INTER-AMERICAN TROPICAL TUNA COMMISSION
COMISIÓN INTERAMERICANA DEL ATÚN TROPICAL

WORKING GROUP ON STOCK ASSESSMENTS

5TH MEETING

LA JOLLA, CALIFORNIA (USA)
11-13 MAY 2004

DOCUMENT SAR-5-05 SKJ

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

Mark N. Maunder and Shelton J. Harley

CONTENTS

1. EXECUTIVE SUMMARY

An age-structured, catch-at-length analysis (A-SCALA) is used to assess skipjack tuna (*Katsuwonus pelamis*) in the eastern Pacific Ocean (EPO). The analysis method is described in IATTC Bulletin, Vol 22, No. 5, and readers are referred to that report for technical details. This method was used for the 2001 and 2002 assessments of skipjack tuna in the EPO. New catch, effort, and length-frequency data for 2002-2003 have been included and data for previous years have been updated.

The stock assessment requires a substantial amount of information. Data on landings, discards, fishing effort, and the size compositions of the catches of several different fisheries have been analyzed. Several assumptions regarding processes such as growth, recruitment, movement, natural mortality, fishing mortality, and stock structure have also been made. The assessment is still considered preliminary because 1) it is not known whether catch per day of fishing for purse-seine fisheries is proportional to abundance, 2) it is possible that there is a population of large skipjack that is invulnerable to the fisheries, and 3) stock structure in relation to the EPO and fish in the western and central Pacific is uncertain. However, results from sensitivity analyses for this assessment are more consistent than those of previous years.

The recruitment of skipjack tuna to the fisheries in the EPO is highly variable. Fishing mortality is estimated to be about the same or less than the rate of natural mortality. These levels of fishing mortality are supported by estimates from tagging data. Biomass fluctuates in response to variations in both recruitment and exploitation. Estimates of absolute biomass are moderately sensitive to weights given to the information about abundance in the catch and effort data for the floating-object fisheries and the monotonic selectivity assumption, but the trends in biomass are not.

The analysis indicates that a group of relatively strong cohorts entered the fishery in 2002-2003 (but not as strong as those of 1998) and that these cohorts increased the biomass and catches during 2003. There

is an indication the most recent recruitments are average, which may lead to lower biomasses and catches. However, these estimates of low recruitment are based on limited information, and are therefore very uncertain.

There is considerable variation in spawning biomass ratio (ratio of the spawning biomass to that for the unfished stock; SBR) for skipjack tuna in the EPO. In 2003 the SBR was at a high level (about 0.61). Estimates based on average maximum sustainable yield (AMSY) and yield-per-recruit indicate that maximum yields are achieved with infinite fishing mortality because the critical weight is less than the average weight at recruitment to the fishery. However, this is uncertain because of uncertainties in the estimates of natural mortality and growth. Estimates of SBR are not sensitive to weights given to the information about abundance in the catch and effort data for the floating-object fisheries and the monotonic selectivity assumption.

2. DATA

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

2.1. Definitions of the fisheries

Skipjack are fished in the EPO by purse seiners (in schools associated with floating objects and in unassociated schools) and by pole-and-line vessels. Vessels of all sizes participate in these fisheries. Most of the catches are made between northern Baja California and southern Peru, but the catches are relatively low off southern Mexico. The fishery extends westward to about 140°W in equatorial waters. Fisheries associated with floating objects take place mostly off Central America and northern South America, but extend far offshore. The floating objects include both flotsam and fish-aggregating devices (FADs). The fisheries directed at unassociated schools take place mostly off Baja California and off Central America and northern South America. Only small amounts of skipjack are caught in sets on dolphin-associated tunas. Only larger vessels participate in that fishery.

Most of the catches of yellowfin, skipjack, and bigeye prior to about 1960 were taken by pole-and-line vessels. These vessels fished from Southern California to northern Chile. The fishery took place mostly within about 250 nautical miles of the coast and in the vicinity of a few offshore islands. There are only a few pole-and-line vessels left now, all of which are registered in Ecuador or Mexico (Anonymous, 2002: Table 2). These vessels are all small, and they fish relatively close to shore off Ecuador and northern Mexico.

Eleven fisheries are defined for the stock assessment of skipjack tuna. These fisheries are defined on the basis of gear type (purse seine and pole and line), purse-seine set type (sets on floating objects, unassociated schools, and dolphins), and IATTC length-frequency sampling area or latitude. The skipjack fisheries are defined in Table 2.1, and the spatial extent of each fishery is illustrated in Figure 2.1. The boundaries of the length-frequency sampling areas are also illustrated in Figure 2.1. The longline fisheries are ignored because they capture a minimal amount of skipjack. The pole-and-line fishery and the purse-seine fishery that makes sets on schools associated with dolphins have been combined because they account for only a small fraction of the total skipjack catch.

In general, fisheries are defined such that, over time, there has been little change in the 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 FADs (Fisheries 1-2, 4, 8-9, and 11), and sets made on a mix of flotsam and FADs (Fisheries 3 and 10).

2.2. Catch and effort data

To conduct the stock assessment of skipjack tuna, the catch and effort data in the IATTC databases are stratified according to the fishery definitions described in Section 2.1 and presented in Table 2.1. The three definitions relating to catch data used in previous reports (landings, discards, and catch) are described by Maunder and Watters (2001). The terminology for this report has been changed to be consistent with the terminology used in other IATTC reports. The correct usage of landings is catch landed in a given year even if it was not caught in that year. Previously, landings referred to retained catch caught in a given year. This catch will now be termed retained catch. Throughout the document the term "catch" will be used to reflect both total catch (discards plus retained catch) and retained catch and the reader is referred to the context to determine the appropriate definition.

All three of these types of data are used to assess the stock of skipjack tuna. Removals by Fisheries 1-4 are retained catches plus some discards resulting from inefficiencies in the fishing process (see Section 2.2.2) (Table 2.1). The removals by Fisheries 5-7 are retained catches plus some discards resulting from inefficiencies in the fishing process and from sorting the catch. Removals by Fisheries 8-11 are only discards resulting from sorting the catch taken by Fisheries 1-4 (see Section 2.2.2) (Table 2.1).

2.2.1. Catch

Trends in the catch of skipjack tuna in the EPO during each month between January 1975 and December 2003 are illustrated in Figure 2.2. The majority of catch of skipjack has been taken by purse-seine sets on skipjack associated with floating objects and in unassociated schools. It should be noted that substantial amounts of skipjack were already being removed from the EPO prior to 1975 (Forsbergh 1989).

There has been substantial annual and monthly variation in the catches of skipjack tuna made by the surface fleet (Figure 2.2). This variation occurs in the total amount of catch, the spatial distribution of the catch, and in the set type of the catch. In general, catches of skipjack have been dominated by sets on floating objects and unassociated schools, with floating-object sets increasing since 1993. There have been some extremely large catches in the central and northern floating-object fisheries (Fisheries 2 and 4) and the southern unassociated fishery (Fishery 6) during 1999, 2000, and 2003.

2.2.2. Effort

The method that is used to estimate the amount of fishing effort, in days fished, exerted by purse-seine vessels is described by Watters and Maunder (2001).

Trends in the amount of fishing effort, in days fishing, exerted by the 11 fisheries defined for the stock assessment of skipjack tuna in the EPO are plotted in Figure 2.3. There has been substantial variation in the amount of fishing effort exerted by surface gears. The total fishing effort directed at tunas associated with floating objects (Figure 2.3, Fisheries 1-4) was relatively high prior to 1985, low from 1986 to 1992, and then increased again from 1993 to present. In the early period (before 1985) the effort was mainly in Fisheries 3 and 4 and in the late period (after 1993) it was in Fisheries 1 and 2. The effort has increased substantially since 1993 in all the floating-object fisheries except the coastal fishery (Figure 2.3, Fisheries 1, 2, and 4). Fishing effort directed at tunas in unassociated schools was higher prior to 1985 (Figure 2.3, Fisheries 5 and 6). It is assumed that the fishing effort in Fisheries 8-11 is equal to that in Fisheries 1-4 (Figure 2.3) because the catches taken by Fisheries 8-11 are derived from those taken by Fisheries 1-4 (see Section 2.2.3). Because Fishery 7 is a combination of both dolphin-associated purse-seine sets and pole-and-line vessels, and these methods represent only a small fraction of the total skipjack catch in the EPO, the effort is assumed constant for this fishery, and it is not used to provide information on biomass.

The large month-to-month 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 skipjack tuna are discarded from catches made by purse-seine vessels for one of two reasons. First, they may be discarded because of inefficiencies in the fishing process (*e.g.* when the catch from a set exceeds the remaining storage capacity of the fishing vessel). Second, they may be discarded because the fishermen sort the catch to select fish that are larger than a certain size. In either case, the amount of skipjack discarded is estimated with information collected at sea by IATTC observers, applying methods described by Maunder and Watters (2003) modified by a smoothing algorithm. The smoothing algorithm used an individual effect for each year and a seasonal effect modeled using a sine function, and was fit to the data weighted by the sample size. The smoothing algorithm removes the temporal variation caused by sampling. Regardless of why skipjack are discarded, it is assumed that all discarded fish die.

Estimates of discards resulting from inefficiencies in the fishing process are added to all the catches made by purse-seine vessels. No observer data are available to estimate discards for surface fisheries that operated prior to 1993, and it is assumed that there were no discards during this period. For surface fisheries, excluding pole-and-line vessels, that have operated since 1993 (Fisheries 1-6), 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 closest time period when observer data were sufficient to estimate the discards. No observer data are available to estimate the discards for the pole-and-line fishery (contained within Fishery 7), and it is assumed that there are no discards in this fishery.

Discards that result from the process of sorting the catch in the floating-object fisheries (Fisheries 1-4) are treated as separate fisheries (Fisheries 8-11). It is important to treat these discards separately because the size-composition data collected from port sampling (see Section 2.3) cannot provide information about the size of these discarded fish. Thus, discards that result from sorting the catch represent removals for which size compositions must be obtained at sea. IATTC observers collect limited information on the sizes of discarded tunas. All that is known about the fish that are discarded during sorting is that they are mostly small fish that weigh less than about 2.5 kg. By creating fisheries whose catch is composed exclusively of small, discarded fish, it is possible to conduct a stock assessment without detailed data on the size composition of the discards. This is possible because the small fish that are discarded during sorting are likely to belong to only one or a few age classes. Estimates of the amount of fish discarded during sorting are made only for fisheries that take skipjack associated with floating objects (Fisheries 1-4) because sorting is infrequent in the other purse-seine fisheries.

2.3. Size-composition data

The fisheries of the EPO all catch skipjack tuna of similar sizes (35-75 cm). The average size composition of the catch from each fishery defined in Table 2.1 is illustrated in Figure 4.2.

Data on the size compositions of discards from fisheries that catch skipjack in association with floating objects (Fisheries 8-11) are limited. IATTC observers collect information on the size composition of the discards, but they do not currently measure the fish. The observers categorize the fish into the following groups: large (greater than 15 kg), medium (2.5-15 kg), and small (less than 2.5 kg). It is assumed that the catches in Fisheries 8-11 are composed entirely of fish in the small category. Thus, using the weight-length relationship presented in Section 3.1.1, this assumption implies that the catches in Fisheries 8-11 are composed entirely of fish less than about 51 cm in length (less than about 16 months old). It is assumed that skipjack are recruited to the discard fisheries when they are about 9 months old and about 30 cm in length and are not vulnerable to those fisheries after they reach 15 months of age.

2.4. Auxiliary data

No auxiliary data were included in the assessment.

3. ASSUMPTIONS AND PARAMETERS

3.1. Biological and demographic information

3.1.1. Growth

The IATTC staff has used a growth rate of 24 cm per year, from Forsbergh (1989), in its yield-per-recruit modeling of skipjack. Bayliff (1988) used tagging data to calculate the following estimates for the parameters of the von Bertalanffy growth equation:

Method	K (annual)	L_∞(mm)
Ungrouped	0.658	885
Grouped	0.829	846

(With the grouped method all fish that were in the same size-at-release (275-324 mm, 325-374 mm, *etc.*) and time-at-liberty (31-40 days, 41-50 days, *etc.*) groups were combined and treated as single fish to reduce the influence of groups containing large numbers of fish.) It should be noted, however, that the results of sensitivity analyses performed by Bayliff (1988) indicated that the estimates of the parameters were imprecise. Maunder (2001) provided estimates similar to those of Bayliff (1988), and concluded that more data for large and small skipjack are needed. We use the grouped estimates of Bayliff (1988) with the assumption that a 30-cm skipjack is 9 months old as a prior for mean length at age (Figure 3.1). The age at 30 cm is based on evidence that skipjack produce about 0.8 rings on their otoliths each day (Wild and Foreman 1980), and a 30-cm skipjack has about 210 rings (Uchiyama and Struhsaker 1981).

The weight-length relationship of skipjack in the EPO is $W = (5.5293 \text{ x } 10^{-6})L^{3.336}$, where W = weight in kilograms and L = length in centimeters (Hennemuth, 1959).

3.1.2. Recruitment and reproduction

Information on the reproduction of skipjack in the EPO is given by Anonymous (1998: 26) and Schaefer (2001). Spawning is fairly widespread between about 15°N and 10°S from the coast of the Americas to about 130°W at sea-surface temperatures (SSTs) equal to or greater than 24°C. It is assumed that skipjack tuna can be recruited to the fishable population during every month of the year.

No strong assumptions are made about the relationship between adult biomass (or abundance) and recruitment in the stock assessment of skipjack. An assumption is made, however, about the way that recruitment can vary around its average level. It is 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 monthly time step, extremely small or large recruitments should not occur more than about once every 8 years.

Skipjack tuna are assumed to be recruited to the discard fisheries in the EPO at about 30 cm (about 9 months old) (see Section 2.3). At this size (age), the fish are vulnerable to the fisheries on floating objects (*i.e.* they are recruited to Fisheries 8-11).

The proportion of females in each age class that are mature is used to estimate the spawning biomass of the stock. All females aged 16 months and more are assumed to be mature. The sex ratio is assumed to be 50-50, based on data from Schaefer (2001).

3.1.3. Movement

Information of the movements of skipjack in the EPO is given by Schaefer *et al.* (1961), Fink and Bayliff (1970), and Hunter *et al*. (1986). The percentage of skipjack released in the western Pacific that were at liberty 0 to 30 days, 31 to 180 days, and more than 180 days that traveled more than 500 nautical miles are 0, about 5, and about 30, respectively. Twenty-seven tagged skipjack released in the EPO have been recaptured in the central or western Pacific (Bayliff, 1988: Appendix 2), but no tagged skipjack released in the central or western Pacific have been recaptured in the EPO. It should be recognized that the amounts of tagged fish recaptured at various locations are dependent on the amounts of fishing effort in those locations. If tagging experiments are initiated where the fishing effort is heavy the distances moved by the fish that are recaptured are likely to be less than they would have been if the tagged fish had been released in areas of both heavy and light fishing. Nevertheless, for the purposes of the current assessment, it is assumed that skipjack move around the EPO at rates that are rapid enough to ensure that the population is randomly mixed at the start of each month of the year.

3.1.4. Natural mortality

Attempts to estimate the natural mortality rate (M) of skipjack, and the many problems associated with these studies, are discussed by Wild and Hampton (1994). The IATTC staff has used a value of 1.5, on an annual basis, for M in yield-per-recruit analyses (Anonymous, 2000: 69). In contrast to yellowfin and bigeye tuna, skipjack do not show an increase in the proportion of males for older fish (Schaefer 2001). Hampton (2000), using tagging data, obtained estimates of natural mortality for skipjack in the western Pacific Ocean (WPO) that were higher for old and young individuals. The results showed much higher natural mortality rates for skipjack of sizes less than 40 cm and greater than 70 cm. The estimates from the WPO (Hampton 2000) were used to develop an age-specific natural mortality curve to use in the assessment (Figure 3.2). Hampton's estimates of high natural mortality for old skipjack may be an artifact of the tagging data due to older fish moving out of the fishery. Therefore it is assumed that natural mortality is constant over high ages. Hampton's estimates of high natural mortality for young skipjack may also be an artifact of the tagging data due to tagging mortality, and a lower natural mortality rate is used here.

3.1.5 Stock structure

Skipjack occur throughout the tropical and subtropical waters of the Pacific Ocean, and it is known that there is considerable exchange of fish among areas. The stock structure of skipjack has been studied by various methods, including analyses of catch statistics, life history, tagging, biochemical genetic data, and data on the chemical composition of the otoliths of the fish. Research in these fields has been conducted by many organizations, including the IATTC, the South Pacific Commission (now the Secretariat of the Pacific Community; SPC), the U.S. National Marine Fisheries Service (NMFS), and various organizations in Japan. The research results pertinent to a solution to this problem were examined by Argue (1981), and the conclusions were discussed in detail by Anonymous (1984: 88-91). In summary, there were two principal hypotheses for skipjack in the Pacific Ocean. The separate-subpopulation hypothesis stated that there are two or more genetically-distinct subpopulations of skipjack in the Pacific Ocean, and the clinal hypothesis stated that separate subpopulations of skipjack do not exist in the Pacific Ocean, but that there is isolation by distance, *i.e.* the probability of any two fish interbreeding is an inverse function of their distance from one another. It was concluded by Argue (1981) that the available data did not favor either the separate-subpopulation or the clinal hypothesis. Subsequent studies, described by Anonymous (1995: 69-71) have not furnished information that would serve better as the basis for management decisions. (Those studies should not be considered as futile, however, as the information from them may eventually be combined with information to be gathered in the future to achieve a greater understanding of the stock structure of skipjack 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.

3.2. Environmental influences

The influences of some environmental variables on the apparent abundance of skipjack in the EPO have been studied by Forsbergh (1989). The abundance of skipjack larvae in the central and western Pacific approximately doubles with each 1-degree increase in SST from 23°C to a maximum of 29°C. The catches of skipjack by surface gear tend to be reduced during El Niño episodes, however, due to the fact that during such times the depth of the thermocline increases, so that the fish spend less time at the surface than during anti-El Niño periods (Joseph and Miller, 1989).

A previous stock assessment (Maunder and Watters 2002a) included the assumption that oceanographic conditions might influence recruitment of skipjack tuna in the EPO. To incorporate the possibility of an environmental influence on recruitment of skipjack in the EPO, a temperature variable was incorporated into the previous stock assessment model to determine whether there is a statistically-significant relationship between this temperature variable and estimates of recruitment. Maunder (2002) conducted the correlation outside the stock assessment model using SST and the Southern Oscillation Index and found no relationship between recruitment and the environmental variables..

4. STOCK ASSESSMENT

An age-structured population dynamics model A-SCALA (Maunder and Watters, 2003) and information contained in catch, effort, and size-composition data are used to assess the status of the skipjack tuna stock in the EPO. This method was used in the assessments of skipjack tuna in the EPO (Maunder and Watters 2002a; Maunder 2002). The model is based on the method described by Fournier *et al.* (1998). The term "statistical" indicates that the method implicitly recognizes that data collected from fisheries do not perfectly represent the population; there is uncertainty in our knowledge about the dynamics of the system and about how the observed data relate to the real population. The assessment model uses monthly time steps to describe the population dynamics. The parameters of the stock assessment model are estimated by comparing the predicted catches and size compositions to data collected from the fishery. After the parameters of the model have been estimated, the model is used to estimate quantities that are useful for managing the stock. Skipjack have a higher natural mortality rate than do yellowfin and bigeye tuna, so a monthly time frame is needed to allow information from individual cohorts to be extracted from the length-frequency data.

Since fisheries data are complex, the ways in which the model is fitted to the observed data are constrained. It is fitted by finding a set of population dynamics and fishing parameters that maximize the likelihood of having observed the catch and size-composition data, given the amount of fishing effort exerted by each fishery. This likelihood is calculated under a set of constraints. Many of these constraints are identified as assumptions in Section 3, but the following list identifies other important constraints that are used to fit the assessment model to observed data on skipjack tuna:

1. The discard fisheries (Fisheries 8-11) should catch only fish of the first few age classes.
2. If a fishery can catch fish of a particular age, it should be able to catch fish that are of somewhat lesser and greater ages.
3. There are random events that can cause the relationship between fishing effort and fishing mortality to change slightly from month to month. On average, the events that cause the fishing mortality to be slightly higher or lower should cancel one another out.
4. The data for fisheries whose catch is composed of discards from sorting (Fisheries 8-11) and the combined dolphin-associated and pole-and-line fishery (Fishery 7) provide relatively little information about biomass levels.

It is important to note that the assessment model can, in fact, make predictions that do not adhere strictly to the constraints above, 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 A-SCALA model has a variety of possible parameter and model structure formulations that can be used. In the 2001 assessment many of these different formulations were applied to the skipjack population in the EPO. These models all gave similar trends in biomass and recruitment. Among the models, the estimates of absolute biomass and the spawning biomass ratio (the ratio of the spawning biomass to the spawning biomass of the unexploited stock; SBR) differed. However, they all indicated that the exploitation rate was low, that recruitment was highly variable, and that recruitment drove the trends in biomass. In 2001 two models were presented that differed in how the initial exploitation rate in 1981 was calculated. In the 2002 assessment two models were presented. The two models differ in their assumptions about selectivity. The first model allowed selectivity for all fisheries, except the discard fisheries, which have fixed selectivities, to be dome-shaped (*i.e.* non-monotonic). In the second model, the selectivities for fisheries 2-7 were forced to be asymptotic (*i.e.* monotonically increasing). Dome-shaped selectivities allow the existence of a population of large skipjack that are invulnerable to the fishery. An asymptotic selectivity ensures that large skipjack are fully selected by the fishery, and, if there are no large skipjack caught, the model will estimate that skipjack do not survive to be large. Therefore, the asymptotic selectivities should provide higher estimates of exploitation rate and lower estimates of biomass. It was suggested that these two analyses will bound the possible exploitation rates for skipjack in the EPO. In this assessment we present analyses based on asymptotic selectivity and present a sensitivity with done-shaped selectivity.

The model has the estimated and fixed parameters as described below. The fishing mortality used to estimate the initial conditions is calculated as the average fishing mortality over the first two years. Deviations around the numbers at age in the initial conditions are estimated for the first 10 age classes.

The following parameters have been estimated for the current stock assessment of skipjack tuna in the EPO:

1. recruitment to the fishery in every month from January 1975 through December 2003;
2. monthly catchability coefficients for the 11 fisheries that take skipjack from the EPO;
3. selectivity curves for 7 of the 11 fisheries (Fisheries 8-11 have an assumed selectivity curve.);
4. initial population size and age structure;
5. mean length at age (Figure 3.1);
6. amount of variation in length at age.

The values of the parameters in the following list are assumed to be known for the current stock assessment of skipjack in the EPO.

1. natural mortality at age (Figure 3.2);
2. maturity of females at age;
3. sex ratio at age;
4. selectivity curves for the discard fisheries (Fisheries 8-11).

In addition to the sensitivity analyses where selectivity is allowed to be domed-shaped, we present a sensitivity where catch and effort data for the floating object fisheries provide very little information on abundance (*i.e*. the catch and effort data are downweighted by increasing the standard deviation in the effort deviate penalty).

4.1. Indices of abundance

The catches per unit of effort (CPUEs) of the 11 fisheries defined for the current assessment of skipjack in the EPO are illustrated in Figure 4.1. A discussion of this figure is provided in the following two paragraphs, but trends in CPUE 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 skipjack tuna of the surface fleet (Figure 4.1, Fisheries 1-6). Prior to 1993, the CPUEs for floating-object sets were fairly consistent, but since then the CPUE has increased, except in the coastal fishery (Fishery 3). The CPUE has been reduced in the most recent years (Figure 4.1, Fisheries 1-4). The CPUEs of skipjack captured in unassociated schools (Figure 4.1, Fisheries 5 and 6) were generally greater in the late 1980s and the late 1990s, with very high CPUEs in 1999 and 2000 for the southern fishery (Fishery 6) and in 1995 and 1999 for the northern fishery (Fishery 5). The northern unassociated fishery has shown more variation. Due to the short period of the fisheries that discarded skipjack from sorting the catches of Fisheries 1-4 (Figure 4.1, Fisheries 8-11), it is not possible to determine whether there were any trends in CPUE for these fisheries. The combined pole-and-line and dolphin-associated fishery (Fishery 7) is not interpretable because constant effort was assumed for this fishery.

4.2. Assessment results

The A-SCALA method provides a reasonably good fit to the catch and size-composition data for the 11 fisheries that catch skipjack tuna in the EPO. The assessment model is constrained to fit the time series of catches made by each fishery almost perfectly. The 11 time series of skipjack catches predicted with the A-SCALA method are almost identical to those plotted in Figure 2.2. It is important to predict the catch data closely, because it is difficult to estimate biomass if the total amount of fish removed from the stock is not well known.

It is also important to predict the size-composition data as accurately as possible, but, in practice, it is more difficult to predict the size composition than to predict the total catch. Accurately predicting the size composition of the catch is important because these data contain most of the information that is necessary for modeling recruitment and growth, and, thus, for estimating the impact of fishing on the stock. Predictions of the size compositions of skipjack tuna caught by Fisheries 1-7 are summarized in Figure 4.2. This figure simultaneously illustrates the average observed size compositions and the average predicted size compositions of the catches for these seven fisheries. (It should be recalled that the size-composition data are not available for discarded fish, so Fisheries 8-11 are not included in this discussion.) The predicted size compositions for all the fisheries with size-composition data (Fisheries 1-7) are good (Figure 4.2). However, there is a tendency to overpredict the frequency of very small and very large fish. A description of the size distribution of the catch for each fishery is given in Section 2.3.

Estimates of growth differed from the prior. The growth rates were much higher for the first few age classes, but lower for the intermediate ages. For the greater ages, the mean lengths at age were highly constrained so that the mean length-at-age essentially equaled the prior.

The results presented in the following section are likely to change in future assessments because (1) future data may provide evidence contrary to these results, (2) the assumptions and constraints used in the assessment model may change, and (3) this is only a preliminary analysis, and future modifications are likely.

4.2.1. Fishing mortality

Fishing mortality increased from 1975 to 1981 and then decreased to 1985. Since 1985 fishing mortality has gradually increased (Figure 4.3b). These changes in fishing mortality correspond to changes in estimated catchability (Figure 4.5). The fishing mortality is greater for the monotonic selectivity assessment than for the non-monotonic selectivity assessment. Fishing mortality increases with age, and has been much greater for the older fish since the floating-object fishery expanded in 1993 (Figure 4.3b). This is a consequence of the higher selectivity for older fish in the floating-object fisheries (Figure 4.4).

4.2.2. Recruitment

Over the range of predicted biomasses, the abundance of skipjack recruits appears to be unrelated to the biomass of spawners at the time of spawning. (Spawners are defined as female skipjack that are mature; see section 3.1.2) (Figure 4.6).

The estimated time series of skipjack recruitment is shown in Figure 4.7, and the total recruitment estimated to occur in each year is presented in Table 4.1. The most conspicuous features of this time series is the very high variation in recruitment from month to month and the large recruitments to the fishery in 1983, 1994-1995, 1998-1999, and 2002-2003. The analysis indicates that a group of strong cohorts entered the fishery in 2002-03 and that these cohorts increased the biomass (Figure 4.9a) and catches (Figure 2.2) during 2003. There is an indication the most recent recruitments are average, which may lead to lower biomasses and catches. However, these estimates of low recruitment are based on limited information, and are therefore very uncertain.

4.2.3. Biomass

Biomass is defined as the total weight of skipjack tuna that are one or more years old. The trends in the biomass of skipjack in the EPO are shown in Figure 4.9a, and estimates of the biomass at the beginning of each year in Table 4.1. The biomass has been highly variable during the 1975-2003 period. The biomass was estimated to decline from 1975 to a very low level in 1982, and then increase rapidly to a peak in 1984. It then declined to a low level in 1994 before rapidly increasing in 1995, and stayed high until another rapid increase in late 1998 and in 1999, dropping again before increasing in to a peak in 2003 and then declining. The variation in biomass can be attributed to both changes in recruitment (Figure 4.9c and 4.9d), and fishing mortality. The fishery impact was greatest in the late 1970s and early 1980s.

4.2.4. Average weights of fish in the catch

The overall average weights of the skipjack tuna caught in the EPO predicted by the analysis have been around 2-4 kg for most of the period from 1975 to 2001, and are similar among fisheries (Figure 4.10). However, average weight was consistently less in the early 1980s, when the fishing mortality rate was estimated to be high.

4.3. Comparisons to external data sources

Tagging data for 1980 and 1981 were used to estimate the fishing mortality rate. The estimated monthly rates of total mortality, using the method of Robson and Chapman (1961), are 0.53 and 0.55, respectively. These estimates include natural and fishing mortality: removing a factor of 0.14 for natural mortality gives estimates of fishing mortality of 0.39 and 0.41. These are likely to be overestimates, as the tagging was conducted in a limited area where most of the catch was taken and are therefore measures of the localized exploitation rate. These estimates include also losses due to emigration, long-term tag loss, and long-term tagging mortality. The average monthly estimates of fishing mortality from the stock assessment model for 1980 and 1981 are 0.10 and 0.12 for ages 9-20 and 0.27 and 0.33 for ages 21+ (Table A.1). Bayliff (1976) analyzed earlier tagging data (1950-1973) and found a range of total monthly mortality rates from around 0.3 to 1.0. This indicates that the stock assessment results are somewhat consistent with the tagging data.

4.4. Sensitivity to assumptions

The trends in the estimated biomass trajectory from the sensitivity analysis that downweights the information about abundance in the catch and effort data for the floating-object fisheries is similar to the base case, but the biomass is higher for most years (Figure B.1). The trends in the estimated biomass trajectory from the sensitivity analysis that allows dome-shaped selectivity is similar to the base case, but the biomass is lower for most years (Figure B.3). This similarity is despite the very different, and variable, estimated selectivity at age (Figure B.5).

4.5. Summary of the results from the assessment model

The recruitment of skipjack tuna to the fisheries in the EPO is variable. Fishing mortality is estimated to be about the same or less than the rate of natural mortality. These levels are supported by estimates from tagging data. Biomass fluctuates in response to both variations in recruitment and exploitation. Estimates of absolute biomass are moderately sensitive to weights given to the information about abundance in the catch and effort data for the floating-object fisheries and the monotonic selectivity assumption, but the trends in biomass are not.

The analysis indicates that a group of strong cohorts entered the fishery in 2002-2003 and that these cohorts increased the biomass (Figure 4.9a and 4.9c) and catches (Figure 2.2) during 2003. There is an indication the most recent recruitments are average, which may lead to lower biomasses and catches. However, these estimates of low recruitment are based on limited information, and are therefore very uncertain.

5. STOCK STATUS

The status of the stock of skipjack 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 Fishing 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} (spawning biomass at AMSY) as a target reference point;
2. $F_{A\text{MSY}}$ (fishing mortality at AMSY) 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 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 (*e.g.* the levels estimated in the early 1980s). A mid-year technical meeting on reference points was held in La Jolla, California, USA, on October 27-29, 2003. The outcome from this meeting was (1) a set of general recommendations on the use of reference points and research, (2) specific recommendations for the IATTC stock assessments. Several of the recommendations have been included in this assessment. Development of reference points that are consistent with the precautionary approach to fisheries management will continue.

5.1. Assessment of stock status based on spawning biomass

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

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

where S_t is the spawning biomass at any time (t) during a period of exploitation, and $S_{F=0}$ is the spawning biomass that might be present if there were no fishing for a long period (*i.e.* the equilibrium spawning biomass if $F = 0$). The SBR has a lower bound of zero. If the SBR is 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 ($\text{SBR}_{\text{AMSY}} = S_{\text{AMSY}}/S_{F=0}$). S_{AMSY} is the spawning biomass at AMSY (see Section 5.3 for details regarding calculation of AMSY and related quantities).

Estimates of monthly SBR_t for skipjack in the EPO have been computed for every month represented in the stock assessment model (the first month of 1975 to the first month of 2004). Estimates of the spawning biomass during the period of harvest (S_t) are presented in Section 4.2.2. The equilibrium spawning biomass after a long period with no harvest ($S_{F=0}$) was estimated by assuming that recruitment occurs at an average level expected from an unexploited population. Unfortunately, the SBR level that would give rise to AMSY (SBR_{AMSY}) cannot be estimated for skipjack, as is discussed in section 5.3, so it is not possible to relate the SBR to the SBR_{AMSY}.

At the beginning of 2004, the spawning stock of skipjack tuna in the EPO was considerably reduced. The estimate of SBR at this time was about 0.61, with lower and upper 95% confidence limits of 0.40 and 0.81.

A time series of SBR estimates for skipjack tuna in the EPO is shown in Figure 5.1. The SBR has been below the average unexploited level for most of the 1975-2001 period, except for the peak in 1999.

5.2. Assessment of stock status based on yield per recruit

Estimates based on yield-per-recruit calculations indicate that the critical age for skipjack is less that the age at recruitment to the fishery. This indicates that the maximum yield per recruit is achieved with an infinite fishing mortality (Figure 5.2). The yield-per-recruit calculations depend on estimates of growth and natural mortality, which are both uncertain.

5.3. Assessment of stock status based on AMSY

Maintaining stocks at levels capable of producing the AMSY is the management objective specified by the IATTC convention. One definition of 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. AMSY calculations are described by Maunder and Watters (2001). The calculations are changed from Maunder and Watters (2001) to include the Beverton-Holt (1957) stock-recruitment relationship where applicable.

The current assessment assumes that there is no stock-recruitment relationship for skipjack tuna, so the relative yield curve is equal to the relative yield-per-recruit curve (Figure 5.2). Therefore, AMSY is achieved by an infinite fishing mortality (Section 5.2). As this is not achievable in reality, no quantities based on AMSY are presented.

5.4. Sensitivity analysis

Estimates of SBR are not sensitive to weights given to the information about abundance in the catch and effort data for the floating-object fisheries (Figure B.2) and the monotonic selectivity assumption (Figure B.4).

5.5. Summary of stock status

There is considerable variation in SBR for skipjack tuna in the EPO. In 2003 the SBR is at a high level (about 0.61). Estimates based on AMSY and yield per recruit indicate that maximum yields are achieved with infinite fishing mortality because the critical weight is less than the average weight at recruitment to the fishery. However, this is uncertain because of uncertainties in the estimates of natural mortality and growth. Estimates of SBR are not sensitive to weights given to the information about abundance in the catch and effort data for the floating-object fisheries and the monotonic selectivity assumption.

6. SIMULATED EFFECTS OF FUTURE FISHING OPERATIONS

Historical biomass of skipjack tuna has been driven by fluctuations in recruitment, so future projections will also be determined by recruitment. This is particularly true for short-lived species such as skipjack. For this reason, no projections of future biomass are provided.

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 skipjack 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 intends to continue developing the assessment for skipjack.

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 skipjack tuna in the EPO. The staff also intends to reinvestigate indices of skipjack 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.

REFERENCES

Anonymous. 1984. Annual Report of the Inter-American Tropical Tuna Commission 1983: 272 pp.

Anonymous. 1995. Annual Report of the Inter-American Tropical Tuna Commission 1994: 296 pp.

Anonymous. 1998. Annual Report of the Inter-American Tropical Tuna Commission 1996: 306 pp.

Anonymous. 2000. Annual Report of the Inter-American Tropical Tuna Commission 1998: 357 pp.

Anonymous. 2002. Annual Report of the Inter-American Tropical Tuna Commission 2001: 148 pp

Argue, A.W. (editor). 1981. Report of the Second Skipjack Survey and Assessment Programme workshop to review results from genetic analysis of skipjack blood samples. South Pacif. Comm., Skipjack Survey and Assessment Programme, Tech. Rep. 6: v, 39 pp.

Bayliff, W. H. 1976. Estimates of the rates of mortality of skipjack tuna in the eastern Pacific Ocean derived from tagging experiments. Inter-Amer. Trop. Tuna Comm. Internal Rep. 10: 59 pp.

Bayliff, W.H. 1988. Growth of skipjack, *Katsuwonus pelamis*, and yellowfin, *Thunnus albacares*, tunas in the eastern Pacific Ocean as estimated from tagging data. Inter-Amer. Trop. Tuna Comm., Bull. 19: 307-385.

Beverton, R.J.H. 1957. On the dynamics of exploited fish populations. Minis. Agri. Fish. Food, Fish. Inves., Ser., 19: 533 pp.

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

Fink, B.D., and W.H. Bayliff. 1970. Migrations of yellowfin and skipjack tuna in the eastern Pacific Ocean as determined by tagging experiments, 1952-1964. Inter-Amer. Trop. Tuna Comm., Bull. 15: 1-227.

Forsbergh, E.D. 1989. The influence of some environmental variables on the apparent abundance of skipjack tuna, *Katsuwonus pelamis*, in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull. 19: 429-569.

Fournier, D.A., J. Hampton, and J.R. Sibert. 1998. MULTIFAN-CL: a length-based, age-structured model for fisheries stock assessment, with application to South Pacific albacore, *Thunnus alalunga*. Can. J. Fish. Aquat. Sci. 55: 2105-2116.

Francis, R.I.C.C. 1993. Monte Carlo evaluation of risks for biological reference points used in New Zealand fishery assessments. *In* Risk evaluation and biological reference points for fisheries management, edited by S.J. Smith, J.J. Hunt, and D. Rivard. Can. Spec. Publ. Fish. Aquat. Sci. 120: 221-230.

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

Hennemuth, R.C. 1959. Additional information on the length-weight relationship of skipjack tuna from the eastern tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull. 4: 23-37.

Hunter, J.R., A.W. Argue, W.H. Bayliff, A.E. Dizon, A. Fonteneau, D. Goodman, and G.R. Seckel. 1986. The dynamics of tuna movements: an evaluation of past and future research. FAO Fish. Tech. Pap. 277: 1-78.

Joseph, J., and F.R. Miller. 1989. El Niño and the surface fishery for tunas in the eastern Pacific. Japan. Soc. Fish. Ocean., Bull. 53: 77-80.

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

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

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

Maunder, M.N. and G. M. Watters. 2002a. Status of skipjack tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Stock Assessment Report 2: 91-146.

Maunder, M.N. and G.M. Watters. 2002b. Status of yellowfin tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Stock Assessment Report 2: 5-90.

Miyake, M.P. 1968. Distribution of skipjack in the Pacific Ocean, based on records of incidental catches by the Japanese longline tuna fishery. Inter-Amer. Trop. Tuna Comm., Bull. 12: 509-608.

Mizuno K., M. Okazaki, H. Nakano, and H. Okamura. 1997. Estimation of underwater shape of tuna longline by using micro-BTs. Bull. Nat. Res. Inst. Far Seas Fish. 34: 1-24.

Robson, D.S., and D.G. Chapman. 1961. Catch curves and mortality rates. Amer. Fish. Soc., Trans., 90: 181-189.

Schaefer, K.M. 2001. An assessment of skipjack tuna (*Katsuwonus pelamis*) spawning in the eastern Pacific Ocean. Fish. Bull. 99: 343-350.

Schaefer, M.B., B.M. Chatwin, and G.C. Broadhead. 1961. Tagging and recovery of tropical tunas, 1955-1959. Inter-Amer. Trop. Tuna Comm., Bull. 5: 341-455.

Thompson, G.G. 1993. A proposal for a threshold stock size and maximum fishing mortality rate. *In* Risk evaluation and biological reference points for fisheries management, edited by S.J. Smith, J.J. Hunt, and D. Rivard. Can. Spec. Publ. Fish. Aquat. Sci. 120: 303-320.

Uchiyama, J.H. and P. Struhsaker. 1981. Age and growth of skipjack tuna, *Katsuwonus pelamis*, and yellowfin tuna, *Thunnus albacares*, as indicated by dailty growth increments of sagittae. Fish. Bull. 79: 151-162.

Watters, G.M. and M.N. Maunder. 2001. Status of bigeye tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Stock Assessment Report 1: 109-211.

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

Wild, A. and T.J. Foreman. 1980. The relationship between otolith increments and time for yellowfin and skipjack tuna marked with tetracycline. Inter-Amer. Trop. Tuna Comm., Bull. 17: 507-560.

Wild, A. and J. Hampton. 1994. A review of the biology and fisheries for skipjack tuna, *Katsuwonus pelamis*, in the Pacific Ocean. FAO Fish. Tech. Pap. 336 (2): 1-51.

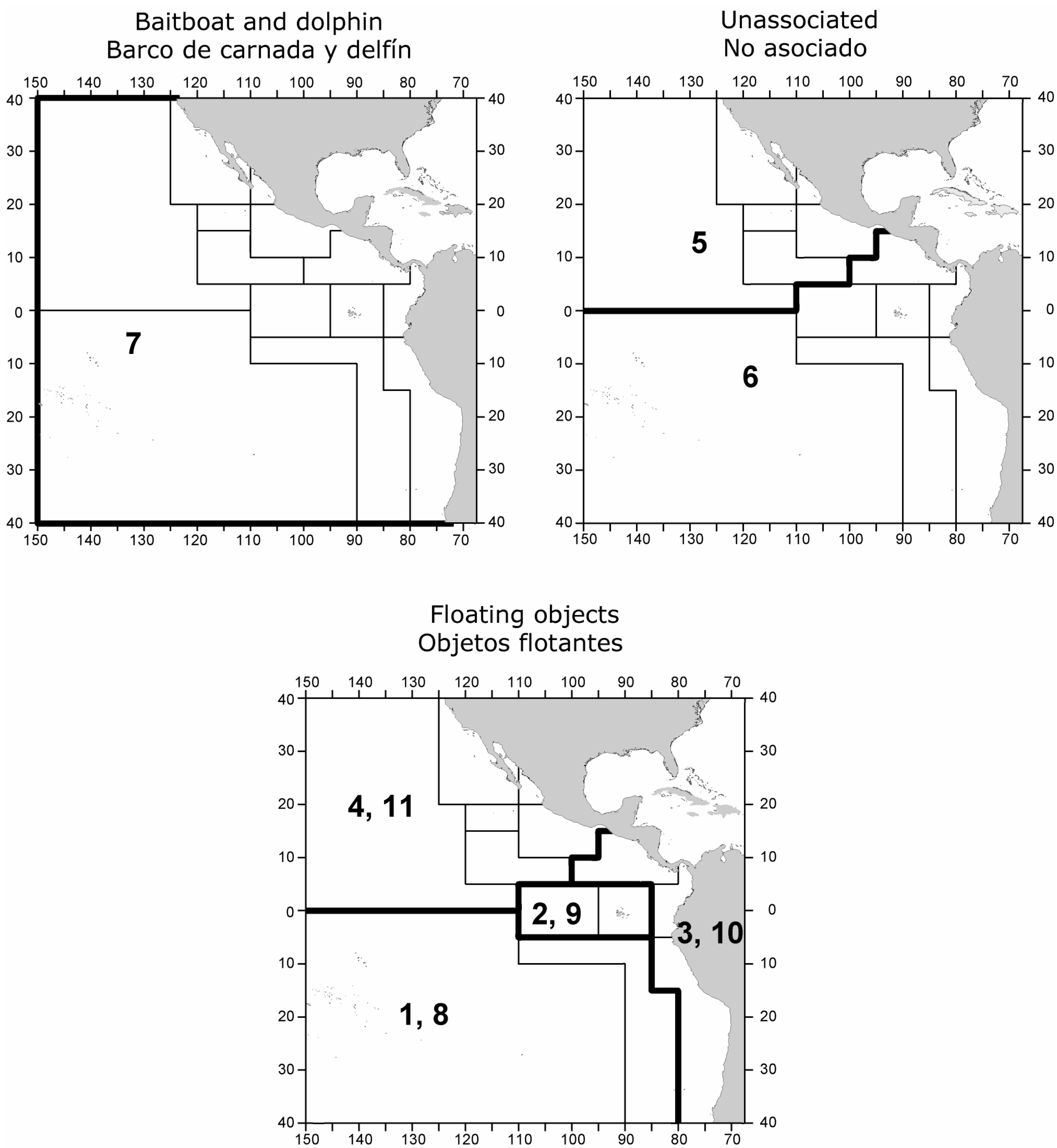

FIGURE 2.1. Spatial extents of the fisheries defined by the IATTC staff for the stock assessment of skipjack tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the bold numbers 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 por el personal de la CIAT para la evaluación del atún barrilete 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.

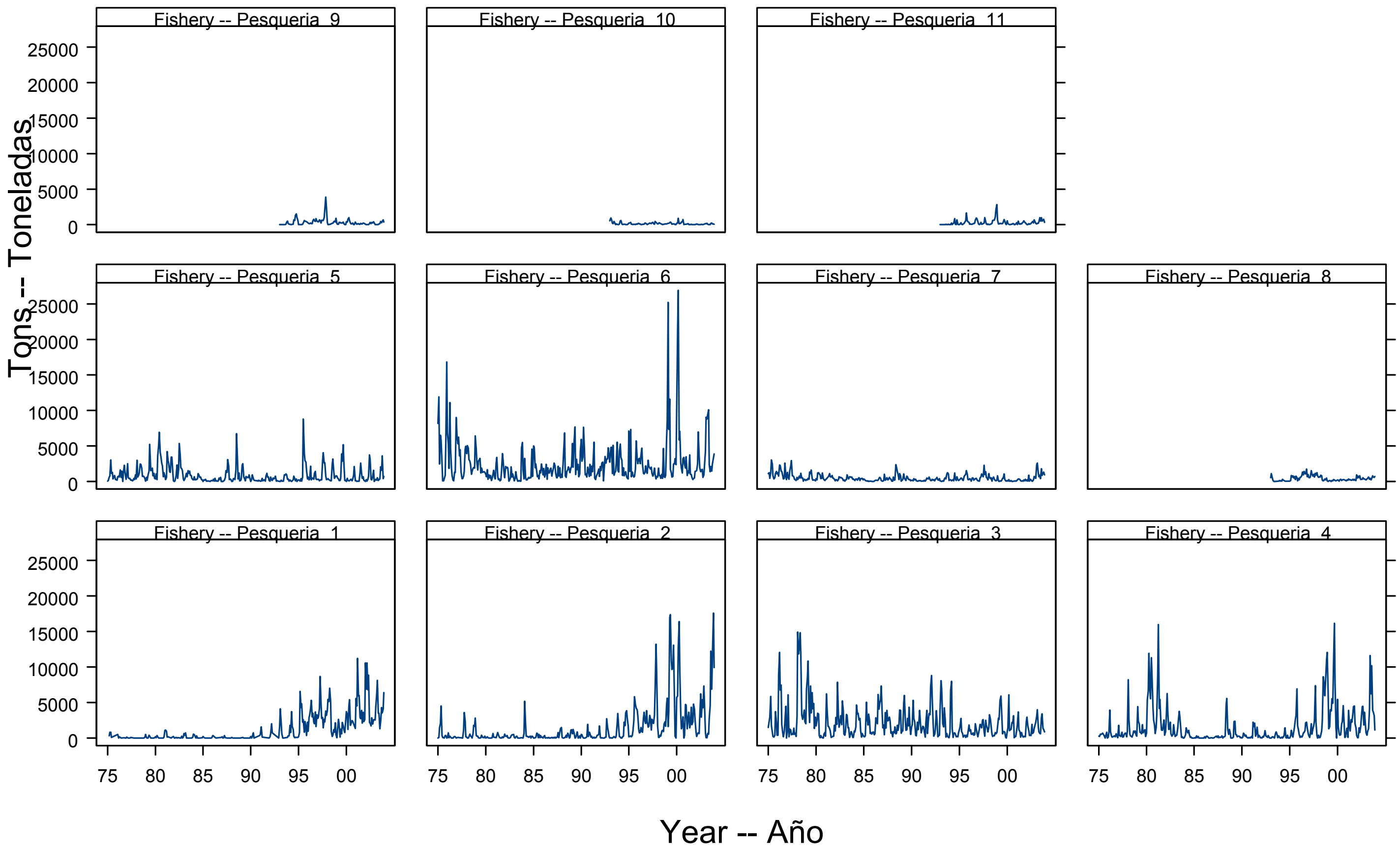

FIGURE 2.2. Catches by the fisheries defined for the stock assessment of skipjack tuna in the EPO (Table 2.1). Since the data were analyzed on a monthly basis, there are 12 observations of catch for each year.

FIGURA 2.2. Capturas de las pesquerías definidas para la evaluación del stock de atún barrilete en el OPO (Tabla 2.1). Ya que se analizaron los datos por mes, hay 12 observaciones de captura para cada año.

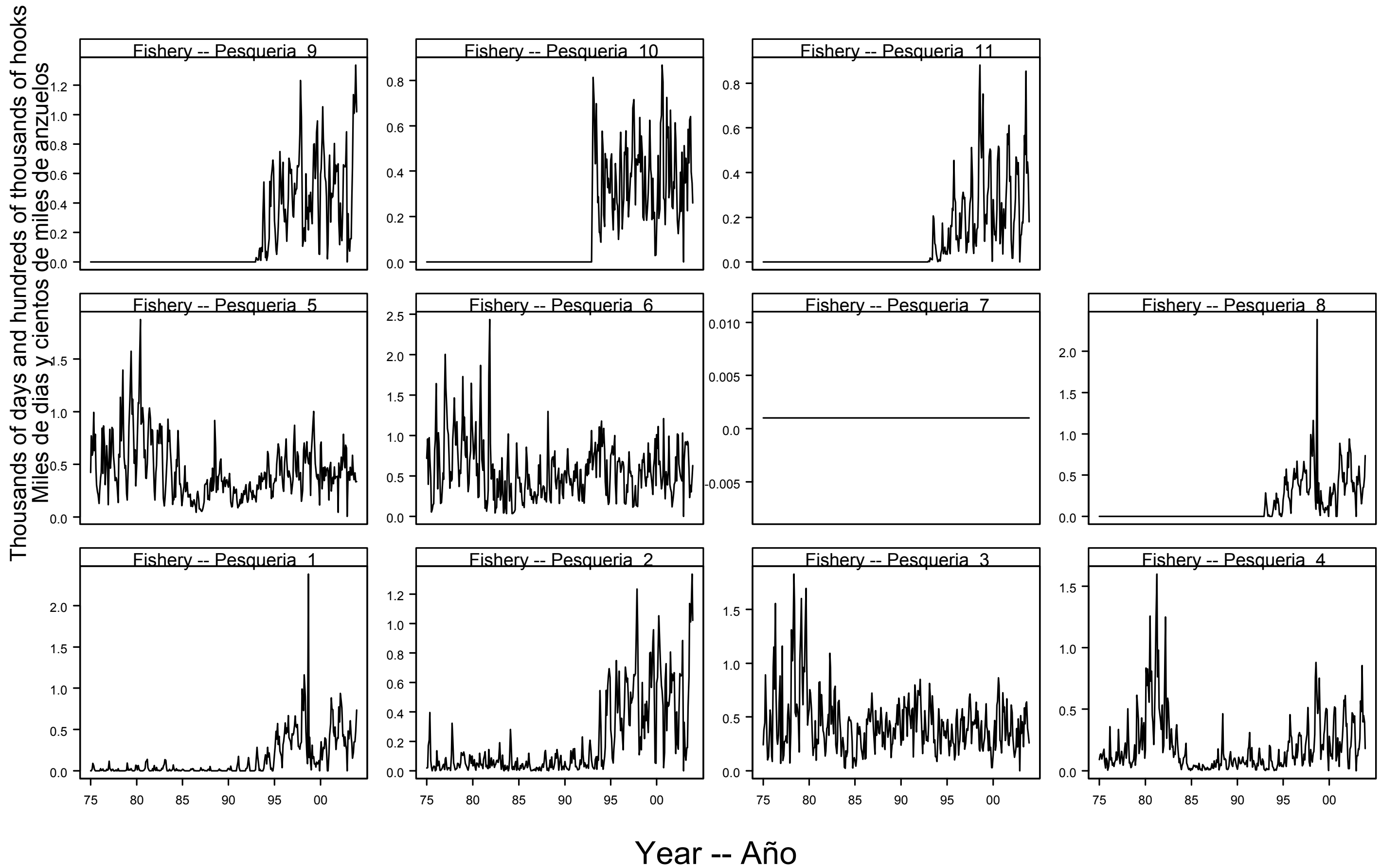

FIGURE 2.3. Fishing effort exerted by the fisheries defined for the stock assessment of skipjack tuna in the EPO (Table 2.1). Since the data were summarized on a monthly basis, there are 12 observations of effort for each year. Constant effort was assumed for Fishery 7.

FIGURA 2.3. Esfuerzo de pesca ejercido por las pesquerías definidas para la evaluación del stock de atún barrilete en el OPO (Tabla 2.1). Ya que se analizaron los datos por mes, hay 12 observaciones de esfuerzo para cada año. Se supuso un esfuerzo constante para la Pesquería 7.

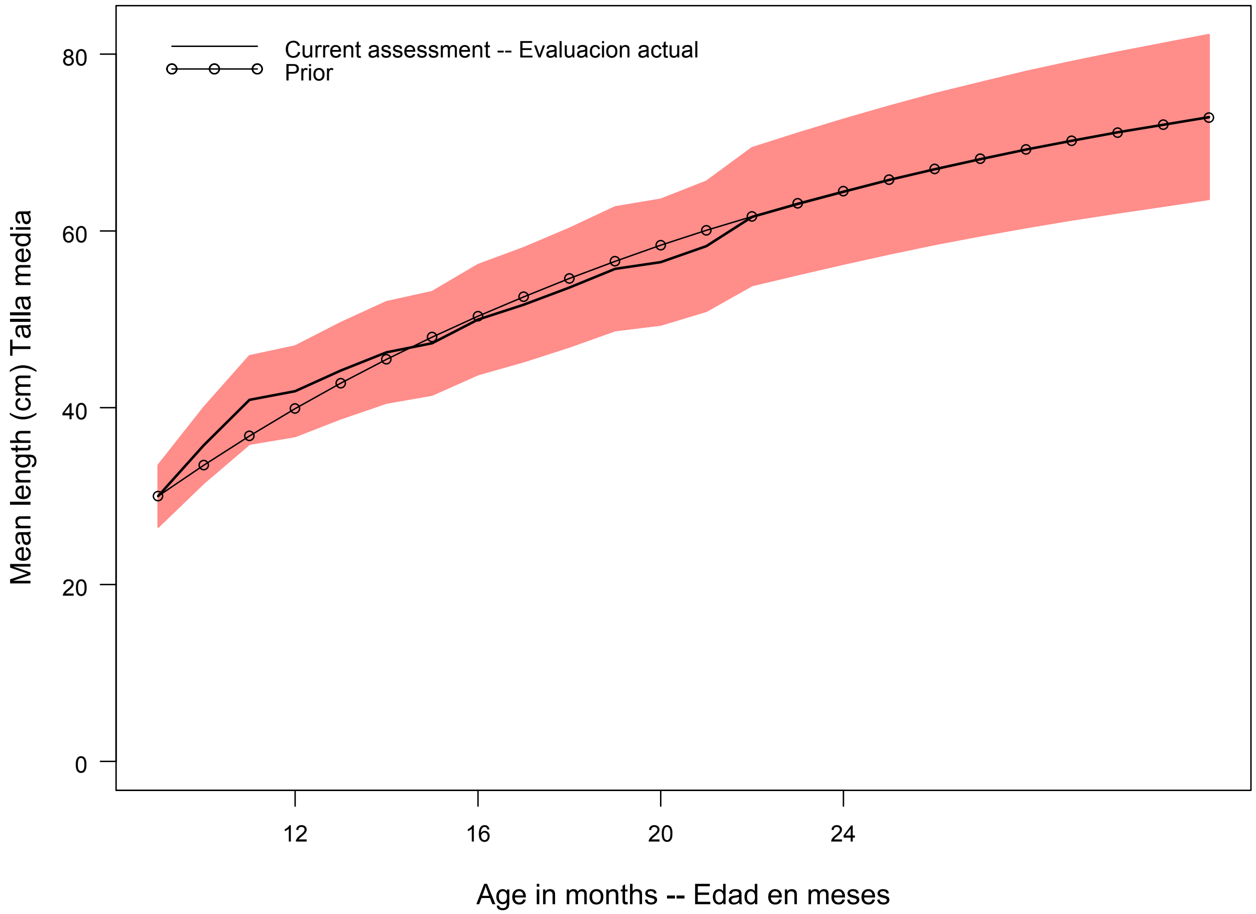

FIGURE 3.1. Growth curve used for the non-monotonic selectivity assessment of skipjack tuna in the EPO. The shaded area represents the variance of length-at-age (plus and minus two standard deviations) and the smooth curve is the prior.
FIGURA 3.1. Curva de crecimiento usada para la evaluación de selectividad no monotónica del atún barrilete en el OPO. La zona sombreada representa la varianza de la talla a edad (más y menos dos desviaciones estándar).

FIGURE 3.2. Natural mortality (*M*) rates, at monthly intervals, used for the assessment of skipjack tuna in the EPO.
FIGURA 3.2. Tasas de mortalidad natural (*M*), a intervalos mensuales, usadas para la evaluación del atún barrilete en el OPO.

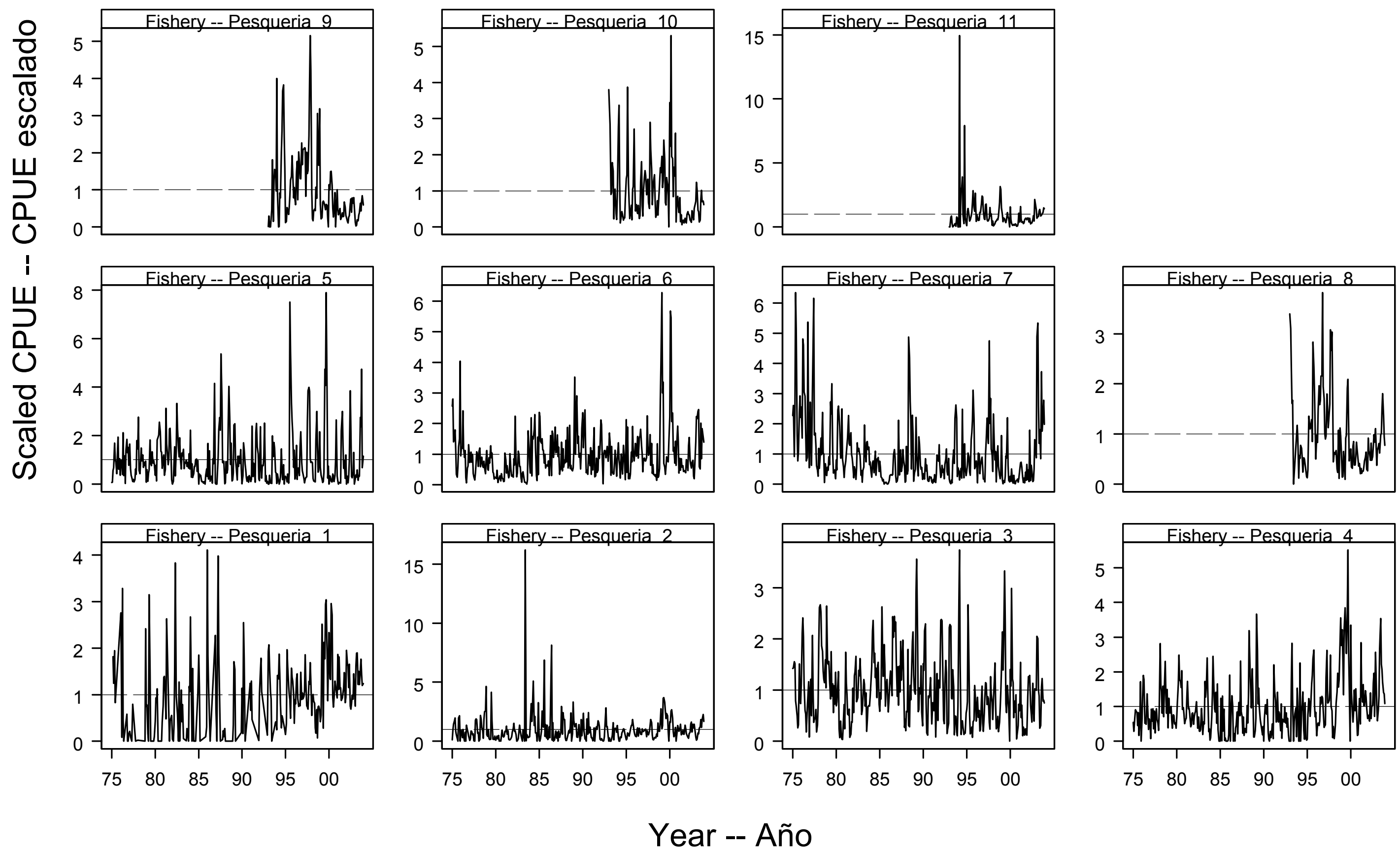

FIGURE 4.1. CPUEs for the fisheries defined for the stock assessment of skipjack tuna in the EPO (Table 2.1). Since the data were summarized on a monthly basis, there are 12 observations of CPUE for each year. The CPUEs are in kilograms per day fished. The data are adjusted so that the mean of each time series is equal to 1.0. It should be noted 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 barrilete en el OPO (Tabla 2.1). Ya que se resumieron los datos por mes, hay 12 observaciones de CPUE para cada año. Se expresan las CPUE en kilogramos por día de pesca. Se ajustaron los datos para que el promedio de cada serie de tiempo equivalga a 1,0. Nótese que las escalas verticales de los recuadros son diferentes.

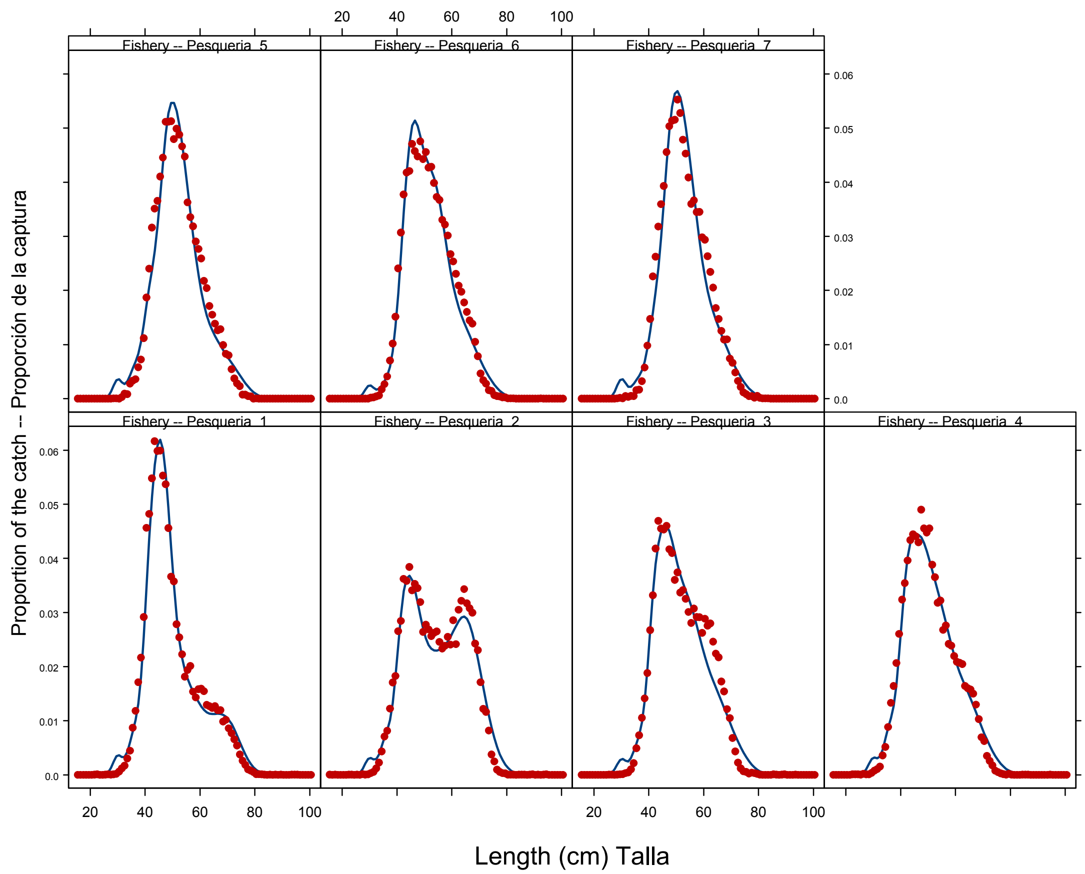

FIGURE 4.2. Average observed (dots) and predicted (curves) size compositions of the catches taken by the fisheries for the non-monotonic selectivity assessment.

FIGURA 4.2. Composición media por tamaño observada (puntos) y predicha (curvas) de las capturas realizadas por las pesquerías definidas para evaluación de selectividad no monotónica.

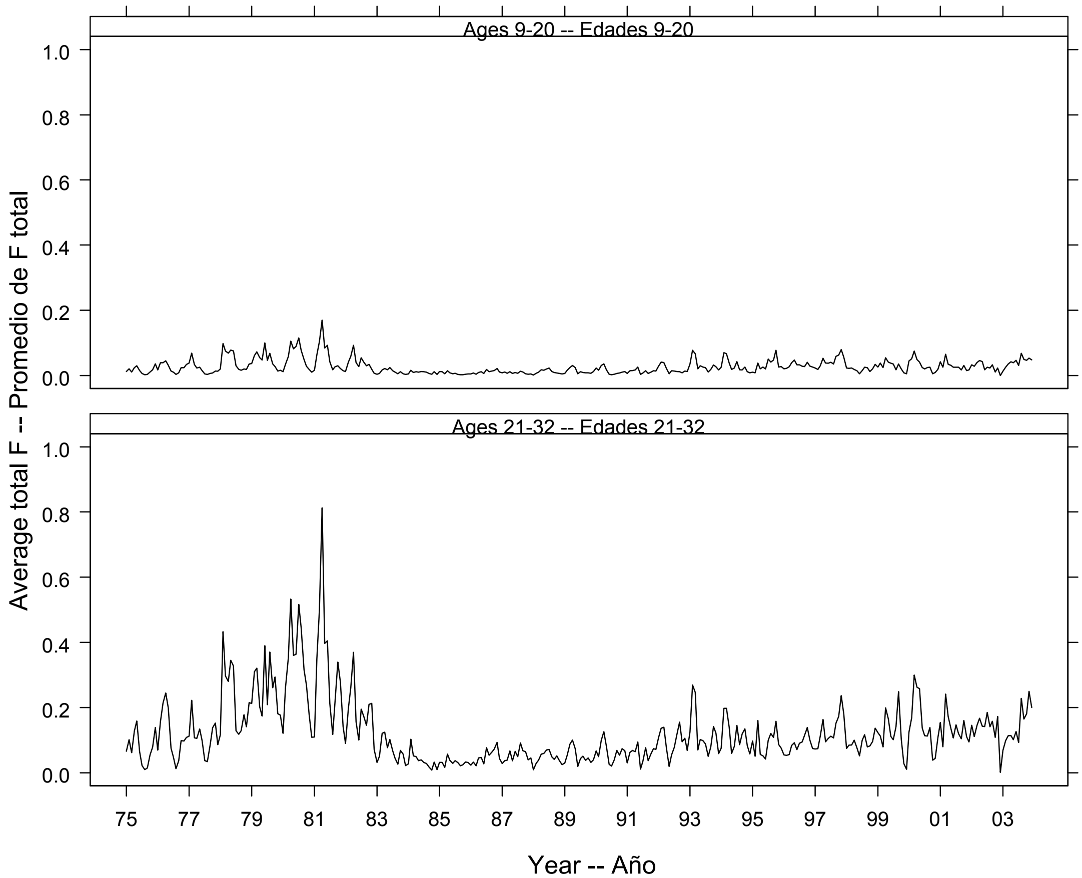

FIGURE 4.3a. Time series of average total monthly fishing mortality of skipjack tuna that have been recruited to the fisheries of the EPO. Each panel illustrates an average of 12 monthly fishing mortality vectors that affected the fish that were as old as the range of ages indicated in the title of each panel. For example, the trend illustrated in the upper panel is an average of the fishing mortalities that affected fish that were 9-20 months old.

FIGURA 4.3a. Series de tiempo de la mortalidad por pesca mensual total media de atún barrilete reclutado a las pesquerías del OPO. Cada recuadro ilustra un promedio de 12 vectores mensuales de mortalidad por pesca que afectaron los peces de la edad indicada en el título de cada recuadro. Por ejemplo, la tendencia ilustrada en el recuadro superior es un promedio de las mortalidades por pesca que afectaron a los peces de entre 9 y 20 meses de edad.

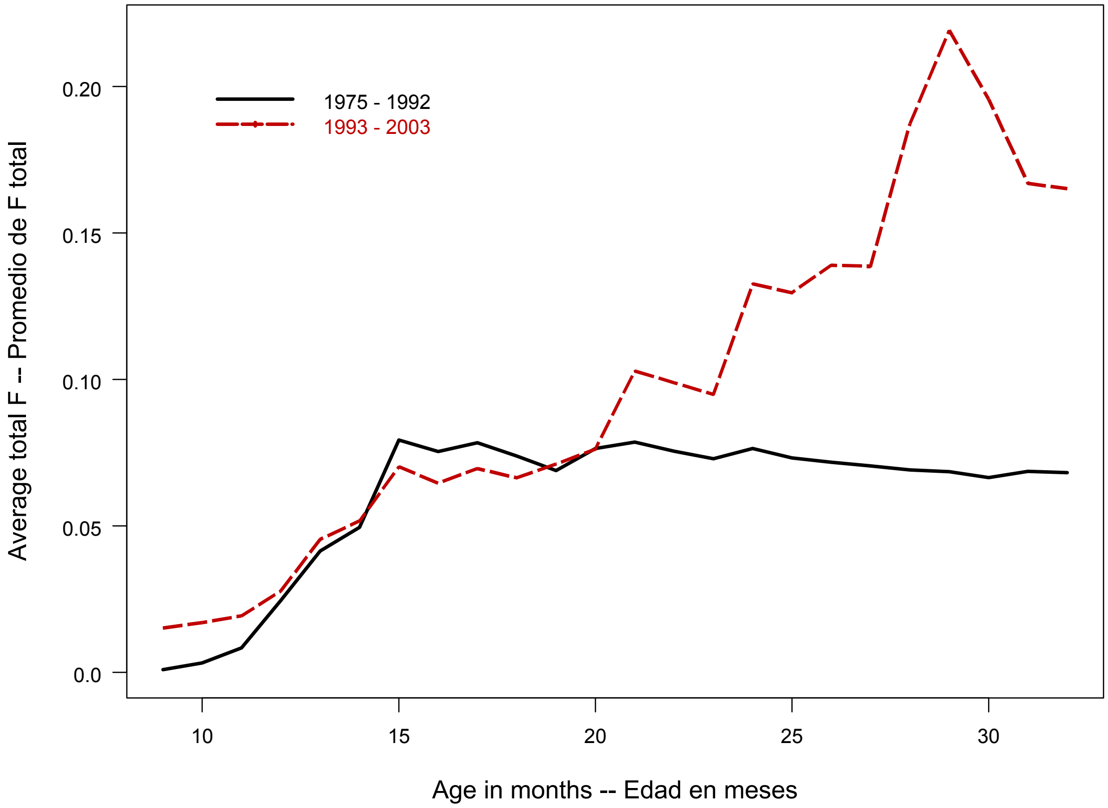

FIGURE 4.3b. Average age-specific fishing mortality of skipjack tuna that have been recruited to the fisheries of the EPO. The estimates are separated into the periods before and after the expansion of the floating-object fisheries.

FIGURA 4.3b. Mortalidad por pesca media por edad de atún barrilete reclutado a las pesquerías del OPO, de la evaluación de selectividad no monotónica. Se separan las estimaciones en los períodos antes y después de la expansión de las pesquerías de objetos flotantes.

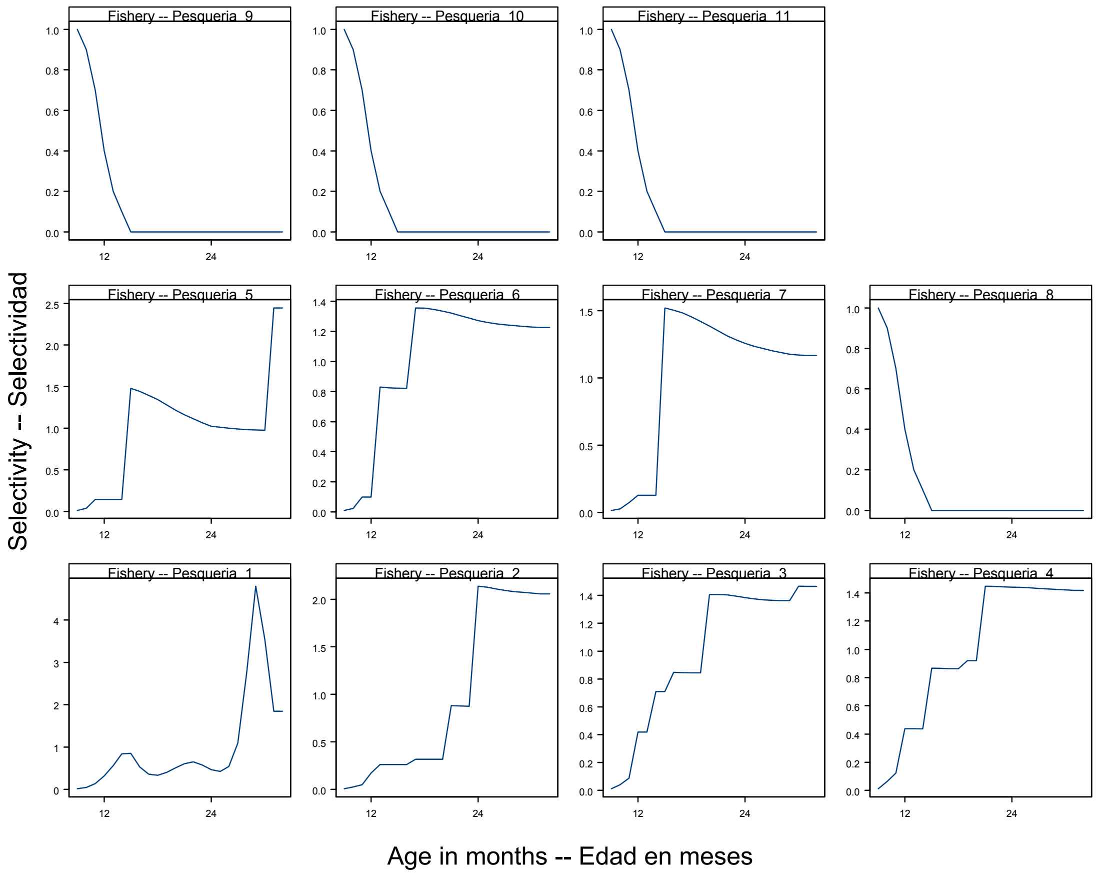

FIGURE 4.4. Selectivity curves for the 11 fisheries that take skipjack tuna in the EPO. The curves for Fisheries 1-7 were estimated with the A-SCALA method. The curves for Fisheries 8-11 are based on assumptions.

FIGURA 4.4. Curvas de selectividad para las 11 pesquerías que capturan atún barrilete en el OPO. Se estimaron las curvas de las Pesquerías 1-7 con el método A-SCALA; las de la Pesquerías 8-11 se basan en supuestos.

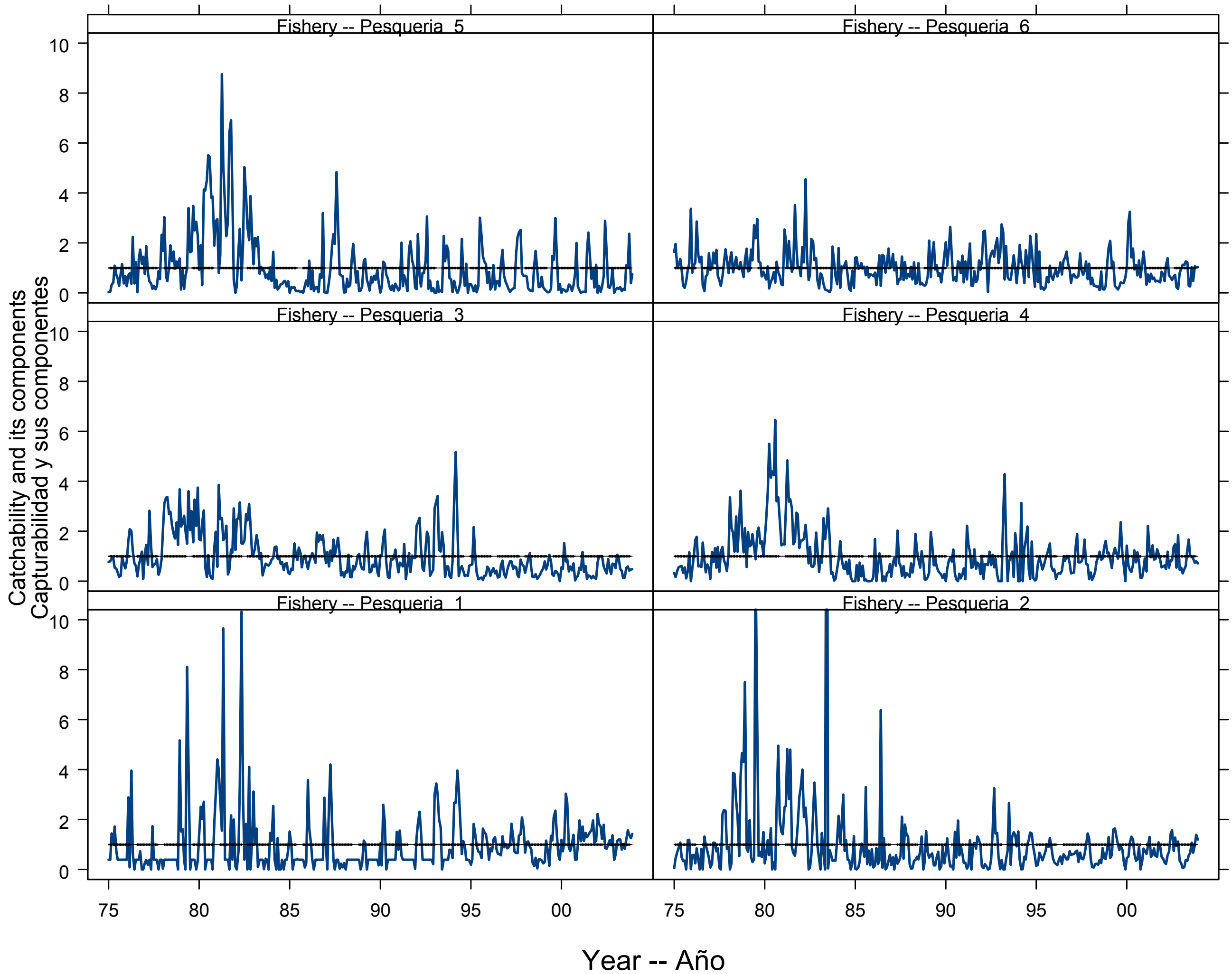

FIGURE 4.5. Trends in catchability (q) for the six main fisheries that take skipjack tuna in the EPO.
FIGURA 4.5. Tendencias en capturabilidad (q) para las seis pesquerías principales que capturan atún barrilete en el OPO.

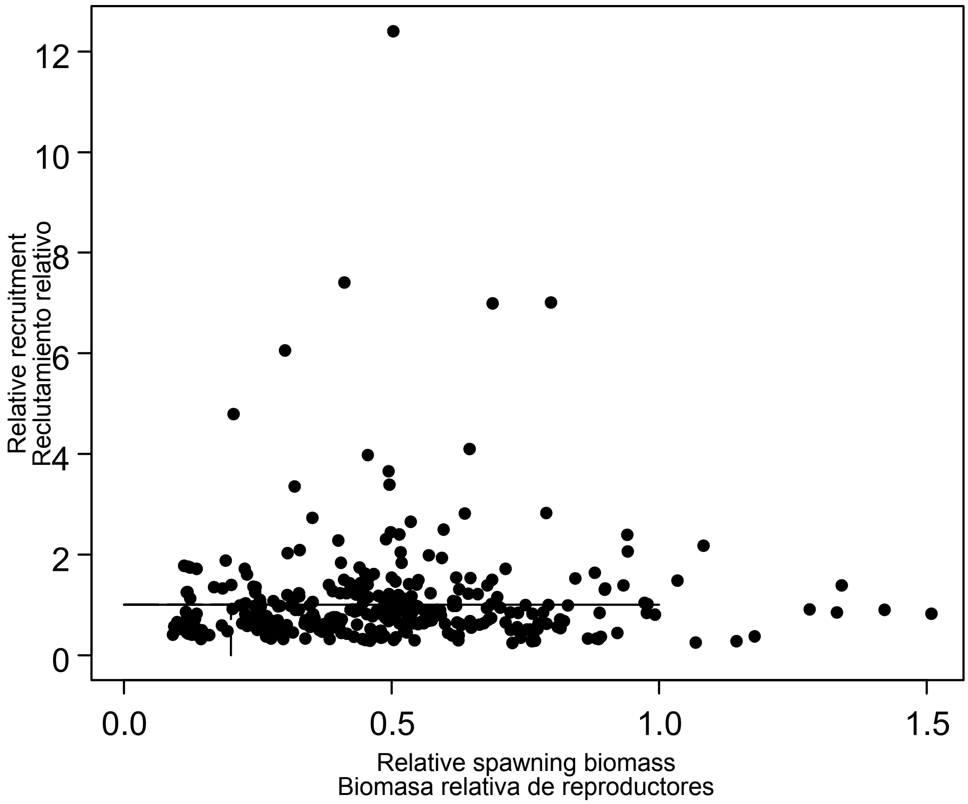

FIGURE 4.6. Estimated relationships between recruitment of skipjack tuna and spawning biomass. The recruitment is scaled so that the average recruitment is equal to 1.0. The spawning biomass is scaled so that the average unexploited spawning biomass is equal to 1.0.

FIGURA 4.6. Relaciones estimadas entre el reclutamiento de atún barrilete y la biomasa reproductora. Se escala el reclutamiento para que el reclutamiento medio equivalga a 1,0, y la biomasa reproductora para que la biomasa reproductora no explotada media equivalga a 1,0.

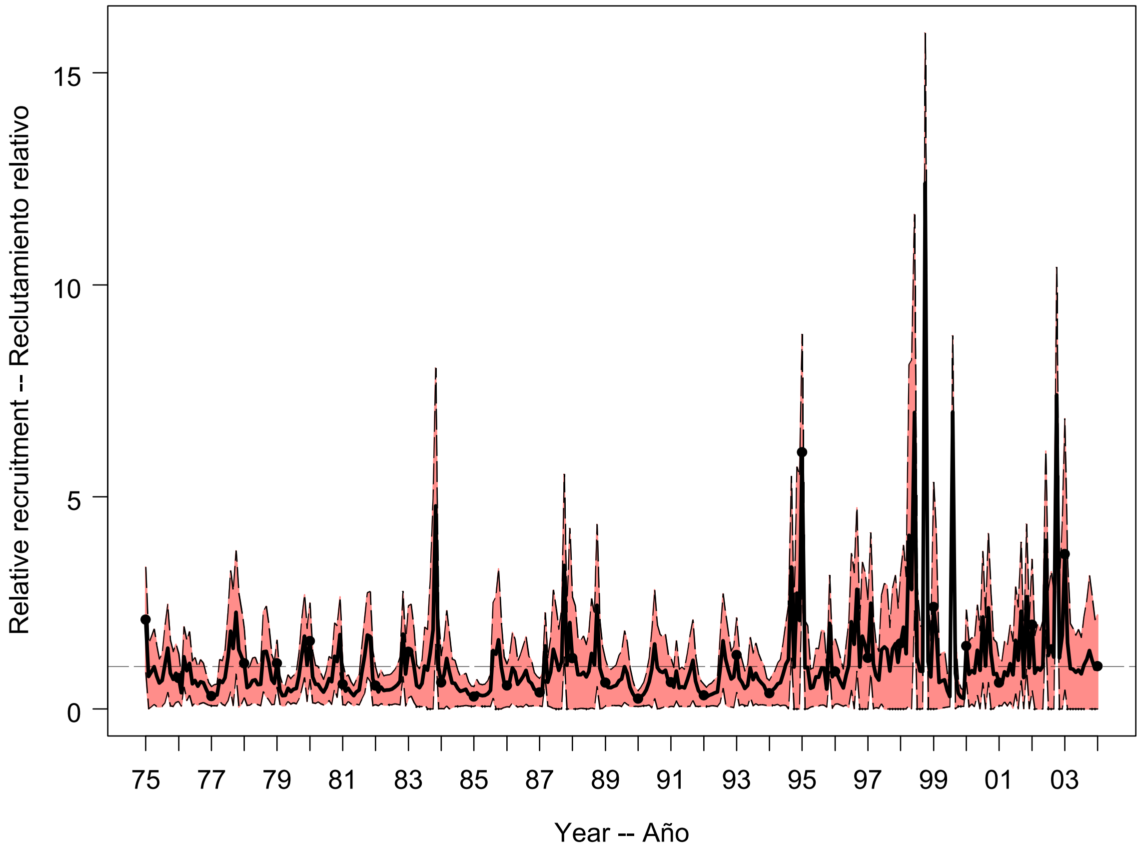

FIGURE 4.7. Estimated recruitment of skipjack tuna to the fisheries of the EPO. The estimates are scaled so that the average recruitment is equal to 1.0. The solid line illustrates the maximum-likelihood estimates, and the dashed line the 95% confidence intervals. The labels on the time axis are drawn at the start of each year, but, since the assessment model represents time on a monthly basis, there are 12 estimates of recruitment for each year.

FIGURA 4.7. Reclutamiento estimado de atún barrilete a las pesquerías del OPO. Se escalan las estimaciones para que el reclutamiento medio equivalga a 1,0. La línea sólida ilustra las estimaciones de probabilidad máxima, y la línea de trazos los intervalos de confianza de 95%. 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 meses, hay 12 estimaciones de reclutamiento para cada año.

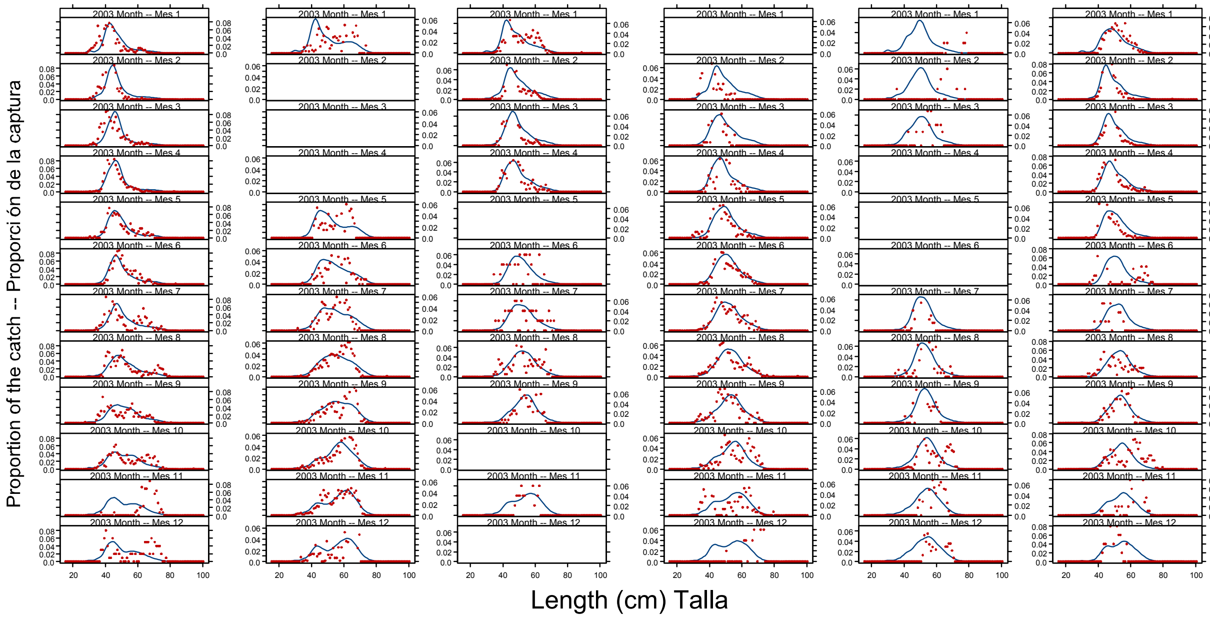

FIGURE 4.8. Observed (dots) and predicted (curves) size compositions of the catches recently taken by the fisheries that take skipjack tuna in association with floating objects and unassociated schools.
FIGURA 4.8. Composiciones por tamaño observadas (puntos) y predichas (curvas) de las capturas recientes de las pesquerías que capturan atún barrilete en asociación con objetos flotantes y no asociado, de la evaluación de selectividad no monotónica.

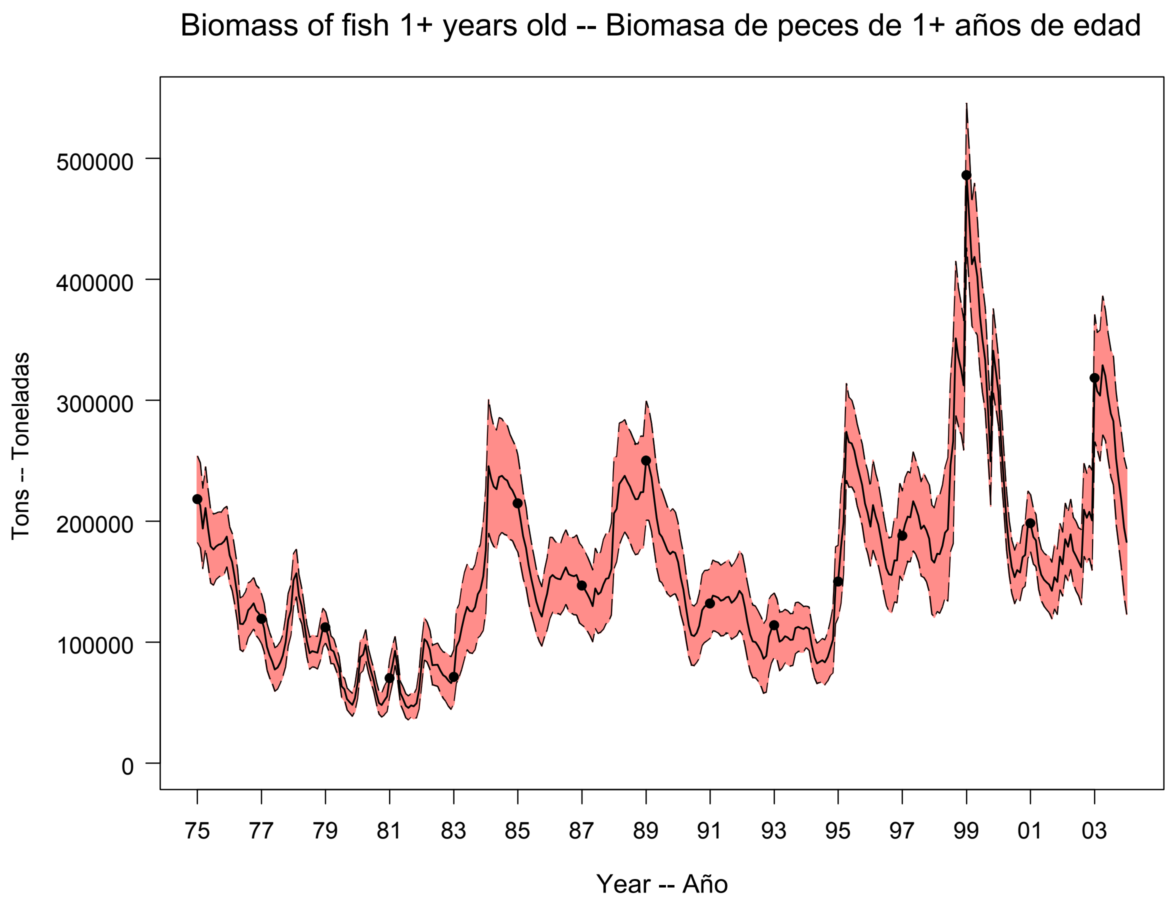

FIGURE 4.9a. Estimated biomass of skipjack tuna in the EPO. Since the assessment model represents time on a monthly basis, there are 12 estimates of biomass for each year.
FIGURA 4.9a. Biomasa estimada de atún barrilete en el OPO. Ya que el modelo de evaluación representa el tiempo por meses, hay 12 estimaciones de biomasa para cada año.

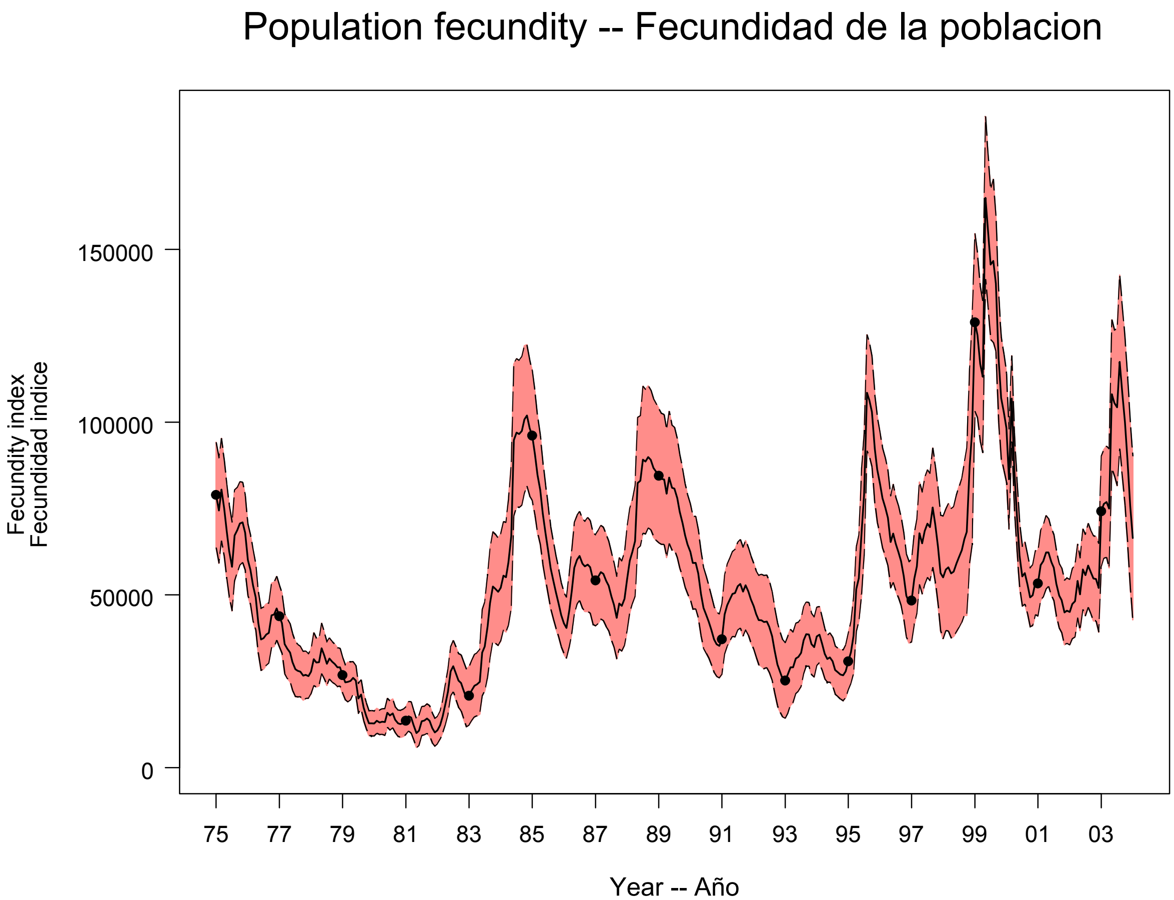

FIGURE 4.9b. Estimated relative spawning biomass of skipjack tuna in the EPO. Since the assessment model represents time on a monthly basis, there are 12 estimates of biomass for each year.
FIGURA 4.9b. Biomasa estimada de atún barrilete en el OPO. Ya que el modelo de evaluación representa el tiempo por meses, hay 12 estimaciones de biomasa para cada año.

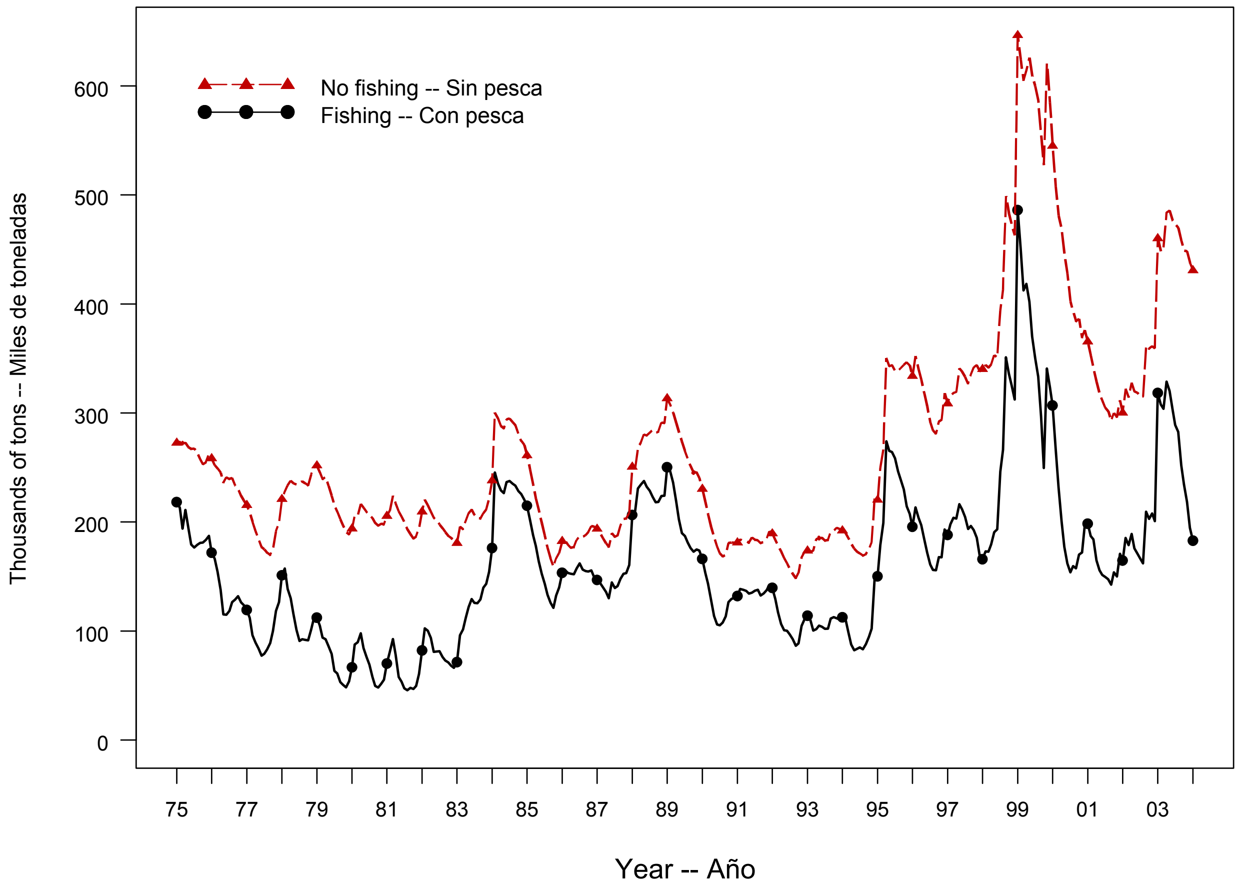

FIGURE 4.9c. Biomass trajectory of a simulated population of skipjack tuna that was not exploited during 1975-2002 (“no fishing”) and that predicted by the stock assessment model (“fishing”).
FIGURA 4.9c. Trayectoria de la biomasa de una población simulada de barrilete no explotada durante 1975-2002 (“sin pesca”) y la que predice el modelo de evaluación (“con pesca”), de la evaluación de selectividad no monotónica.

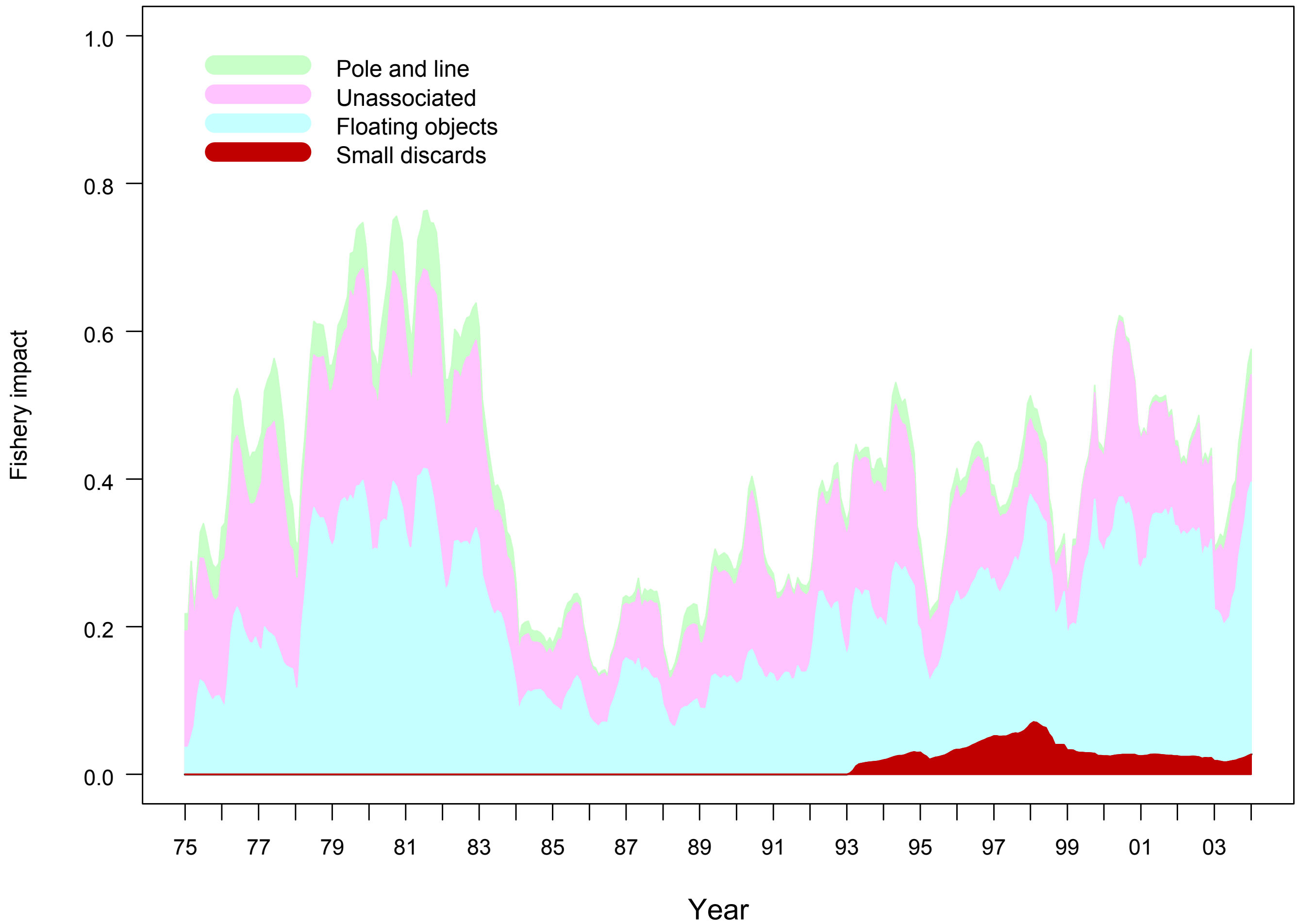

FIGURE 4.9d. Fishery impacts.
FIGURA 4.9d. Efecto de las pes querías

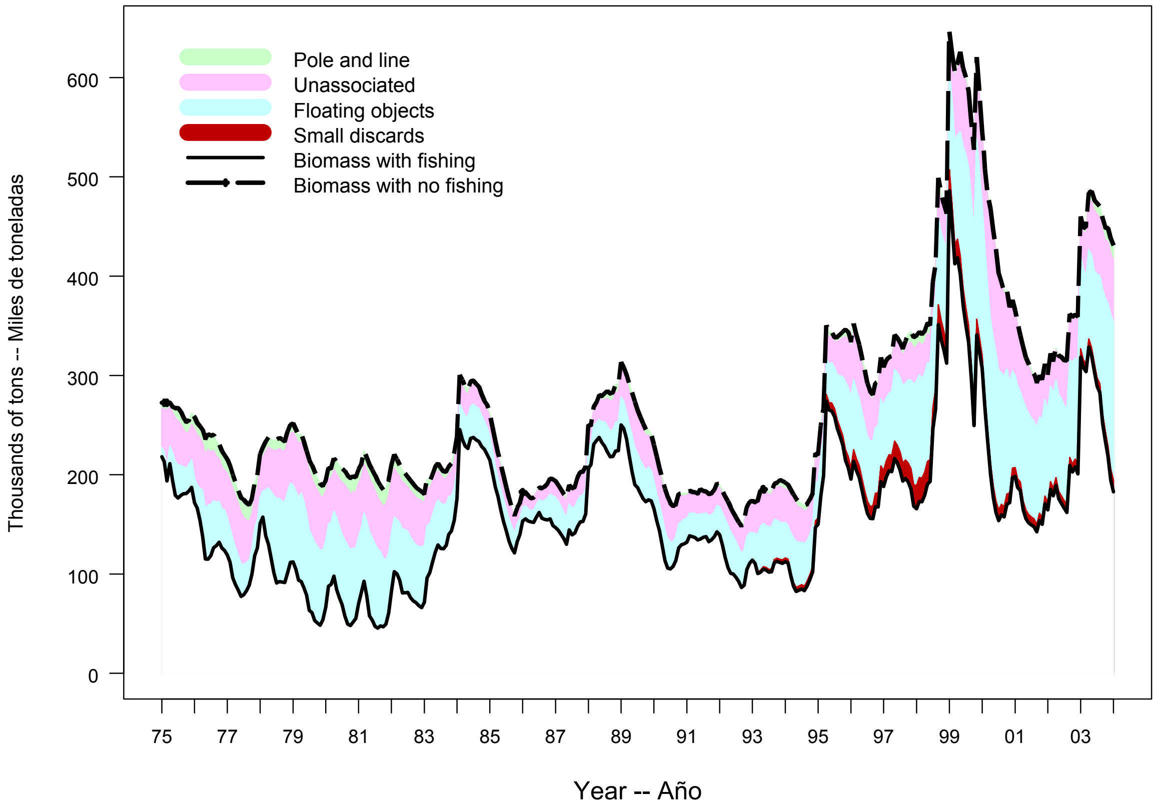

FIGURE 4.9e. Biomass trajectory of a simulated population of skipjack tuna that was not exploited during 1975-2002 ("Biomass with no fishing") and that predicted by the stock assessment model ("Biomass with fishing"). The shaded areas between the two lines show the portion of the fishery impact attributed to each fishing method.

FIGURA 4.9e. Trayectoria de la biomasa de una población simulada de barrilete no explotada durante 1975-2002 ("Biomasa sin pesca") y la que predice el modelo de evaluación ("Biomasa con pesca"). Las áreas sombreadas entre las dos líneas muestran la proporción del efecto de la pesqería por cada métedo de pesca.

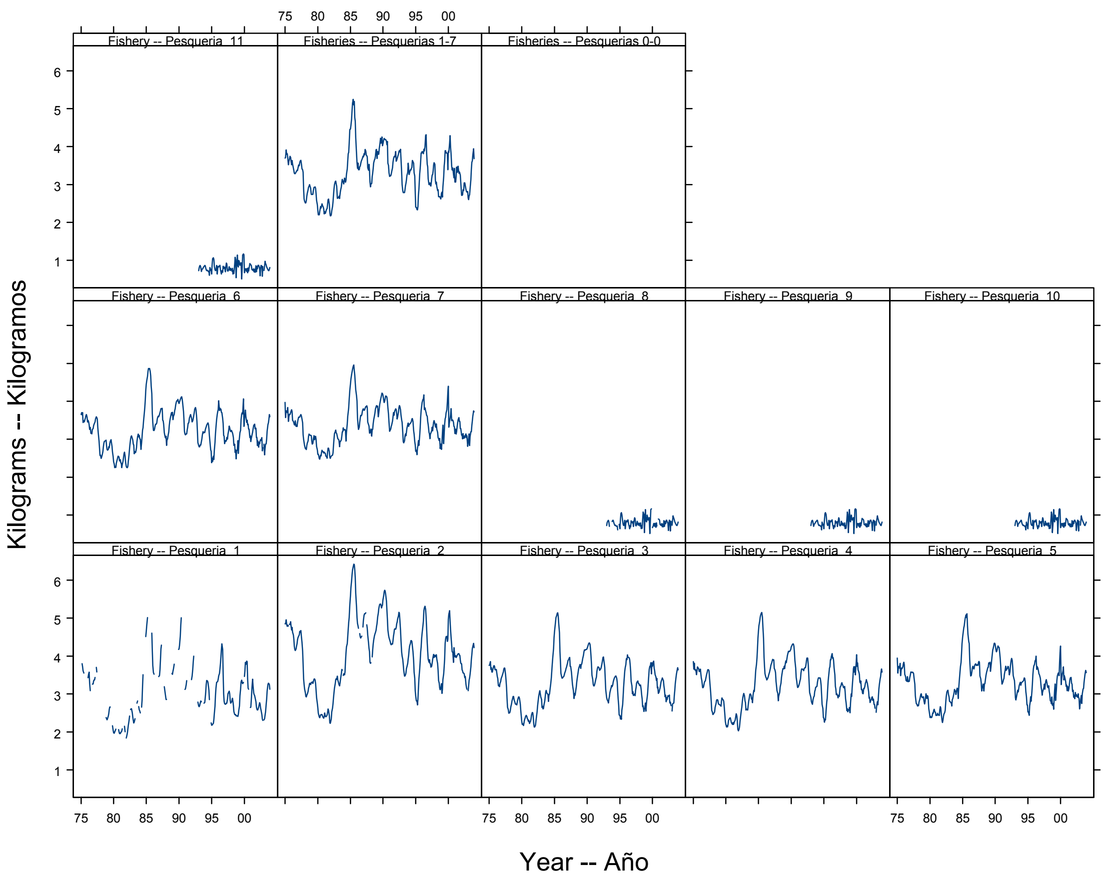

FIGURE 4.10. Estimated average weights of skipjack tuna caught by the fisheries of the EPO. The time series for "Fisheries 1-7" is an average of Fisheries 1 through 7.

FIGURA 4.10. Peso medio estimado de atún barrilete capturado en las pesquerías del OPO. La serie de tiempo de "Pesquerías 1-7" es un promedio de las Pesquerías 1 a 7.

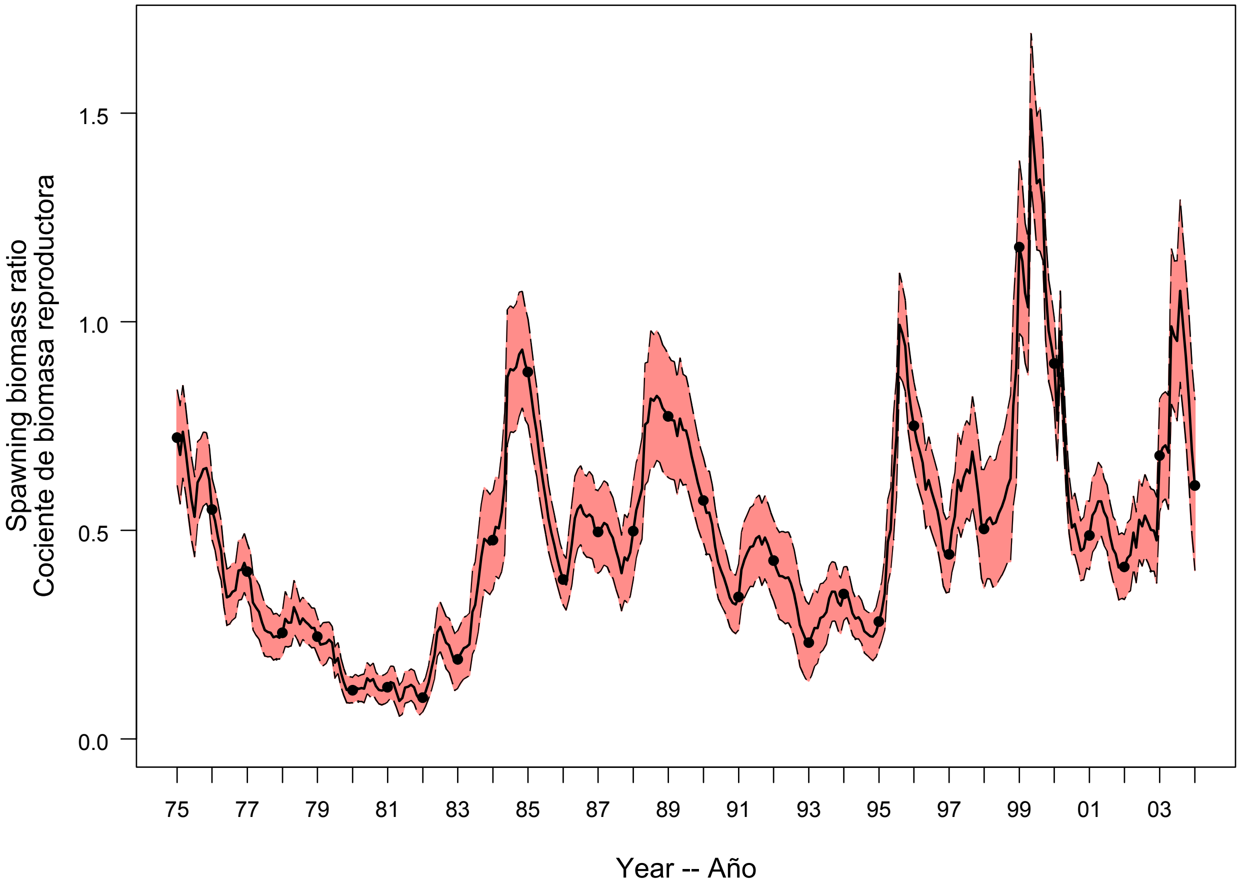

FIGURE 5.1. Estimated time series of spawning biomass ratios (SBRs) for skipjack tuna in the EPO.
FIGURA 5.1. Series de tiempo estimadas de los cocientes de biomasa reproductora (SBR) de atún barrilete en el OPO.

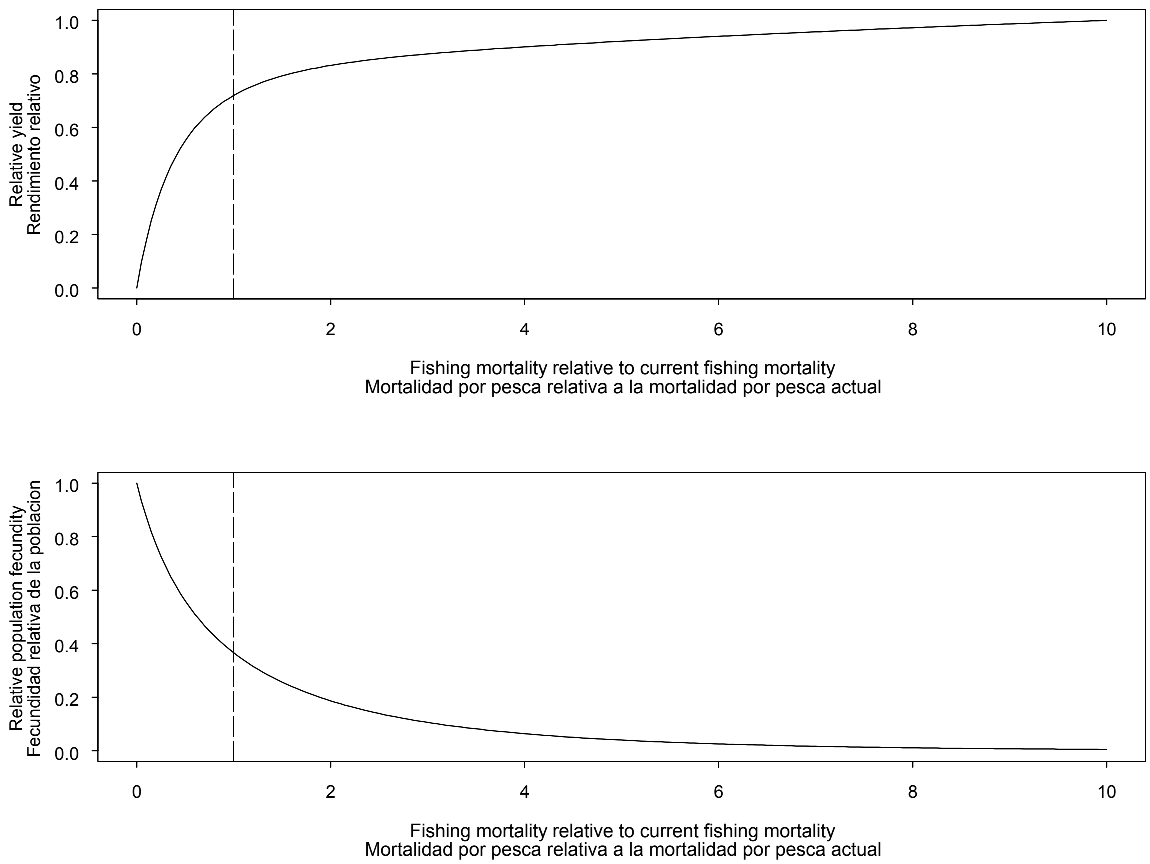

FIGURE 5.2. Estimated yield curve.

TABLE 2.1. Fisheries defined by the IATTC staff for the stock assessment of skipjack tuna in the EPO. PS = purse seine; LP = pole and line; 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 por el personal de la CIAT para la evaluación del stock de atún barrilete en el OPO. PS = red de cerco; LP = carnada; FLT = lance sobre objeto flotante; UNA = lance 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 type	Set type	Years	Sampling areas	Catch data
Pesquería	**Tipo de arte**	**Tipo de lance**	**Año**	**Zonas de muestreo**	**Datos de captura**
1	PS	FLT	1981-2003	11-12	retained catches + discards from inefficiencies in fishing process–descargas + descartes de ineficacias en el proceso de pesca
2	PS	FLT	1981-2003	7, 9	
3	PS	FLT	1981-2003	5-6, 13	
4	PS	FLT	1981-2003	1-4, 8, 10	
5	PS	UNA	1981-2003	1-4, 8, 10	retained catches + discards–descargas + descartes
6	PS	UNA	1981-2003	5-7, 9, 11-13	
7	PS-BB	DOL	1981-2003	1-13	
8	PS	FLT	1993-2003	11-12	discards of small fish from size-sorting the catch by Fishery 1–descartes de peces pequeños de clasificación por tamaño en la Pesquería 1
9	PS	FLT	1993-2003	7, 9	discards of small fish from size-sorting the catch by Fishery 2–descartes de peces pequeños de clasificación por tamaño en la Pesquería 2
10	PS	FLT	1993-2003	5-6, 13	discards of small fish from size-sorting the catch by Fishery 3–descartes de peces pequeños de clasificación por tamaño en la Pesquería 3
11	PS	FLT	1993-2003	1-4, 8, 10	discards of small fish from size-sorting the catch by Fishery 4–descartes de peces pequeños de clasificación por tamaño en la Pesquería 4

TABLE 4.1. Estimated total annual recruitment to the fishery at the age of 9 months (millions of fish), initial biomass (metric tons present at the beginning of the year), and relative spawning biomass of skipjack tuna in the EPO for the non-monotonic selectivity assessment. Biomass is defined as the total weight of skipjack one year of age and older; spawning biomass is estimated with the maturity schedule and sex ratio data.

TABLA 4.1. Reclutamiento anual total estimado a la pesquería a la edad de 9 meses (en millones de peces), biomasa inicial (toneladas métricas presentes al principio de año), y biomasa reproductora relativadel atún barrilete en el OPO para la evaluación de selectividad no monotónica. Se define la biomasa como el peso total de barrilete de un año o más de edad; se estima la biomasa reproductora con el calendario de madurez y datos de proporciones de sexos.

Year Año	Total recruitment Reclutamiento total	Biomass of age-1+ fish Biomasa de peces de edad 1+	Relative spawning biomass Biomasa reproductora relativa
1975	2,107	773,493	0.31
1976	1,110	575,413	0.23
1977	1,510	392,144	0.15
1978	1,324	400,493	0.07
1979	890	323,813	0.07
1980	1,087	140,292	0.02
1981	940	120,793	0.01
1982	941	135,086	0.01
1983	2,221	158,147	0.03
1984	1,635	391,802	0.13
1985	1,317	780,717	0.36
1986	1,476	521,343	0.20
1987	1,684	531,962	0.20
1988	1,928	496,278	0.16
1989	967	628,352	0.22
1990	1,502	385,367	0.16
1991	1,521	445,062	0.08
1992	1,140	553,849	0.17
1993	742	429,152	0.13
1994	2,116	201,523	0.03
1995	2,496	474,700	0.04
1996	2,346	757,680	0.29
1997	2,414	700,881	0.18
1998	7,385	595,865	0.19
1999	5,650	2,017,829	0.42
2000	1,890	2,140,851	1.00
2001	1,294	636,298	0.39
2002		773,493	0.31

TABLE 4.2. Estimates of the average sizes of skipjack tuna for the non-monotonic selectivity assessment. The ages are expressed in months after hatching.

TABLA 4.2. Estimaciones del tamaño medio de atún barrilete de la evaluación de selectividad no monotónica. Se expresan las edades en meses desde la cría.

Age (months)	Average length (cm)	Average weight (kg)	Age (months)	Average length (cm)	Average weight (kg)
Edad (trimestres)	**Talla media (cm)**	**Peso medio (kg)**	**Edad (trimestres)**	**Talla media (cm)**	**Peso medio (kg)**
9	30	0.47	21	58.28	4.36
10	35.76	0.85	22	61.60	5.24
11	40.89	1.33	23	63.07	5.67
12	41.88	1.45	24	64.44	6.09
13	44.20	1.73	25	65.76	6.52
14	46.27	2.02	26	66.99	6.93
15	47.29	2.17	27	68.13	7.34
16	49.98	2.61	28	69.21	7.73
17	51.67	2.91	29	70.21	8.11
18	53.60	3.29	30	71.14	8.48
19	55.71	3.75	31	72.02	8.83
20	56.48	3.92	32	72.88	9.19

APPENDIX A: ADDITIONAL RESULTS FROM THE ASSESSMENTS

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

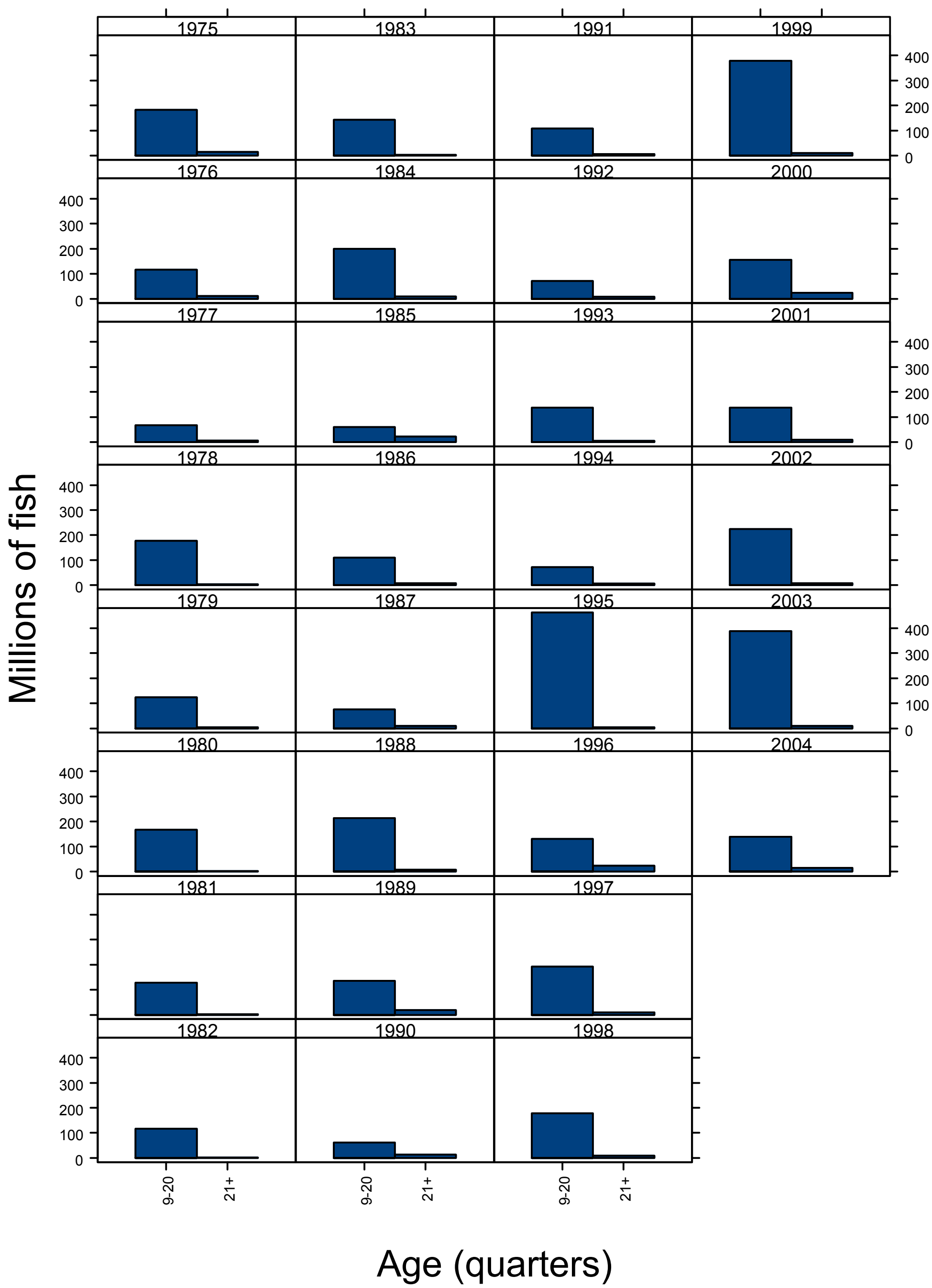

FIGURE A.1. Numbers of skipjack tuna present in the EPO on January 1 of each calendar year, from the non-monotonic selectivity assessment.

FIGURA A.1. Número de atunes barrilete presentes en el OPO el 1 de enero de cada año, de la evaluación de selectividad no monotónica..

TABLE A.1. Average annual fishing mortality rates on skipjack tuna in the EPO.
TABLA A.1. Tasas de mortalidad por pesca anual media para el atún barrilete en el OPO.

Year	Basecase	
	Ages 9-20	Ages 21+
Año	Selectividad no monotónica	
	Edad 9-20	Edad 21+
1975	0.4140	1.0211
1976	0.7592	1.6470
1977	0.8278	1.5408
1978	1.1968	3.1791
1979	1.2188	3.1335
1980	1.1848	3.2645
1981	1.4563	3.9536
1982	0.9699	2.2584
1983	0.3425	0.8541
1984	0.2071	0.5959
1985	0.2514	0.3941
1986	0.2922	0.4821
1987	0.3631	0.5827
1988	0.2871	0.5012
1989	0.3620	0.6812
1990	0.5015	0.8465
1991	0.3574	0.6774
1992	0.6510	1.2715
1993	0.7773	1.9557
1994	0.7967	1.6854
1995	0.3675	1.2760
1996	0.4698	0.9469
1997	0.6371	1.4708
1998	0.5190	1.1371
1999	0.6364	1.8473
2000	0.8691	2.3969
2001	0.7830	2.1682
2002	0.6946	2.0077
2003	0.6221	1.4732

APPENDIX B: ADDITIONAL RESULTS FROM THE SENSITIVITY ANALYSES

This appendix contains additional results from the sensitivity analyses of skipjack tuna in the EPO.

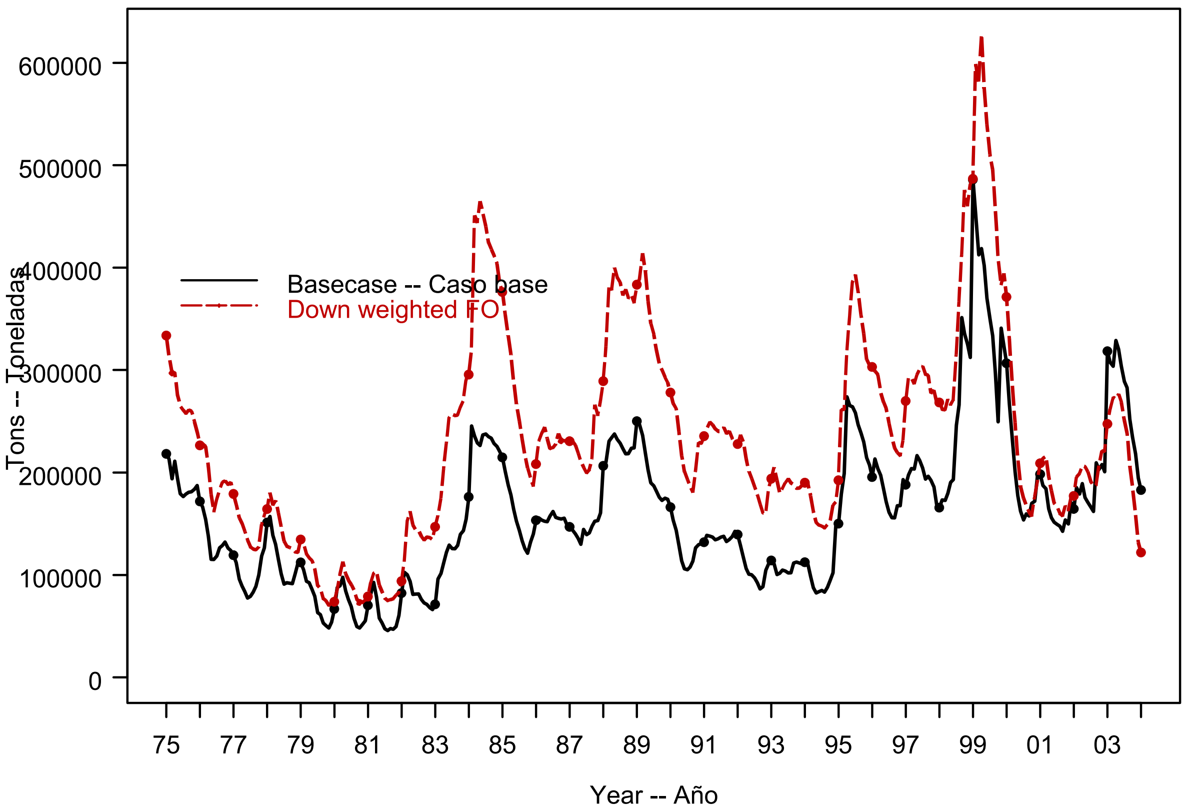

FIGURE B.1. Comparison of estimates of biomass of skipjack tuna from the base case and from the sensitivity analysis that downweights the information about abundance in the catch and effort data for the floating-object fisheries

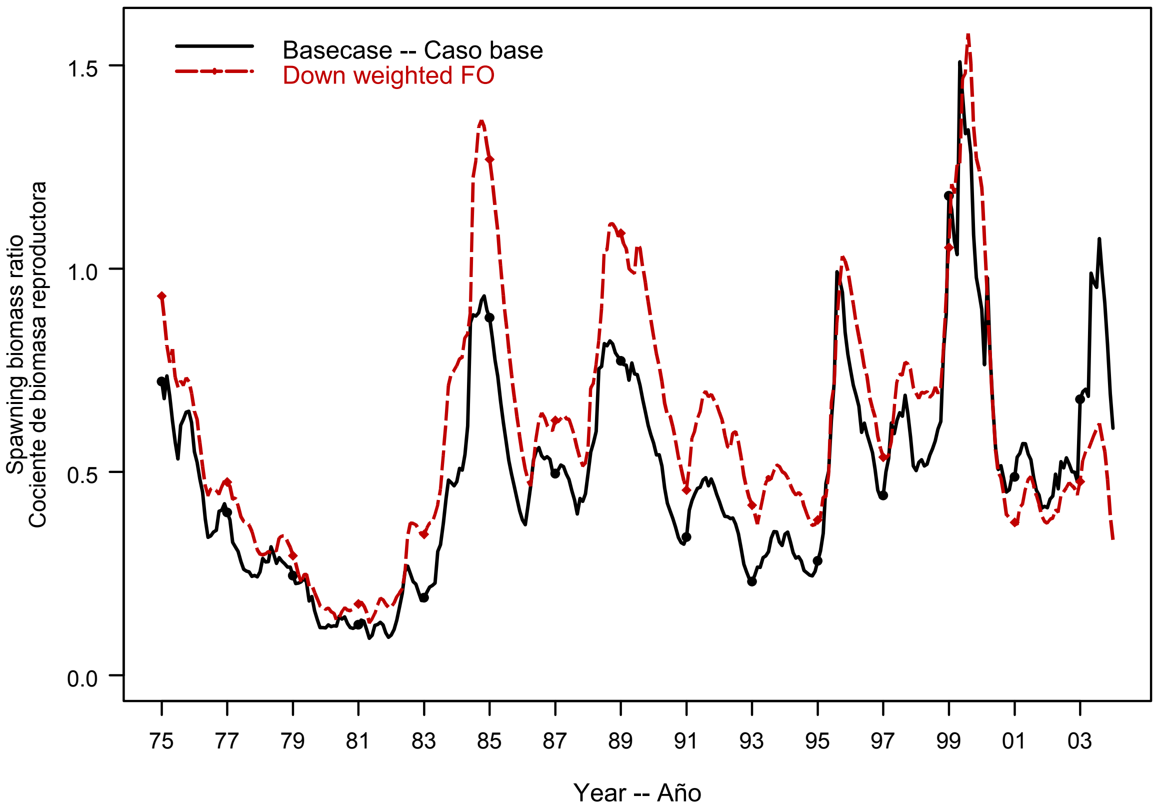

FIGURE B.2. Comparison of estimates of SBR of skipjack tuna from the base case and from the sensitivity analysis that down weights the information about abundance in the catch and effort data for the floating-object fisheries

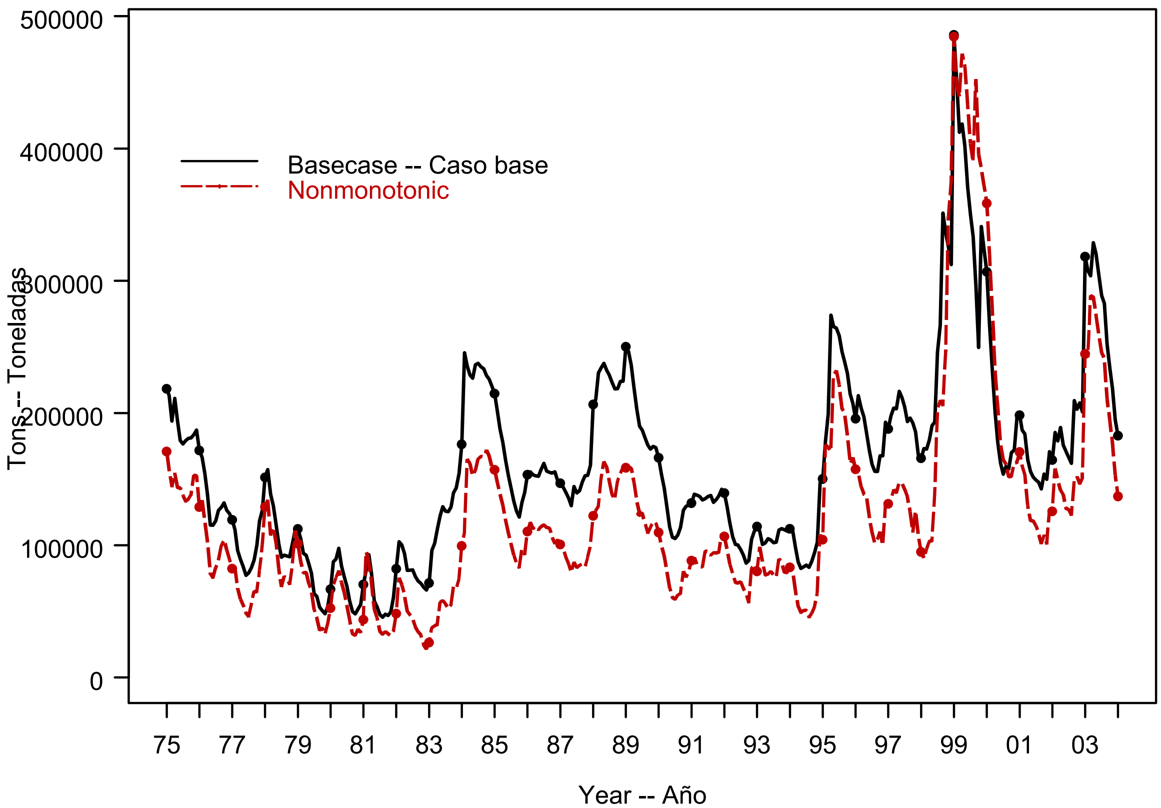

FIGURE B.3. Comparison of estimates of biomass of skipjack tuna from the base case and from the sensitivity analysis that allows dome-shaped selectivity.

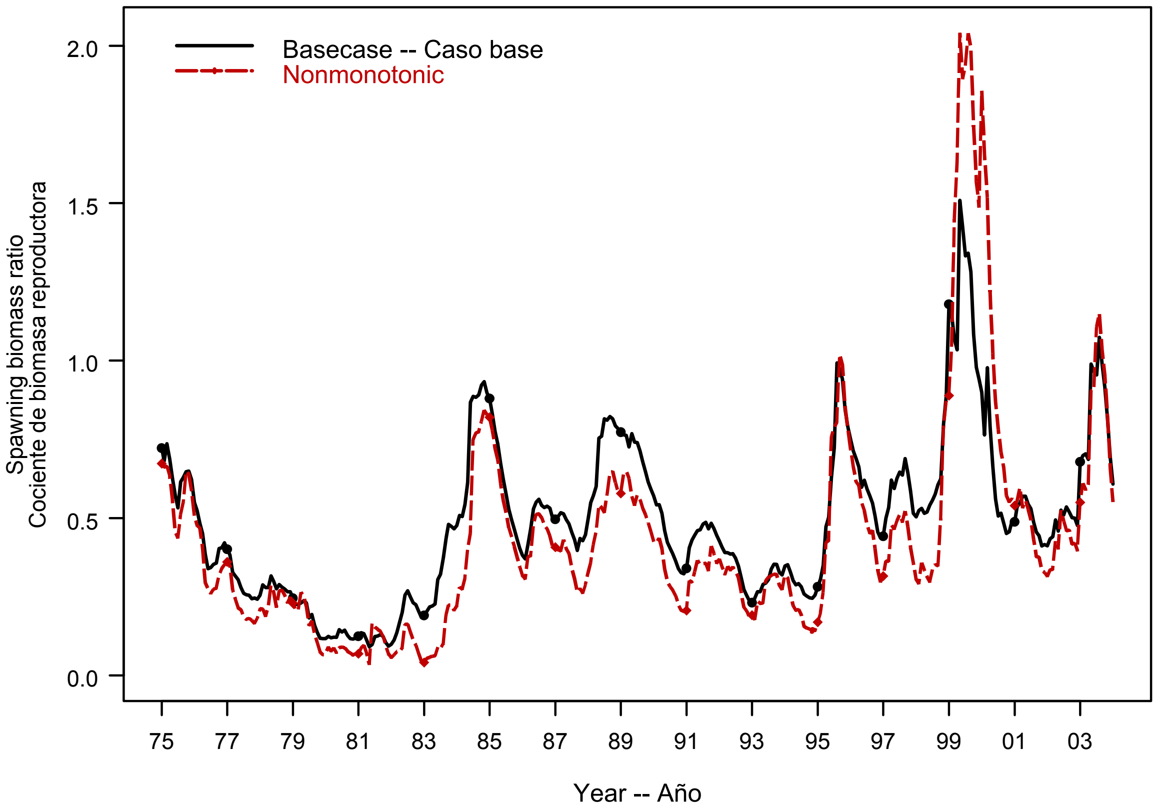

FIGURE B.4. Comparison of estimates of SBR of skipjack tuna from the base case and from the sensitivity analysis that allows dome-shaped selectivity

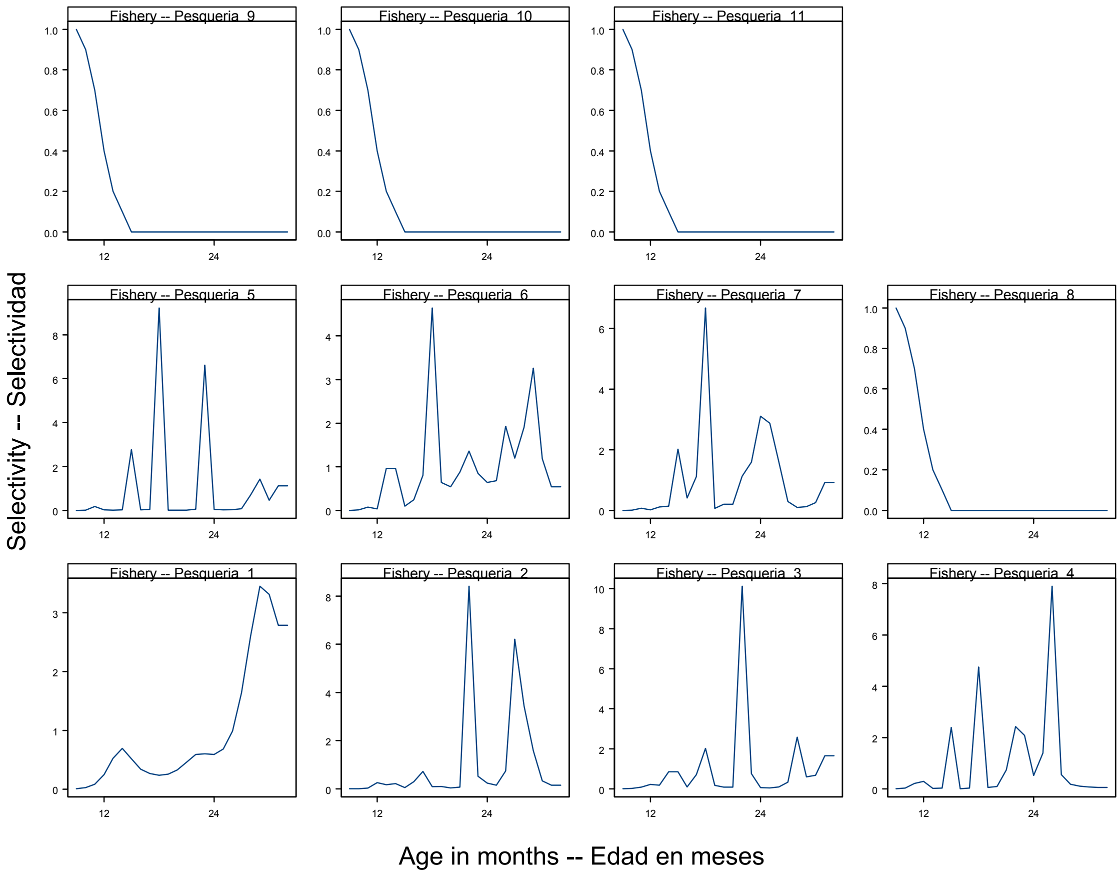

FIGURE B.5. Estimates of selectivity from the base case and from the sensitivity analysis that allows dome-shaped selectivity.