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

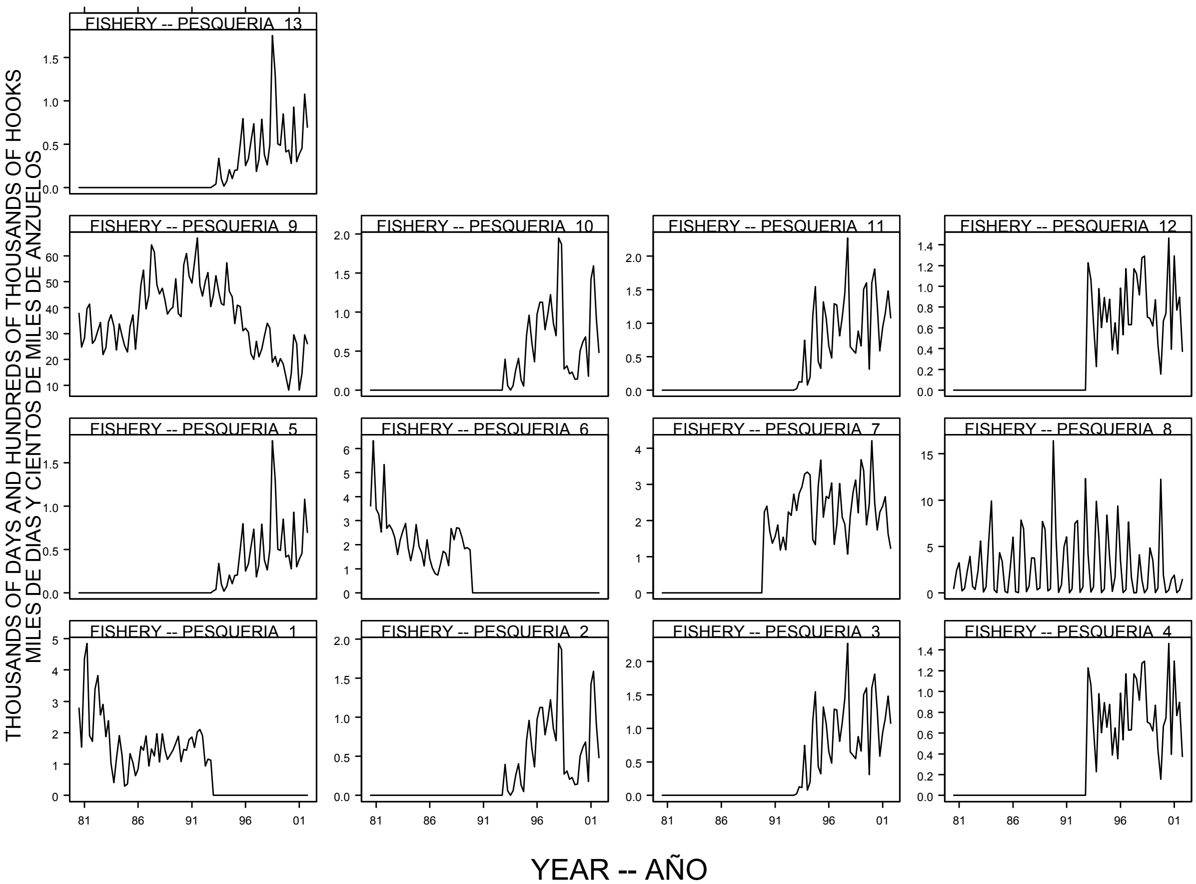


FIGURE 2.3. Fishing effort exerted by the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of effort for each year. The effort for Fisheries 1-7 and 10-13 is in days fished, and that for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

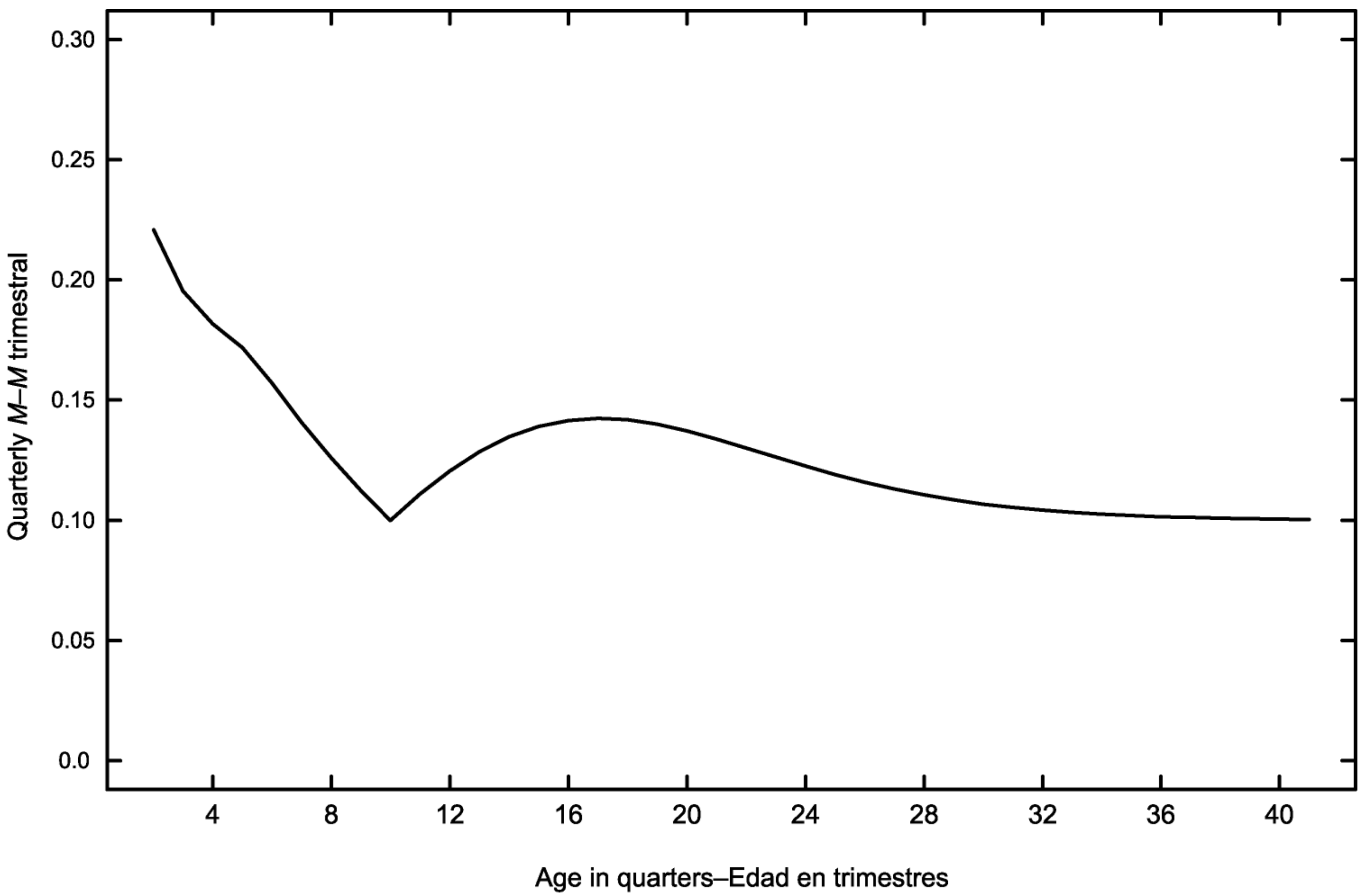


FIGURE 3.1. Quarterly natural mortality (*M*) rates used for the basecase assessment of bigeye tuna in the EPO.

FIGURA 3.1. Tasas de mortalidad natural (*M*) trimestral usadas para la evaluación del caso base de atún patudo en el OPO.

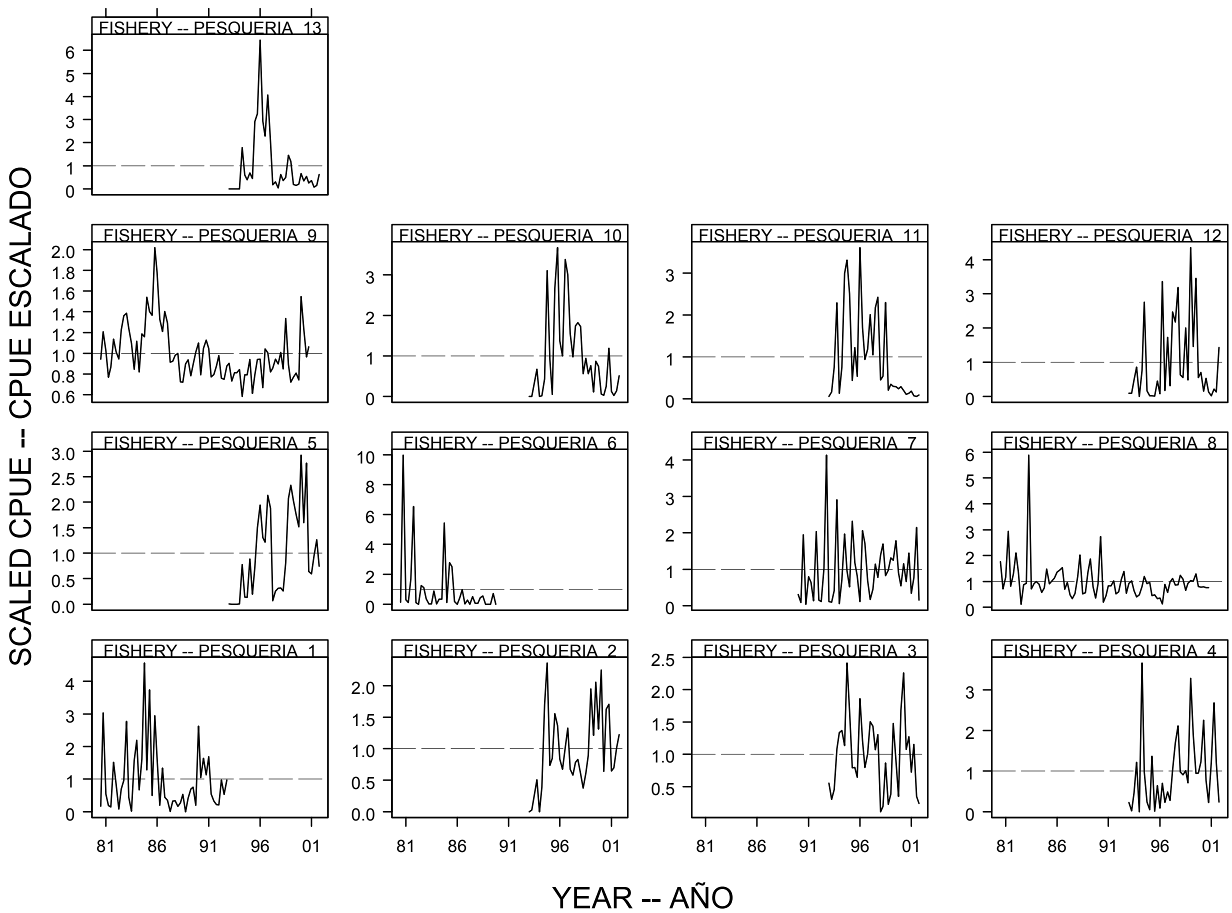


FIGURE 4.1. CPUEs of the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of CPUE for each year. The CPUEs for Fisheries 1-7 and 10-13 are in kilograms per day fished, and those for Fisheries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

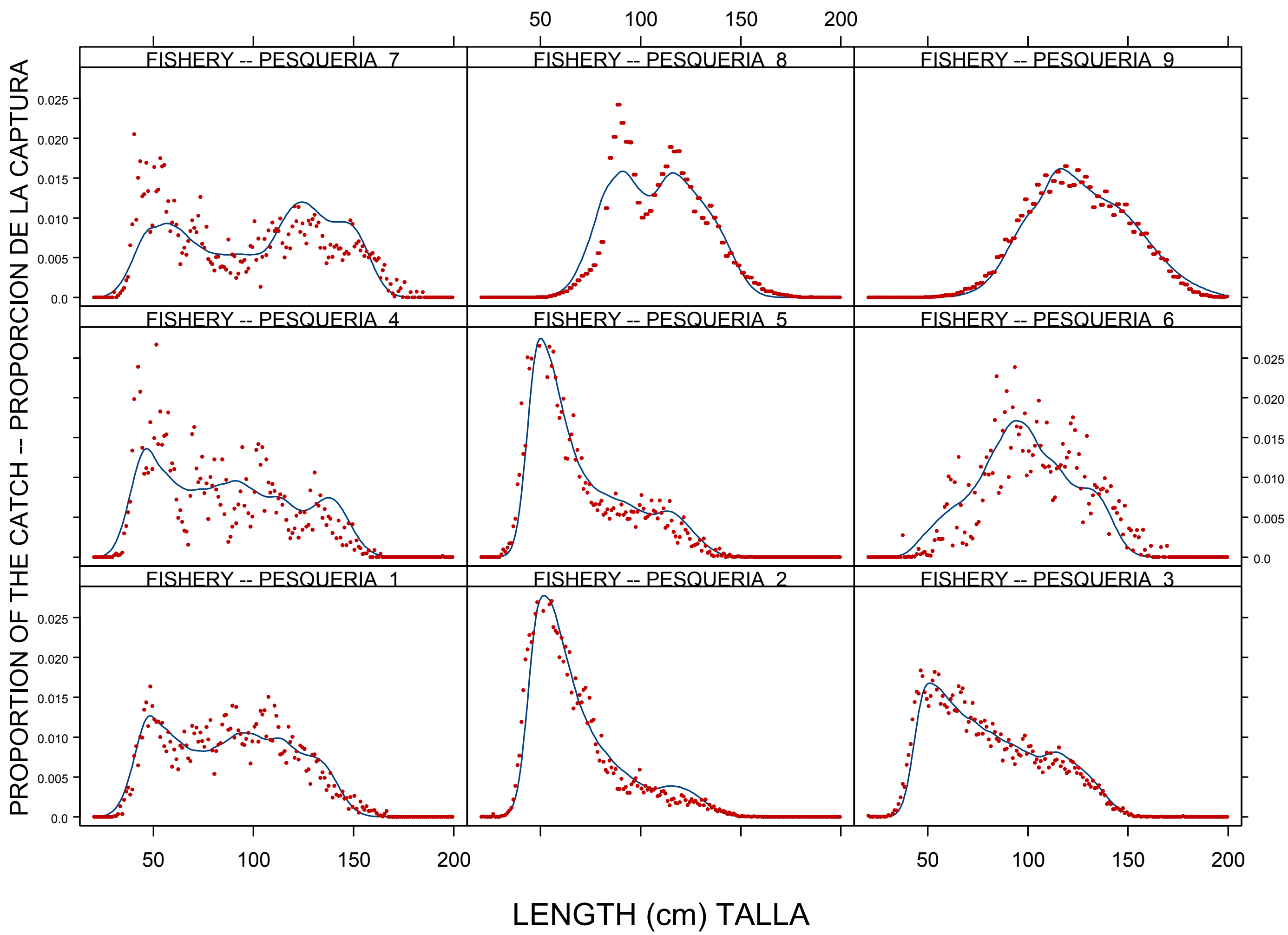


FIGURE 4.2. Average observed (solid circles) and predicted (curves) size compositions of the catches taken by the fisheries defined for the stock assessment of bigeye tuna in the EPO.

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.

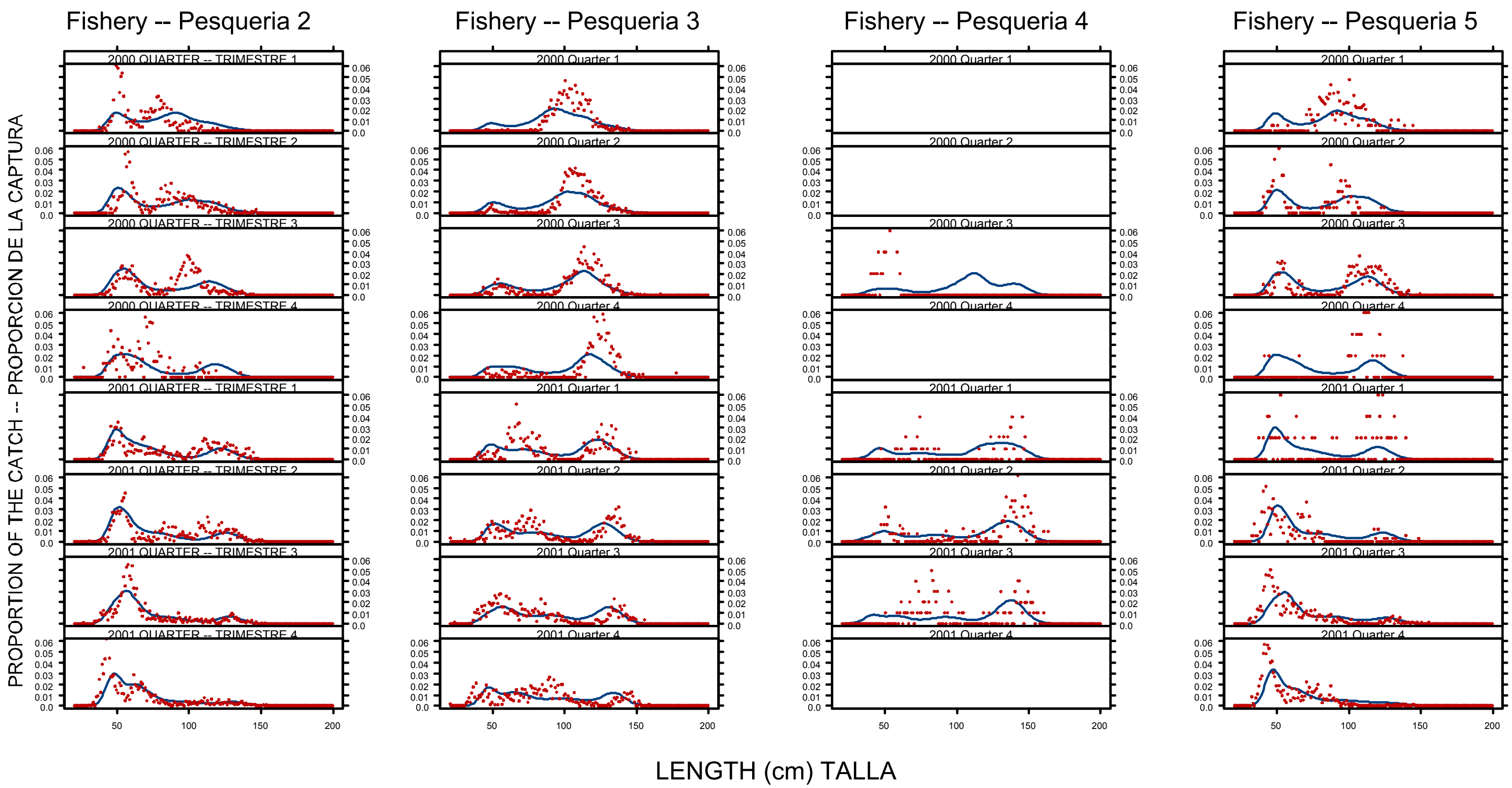


FIGURE 4.3a. Recent size compositions of the catches of bigeye tuna taken by the fisheries that operate in the EPO. The solid circles are observations and the curves are predictions from the basecase assessment.

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.

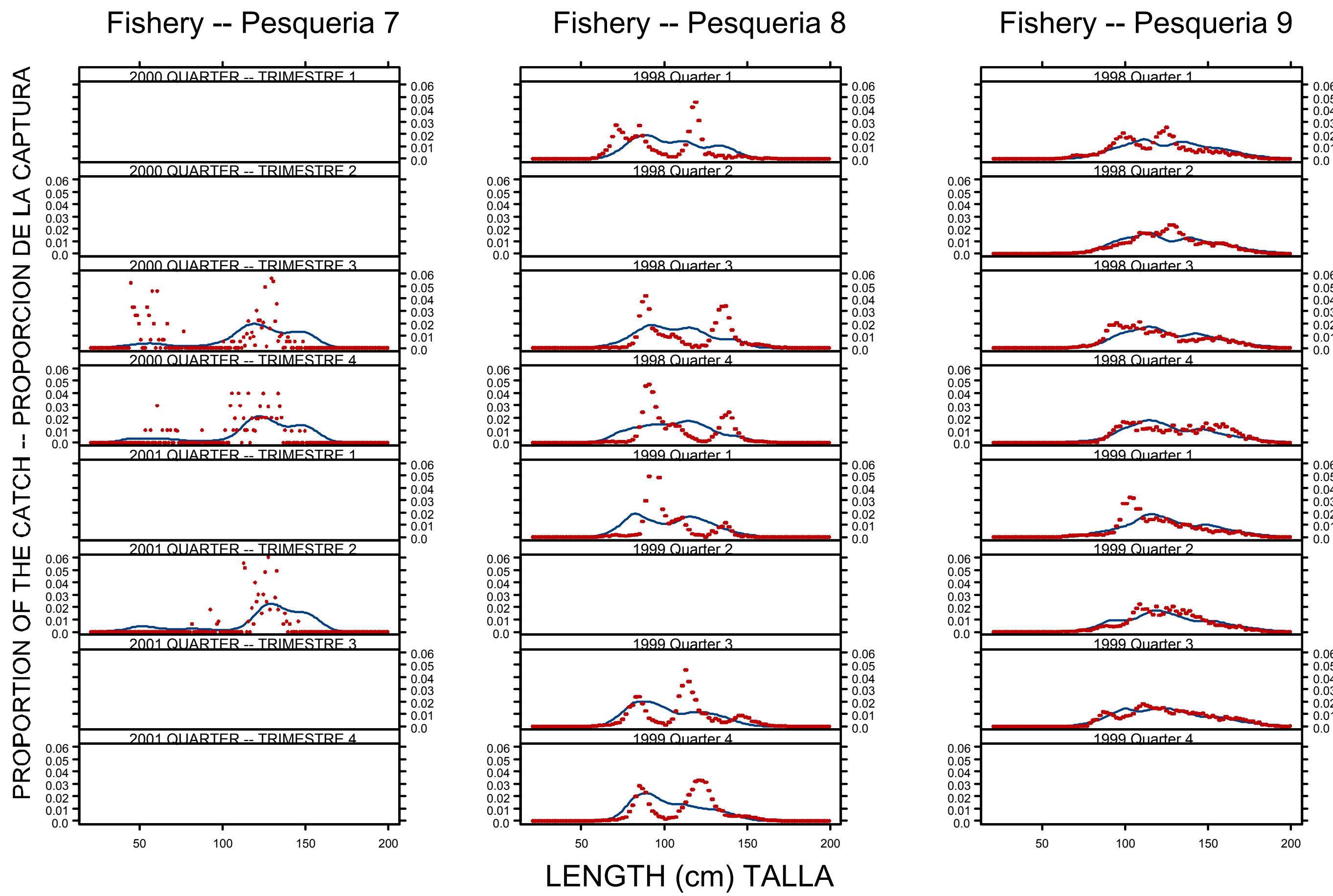


FIGURE 4.3b. Recent size compositions of the catches of bigeye tuna taken by the fisheries that operate in the EPO. The solid circles are observations and the curves are predictions from the basecase assessment.

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.

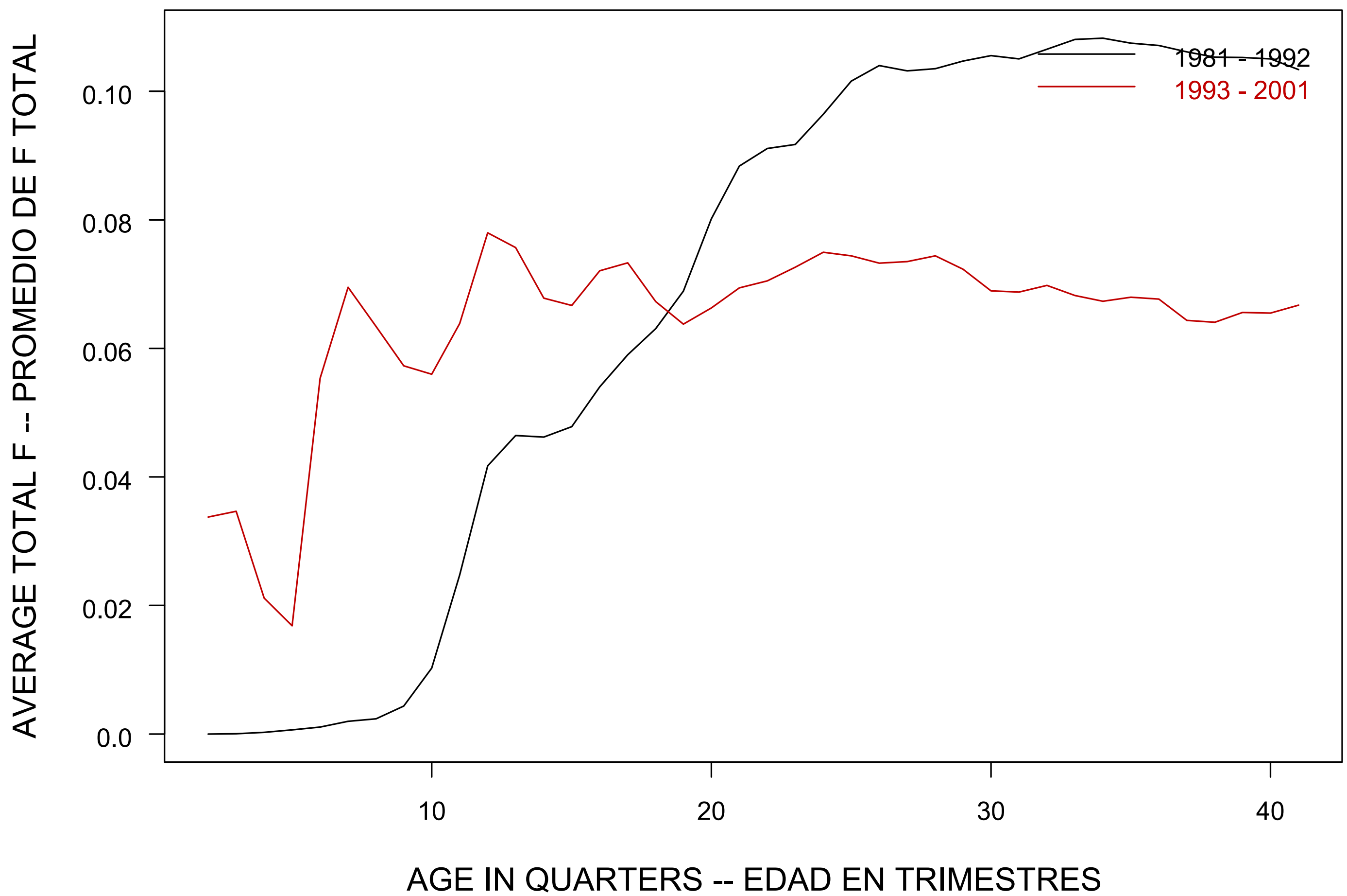


FIGURE 4.4. Average total quarterly fishing mortality at age on bigeye tuna in the EPO. The curve for 1981-1992 displays averages for the period prior to the expansion of the floating-object fisheries. The curve for 1993-2001 displays averages for the period since this expansion.

FIGURA 4.4. Mortalidad por pesca trimestral total media a edad sobre atún patudo en el OPO. La curva para 1981-1992 muestra los promedios para el período previo a la expansión de la pesquería sobre objetos flotantes. La curva para 1993-2001 indica los promedios para el periodo desde esta expansión.

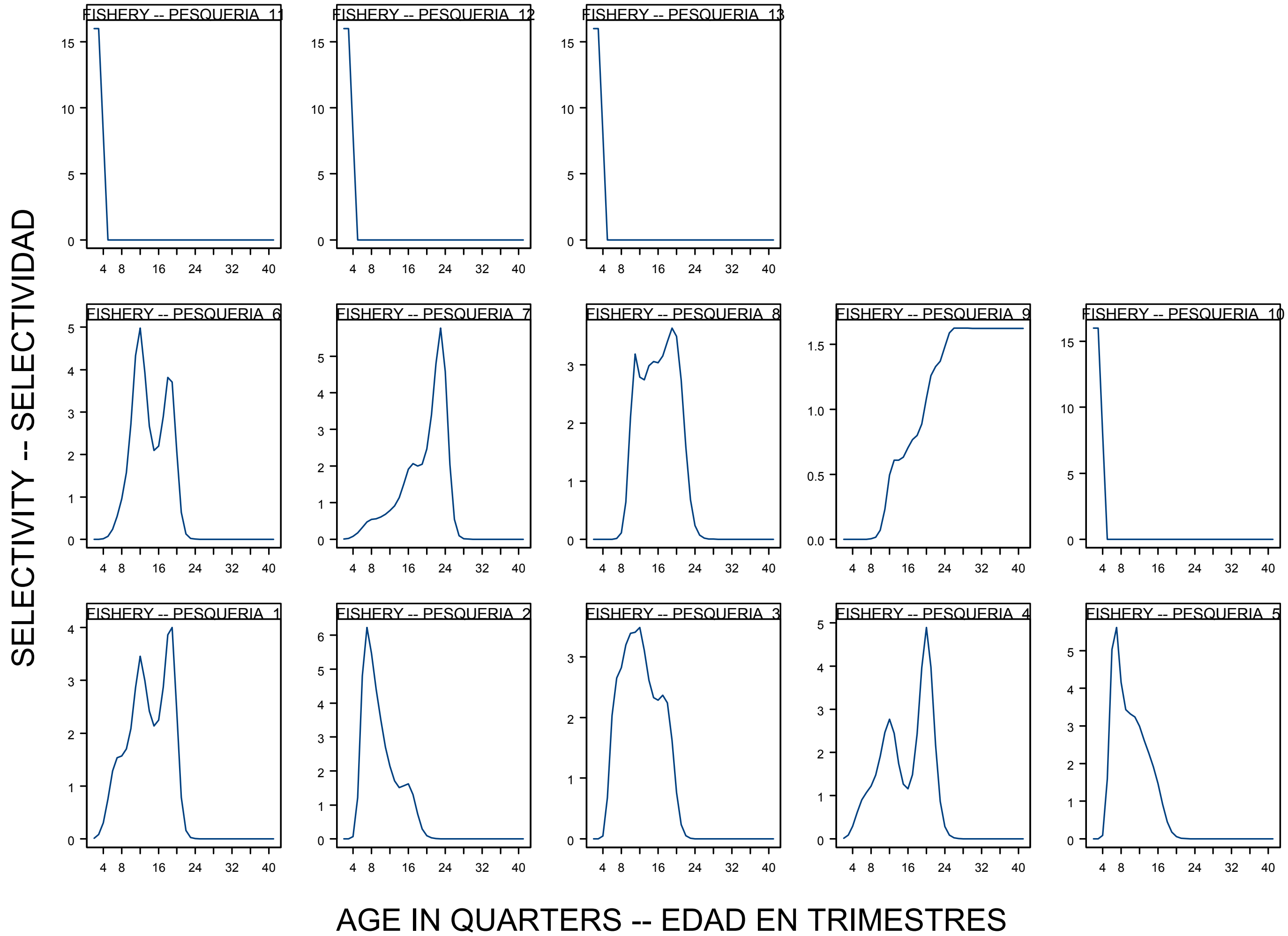


FIGURE 4.5. Selectivity curves for the 13 fisheries that take bigeye tuna in the EPO. The selectivity curves for Fisheries 1 through 9 were estimated with the A-SCALA method. The curves for Fisheries 10-13 are based on assumptions.

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 4.6. 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 4.6. 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.

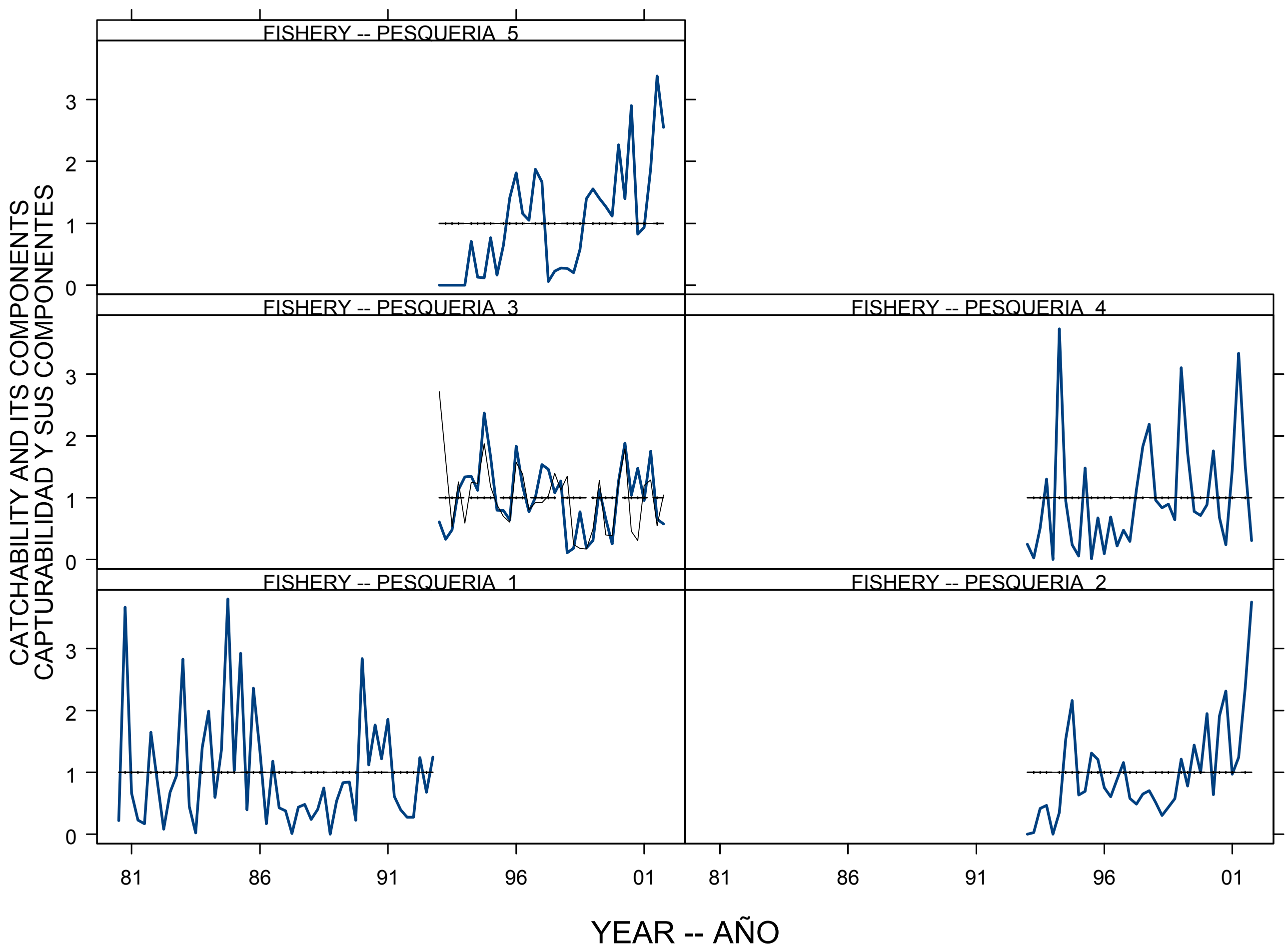
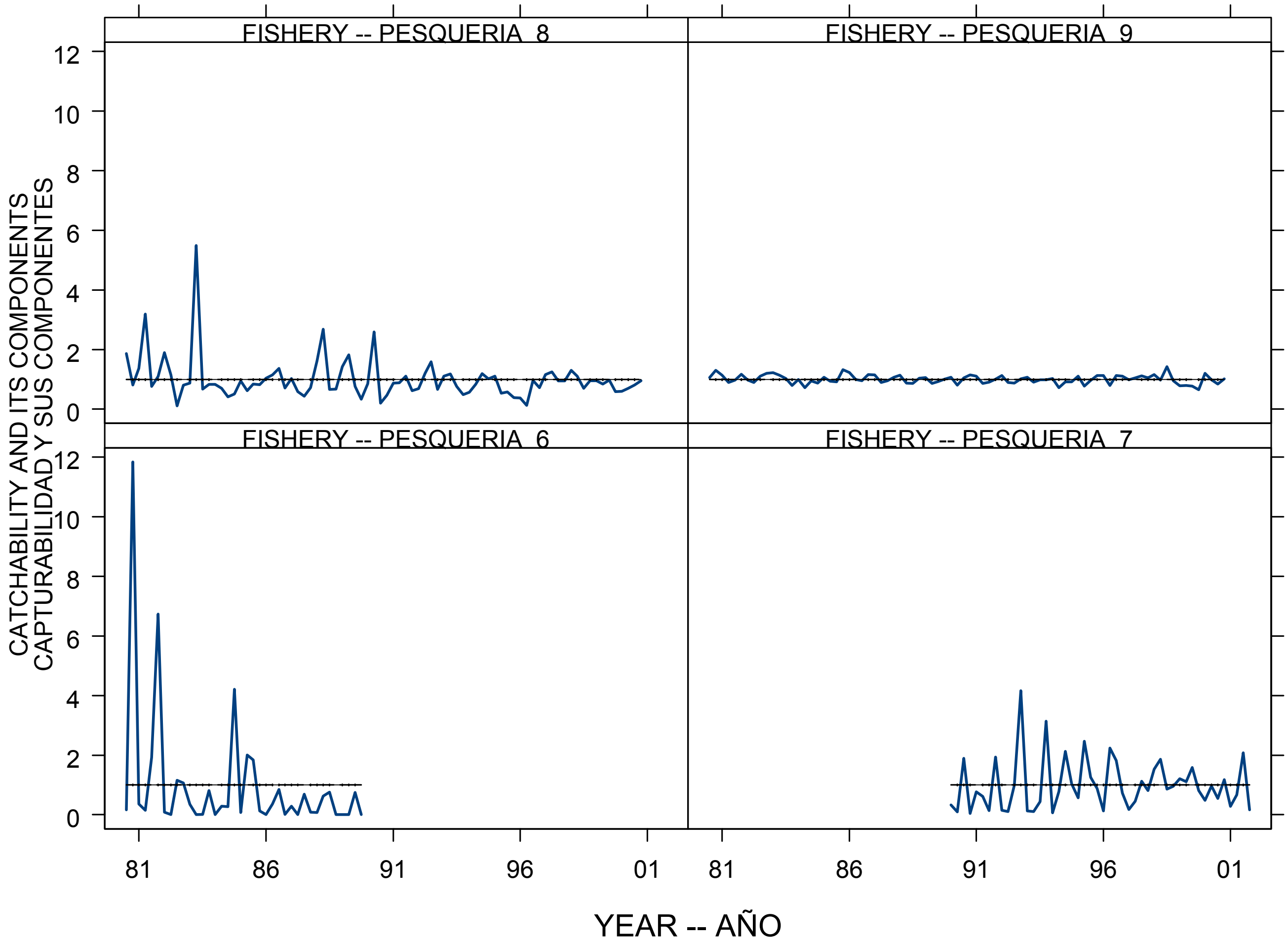


FIGURE 4.7a. Trends in catchability (q) for the 13 fisheries that take bigeye tuna in the EPO. The estimates are scaled to the first estimate of q for each fishery (dashed line). The thin line (Fishery 3 only) illustrates the environment index for q. The bold lines include random effects, and illustrate the overall trends in catchability. When the thin lines and bold lines follow the same trend the environmental conditions may be considered to explain patterns 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. Cuando las líneas delgada y gruesa siguen la misma tendencia, se considera que las condiciones ambientales explican los patrones de 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.

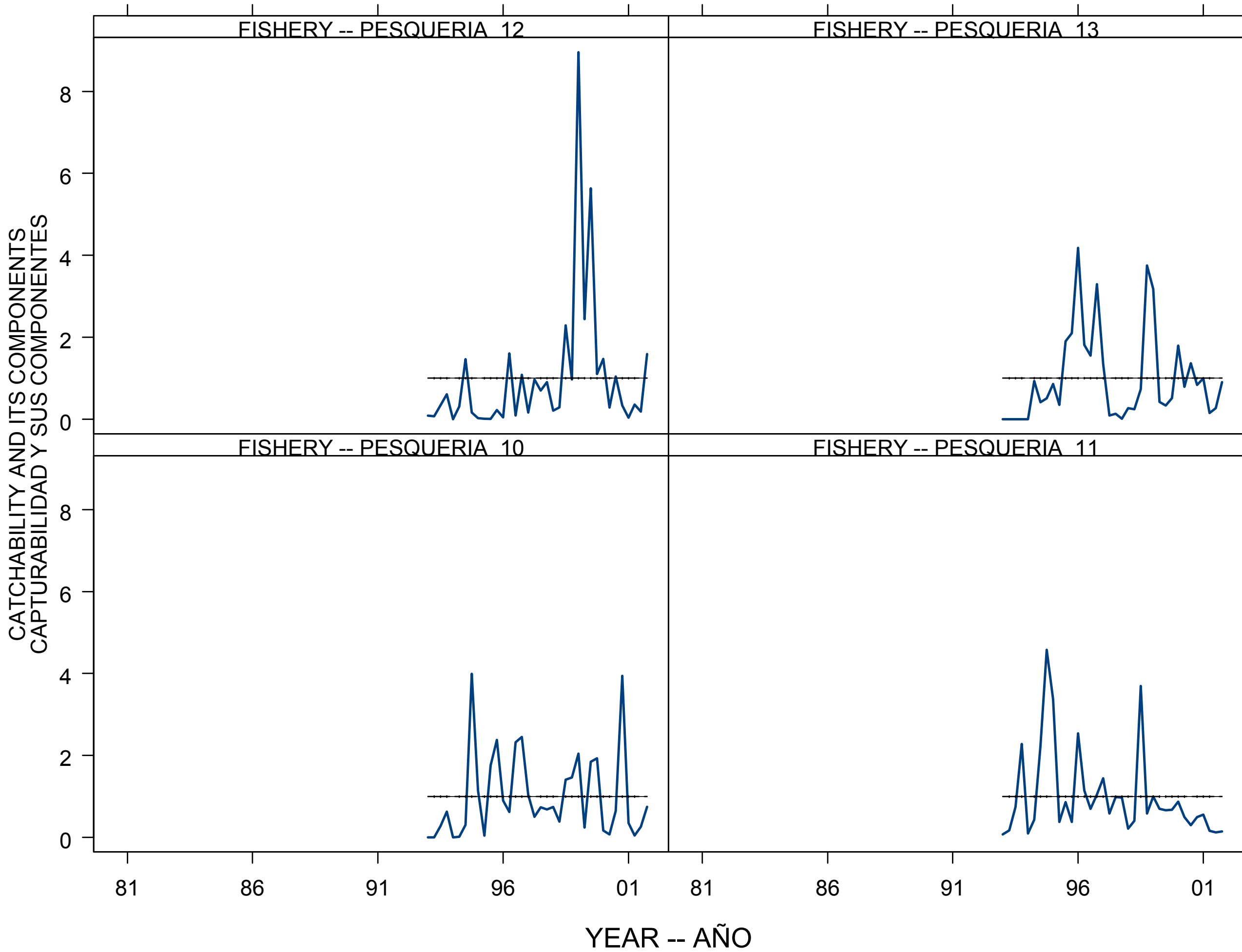


FIGURE 4.7c. Trends in catchability (q) for the 13 fisheries that take bigeye tuna in the EPO. See Figure 4.7a for additional details.

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.

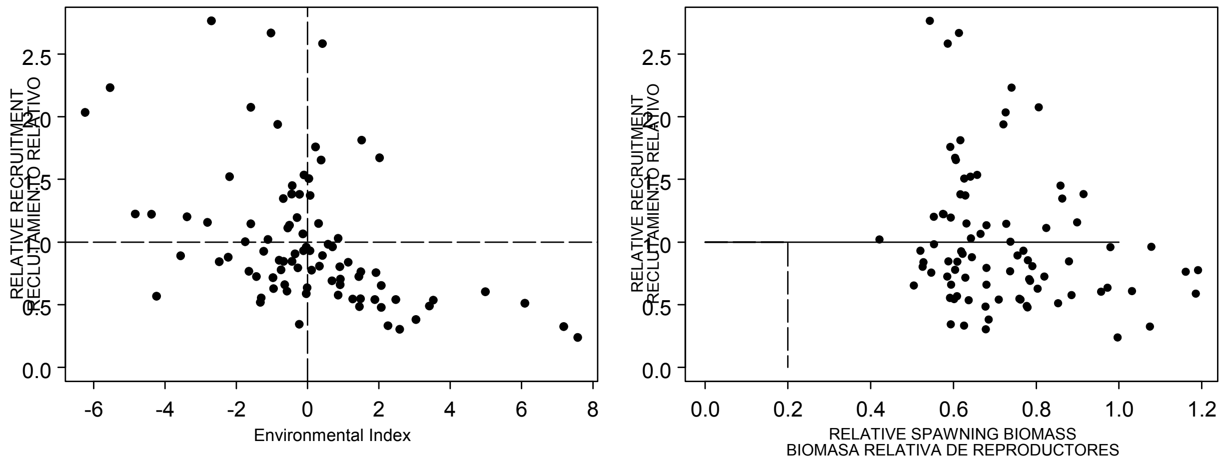


FIGURE 4.8. Estimated relationships between the recruitment of bigeye tuna and zonal-velocity anomalies at the assumed time of hatching (upper panel) and between recruitment and spawning biomass (lower panel). The recruitment is scaled so that the estimate of virgin recruitment is equal to 1.0. The spawning biomass (females at least 3 years old) is scaled so that the estimate of virgin spawning biomass is equal to 1.0. The curve displayed in the lower panel is the estimated 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.

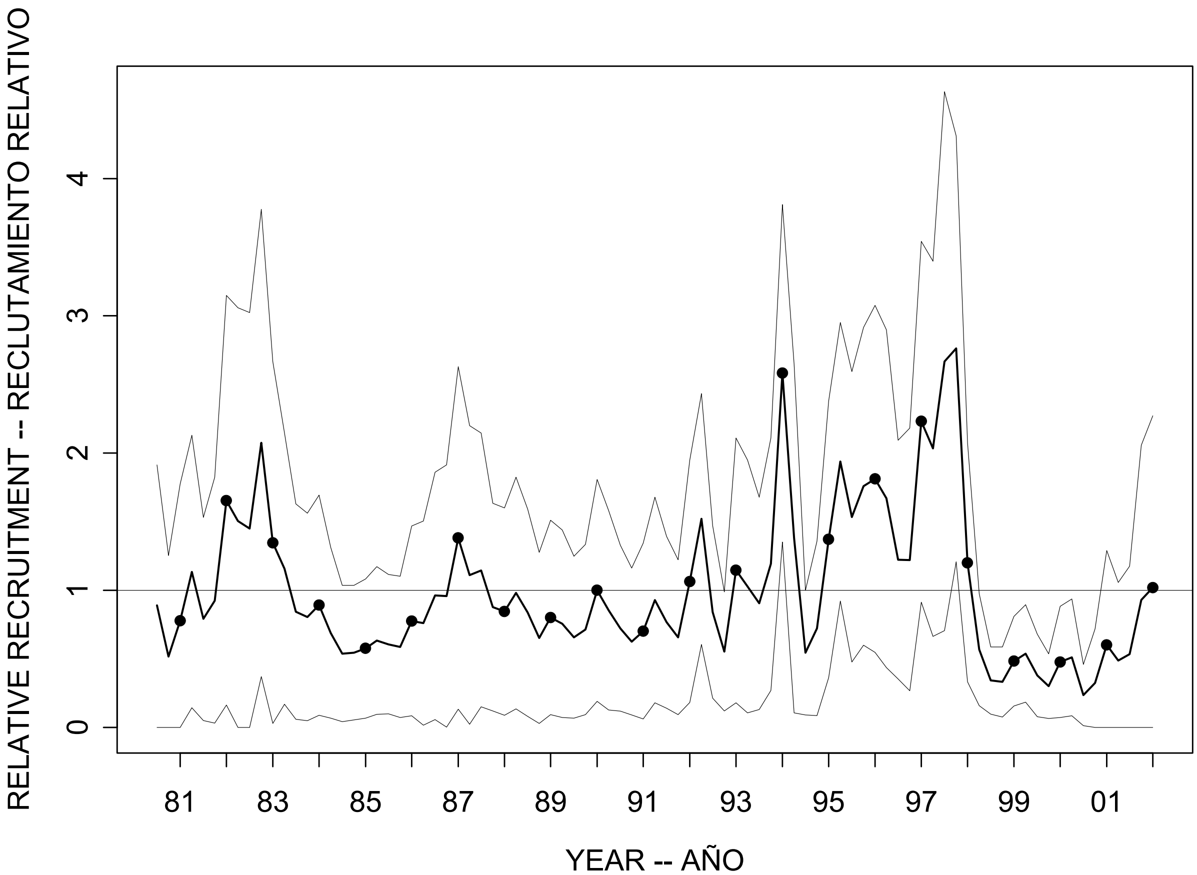


FIGURE 4.9. Estimated recruitment of bigeye tuna to the fisheries of the EPO. The estimates are scaled so that the estimate of virgin recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the thin lines are confidence intervals (±2 standard errors)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

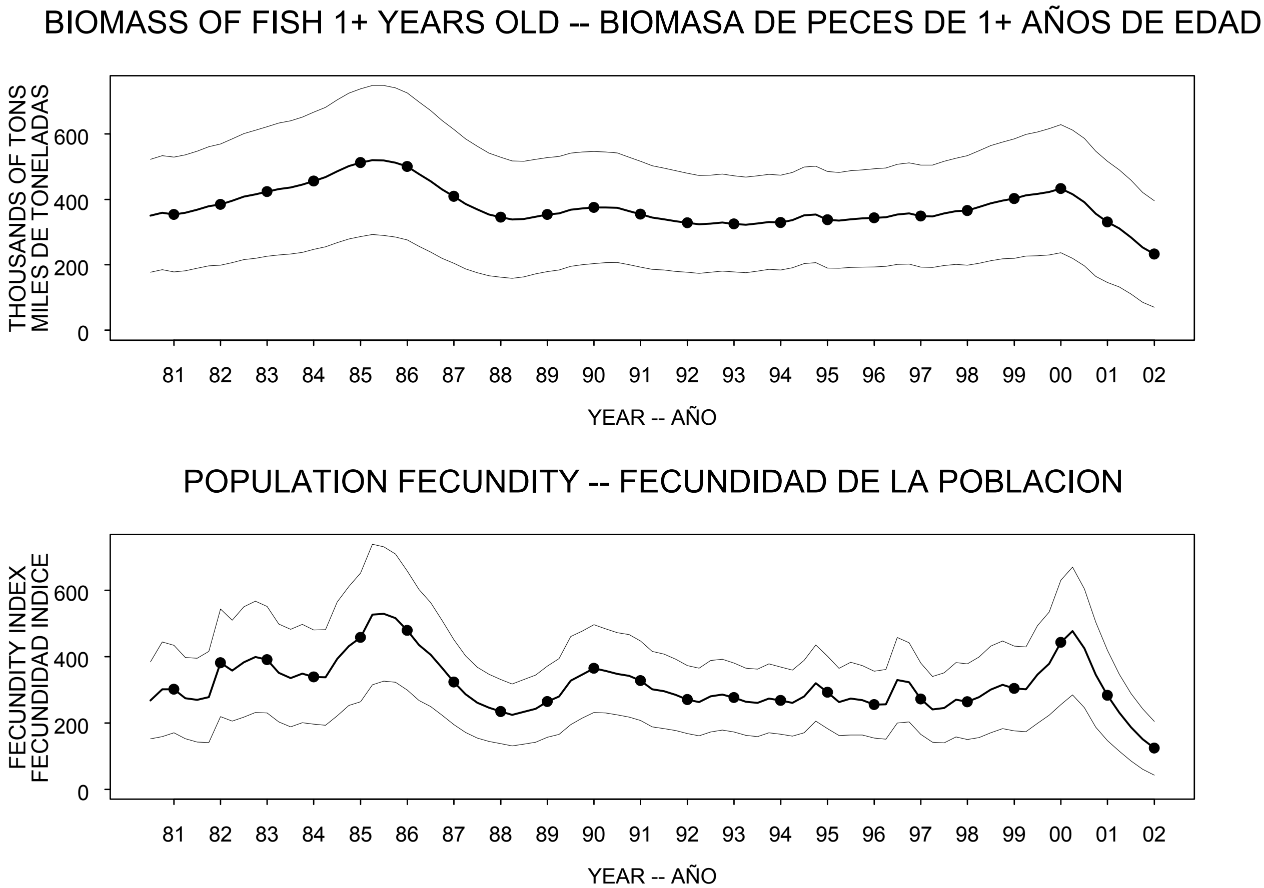


FIGURE 4.10. Estimated biomass and fecundity index (see Section 3.1.2) of bigeye tuna in the EPO. The bold lines illustrate the maximum likelihood estimates of the biomass, and the thin lines are confidence intervals (±2 standard errors) around those estimates. Since the assessment model represents time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

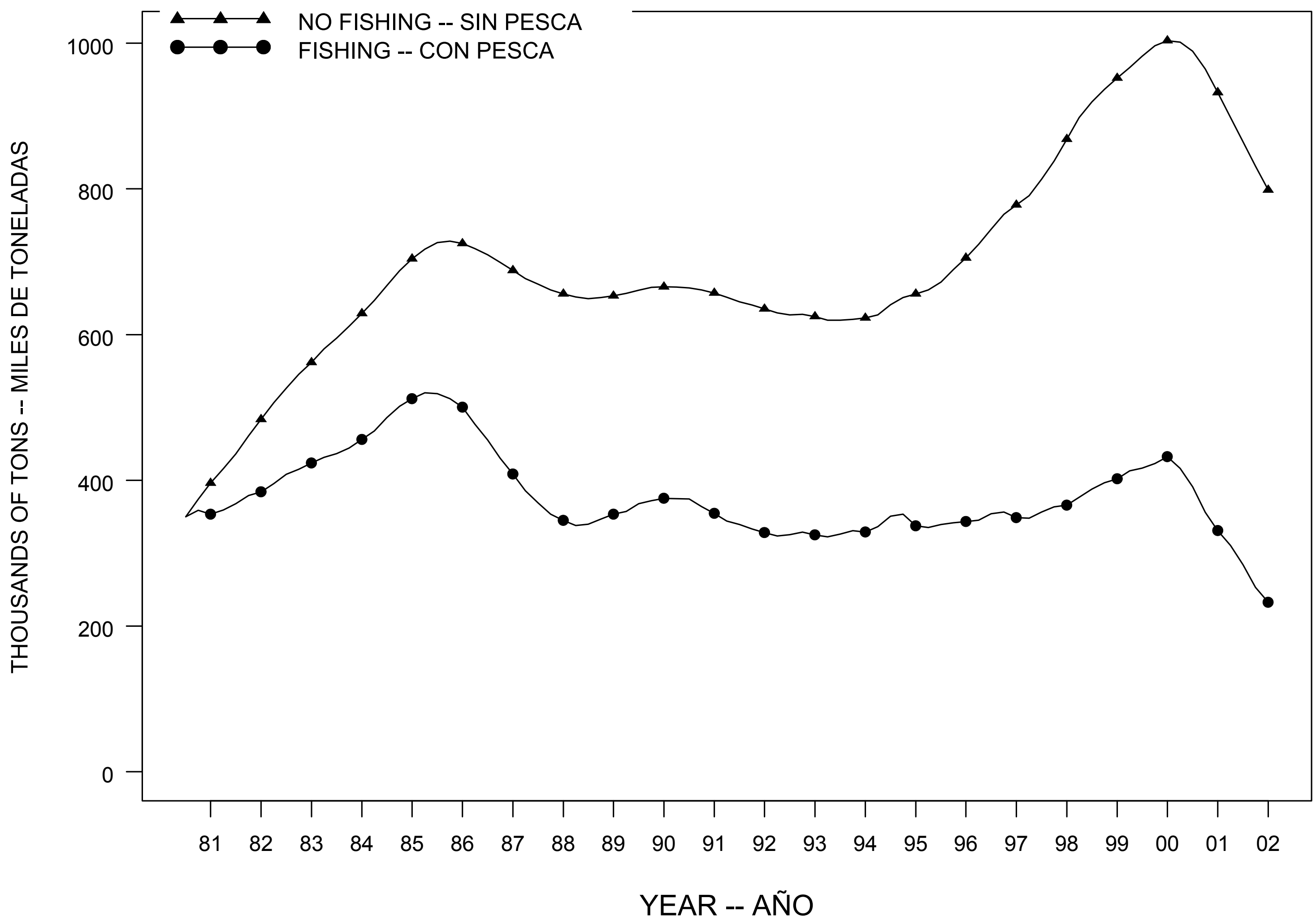


FIGURE 4.11. Biomass trajectory of a simulated population of bigeye tuna that was not exploited during July 1980 through December 2001 ("no fishing") and that predicted by the stock assessment model ("fishing").

FIGURA 4.11. Trayectoria de biomasa de una población simulada de atún patudo no explotada durante julio de 1980 a diciembre de 2001 ("sin pesca") y la predicha por el modelo de evaluación del stock ("con pesca").

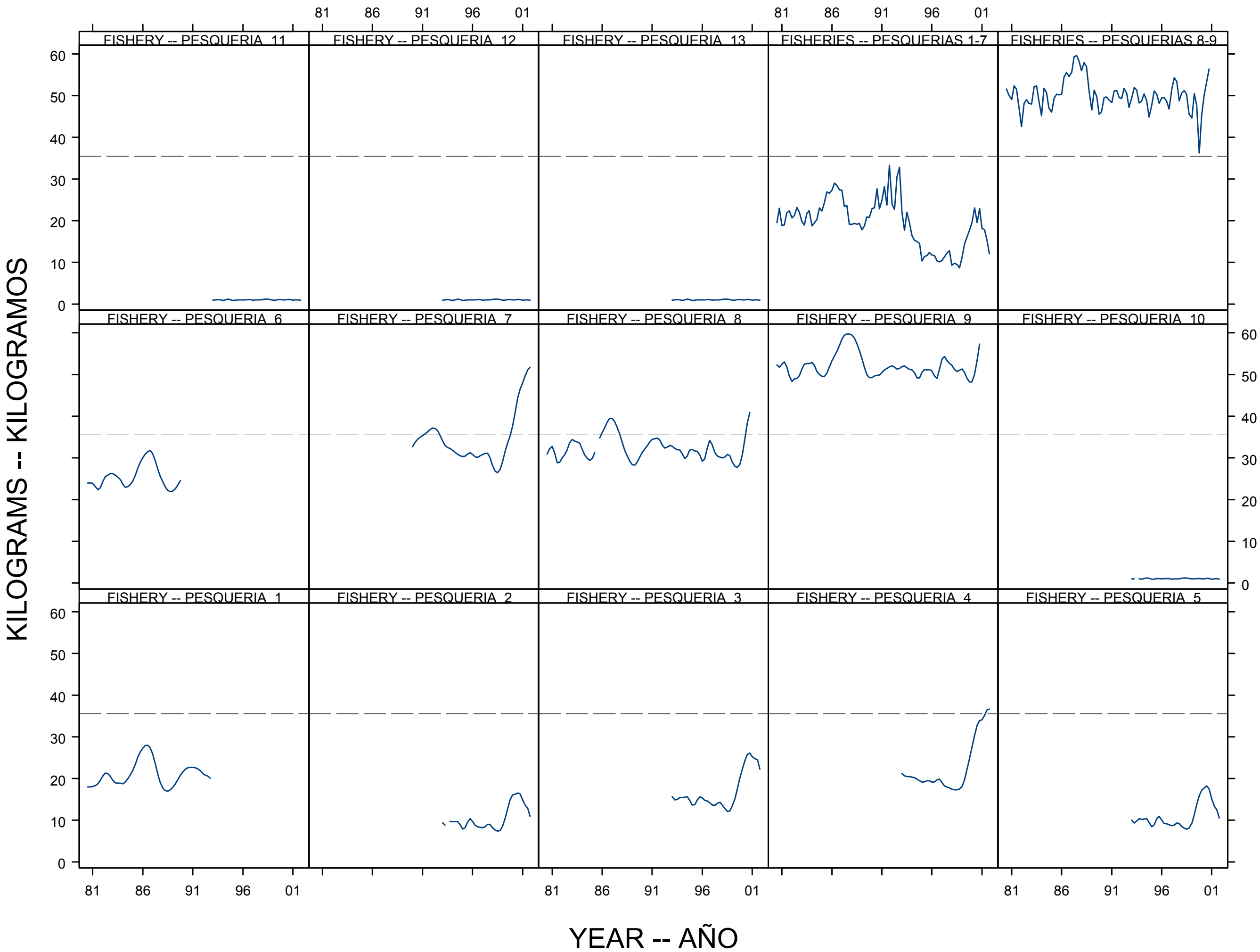


FIGURE 4.12. Estimated average weights of bigeye tuna caught by the fisheries of the EPO. The time series for "Fisheries 1-7" is an average of Fisheries 1 through 7, and the time series for "Fisheries 8-9" is an average of Fisheries 8 and 9. The dashed horizontal line (at about 35.5 kg) identifies the 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 35,5 kg) identifica el peso crítico.

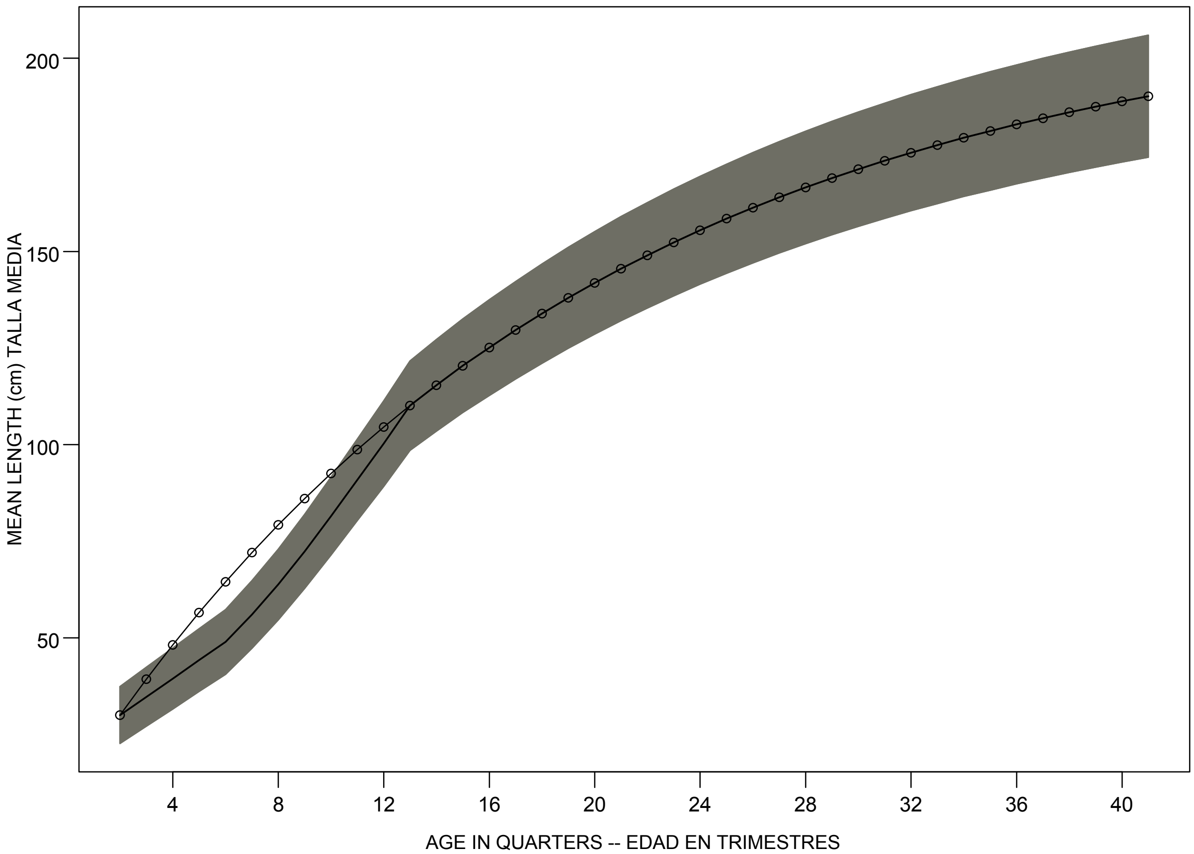


FIGURE 4.13. Estimated average lengths at age for bigeye tuna in the EPO. The filled area indicates the range of lengths estimated to be covered by two standard deviations of the length at age. The line with circles represent the growth curve from Suda and Kume (1967), which is used as a prior.

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.

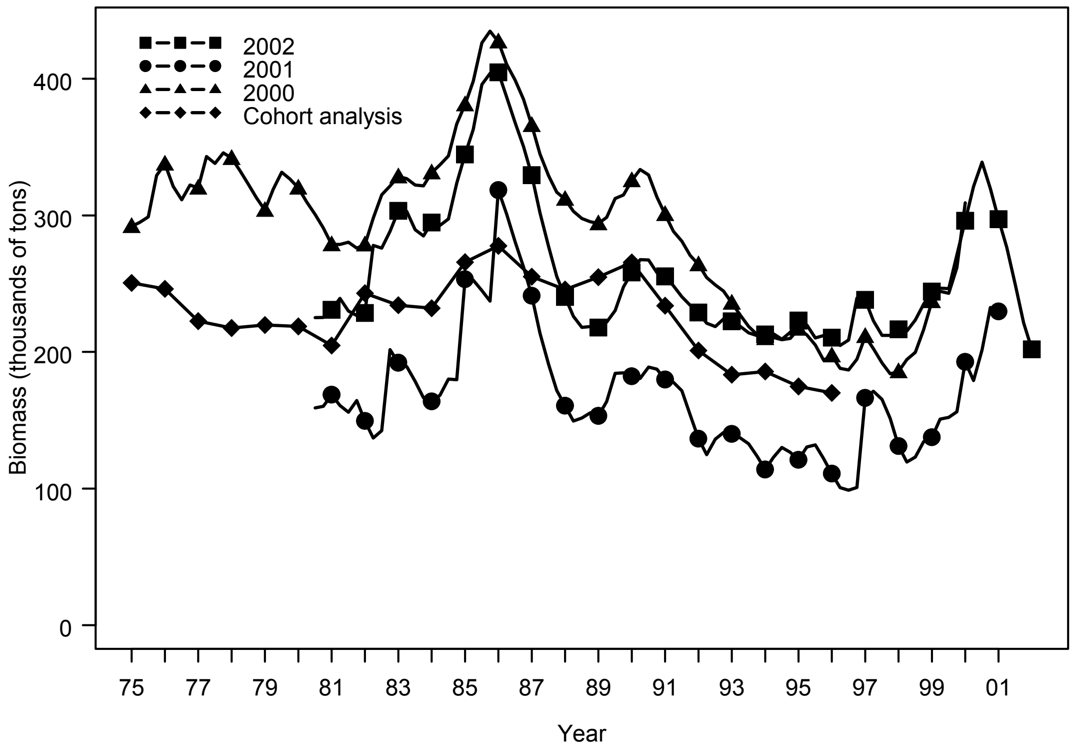


FIGURE 4.14. Comparison of biomass (ages 3 years and older) from previous assessments and the current assessment.

FIGURA 4.14. Comparación de biomasa (edad 3 años y mayores) de evaluaciones previas y la evaluación actual.

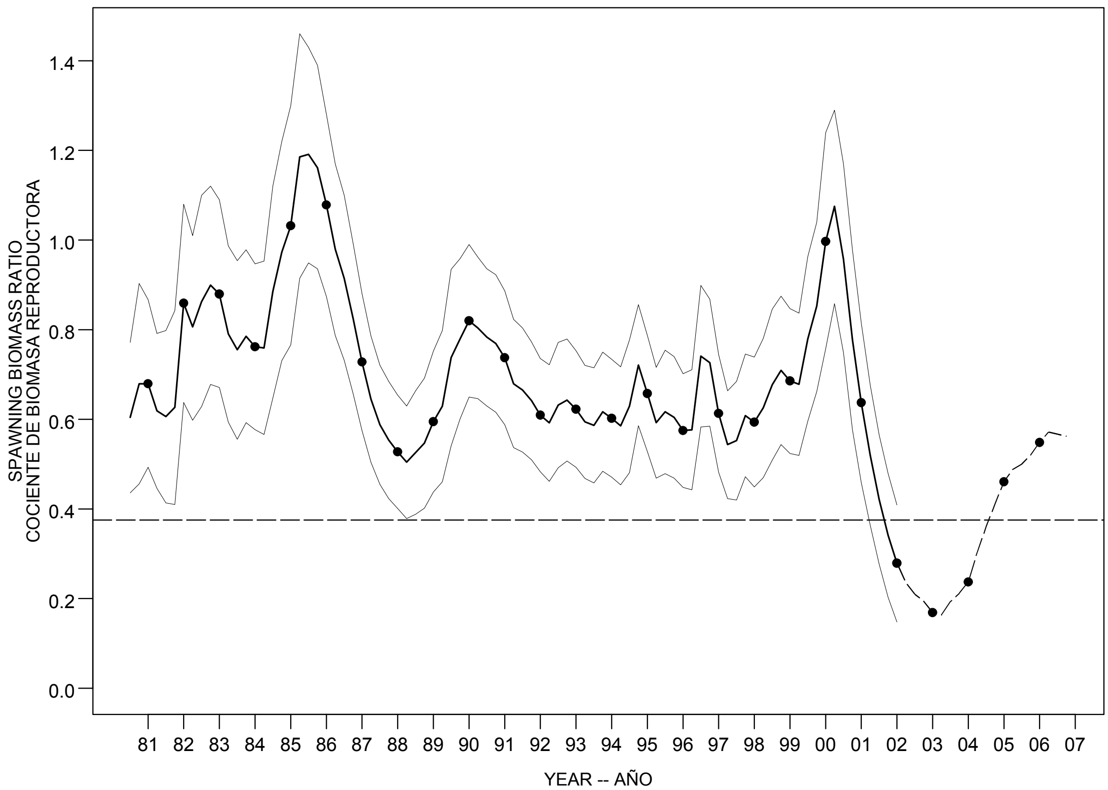


FIGURE 5.1. Estimated time series of spawning biomass ratios (SBRs) for bigeye tuna in the EPO. The dashed horizontal line (at about 0.38) identifies the SBR at AMSY. The solid lines illustrate the maximum likelihood estimates, and the dashed lines are confidence intervals (±2 standard errors) around those estimates. The dashed line continuing the SBR trend indicates the average SBR predicted to occur if average levels of fishing mortality and 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 0,38) 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).

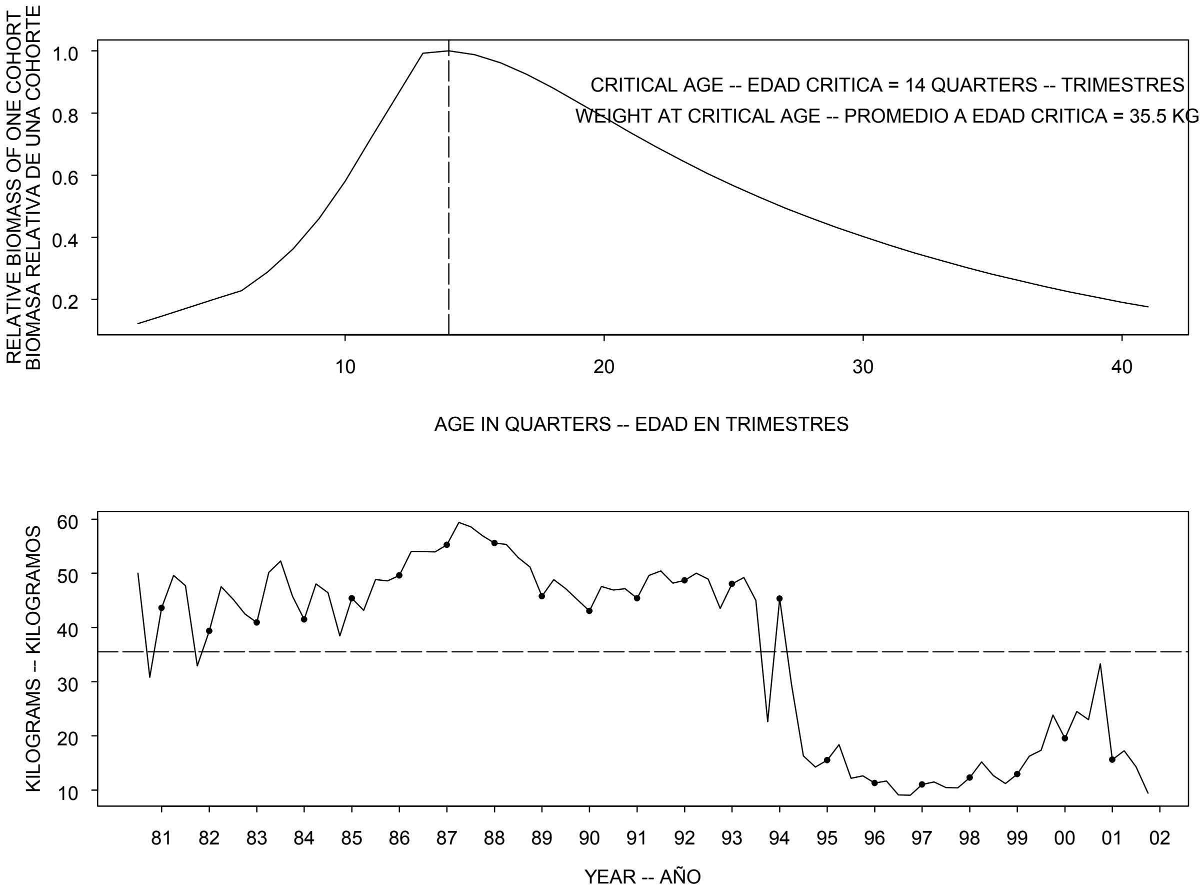


FIGURE 5.2. Combined performance of all fisheries that take bigeye tuna in the EPO at achieving the maximum yield per recruit. The upper panel illustrates the growth (in weight) of a single cohort of bigeye, and identifies the critical age and critical weight (Section 5). The critical weight is drawn 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.

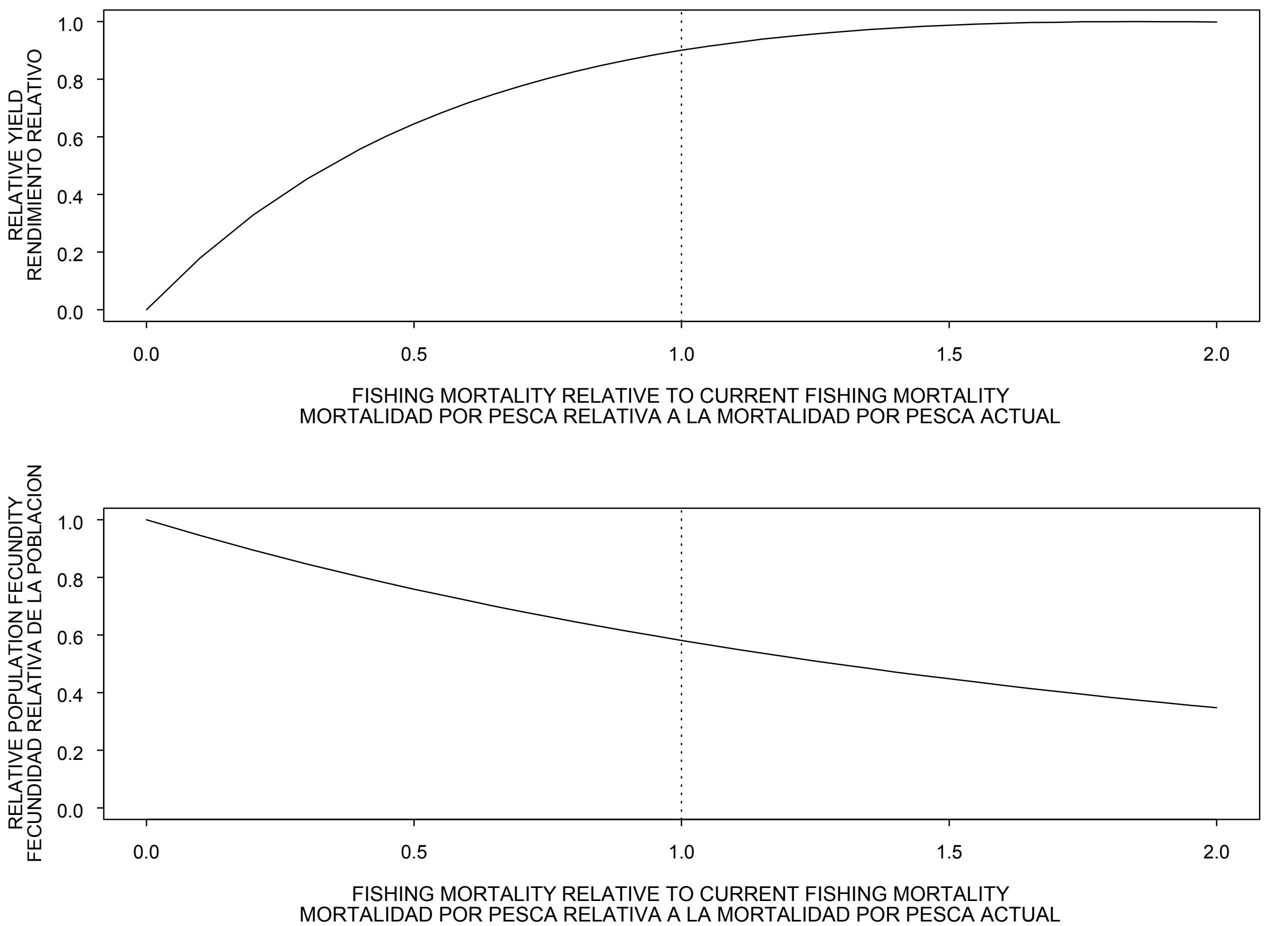


FIGURE 5.3. Predicted effects of long-term changes in fishing effort on the yield (upper panel) and spawning biomass (lower panel) of bigeye tuna under equilibrium conditions with the current age-specific selectivity pattern of all fisheries combined. The yield estimates are scaled so that the AMSY is 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.

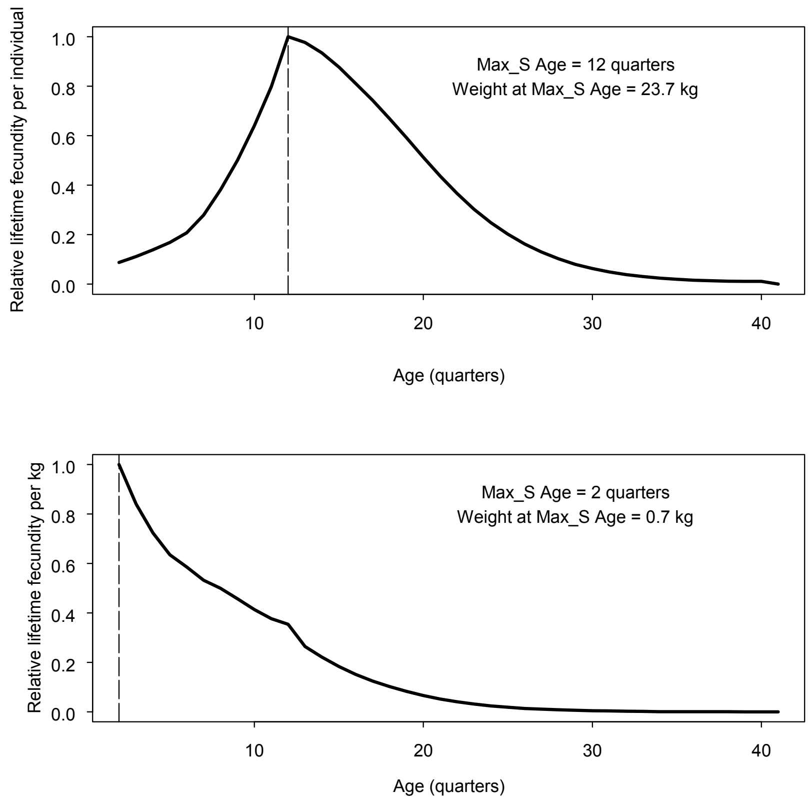


FIGURE 5.4. Marginal relative lifetime reproductive potential at age, based on individuals (upper panel) and weight (lower panel). The vertical lines represent the ages at which marginal relative lifetime reproductive potential is maximized.

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.

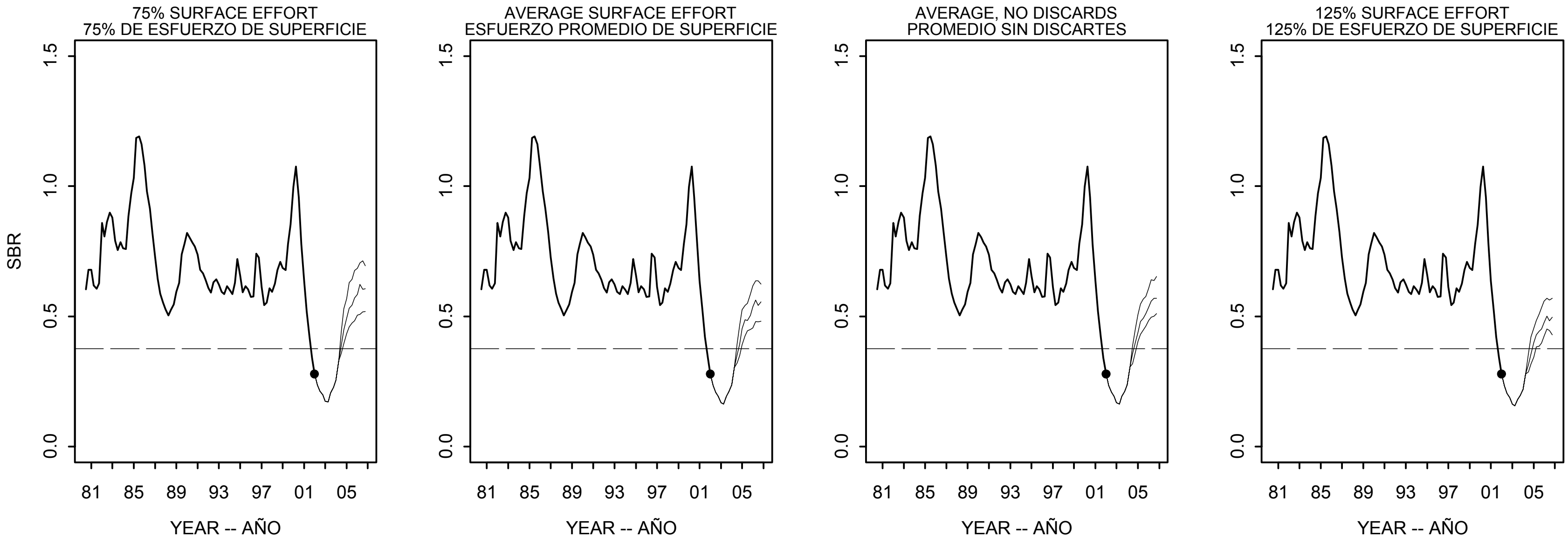


FIGURE 6.1a. Simulated SBRs during 2002-2006 for bigeye tuna in the EPO. Each panel illustrates the results of 101 simulations using the different scenarios described in Sections 6.1 and 6.2. The median estimates of the simulated SBRs are indicated by the solid lines to the right of each solid dot. The shaded areas indicate the regions bounded by the 20% and 80% quantiles of the simulated SBRs. The dashed horizontal lines indicate the SBR_{AMSY} (0.38).

FIGURA 6.1a. SBR simulados durante 2002-2006 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} (0,38).

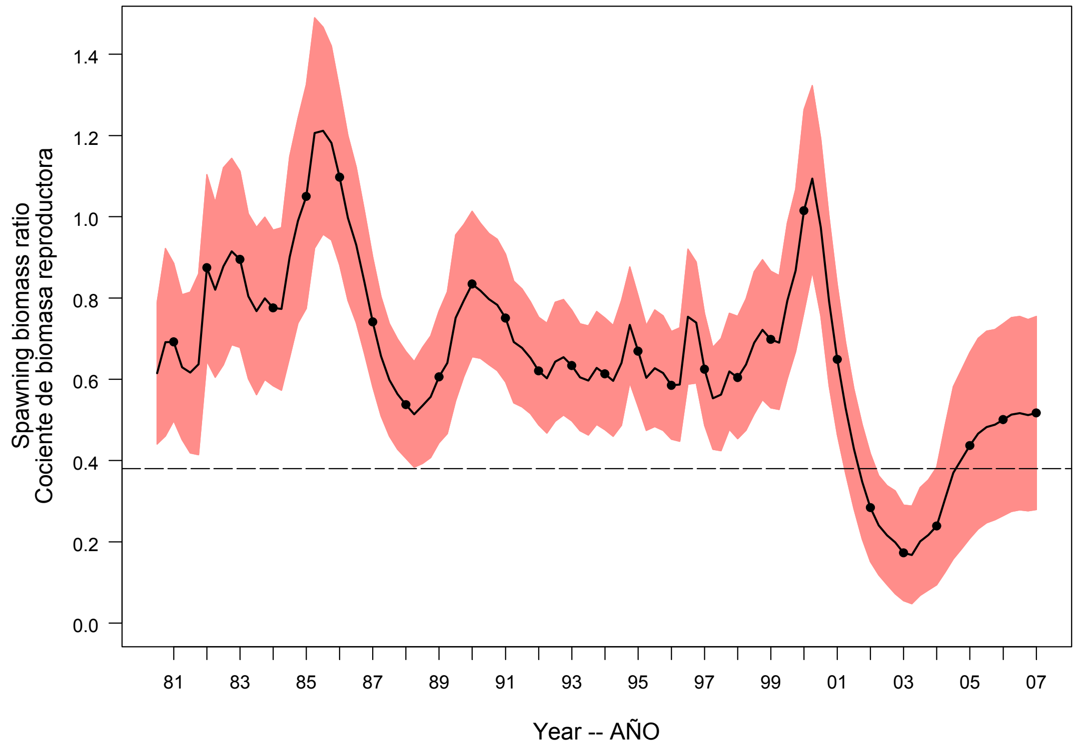


FIGURE 6.1b. SBRs, including projections for 2002-2006 under current effort levels for bigeye tuna in the EPO. These calculations include parameter estimation uncertainty and uncertainty about future recruitment. The shaded areas indicate the 95% confidence intervals. The dashed line indicates the SBR_{AMSY} (0.38).

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).

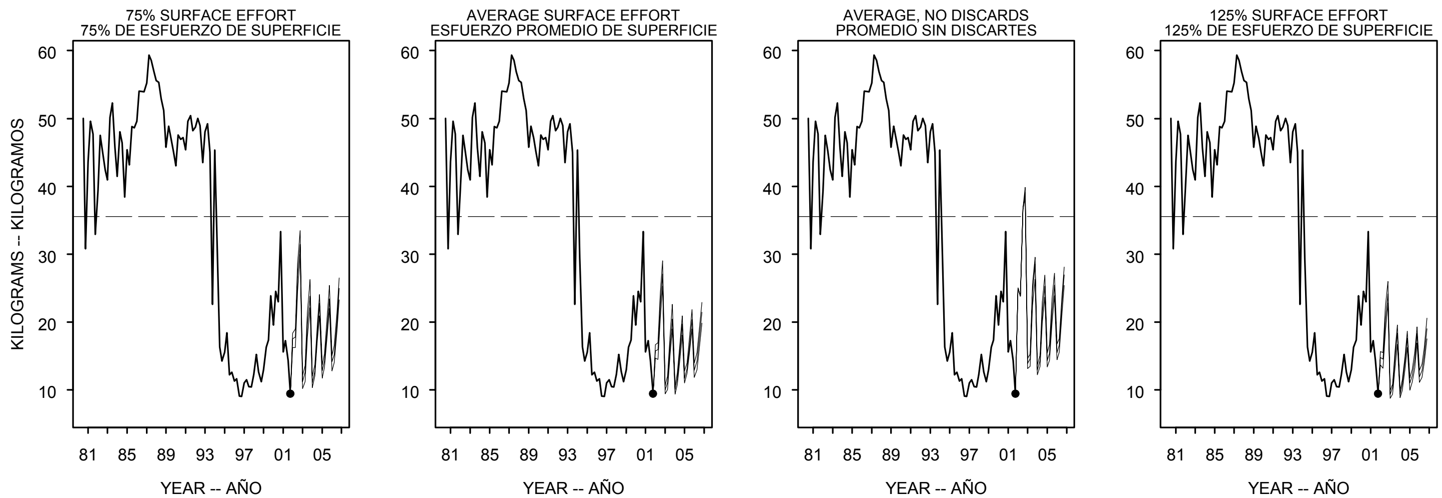


FIGURE 6.2. Simulated estimates of the average weight of bigeye tuna in the combined catch during 2002-2006. Each panel illustrates the results of 101 simulations using the different scenarios described in Sections 6.1 and 6.2. The median estimates of the simulated average weights are indicated by the 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 (39 kg).

FIGURA 6.2. Estimaciones simuladas del peso medio de atún patudo en la captura combinada durante 2002-2006. 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 (39 kg).

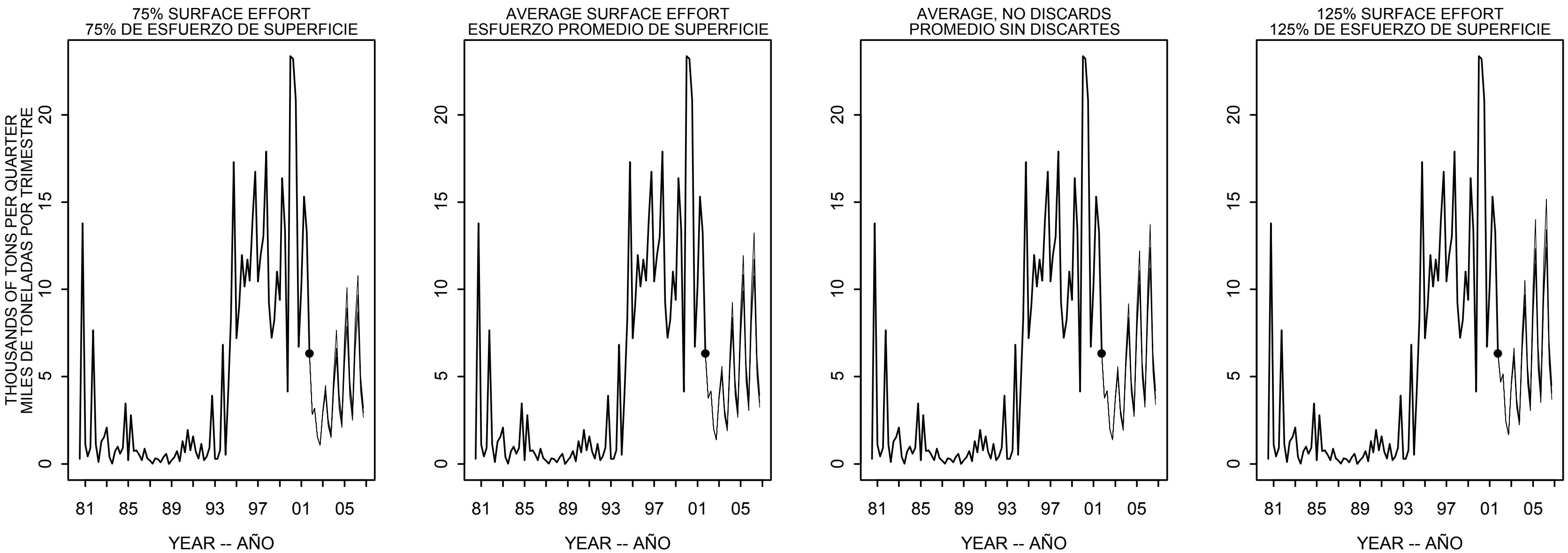


FIGURE 6.3. Simulated catches of bigeye tuna taken by the primary surface fleet (Fisheries 2-5 and 7) during 2002-2006. Each panel illustrates the results of 101 simulations using the different scenarios described in Sections 6.1 and 6.2. The median estimates of the simulated catches taken by these fisheries 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 2002-2006. 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.

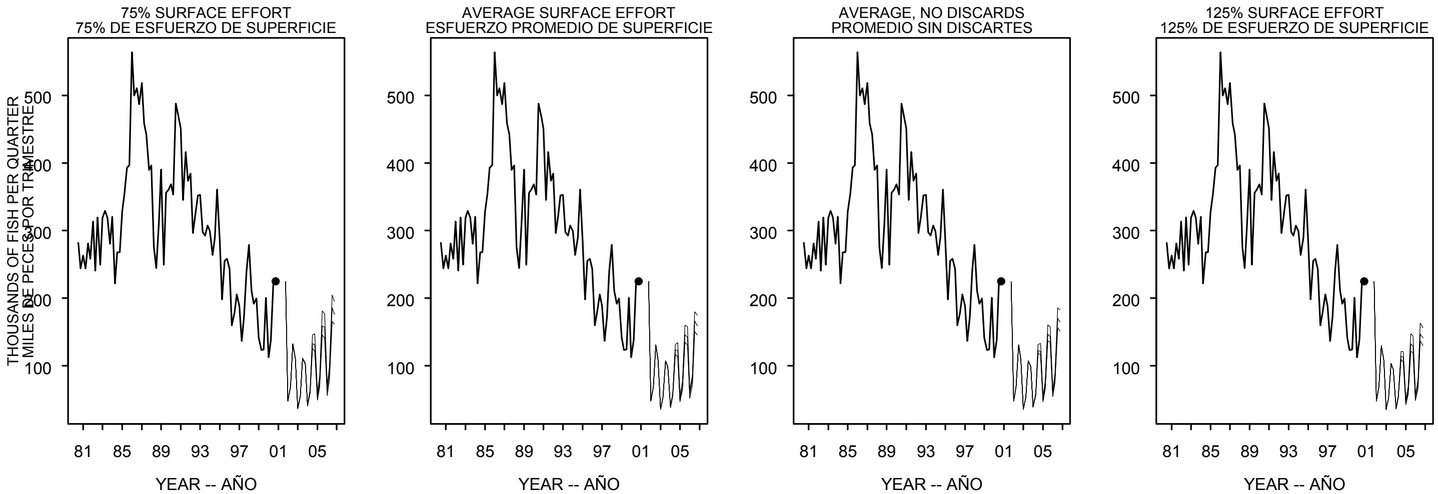


FIGURE 6.4. Simulated catches of bigeye tuna taken by the longline fleet (Fisheries 8 and 9) during 2002-2006. Each panel illustrates the results of 101 simulations using the different scenarios described in Sections 6.1 and 6.2. The median estimates of the simulated catches taken by these fisheries 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 2002-2006. 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.

TABLE 2.1. Fishery definitions used for the stock assessment of bigeye tuna in the EPO. PS = purse seine; BB = baitboat; 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	landings only–descargas solamente
2	PS	FLT	1993-2001	11-12	landings + 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 BB	UNA DOL	1980-1989	1-13	landings only–escargas solamente
7	PS BB	UNA DOL	1990-2001	1-13	landings + discards from inefficiencies in fishing process–descargas + descartes de ineficacias en el proceso de pesca
8	LL		1980-2001	N of–de 15°N	landings 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. Females less than 3 years (12 quarters) old are assumed to be immature.
TABLA 3.1. Proporciones de patudo hembra por edad e índices de fecundidad usados para definir la biomasa reproductora. Se supone que las hembras de menos de 3 años (12 trimestres) de edad son inmaduras.

Age in quarters	Proportion female	Index of fecundity
Edad en trimestres	Proporción hembra	Indice de fecundidad
12	0.3934	153.22
13	0.3810	163.59
14	0.3635	172.36
15	0.3417	179.71
16	0.3165	185.84
17	0.2888	190.93
18	0.2596	195.14
19	0.2299	198.60
20	0.2006	201.45
21	0.1725	203.78
22	0.1463	205.69
23	0.1224	207.26
24	0.1012	208.53
25	0.0827	209.58
26	0.0668	210.43
27	0.0535	211.12
28	0.0425	211.69
29	0.0335	212.15
30	0.0262	212.52
31	0.0204	212.83
32	0.0158	213.08
33	0.0122	213.28
34	0.0093	213.44
35	0.0071	213.58
36	0.0054	213.69
37	0.0041	213.78
38	0.0031	213.85
39	0.0024	213.91
40	0.0018	213.95
41	0.0013	213.99

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 2000 to 2001.
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 2000 a 2001.

Quarter	Fishery 2	Fishery 3	Fishery 4	Fishery 5	Fishery 7
Trimestre	Pesquería 2	Pesquería 3	Pesquería 4	Pesquería 5	Pesquería 7
1	-71%	-57%	0%	-80%	-38%
2	8%	-49%	19%	-41%	-33%
3	-38%	-67%	58%	-54%	223%
4	-28%	-81%	6%	17%	-89%

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
1981	20,296	353,442	301,712
1982	37,353	384,036	381,390
1983	23,211	423,858	390,513
1984	14,912	456,258	338,292
1985	13,444	512,062	458,025
1986	19,338	500,481	478,713
1987	25,256	408,821	323,159
1988	18,538	344,873	234,220
1989	16,396	353,358	264,076
1990	17,917	375,195	364,036
1991	17,095	354,454	327,348
1992	22,262	328,315	270,526
1993	23,893	324,923	276,367
1994	29,238	329,001	267,386
1995	36,910	337,433	291,804
1996	33,126	343,451	255,183
1997	54,211	348,707	272,266
1998	13,664	365,936	263,661
1999	9,543	402,169	304,332
2000	8,679	432,565	442,651
2001	14,296	331,049	282,934
2002		232,412	123,824

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	74.55
3	34.73	1.12	23	152.33	79.46
4	39.47	1.61	24	155.48	84.31
5	44.20	2.23	25	158.47	89.08
6	48.93	2.99	26	161.30	93.78
7	56.04	4.41	27	163.99	98.39
8	63.80	6.41	28	166.55	102.90
9	72.38	9.23	29	168.98	107.31
10	81.52	13.01	30	171.29	111.61
11	90.90	17.82	31	173.48	115.80
12	100.28	23.68	32	175.56	119.87
13	110.09	31.02	33	177.53	123.81
14	115.37	35.53	34	179.41	127.64
15	120.38	40.18	35	181.19	131.35
16	125.13	44.95	36	182.88	134.94
17	129.65	49.81	37	184.49	138.40
18	133.93	54.73	38	186.01	141.75
19	138.00	59.68	39	187.46	144.97
20	141.87	64.65	40	188.84	148.08
21	145.53	69.61	41	190.14	151.06

TABLE 5.1 Estimates of the AMSY and its associated quantities. 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.
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	Current catchability	Stock-recruitment relationship
	Caso base	Capturabilidad actual	Relación stock-reclutamiento
AMSY (mt)—RMSP (tm)	70,061	59,462	61,780
B_{AMSY} (mt)—B_{RMSP} (tm)	211,702	189,557	231,968
S_{AMSY}—S_{RMSP}	166,647	133,054	186,814
B_{AMSY}/B_0—B_{RMSP}/B_0	0.29	0.26	0.30
S_{AMSY}/S_0—S_{RMSP}/S_0	0.38	0.30	0.40
C_{recent}/AMSY—C_{recent}/RMSP	1.11	1.31	1.26
$B_{\mathrm{recent}}/B_{\mathrm{AMSY}}$—$B_{\mathrm{recent}}/B_{\mathrm{RMSP}}$	1.10	1.23	1.01
$S_{\mathrm{recent}}/S_{\mathrm{AMSY}}$—$S_{\mathrm{recent}}/S_{\mathrm{RMSP}}$	0.74	0.93	0.67
F multiplier—Multiplicador de F	1.85	0.99	0.97

TABLE 5.2. 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. Values in parentheses indicate the tonnage that would be discarded if small fish were removed from the catch during sorting. If sorting does not occur, the values in parentheses can be added to the upper values to obtain estimates of the AMSY. 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 the last two years.
TABLA 5.2. 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	AMSY	B_{AMSY}	S_{AMSY}	$B_{\text{AMSY}}/B_{F=0}$	$S_{\text{AMSY}}/S_{F=0}$	F multiplier
Pesquería	RMSP	B_{RMSP}	S_{RMSP}	$B_{\text{RMSP}}/B_{F=0}$	$S_{\text{RMSP}}/S_{F=0}$	Multiplicador de F
1	Not currently operating in the EPO–No opera actualmente en el OPO					
2	42,980 (724)	141,734	76,984	0.20	0.17	3.19
3	57,243 (1,515)	166,276	102,716	0.23	0.23	4.96
4	59,736 (3,492)	194,634	146,884	0.27	0.33	54.55
5	41,665 (1,881)	151,445	84,796	0.21	0.19	6.36
6	Not currently operating in the EPO–No opera actualmente en el OPO					
7	92,777	225,705	208,326	0.31	0.47	87.60
8	98,930	174,819	127,042	0.24	0.29	237.02
9	113,700	197,581	176,509	0.27	0.40	16.88

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 2006–SBR para el cuarto trimestre de 2006				
20%	0.54	0.49	0.52	0.44
50%	0.62	0.56	0.58	0.50
80%	0.71	0.64	0.66	0.57
Average weight (kg) of fish in the combined catch during 2006–Peso medio (kg) de los peces en la captura combinada durante 2006				
20%	14.2	12.9	16.1	12.0
50%	17.5	15.5	19.7	13.9
80%	23.6	20.3	26.0	17.7
Median of quarterly catches (mt) by the primary surface fleet (Fisheries 2-5 and 7) during 2006–Mediana de las capturas trimestrales (tm) por la flota primaria de superficie (Pesquerías 2-5 y 7) durante 2006				
20%	3,249	3,981	4,114	4,530
50%	5,927	7,252	7,513	8,233
80%	9,102	11,091	11,680	12,715
Median of quarterly catches, in thousands of fish, by the longline fleet (Fisheries 8 and 9) during 2006–Mediana de las capturas trimestrales, en miles de peces, por la flota palangrera (Pesquerías 8 y 9) durante 2006				
20%	71	64	66	57
50%	135	120	120	103
80%	187	169	174	151

APPENDIX A: STEEPNESS SENSITIVITY ANALYSIS
ANEXO A: ANALISIS DE SENSIBILIDAD A LA INCLINACION

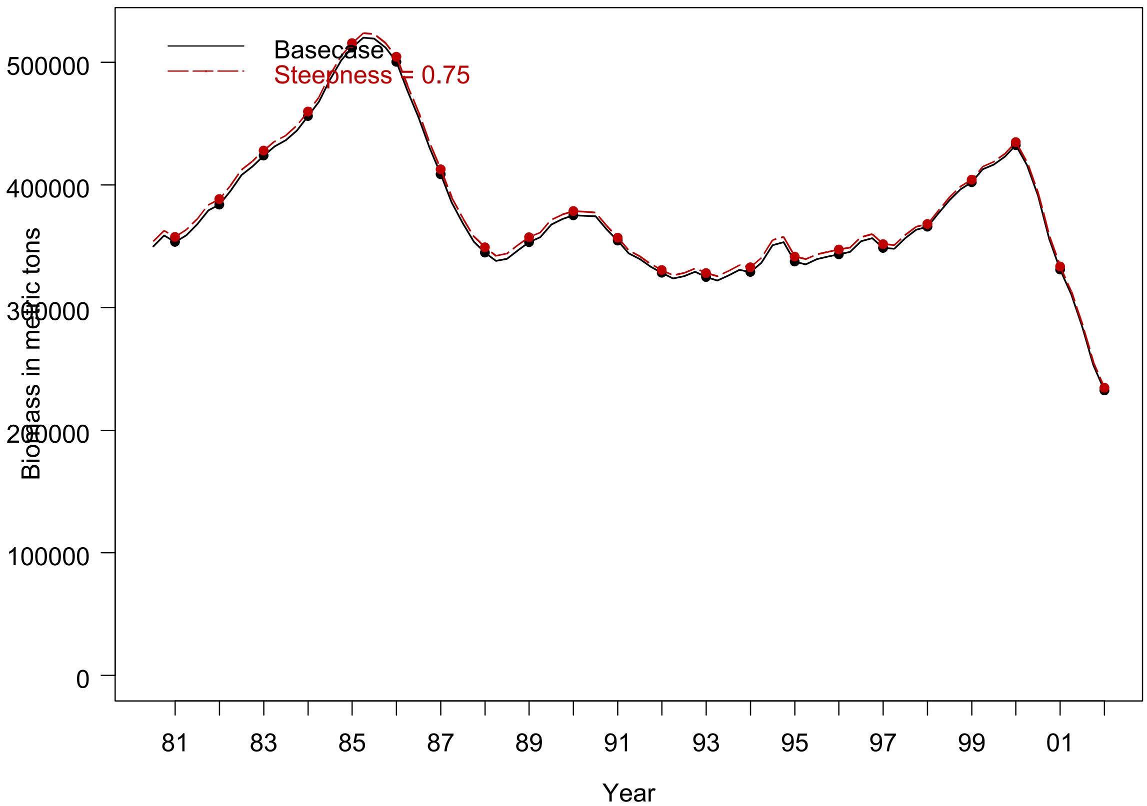


FIGURE A.1. Comparison of estimates of biomass from the analysis without a stock recruitment relationship (base case) and with a stock recruitment relationship (steepness = 0.75).

FIGURA A.1. Comparación de las estimaciones de biomasa del análisis sin relación de reclutamiento de stock (caso base) y con (inclinación = 0,75).

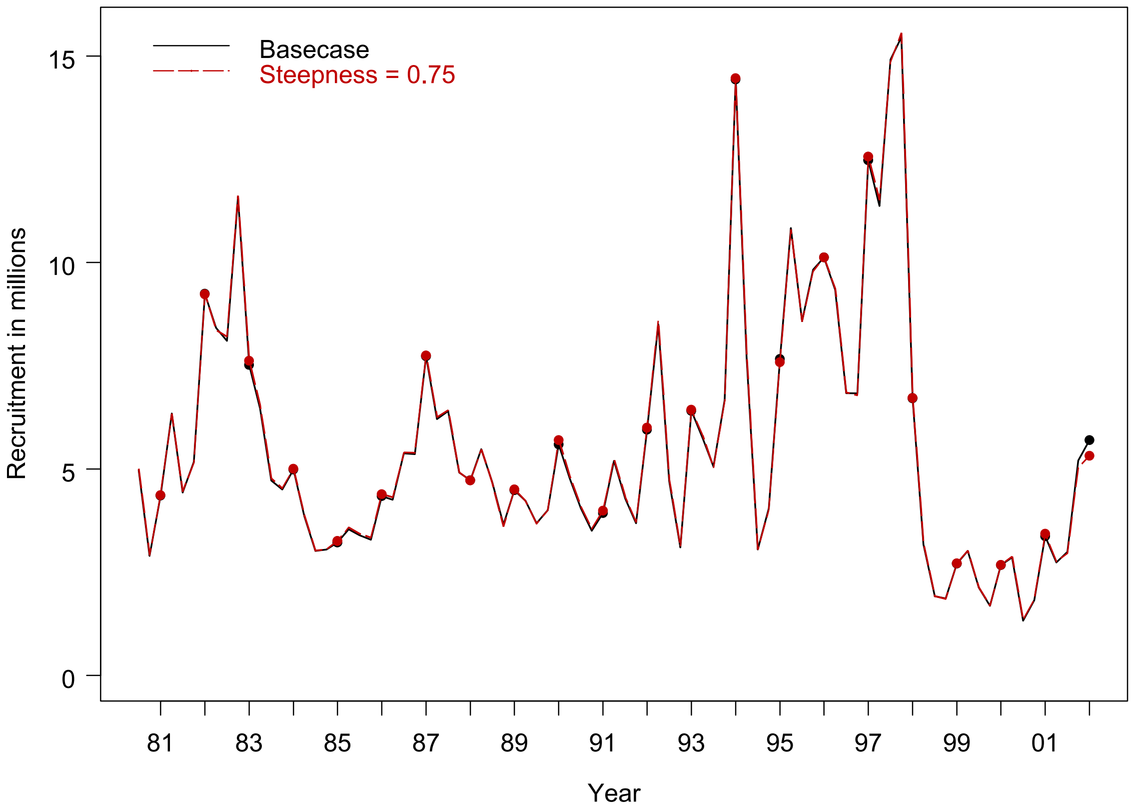


FIGURE A.2. Comparison of estimates of recruitment from the analysis without a stock recruitment relationship (base case) and with a stock recruitment relationship (steepness = 0.75).

FIGURA A.2. Comparación de las estimaciones de reclutamiento del análisis sin relación de reclutamiento de stock (caso base) y con (inclinación = 0,75).

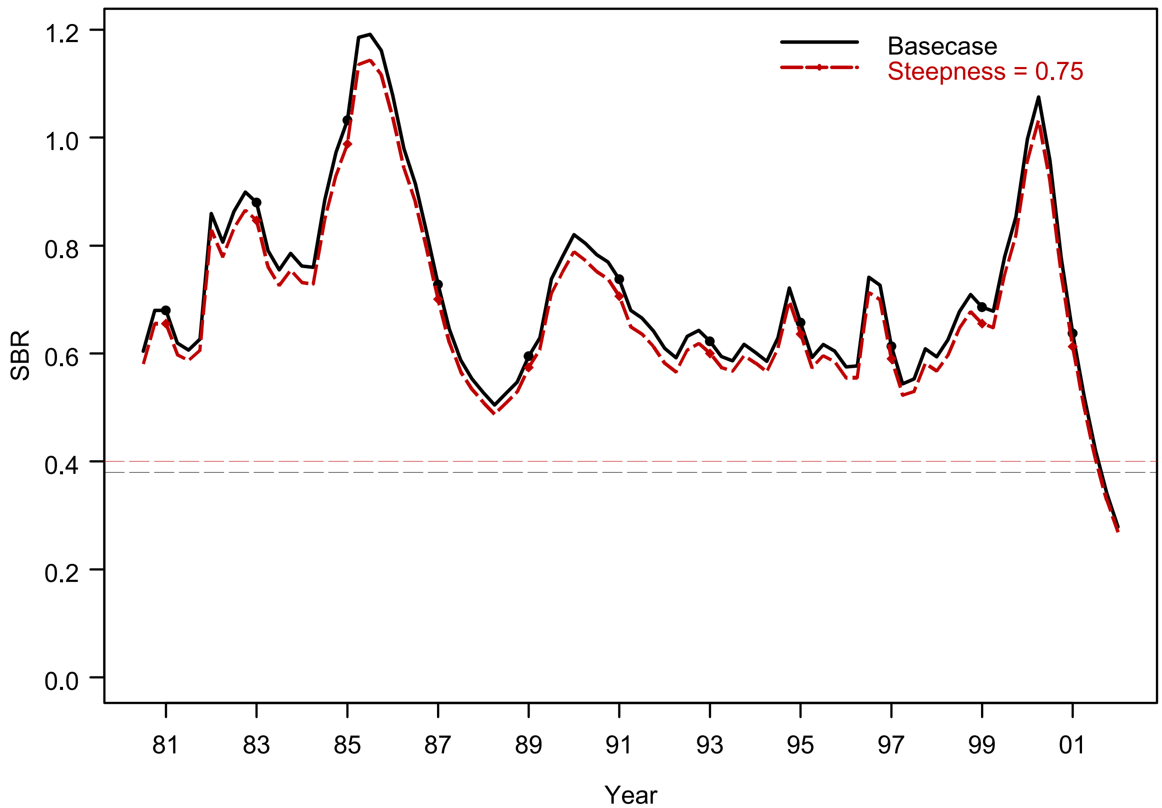


FIGURE A.3. Comparison of estimates of the spawning biomass ratio (SBR) from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). The horizontal lines represent the SBR associated with AMSY.

FIGURA A.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.

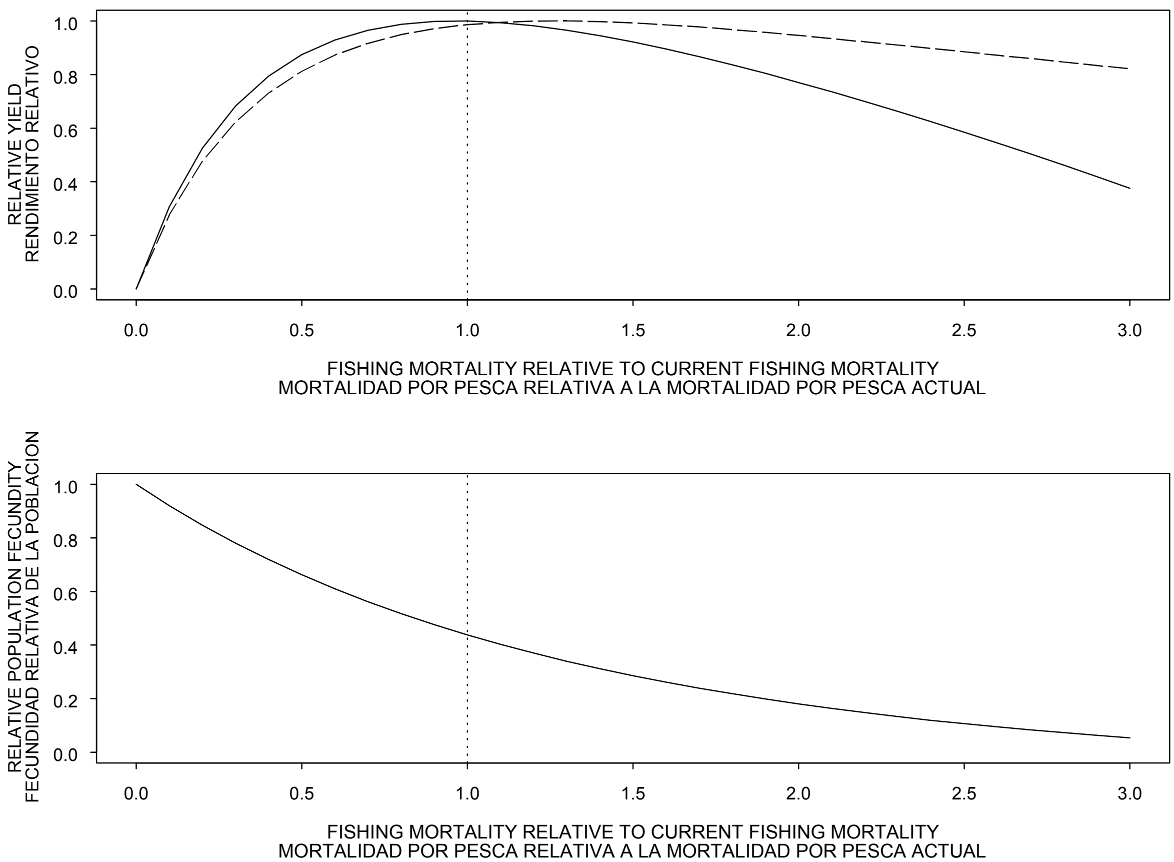


FIGURE A.4. Comparison of the relative yield (top panel solid line) with the relative yield per recruit (top panel, dashed line) when the stock assessment model has a stock recruitment relationship (steepness = 0.75).

FIGURA A4. 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 recluamiento de stock (inclinación = 0.75).

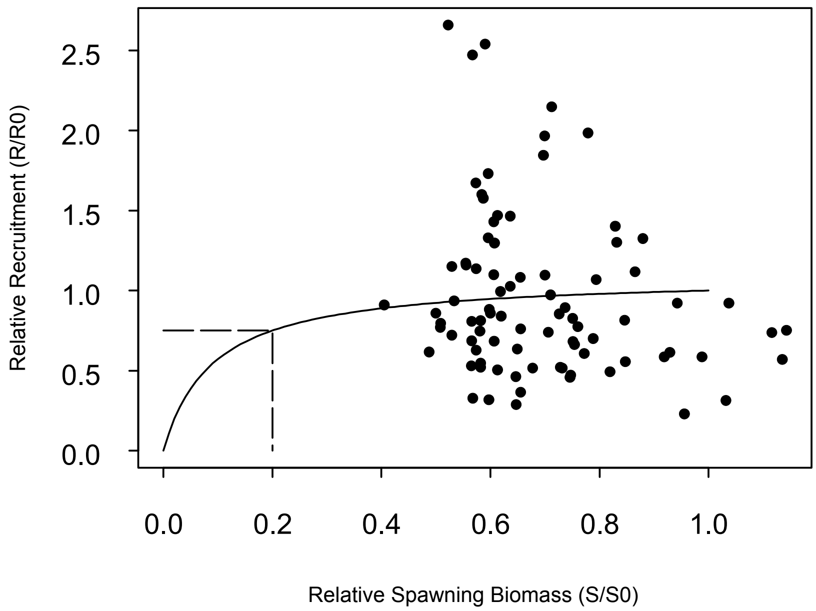


FIGURE A.5. Recruitment plotted against spawning biomass when the analysis has a stock-recruitment relationship (steepness = 0.75).

FIGURA A.5. Reclutamiento graficado contra biomasa reproductora cuando el análisis tiene una relación de reclutamiento de stock (inclinación = 0,75).

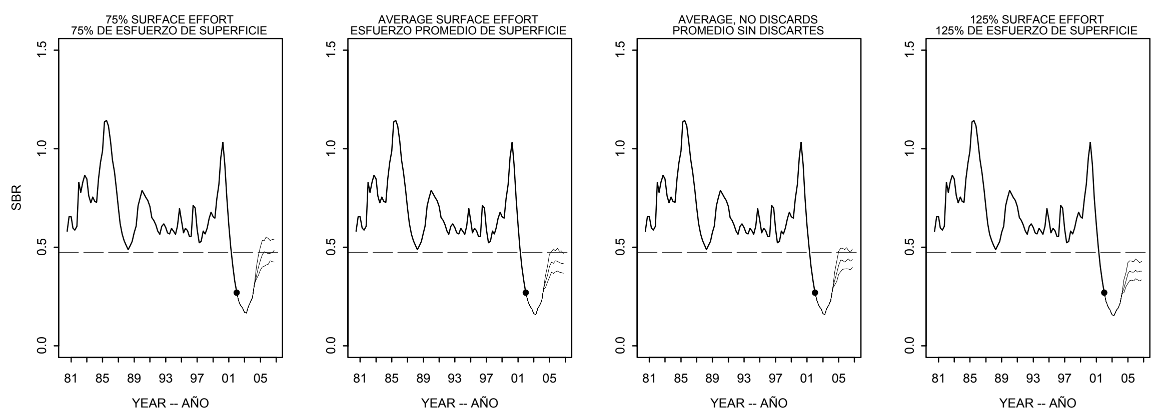


FIGURE A.6 Simulated SBRs during 2002-2006 for bigeye tuna in the EPO. Each panel illustrates the results of 101 simulations using the different scenarios described in Sections 6.1 and 6.2. The median estimates of the simulated SBRs are indicated by the solid lines to the right of each solid dot. The shaded areas indicate the regions bounded by the 20% and 80% quantiles of the simulated SBRs. The dashed horizontal lines indicate the SBR_{AMSY} (0.40).

FIGURA A.6 SBR simulados durante 2002-2006 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} (0,40).

APPENDIX B: SPC KOREAN CATCH SENSITIVITY ANALYSIS
ANEXO B: ANALISIS DE SENSIBILIDAD A LAS CAPTURAS COREANAS DE SPC

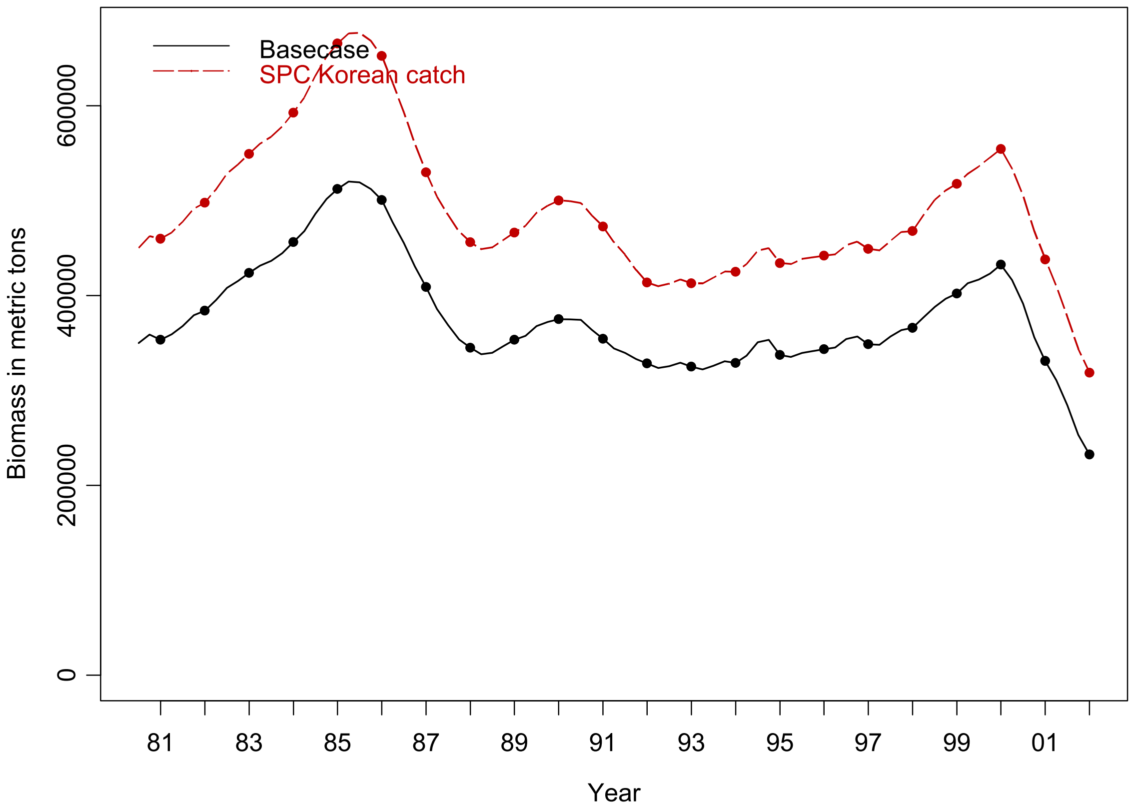


FIGURE B.1. Comparison of estimates of biomass from the base case and with the SPC-estimated Korean longline catch.

FIGURA B.1. Comparación de las estimaciones de biomasa del caso base y con la captura coreana estimada por SPC.

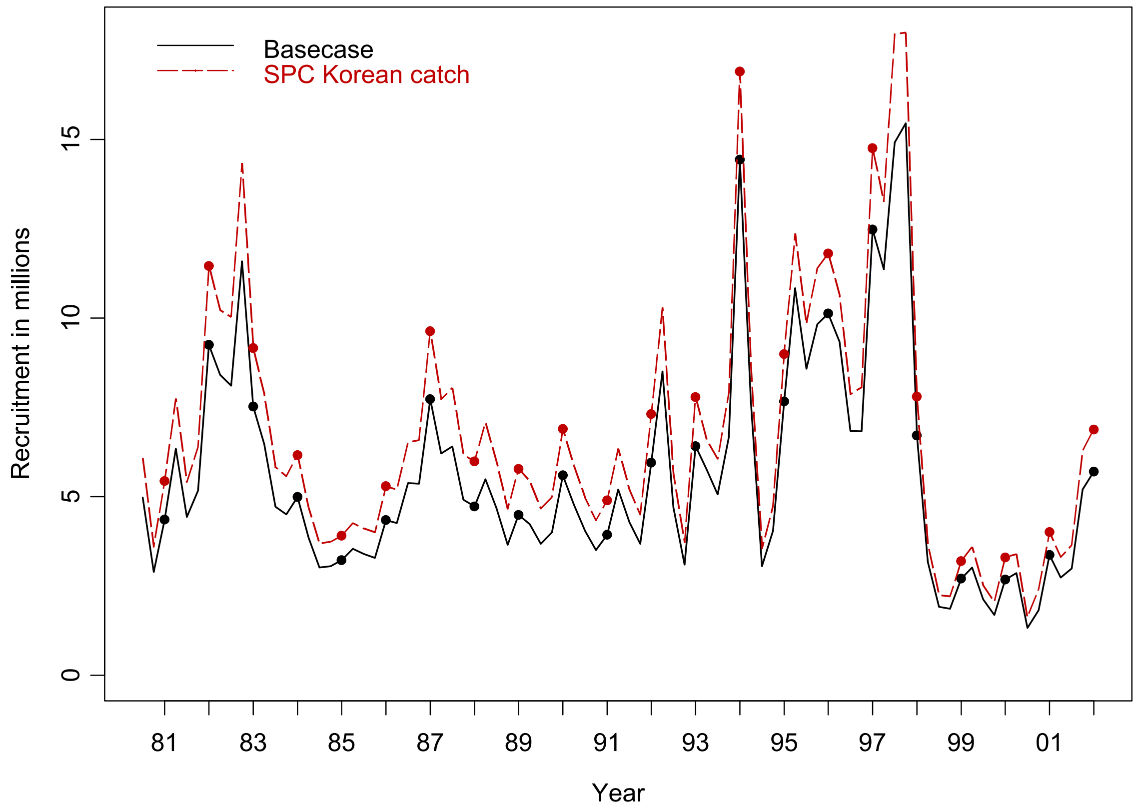


FIGURE B.2. Comparison of estimates of recruitment from the base case and with the SPC-estimated Korean longline catch.

FIGURA B.2. Comparación de las estimaciones de reclutamiento del caso base y con la captura coreana estimada por SPC.

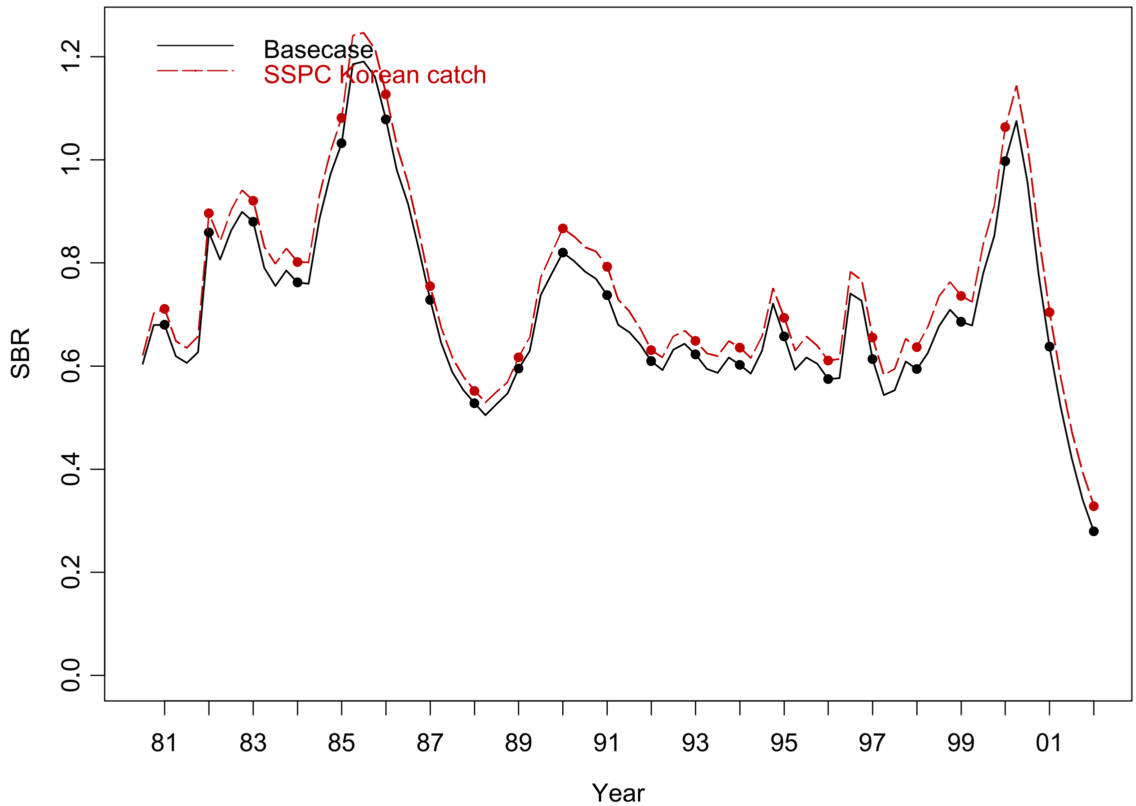


FIGURE B.3. Comparison of estimates of the spawning biomass ratio (SBR) from the base case and with the SPC-estimated Korean longline catch.

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

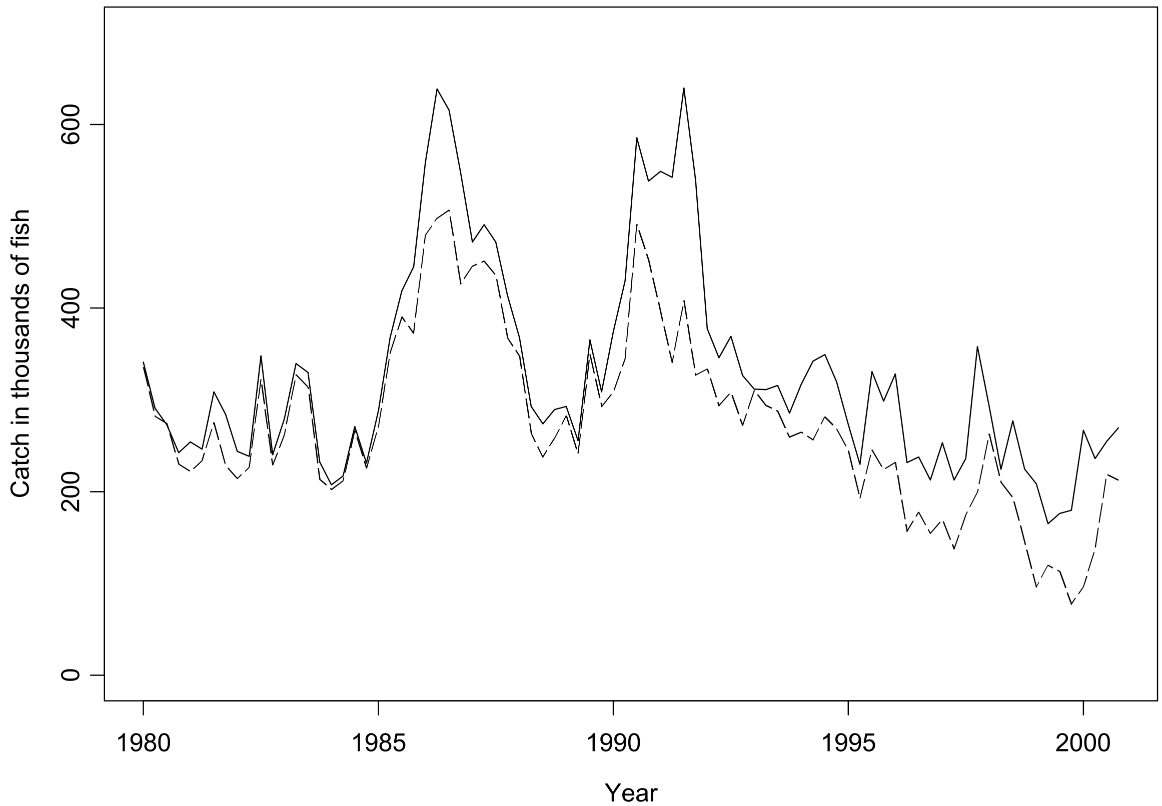


FIGURE B.4. Total longline catch used in the basecase (dashed line) and the sensitivity analysis based on the SPC estimates of Korean catch (solid line).

FIGURA B.4. 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).

APPENDIX C: ANALYSIS OF THE SENSITIVITY OF YIELD AND PROJECTIONS TO THE METHOD USED TO CALCULATE FISHING MORTALITY RATES
ANEXO C: ANALISIS DE LA SENSIBILIDAD DEL RENDIMIENTO Y LAS PROYECCIONES AL METODO USADO PARA CALCULAR LAS TASAS DE MORTALIDAD POR PESCA

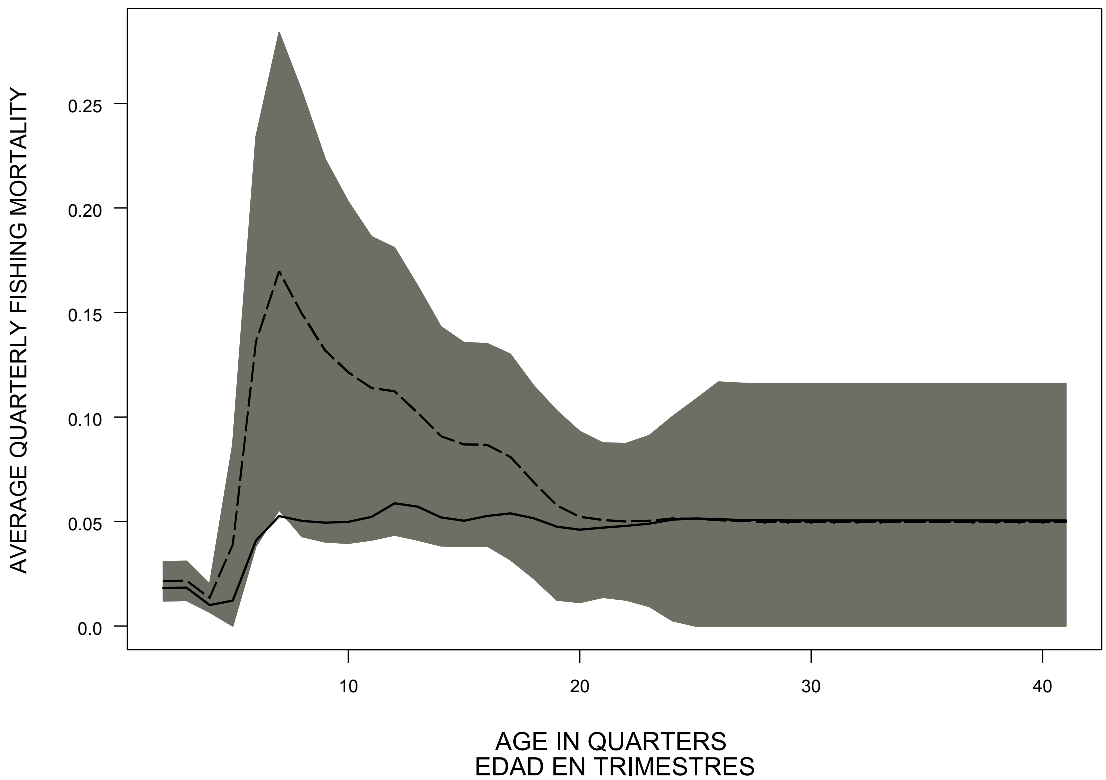


FIGURE C.1. Average quarterly age-specific fishing mortality used in the yield calculations and projections for the basecase (solid line) and sensitivity analysis (dashed line). The basecase is based on average catchability over the whole modeling time period and the sensitivity is based on average catchability over the last two years. The shaded area represents the 95% confidence intervals for the estimated average quarterly age-specific fishing mortality used in the sensitivity analysis.

FIGURA C.1. Mortalidad por pesca trimestral media por edad usada en los cálculos y proyecciones del rendimiento para el caso base (línea sólida) y el análisis de sensibilidad (línea de trazos). El caso base se basa en la capturabilidad media durante todo el período del modelo, y la sensibilidad en la capturabilidad media en los dos últimos años. La zona sombreada representa los intervalos de confianza de 95% de la mortalidad por pesca trimestral media por edad estimada usada en el análisis de sensibilidad.

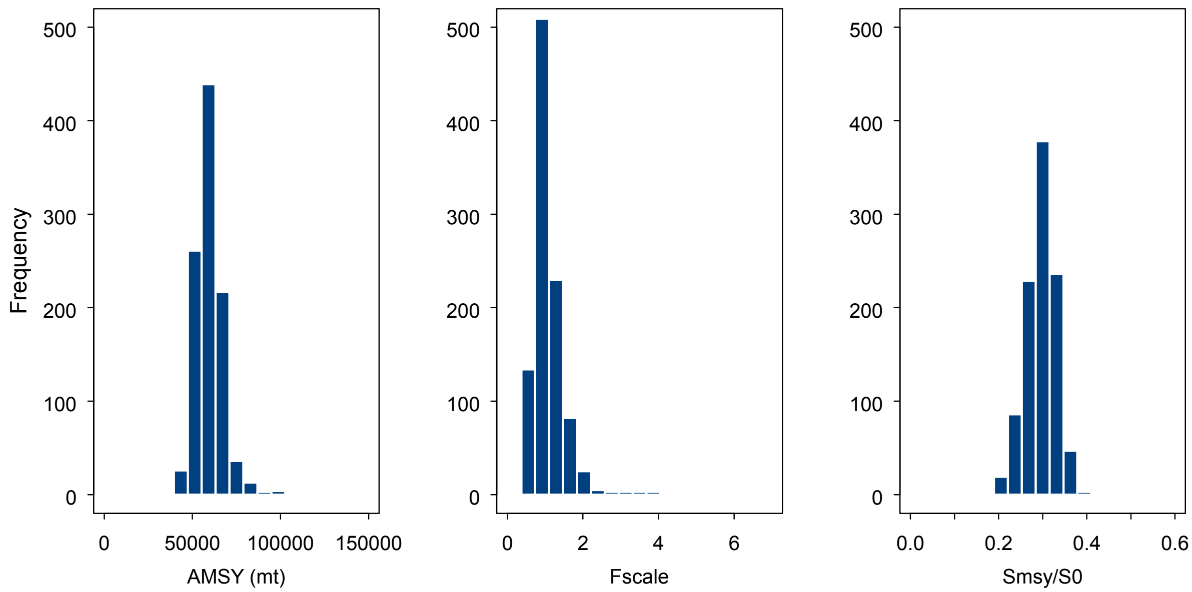


FIGURE C.2. Frequency distributions of AMSY, the proportion of current effort that would produce AMSY, and the SBR that would produce AMSY. These values are calculated using the uncertainty in the estimates of fishing mortality rates averaged over the last two years of the modeling time period.

FIGURA C.2. Distribuciones de frecuencia de RMSP, la proporción del esfuerzo actual que produciría el RMSP, y el SBR que produciría el RMSP. Se calcularon estos valores usando la incertidumbre en las estimaciones de tasas de mortalidad por pesca promediadas para los últimos dos años del período del modelo.

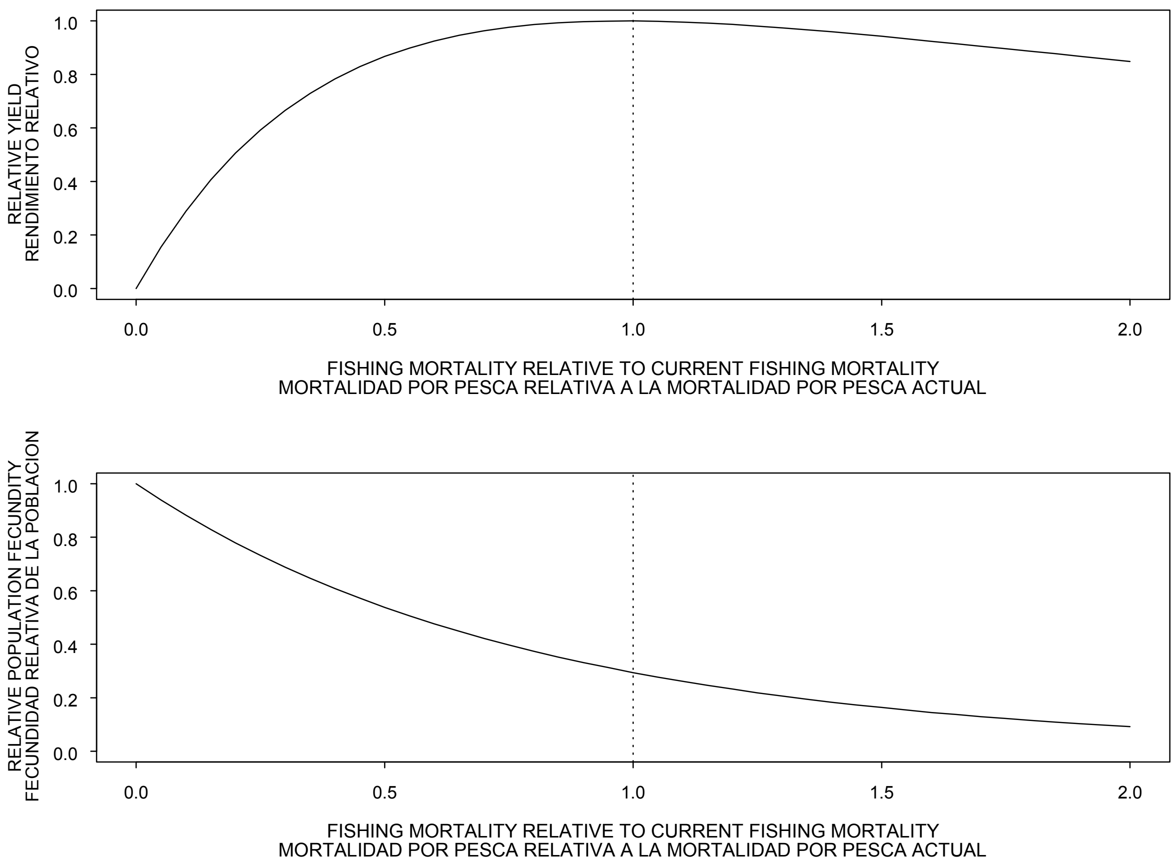


FIGURE C.3. Predicted effects of long-term changes in fishing effort on the yield (upper panel) and spawning biomass (lower panel) of bigeye tuna under equilibrium conditions with the current age-specific selectivity pattern of all fisheries combined. The yield estimates are scaled so that the AMSY is at 1.0, and the spawning biomass estimates so that the spawning biomass is equal to 1.0 in the absence of exploitation.

FIGURA C.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.

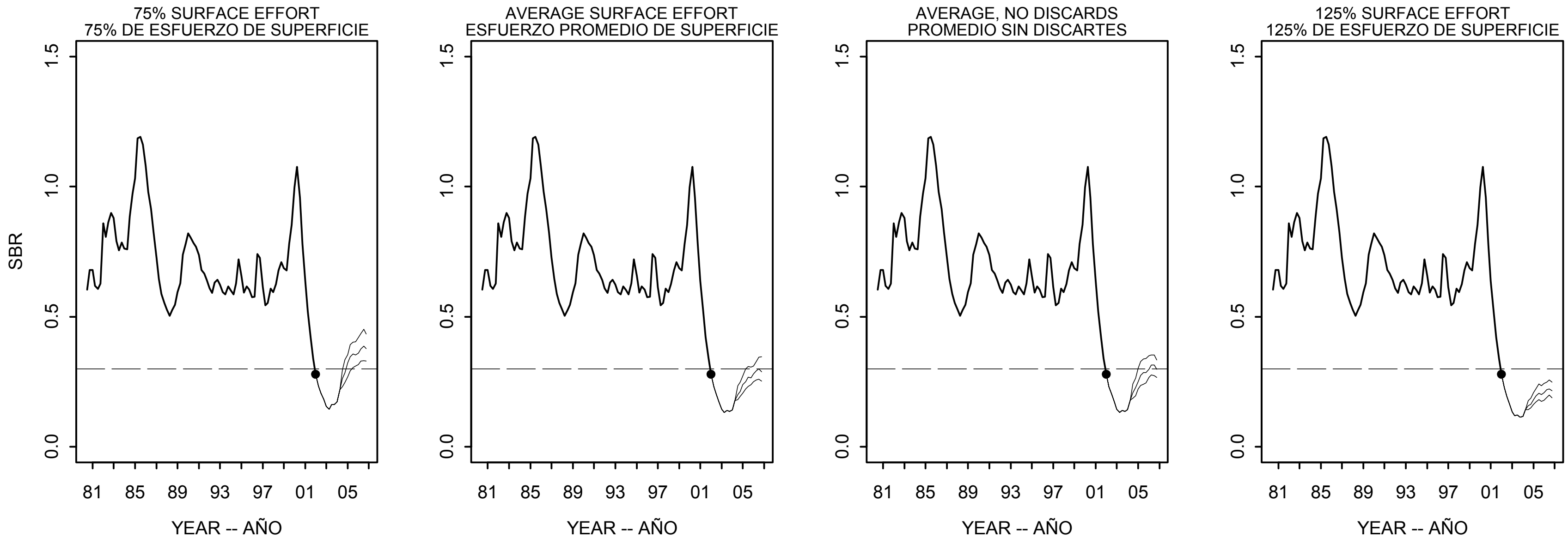


FIGURE C.4. Simulated SBRs during 2002-2006 for bigeye tuna in the EPO. Each panel illustrates the results of 101 simulations using the different scenarios described in Sections 6.1 and 6.2. The median estimates of the simulated SBRs are indicated by the solid lines to the right of each solid dot. The shaded areas indicate the regions bounded by the 20% and 80% quantiles of the simulated SBRs. The dashed horizontal lines indicate the SBR_{AMSY} (0.30).

FIGURA C.4. SBR simulados durante 2002-2006 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} (0,30).

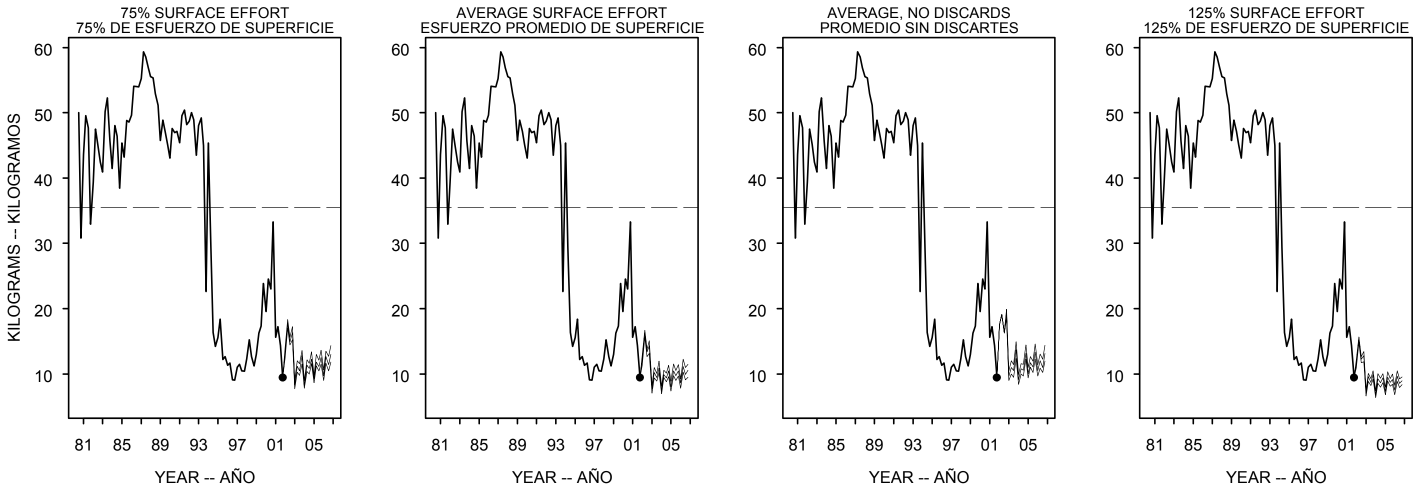


FIGURE C.5. Simulated estimates of the average weight of bigeye tuna in the combined catch during 2002-2006. Each panel illustrates the results of 101 simulations using the different scenarios described in Sections 6.1 and 6.2. The median estimates of the simulated average weights are indicated by the 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 (39 kg).

FIGURA C.5. Estimaciones simuladas del peso medio de atún patudo en la captura combinada durante 2002-2006. 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 (39 kg).

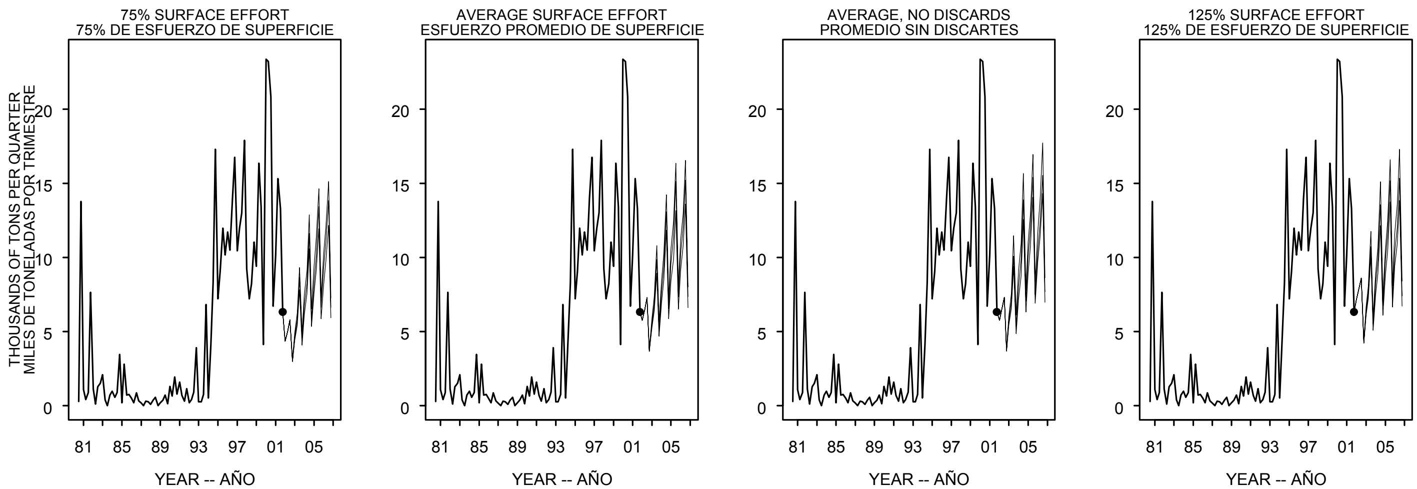


FIGURE C.6. Simulated catches of bigeye tuna taken by the primary surface fleet (Fisheries 2-5 and 7) during 2002-2006. Each panel illustrates the results of 101 simulations using the different scenarios described in Sections 6.1 and 6.2. The median estimates of the simulated catches taken by these fisheries 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 C.6. Capturas simuladas de atún patudo logradas por la flota primaria de superficie (Pesquerías 2-5 y 7) durante 2002-2006. 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.

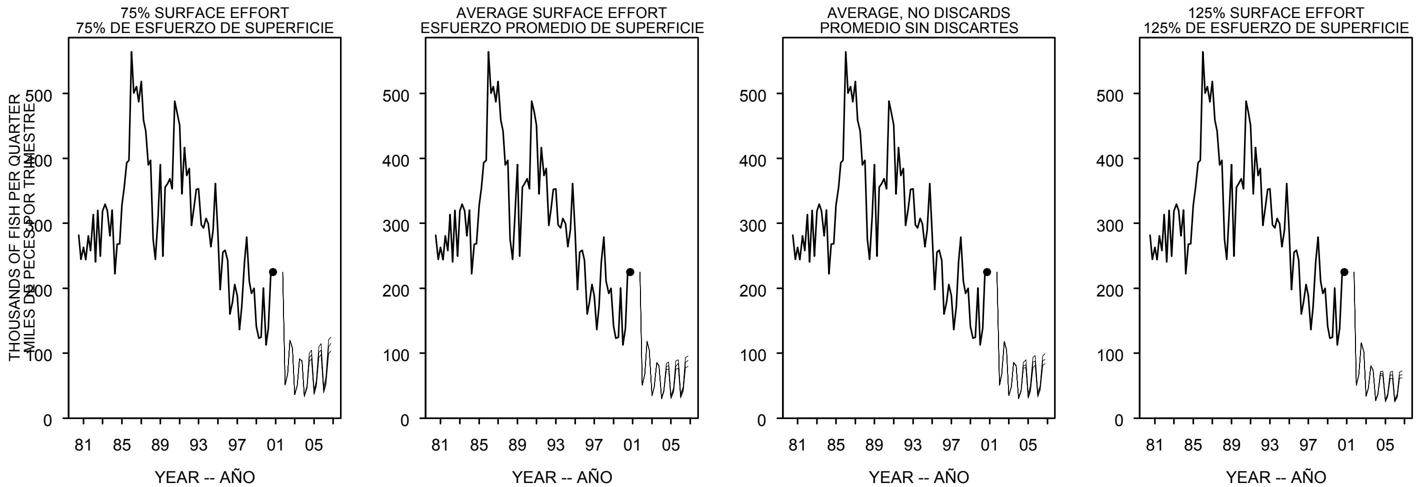


FIGURE C.7. Simulated catches of bigeye tuna taken by the longline fleet (Fisheries 8 and 9) during 2002-2006. Each panel illustrates the results of 101 simulations using the different scenarios described in Sections 6.1 and 6.2. The median estimates of the simulated catches taken by these fisheries 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 C.7. Capturas simuladas de atún patudo logradas por la flota palangrera (Pesquerías 8 y 9) durante 2002-2006. 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.

TABLE C.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 C.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 2006–SBR para el cuarto trimestre de 2006				
20%	0.33	0.25	0.26	0.19
50%	0.37	0.28	0.30	0.21
80%	0.42	0.32	0.34	0.25
Average weight (kg) of fish in the combined catch during 2006–Peso medio (kg) de los peces en la captura combinada durante 2006				
20%	10.1	8.8	10.3	7.8
50%	11.7	10.0	11.6	8.8
80%	13.1	11.2	13.1	9.8
Median of quarterly catches (mt) by the primary surface fleet (Fisheries 2-5 and 7) during 2006–Mediana de las capturas trimestrales (tm) por la flota primaria de superficie (Pesquerías 2-5 y 7) durante 2006				
20%	7,152	7,835	8,297	8,143
50%	9,903	10,722	11,455	11,213
80%	12,716	13,759	14,720	14,360
Median of quarterly catches, in thousands of fish, by the longline fleet (Fisheries 8 and 9) during 2006–Mediana de las capturas trimestrales, en miles de peces, por la flota palangrera (Pesquerías 8 y 9) durante 2006				
20%	46	36	38	29
50%	79	62	63	49
80%	113	87	91	68

APPENDIX D: 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.

ANEXO D: RESULTADOS ADICIONALES DE LA EVALUACION DEL CASO BASE

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

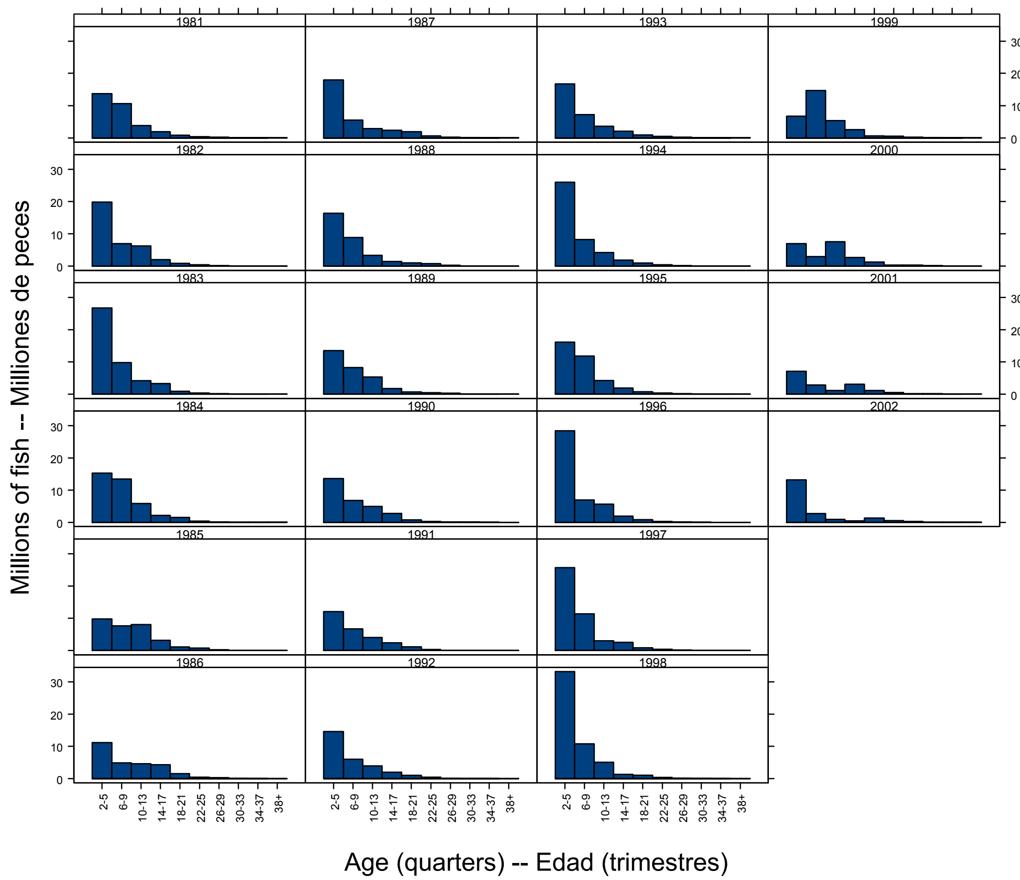


FIGURE D.1. Numbers of bigeye tuna present in the EPO on 1 January of each year.

FIGURA D.1. Número de atunes aleta amarilla presentes en el OPO el 1 de enero de cada año.

TABLE D.1. Average annual fishing mortality rates on bigeye tuna in the EPO.
TABLA D.1. Tasas anuales medias de mortalidad por pesca para el atún patudo en el OPO.

Year	Age (quarters)– Edad (trimestres)									
Año	2-5	6-9	10-13	14-17	18-21	22-25	26-29	30-33	34-37	38-41
1981	0.0057	0.0487	0.1577	0.2115	0.2760	0.3376	0.3606	0.3605	0.3606	0.3606
1982	0.0025	0.0285	0.1250	0.1778	0.2436	0.2905	0.3076	0.3076	0.3076	0.3077
1983	0.0015	0.0225	0.1368	0.1903	0.2781	0.3297	0.3521	0.3519	0.3519	0.3519
1984	0.0029	0.0250	0.1043	0.1548	0.2077	0.2432	0.2546	0.2544	0.2544	0.2544
1985	0.0022	0.0244	0.1175	0.1615	0.2387	0.2916	0.3093	0.3094	0.3095	0.3095
1986	0.0013	0.0297	0.1727	0.2507	0.3572	0.4632	0.4911	0.4911	0.4911	0.4911
1987	0.0008	0.0253	0.1909	0.2858	0.4205	0.5308	0.5741	0.5740	0.5740	0.5740
1988	0.0010	0.0203	0.1495	0.2314	0.3353	0.4220	0.4547	0.4540	0.4538	0.4537
1989	0.0014	0.0281	0.1484	0.2246	0.3244	0.3963	0.4206	0.4204	0.4204	0.4204
1990	0.0032	0.0388	0.1949	0.2695	0.3989	0.4973	0.5209	0.5212	0.5215	0.5216
1991	0.0023	0.0299	0.1943	0.2893	0.4138	0.5282	0.5600	0.5595	0.5595	0.5594
1992	0.0037	0.0359	0.1690	0.2645	0.3906	0.4581	0.4865	0.4860	0.4859	0.4859
1993	0.0138	0.0462	0.1804	0.2558	0.3772	0.4564	0.4809	0.4804	0.4803	0.4803
1994	0.0579	0.1583	0.2466	0.2932	0.3443	0.4182	0.4347	0.4344	0.4343	0.4343
1995	0.1282	0.2357	0.2659	0.2870	0.3298	0.3859	0.3751	0.3743	0.3743	0.3743
1996	0.2038	0.3310	0.2996	0.2777	0.2613	0.2941	0.2927	0.2918	0.2917	0.2916
1997	0.1495	0.3066	0.3087	0.2892	0.2556	0.2631	0.2722	0.2720	0.2721	0.2721
1998	0.1231	0.2134	0.2200	0.2328	0.2674	0.3324	0.3252	0.3236	0.3234	0.3233
1999	0.1403	0.1974	0.2050	0.1844	0.1710	0.1698	0.1412	0.1401	0.1400	0.1400
2000	0.1906	0.4536	0.3950	0.3121	0.2222	0.1928	0.1856	0.1855	0.1857	0.1858
2001	0.2431	0.6301	0.4412	0.3103	0.2170	0.1945	0.1890	0.1892	0.1895	0.1896