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STATUS OF BIGEYE TUNA IN THE EASTERN PACIFIC OCEAN

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1. EXECUTIVE SUMMARY

This report presents the current stock assessment of bigeye tuna (*Thunnus obesus*) in the eastern Pacific Ocean (EPO). Unlike previous assessments, this assessment was conducted using Stock Synthesis II. Previous assessments were conducted with A-SCALA. There are several differences between Stock Synthesis II and A-SCALA, but the general model structure and data used are the same. The assessment reported here is based on the assumption that there is a single stock of bigeye in the EPO, and that there is no exchange of fish between the EPO and the western and central Pacific Ocean.

The stock assessment requires a substantial amount of information. Data on retained catch, discards, catch per unit of effort based indices of abundance, and size compositions of the catches from several different fisheries have been analyzed. Several assumptions regarding processes such as growth, recruitment, movement, natural mortality, fishing mortality, and stock structure have also been made. Catch, Catch per unit of effort, and length-frequency data for the surface fisheries have been updated to include new data for 2006 and revised data for 2000-2005.

Analyses were carried out to assess the sensitivity of results to: 1) sensitivity to the stock–recruitment relationship; 2) use of the southern longline CPUE data only; 3) estimating growth and assuming estimates for the asymptotic length parameter of the von Bertalanffy growth curve; 4) fitting to initial equilibrium catch; 5) iterative reweighing; and 6) using two time blocks for selectivity and catchability of the southern longnline fishery.

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 15 quarters old has increased substantially since 1993, and that on fish more than about 15 quarters old has increased slightly since then. The increase in fishing mortality on the younger fish was caused by the expansion of the fisheries that catch bigeye in association with floating objects.

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

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

The biomass of 3+-quarter-old bigeye increased during 1983-1984, and reached its peak level of about 614,898 t in 1986, after which it decreased to an historic low of about 278,962 t at the beginning of 2005. Spawning biomass has generally followed a trend similar to that for the biomass of 3+-quarter-olds, but lagged by 1-2 years. There is uncertainty in the estimated biomasses of both 3+-quarter-old bigeye and spawners. Nevertheless, it is apparent that fishing has reduced the total biomass of bigeye in the EPO. The biomasses of both 3+-quarter-old fish and spawners were estimated to have increased in recent years.

The estimates of recruitment and biomass are only moderately sensitive to the steepness of the stock-recruitment relationship. The same estimates are very sensitive to the assumed value of the asymptotic length parameter in the von Bertalanffy growth equation. A lesser value of the asssymptotic length parameter gave greater biomasses and recruitments. When only the CPUE for the southern longline fishery was used the biomass was estimated to decline in the most recent years as a result of lower estimated recruiment.

When interative reweighting of the standard deviations and effective sample sizes of the likelihood functions was applied, more weight was given to the length frequency data and the biomass was estimated to be lower in the early and later segments of the time series, when compared to the base case.

When time blocks were applied to the selectivity and catchability of the southern logline fishery, the residual pattern of the model fit to the size composition data for this fishery was improved. Unlike when applying iterative reweighting to the base case without considering time blocking, the model fit to the southern longline CPUE index of abundance very closely. Biomass was similar to that estimated in the base case using iterative reweighting.

At the beginning of January 2007, the spawning biomass of bigeye tuna in the EPO was near the historic low level. At that time the SBR was about 0.20, about 10% less than the level corresponding to the AMSY.

Recent catches are estimated to have been about 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 corresponding to the AMSY is about 77% of the current (2004-2005) level of effort. The AMSY of bigeye in the EPO could be maximized if the age-specific selectivity pattern were similar to that for the longline fishery that operates south of 15°N because it catches larger individuals that are close to the critical weight. Before the expansion of the floating-object fishery that began in 1993, the AMSY was greater than the current AMSY and the fishing mortality was less than F_{AMSY}.

All analyses, except that incorporating the low assumed value for the asymptotic length parameter of the von Bertalanffy growth curve, suggest that at the beginning of 2007 the spawning biomass was below S_{AMSY}. AMSY and the *F* multiplier are sensitive to how the assessment model is parameterized, the data that are included in the assessment, and the periods assumed to represent average fishing mortality, but under all scenarios considered, except that incorporating the time blocks for the selectivity and catchability for the southern longline fishery witout iterative reweighting or low assumed value for the asymptotic length, fishing mortality is well above F_{AMSY}.

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

The effects of IATTC Resolution C-04-09 are estimated to be insufficient to allow the stock to remain at levels that would support AMSY.

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

2. DATA

Catch, effort, and size-composition data for January 1975 through December 2006 were used to conduct the stock assessment of bigeye tuna, *Thunnus obesus*, in the eastern Pacific Ocean (EPO). The data for 2006, which are preliminary, include records that had been entered into the IATTC databases as of mid-March 2007. All data are summarized and analyzed on a quarterly basis.

2.1. Definitions of the fisheries

Thirteen fisheries are defined for the stock assessment of bigeye tuna. These fisheries are defined on the basis of gear type (purse seine, pole and line, and longline), purse-seine set type (sets on floating objects, unassociated schools, and dolphins), time period, and IATTC length-frequency sampling area or latitude. The bigeye fisheries are defined in Table 2.1. 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 mixture of flotsam and FADs (Fisheries 4 and 12). It is assumed that it is appropriate to pool data relating to catches by pole-and-line gear and by purse-seine vessels setting on dolphins and unassociated schools (Fisheries 6 and 7). Relatively few bigeye are captured by the first two methods, and the data from Fisheries 6 and 7 are dominated by information on catches from unassociated schools of bigeye. Given this latter fact, Fisheries 6 and 7 will be referred to as fisheries that catch bigeye in unassociated schools in the remainder of this report.

2.2. Catch

To conduct the stock assessment of bigeye tuna, the catch and effort data in the IATTC databases are stratified according to the fishery definitions described in Section 2.1 and presented in Table 2.1. The three definitions relating to catch data used in previous reports (landings, discards, and catch) are described by Maunder and Watters (2001). The terminology in this report is consistent with the standard terminology used in other IATTC reports. Catches taken in a given year are assigned to that year even if they were not landed until the following year. Catches are assigned to two categories, retained catches and discards. Throughout the document the term "catch" will be used to reflect either total catch (discards plus retained catch) or retained catch, and the reader is referred to the context to determine the appropriate definition.

Three types of catch data are used to assess the stock of bigeye tuna (Table 2.1). Removals by Fisheries 1 and 8-9 are simply retained catch. Removals by Fisheries 2-5 and 7 are retained catch, plus some discards resulting from inefficiencies in the fishing process (see Section 2.2.3). Removals by Fisheries 10-13 are discards resulting only from sorting the catch taken by Fisheries 2-5 (see Section 2.2.3).

Updated and new catch data for the surface fisheries (Fisheries 1-7 and 10-13) have been incorporated into the current assessment. The species-composition method (Tomlinson 2002) was used to estimate catches of the surface fisheries. We calculated average scaling factors for 2000-2005 by dividing the total catch for all years and quarters for the species composition estimates by the total catch for all years and quarters for the standard estimates and applied these to the cannery and unloading estimates for 1975-1999. For Fisheries 1, 6, and 7 we used the average over Fisheries 2-5, for Fisheries 2 and 3 we used the average over Fisheries 2 and 3, and for Fisheries 4 and 5 we used the average over Fisheries 4 and 5. Harley and Maunder (2005) provide a sensitivity analysis that compares the results from the stock assessment using the species composition estimates of purse-seine fishery landings with the results from the stock assessment using cannery unloading estimates. Watters and Maunder (2001) provide a brief description of the method that is used to estimate surface fishing effort.

Updates and new catch and effort data for the longline fisheries (Fisheries 8 and 9) have also been incorporated into the current assessment. New or updated catch data were available for Chinese Taipei (2002-2005), the Peoples Republic of China (2001-2005), and Korea (2003-2005). Catch data for 2006 are available for Chinese Taipei, the Peoples Republic of China, the Republic of Korea, Japan, the United States, and Vanuatu from the monthly reporting statistics.

Trends in the catches of bigeye tuna taken from the EPO during each quarter from January 1975 through December 2006 are shown in Figure 2.2. There has been substantial annual and quarterly variation in the catches of bigeye made by all fisheries operating in the EPO (Figure 2.2). Prior to 1996, the longline fleet (Fisheries 8 and 9) removed more bigeye (in weight) from the EPO than did the surface fleet (Fisheries 1-7 and 10-13) (Figure 2.2). Since 1996, however, the catches by the surface fleet have mostly been greater than those by the longline fleet (Figure 2.2). It should be noted that the assessment presented in this report uses data starting from January 1, 1975, and substantial amounts of bigeye were already being removed from the EPO by that time.

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

2.2.1. 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 either case, the amount of discarded bigeye is estimated with information collected by IATTC or national observers, applying methods described by Maunder and Watters (2003). Regardless of why bigeye are discarded, it is assumed that all discarded fish die.

Estimates of discards resulting from inefficiencies in the fishing process are added to the retained catches made by purse-seine vessels (Table 2.1). No observer data are available to estimate discards for surface fisheries that operated prior to 1993 (Fisheries 1 and 6), and it is assumed that there were no discards from these fisheries. For surface fisheries that have operated since 1993 (Fisheries 2-5 and 7), there are periods for which observer data are not sufficient to estimate the discards. For these periods, it is assumed that the discard rate (discards/retained catches) is equal to the discard rate for the same quarter of the previous year or, if not available, a proximate 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 (Maunder and Hoyle, 2007). Watters and Maunder (2001) provide a rationale for treating such discards as separate fisheries. Estimates of the amounts of fish discarded during sorting are made only for fisheries that take bigeye associated with floating objects (Fisheries 2-5) because sorting is thought to be infrequent in the other purse-seine fisheries.

Time series of discards as proportions of the retained catches for the surface fisheries that catch bigeye tuna in association with floating objects are shown in Figure 2.4. For the largest floating-object fisheries (2, 3, and 5), the proportions of the catches discarded have been low for the last seven years relative to those observed during fishing on the strong cohorts produced in 1997. There is strong evidence that some of this is due to the weak year classes after 1997. However, there have been two large recruitments recently (Figure 4.5). It is possible that regulations prohibiting discarding of tuna have caused the proportion of discarded fish to decrease.

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

2.3. Indices of abundance

Indices of abundance were derived from purse-seine and longline catch and effort data. Fishing effort data for the surface fisheries (Fisheries 1-7 and 10-13) has been updated for 2000-2005 and new data included for 2006. No new catch and effort data were available from the Japanese longline fisheries. Trends in the amount of fishing effort exerted by the 13 fisheries defined for the stock assessment of bigeye tuna in the EPO are shown in Figure 2.3. Fishing effort for surface gears is in days of fishing, and that for longliners (Fisheries 8 and 9) is in standardized hooks.

Estimates of standardized carch per unit effort (1975-2004) were obtained for the longline fisheries (8 and 9). A delta-lognormal general linear model, in which the explanatory variables were latitude, longitude, and hooks per basket was used (Hoyle and Maunder, 2006 - weblink).

CPUE for the purse-seine fisheries was calculated as catch divided by numbers of days fished. The number of days fished by set type was calculated from the number of sets, using a multiple regression of total days fished against number of sets by set type (Maunder and Waters, 2001).

The CPUE time series for the different fisheries are presented in Figure 2.5. The indices of abundance that were considered appropriate for use in the assessment were those from fisheries 2, 3, and 5 (purse-seine sets on floating objects) and 8 and 9 (longline fisheries). The fisheries excluded were considered inappropriate because the catch rates were extremely low. In addition, the first two years of the purse-seine fisheries were excluded because these fisheries were still expanding. Data points with low effort data were also excluded.

2.4. Size composition data

New length-frequency data for 2006 and updated data for 2000-2005 are available for the surface fisheries. No new longline length-frequency data for the Japanese fleet are available. Size composition data for the other longline fleets are not used in the 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 previous assessments. The fisheries that catch bigeye associated with floating objects typically catch small (<75 cm) and medium-sized (75 to 125 cm) bigeye (Figure 2.6a-h, Fisheries 1-5). Prior to 1993, the catch of small bigeye was roughly equal to that of medium-sized bigeye (Figure 2.6a , Fishery 1). Since 1993, however, small bigeye from fisheries that catch bigeye in association with floating objects have dominated the catches (Figure 2.6b to 2.6e, Fisheries 2-5). An exception is the 1999-2002 period when a strong cohort moved through the fishery and large fish dominated the catch.

Prior to 1990, mostly medium-sized bigeye were captured in unassociated schools (Figure 2.6f, Fishery 6). Since 1990, more small and large (>125 cm long) bigeye have been captured in unassociated schools (Figure 2.6g, 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 (Fishery 8), longliners catch mostly medium-sized fish, and the average size composition has two distinct peaks (these appear as bands at 80 cm and 120 cm in Figure 2.6h.) In the area south of 15ºN (Fishery 9), longliners catch substantial numbers of both medium-sized and large bigeye (Figure 2.6i). However, there appears to have been a transition from medium to large fish in about 1984.

The length-frequency data for the Chinese Taipei fleet include more smaller fish than those for the Japanese fleet. However, there is concern about the representativeness of the length-frequency samples from the Chinese Taipei fleet (Stocker 2005, Anonymous 2006). Maunder and Hoyle (2007) conducted a sensitivity analysis, using the Chinese Taipei fleet as a separate fishery.

3. ASSUMPTIONS AND PARAMETERS

3.1. Biological and demographic information

3.1.1. Growth

Schaefer and Fuller (2006) used both tag-recapture data and otolith daily increments to estimate growth curves for bigeye tuna in the EPO. The two data sources provided similar estimates, with an apparent bias in the tagging data, which is hypothesized to be due to shrinkage because the recaptured bigeye tuna were measured at unloading (after they had been stored frozen). The growth curve estimated by Schaefer and Fuller (2006) is substantially different from the growth curves used in previous assessments (Figure 3.1). In particular, it shows growth to be approximately linear, and produces larger fish for a given age. The asymptotic length of the von Bertalanffy growth curve estimated by Schaefer and Fuller (2006) is much greater than any length recorded. This is reasonable as long as no biological meaning is given to the asymptotic length parameter and that the model is used only as a representation of the ages of fish that they sampled. The maximum age of the bigeye tuna in their data set is around 4 years (16 quarters) and their von Bertalanffy growth curve is not considered appropriate for ages greater than this. Mauder and Hoyle (2006) fit a Richards growth curve, using a lognormal likelihood function with constant variance and the asymptotic length parameter set at about the length of the largest-sized bigeye in the data (186.5 cm). Maunder and Hoyle (2007) used the resulting growth curve was used as a prior for all ages in the stock assessment. This growth curve is also used to convert the other biological parameters to age from length and for the estimation of natural mortality.

Previous assessments (*e.g.* Harley and Maunder 2005), the EPO yellowfin tuna assessments (*e.g.* Maunder 2002), and tuna assessments in the western and central Pacific Ocean (Lehodey *et al*. 1999; Hampton and Fournier 2001a, 2001b;) suggest that tuna growth does not follow a von Bertalanffy growth curve for the younger fish. However, this observation may be a consequence of length specific selectivity for small fish.

Length at age used in the assessment model is based on the von Bertalanffy growth curve. The parameters of the growth curve were estimated by obtaining the best correspondence of length at age used by Maunder and Hoyle (2007).

Hampton and Maunder (2005) found that the results of the stock assessment are very sensitive to the assumed value for the asymptotic length parameter. Therefore, sensitivity analyses were conducted by Maunder and Hoyle (2007) to investigate the influence of the assumed value of that parameter. A lower value of 171.5 cm, which is around the value estimated by stock assessments for the western and central Pacific Ocean (Adam Langley, Secretariat of the Pacific Community, pers. com.), and an upper value of 201.5 cm were investigated.

Another important component of growth used in age-structured statistical catch-at-length models is the variation in length at age. Age-length information contains information about variation of length at age, in addition to information about mean length at age. Variation in length at age was taken from the previous assessment. A sensitivy analysis that estimated mean length and variation of length at age by integrating age-length data from otolith readings (Schaefer and Fuller, 2006) in the assessment model was condcted.

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. Natural mortality

Age-specific vectors of natural mortality (M) are based on fitting to age-specific proportions of females, maturity at age, and natural mortality estimates of Hampton (2000) (Figure 3.2). Maunder and Hoyle (2007) used a combined sex natural mortality schedule. This assessment uses a sex-specific model and therefore natural mortality schedules are provided for each sex. It is assumed that female natural mortality increases after they mature. The previous observation that different levels of natural mortality had a large influence on the absolute population size and the population size relative to that corresponding to the average maximum sustainable yield (AMSY) (Watters and Maunder 2001) is retained. Harley and Maunder (2005) performed a sensitivity analysis to assess the effect of increasing natural mortality for bigeye younger than 10 quarters.

3.1.3. 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; Schaefer *et al*. 2005).

Both SS2 (the current stock assessment model described in section 4) and the previous stock assessment model (A-SCALA) allow a Beverton-Holt (1957) stock-recruitment relationship to be specified. The Beverton-Holt curve is parameterized so that the relationship between spawning biomass (biomass of mature females) and recruitment is determined by estimating the average recruitment produced by an unexploited population (virgin recruitment), a parameter called steepness, and the initial age structure of the population. Steepness controls how quickly recruitment decreases when the spawning biomass is reduced. It is defined as the fraction of virgin recruitment that is produced if the spawning biomass is reduced to 20% of its unexploited level. Steepness can vary between 0.2 (in which case recruitment is a linear function of spawning biomass) and 1.0 (in which case recruitment is independent of spawning biomass). In practice, it is often difficult to estimate steepness because of a lack of contrast in spawning biomass and because there are other factors (*e.g.* environmental influences) that can cause recruitment to be extremely variable. For the current assessment, recruitment is assumed to be independent of stock size (steepness = 1). There is no evidence that recruitment is related to spawning stock size for bigeye in the EPO and, if steepness is estimated as a free parameter, it is estimated to be close to 1. We also present a sensitivity analysis with steepness = 0.75. In addition to the assumptions required for the stock-recruitment relationship, a constraint on quarterly recruitment deviates with a standard deviation of 0.6 is applied.

Reproductive inputs are based on the results of Schaefer *et al*. (2005) and data provided by Dr. N. Miyabe of the National Research Institute of Far Seas Fisheries of Japan (NRIFSF). Information on age-at-length (Schaefer and Fuller 2006) was used to convert fecundity, and proportion mature at length into ages (Figure 3.3). The fecundity indices used in the current assessment are provided in Table 3.1.

3.1.4. 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 beginning 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.

3.1.5. Stock structure

There are not enough data available to determine whether there are one or several stocks of bigeye tuna in the Pacific Ocean. For the purposes of the current stock assessment, it is assumed that there are two stocks, one in the EPO and the other in the western and central Pacific, and that there is no net exchange of fish between these regions. The IATTC staff currently conducts a Pacific-wide assessment of bigeye in collaboration with scientists of the Oceanic Fisheries Programme of the Secretariat of the Pacific Community, and of the NRIFSF of Japan. This work may help indicate how the assumption of a single stock in the EPO is likely to affect interpretation of the results obtained from the A-SCALA method. Recent analyses (Hampton *et al*. 2003) that estimate movement rates within the Pacific Ocean, provided biomass trends very similar to those estimated by Harley and Maunder (2004).

3.2. Environmental influences

Oceanographic conditions might influence the recruitment of bigeye tuna to fisheries in the EPO. In previous assessments (e.g. Watters and Maunder 2001), zonal-velocity anomalies (velocity anomalies in the east-west direction) at 240 m depth and in an area from 8°N to 15°S and 100° to 150°W were used as the candidate environmental variable for affecting recruitment. The zonal-velocity anomalies were estimated from the hind cast results of a general circulation model obtained at http://ingrid.ldeo.columbia.edu. A sensitivity analysis was conducted by Maunder and Hoyle (2007) to investigate the relationship between recruitment and the El Niño index. The analysis showed that there was a significant negative relationship between recruitment and the El Nino index, but this explained a small proportion of the total variability in the recruitment.

In previous assessments (Watters and Maunder 2001 and 2002; Maunder and Harley 2002) it was assumed that oceanographic conditions might influence the efficiency of the fisheries that catch bigeye associated with floating objects (Fisheries 1-5). In the assessment of Maunder and Harley (2002) an environmental influence on catchability was assumed only for Fishery 3. It was found that including this effect did not greatly improve the results and no environmental influences on catchability have been considered in this assessment.

4. STOCK ASSESSMENT

The Stock Synthesis II method (SS2; Methot 2005) is used to assess the status of the bigeye tuna stock in the EPO. The SS2 method was investigated for use in the EPO tuna assessments and compared to A-SCALA and other assessment methods in a workshop on stock assessment methods organized by the

IATTC in 2005 (Maunder, 2006). Further investigations and comparison to A-SCALA were conducted at a workshop on management strategies held at the IATTC in 2006 (Maunder, 2007). The SS2 method and software were demonstrated to the participants of the workshop in a special one day tutorial.

SS2 differs from A-SCALA in several aspects, but the general concept of an integrated (fit to many different types of data) statistical stock assessment model is the same. One important difference is how catch is modeled. A-SCALA follows the MULTIFAN-CL approach and fits to observed catch data. Predicted catch is based on the Baranov catch equation. The fishing mortality effort relationship includes a temporal effort deviate that is estimated as a model parameter with a penalty based on the distributional assumption. These assumptions extract the abundance information from the catch and effort data. SS2 models catch taken out at the middle of the time period, and integrates abundance information from catch and effort in the form of relative indices of abundance.

The current version of SS2 is limited in the structural form that can be used for growth and natural mortality compared to that used in A-SCALA. The growth follows a von Bertalanffy curve and the natural mortality can have only two levels, for old young and old individuals, with a linear relationship to interpolate between these values.

The assessment model is fitted to the observed data (relative indices of abundance and size compositions) by finding a set of population dynamics and fishing parameters that maximize a constrained likelihood, given the amount of catch expended by each fishery. Many aspects of the assessment model are described in Section 3. The following list identifies additional important model assumptions.

1. Bigeye tuna are recruited to the discard fisheries (Fisheries 10-13) one quarter after hatching, and these discard fisheries catch only fish of the first few age classes.
2. As bigeye tuna age, they become more vulnerable to longlining in the area south of 15°N and Fishery 7, and the oldest fish are the most vulnerable to these gears (*i.e.* the selectivity curve for Fisheries 7 and 9 are monotonically increasing).
3. The data for fisheries that catch bigeye tuna from unassociated schools (Fisheries 6 and 7), the early and coastal floating-object fisheries (Fisheries 1 and 4) 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. For this reason, the CPUE time series for these fisheries were not used as indices of abundance.

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

1. recruitment in every quarter from the first quarter of 1975 through the first quarter of 2007 (This includes estimation of virgin recruitment and temporal recruitment anomalies);
2. catchability coefficients for the five CPUE time series that are used as indices of abundance;
3. selectivity curves for 9 of the 13 fisheries (Fisheries 10-13 have an assumed selectivity curve.);
4. 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. sex- and age-specific natural mortality rates (Figure 3.2);
2. age-specific fecundity indices (Table 3.1 and Figure 3.3);
3. selectivity curves for the discard fisheries (Fisheries 10-13);
4. the steepness of the stock-recruitment relationship;

5. mean length at age (Section 3.1.1., Figure 3.1)
6. parameters of a linear model relating the standard deviations in length at age to the mean lengths at age.

AMSY calculations and future projections were based on estimates of average harvest rates, by gear, for 2004 and 2005, so the most recent estimates were not included in these calculations. It was determined by retrospective analysis (Maunder and Harley 2003) that the most recent estimates were uncertain and should not be considered. The sensitivity of estimates of key management quantities to this assumption was tested.

There is uncertainty in the results of the current stock assessment. This uncertainty arises because the observed data do not perfectly represent the population of bigeye tuna in the EPO. Also, the stock assessment model may not perfectly represent the dynamics of the bigeye population nor of the fisheries that operate in the EPO. Uncertainty is expressed as approximate confidence intervals and coefficients of variation (CVs). The confidence intervals and CVs have been estimated under the assumption that the stock assessment model perfectly represents the dynamics of the system. Since it is unlikely that this assumption is satisfied, these values may underestimate the amount of uncertainty in the results of the current assessment.

4.1. Assessment results

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

1. Base case assessment: steepness of the stock-recruitment relationship equals 1 (no relationship between stock and recruitment), species-composition estimates of surface fishery catches scaled back to 1975, delta-lognormal general linear model standardized longline CPUE, and assumed sample sizes for the length-frequency data.
2. Sensitivity to the steepness of the stock-recruitment relationship. The base case assessment included an assumption that recruitment was independent of stock size, and a Beverton-Holt (1957) stock-recruitment relationship with steepness of 0.75 was used for the sensitivity analysis.
3. Sensitivity to the indices of abundance. The base case assessment included the CPUE time series for Fisheries 2, 3, and 5 (purse-seine sets on floating objects) and 8 and 9 (longline fisheries). A sensitivity of the assessment results to the use of only the standardized CPUE for longline Fishery 9 was conducted. Standardized CPUE for the longline Fishery 8 were not included, due to the seasonal nature of this fishery.
4. Sensitivity to estimating growth from length-at-age observations derived from otolith readings. The parameters of the von Bertalanffy growth equation were estimated from the otolith data. The parameters of the linear relationship for variation of length at age were also estimated. In addition, sensitivity analyses to fixing the asymptotic length parameter to a lower value of 171.5 cm and an upper value of 201.5 cm were conducted.
5. Sensitivity to the fitting to the initial equilibrium catch. This sensitivity makes the assumption that the catch prior to the start of the modeling period (1975) is similar to that for 1975-1976.
6. Sensitivity to the use of iterative reweighting of the data. The standard deviations of the likelihood functions for the indices of abundance and the sample sizes for the likelihood functions for the length-frequency data are adjusted, based on the mean squared error of the model fit to the respective data set.
7. Sensitivity to considering two time blocks of selectivity and catchability for the southern longline fishery (Fishery 9) and CPUE index of abundance. This analysis was conducted as an attempt to improve the residual pattern of the base case model fit to the size composition data.

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.

4.1.1. 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 fish less than about 15 quarters old has increased since 1993, and that on fish more than about 15 quarters old has increased slightly since then (Figure 4.1). 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 generally less than about 100 cm in length (Figure 4.2), and have expended a relatively large amount of fishing effort since 1993 (Figure 2.3).

Temporal trends in the age-specific amounts of fishing mortality on bigeye tuna are shown in Figure 4.3. These trends reflect the distribution of fishing effort among the various fisheries that catch bigeye (see Figure 2.3) and changes in catchability. The trend in fishing mortality rate by time shows that fishing mortality has increased greatly for young fish and only slightly for older fish since about 1993. An annual summary of the estimates of total fishing mortality is presented in Appendix G (Table G.1).

4.1.2. Recruitment

Previous assessments found that abundance of bigeye tuna being recruited to the fisheries in the EPO appeared to be related to zonal-velocity anomalies at 240 m during the time that these fish are assumed to have hatched (Watters and Maunder 2002). The mechanism that is responsible for this relationship has not been identified, and correlations between recruitment and environmental indices are often spurious, so the relationship between zonal-velocity and bigeye recruitment should be viewed with skepticism. Nevertheless, this relationship tends to indicate that bigeye recruitment is increased by strong El Niño events and decreased by strong La Niña events. Analyses in which no environmental indices were included gave estimates of recruitment similar to those using zonal-velocity (Harley and Maunder 2004). This suggests that there is sufficient information in the length-frequency data to estimate most historical year class strengths, but the index may be useful for reducing uncertainty in estimates of the strengths of the most recent cohorts for which few size-composition samples are available. In the previous assessment the environmental index was not statistically significant (Maunder and Hoyle 2006) or explained only a small proportion of the total recruitment variation (Maunder and Hoyle 2007), and therefore it was not included in the analysis.

Over the range of estimated spawning biomasses shown in Figure 4.7, the abundance of bigeye recruits appears to be unrelated to the spawning biomass of adult females at the time of hatching (Figure 4.4). Previous assessments of bigeye in the EPO (*e.g.* Watters and Maunder 2001, 2002) also failed to show a relationship between adult biomass and recruitment over the estimated range of spawning biomasses. The base case estimate of steepness is fixed at 1, which produces a model with a weak assumption that recruitment is independent of stock size. The consequences of overestimating steepness, in terms of lost yield and potential for recruitment overfishing, are far worse than those of underestimating it (Harley *et al*. unpublished analysis). A sensitivity analysis is presented in Appendix B that assumes that recruitment is moderately related to stock size (steepness = 0.75).

The time series of estimated recruitment of bigeye is shown in Figure 4.5, and the total recruitment estimated to occur during each year is presented in Table 4.1. There are several important features in the time series of estimated recruitment of bigeye. First, estimates of recruitment before 1993 are very uncertain, as the techniques for catching small bigeye associated with floating-objects were not in use. There was a period of above-average recruitment in 1995-1998, followed by a period of below-average recruitment in 1999-2000. The recruitments were above average since 2000 and were particulaly large in in 2005. The most recent recruitment is very uncertain, due to the fact that recently-recruited bigeye are represented in only a few length-frequency data sets. The extended period of relatively large recruitments in 1995-1998 coincided with the expansion of the fisheries that catch bigeye in association with floating objects.

4.1.3. Biomass

Trends in the biomass of 3+-quarter-old bigeye tuna in the EPO are shown in Figure 4.6, and estimates of the biomass at the beginning of each year are presented in Table 4.1. The biomass of 3+-quarter-old bigeye increased during 1983-1984, and reached its peak level of about 615,000 metric tons (t) in 1986, after which it decreased to an historic low of about 279,000 t at the beginning of 2005.

The trend in spawning biomass is also shown in Figure 4.7, and estimates of the spawning biomass at the beginning of each year are presented in Table 4.1. The spawning biomass has generally followed a trend similar to that for the biomass of 3+-quarter-old bigeye, but is lagged by 1 to 2 years.

There is uncertainty in the estimated biomasses of both 3+-quarter-old bigeye and of spawners. The average CV of spawning biomass estimates is 0.13.

Given the amount of uncertainty in the estimates of both biomass and recruitment (Section 4.1.2), it is difficult to determine whether trends in the biomass of bigeye have been influenced more by variation in fishing mortality or recruitment. Nevertheless, the assessment suggests two conclusions. First, it is apparent that fishing has reduced the total biomass of bigeye present in the EPO. This conclusion is drawn from the results of a simulation in which the biomass of bigeye tuna estimated to be present in the EPO if fishing had not occurred was projected, using the time series of estimated recruitment anomalies, and the estimated environmental effect, in the absence of fishing. The simulated biomass estimates are always greater than the biomass estimates from the base case assessment (Figure 4.8). Second, the biomass of bigeye can be substantially increased by strong recruitment events. Both peaks in the biomass of 3+-quarter-old bigeye (1986 and 2000; Figure 4.6) were preceded by peak levels of recruitment (1982-1983 and 1997-1998, respectively; Figure 4.8) as is the recent upturn in biomass.

To estimate the impact that different fisheries have had on the depletion of the stock, we ran simulations in which each gear was excluded and the model was run forward as is done in the no-fishing simulation. The results of this analysis are also provided in Figure 4.8. It is clear that the longline fishery had the greatest impact on the stock prior to 1995, but with the decrease in effort from the longline fisheries, and expansion of the floating-object fishery, at present the impact of the purse-seine fishery is far greater than that of the longline fishery on the population. The discarding of small bigeye has a small, but detectable, impact on the depletion of the stock. Overall the spawning biomass is estimated to be about 17% of that expected had no fishing occurred.

4.1.4. Average weights of fish in the catch

Trends in the average weights of bigeye captured by the fisheries that operate in the EPO are shown in Figure 4.9. The fisheries that catch bigeye in association with floating objects (Fisheries 1-5) have taken mostly small fish that, on average, weigh less than the critical weight, which indicates that these fisheries do not maximize the yield per recruit (see Maunder and Hoyle, 2007). The average weight of bigeye taken by the longline fisheries (Fisheries 8 and 9) has been around the critical weight, which indicates that this fishery tends to maximize the yield per recruit (see Maunder and Hoyle, 2007). The average weight for all fisheries combined declined substantially after 1993 as the amount of purse-seine effort of floating objects increased.

The average weight in both surface and longline fisheries declined around 1997-1998 as a strong cohort entered the fishery. The average weights then increased as the fish in that cohort increased in size. The average weight then declined as that cohort was removed from the population.

The model average weights for the surface fishery predicted by the model differ from the "observed" mean weights, particularly before 1984. The “observed” average weights are estimated by scaling up the length-frequency samples to the total catch, which differs from the method used in the stock assessment model which uses the constant selectivity curves and estimated harvest rates for each fishery to estimate the average weight.

4.2. Comparisons to external data sources

No comparisons to external data were made in this assessment.

4.3. Diagnostics

Diagnostics are discussed in two sections: (1) residual and (2) retrospective analysis.

4.3.1. Residuals

The model fits to the CPUE data from different fisheries are presented in Figure 4.10. As expected, the model fits the southern longline CPUE observations closely. The fits to the other CPUE data series are less satisfactory, which reflects the assumptions about the standard deviations used in the likelihood functions.

Pearson residual plots are presented for the model fits to the length composition data (Figures 4.11a to 4.11i). Solid circles represent observations that are less than the model predictions, open circles correspond to observations that are greater than model predictions. The area of the circles is proportional to the absolute value of the residuals. There are several notable characteristics of the residuals. The model overestimates the large and small fish for the post-1993 floating-object fisheries. In particular, the model overestimates the large fish between 1999 trough 2002, when a strong cohort moved through the fishery. Conversely, the model overestimates medium-sized fish for the southern longline fishery. This overestimation is centered around 80 cm pre 1988 and then increases to 180 cm, indicating a change in selectivity.

The fit to the data as measured by root mean square error suggests that the model fits the CPUE index for Fisheries 2 and 9 better than reflected in the CVs assumed in the likelihood functions. The model fits to the CPUE data of the other fisheries worse than reflected in the assumed CVs in the likelihood functions. With respect to the length-frequency data, the model fits the data better (as indicated by the estimated effective sample size) than reflected by the assumed sample sizes used in the likelihood functions. A sensitivity analysis, using iterative reweighting to determine the appropriate standard deviations and sample sizes for the likelihood functions based on the fit to the data was carried out to investigate the weighting of the data sets.

4.3.2. Retrospective analysis

Retrospective analysis is useful for determining how consistent a stock assessment method is from one year to the next. Inconsistencies can often highlight inadequacies in the stock assessment method. This approach is different from the comparison of recent assessments (Section 4.5), in which the model assumptions differ among these assessments, and differences would be expected. Retrospective analyses are usually carried out by repeatedly eliminating one year of data from the analysis while using the same method and assumptions. This allows the analyst to determine the change in estimated quantities as more data are included in the model. Estimates for the most recent years are often uncertain and biased. Retrospective analysis, and the assumption that the use of more data improves the estimates, can be used to determine if there are consistent biases in the estimates.

Restrospective analyses were conducted by removing one year (2006) or 2 years (2006 and 2005) of data (Figure 4.12). The retrospective analyses show an an increase in biomass over the most recent years (2004 and 2005), whereas the base case shows a stable trend over the same period. This corroborates results of previous retrospective analyses conducted using A-SCALA, which show that the recent estimates of biomass are subject to retrospective bias (Harley and Maunder, 2004).

4.4. Sensitivity analysis

Results from the five sensitivity analyses conducted are presented in appendices: sensitivity to the stock–recruitment relationship (Appendix A), use of the southern longline CPUE data only (Appendix B), estimating growth and assuming estimates for the asymptotic length parameter of the von Bertalanffy growth curve (Appendix C), fitting to initial equilibrium catch (Appendix D), iterative reweighing (Appendix E), and using two time blocks for selectivity and catchability of the southern longnline fishery (Appendix F). Here we describe differences in model fit and model prediction, and defer our discussion of differences in yields and stock status to Section 5. A comparison table of the likelihoods for the base case and sensitivity analyses is provided in Table 4.4.

The steepness of the Beverton-Holt (1957) stock-recruitment relationship was set equal to 0.75. The estimates of biomass (Figure B.1) are greater than those estimated in the base case assessment, but the trends are similar. The recruitment time series is similar to the base case (Figure B.2).

When only the CPUE for the southern longline fishery was used, the estimated biomass is generally greater. However, the estimated biomass declines in the most recent year in the sensitivity, but not in the base case (Figure C.1). This is a result of lower recruitment estimated in the sensitivity analysis (Figure C.2).

When mean length at age and variation of length at age were estimated in the model, the estimated biomass was higher than the base case. The estimated recruitment is lower and the recruitment occurs one quarter later. All models estimated higher growth rates for younger fish relative to the base case and lower standard deviations of variations in length-at-age for older fish (Figure C.4). The assumed value for the asymptotic length parameter of the von Bertalanffy growth curve was fixed at a lower value of 171.5 cm, which is around the value estimated by stock assessments for the western and central Pacific Ocean (Adam Langley, Secretariat of the Pacific Community, pers. com.), and at an upper value of 201.5 cm. The estimated biomass and recruitment are very sensitive to the value of the asymptotic length parameter (Figures C.1 and C.2); they are greater for a lesser value for that parameter. Similar results were obtained by Maunder and Hoyle (2007) using A-SCALA. This can be explained by the need to fit to the length-frequency data with an asymptotic selectivity for the southern longline fishery (Maunder and Hoyle, 2007).

When the model was fit to an assumed equilibrium catch, the biomass was estimated to be greater than in the base case and declines from 1975 to 1980 (Figure D.1). Recruitment was generally higher that the base case (Figure D.2).

When iterative reweighting of the standard deviations and effective samples sizes of the likelihood functions was applied, the estimated biomass was lower than the base case (Figure E.1). The differences were particularly larger at the beginning and end of the time series. Recruitment was generally greater than in the base case (Figure E.2). As expect for Fishery 2, the standard deviations of the CPUE indices were increased resulting in less weight given to the indices of abundance. Effective sample sizes of all length frequency data increased, which resulted in more weight given to these data. The results indicate that further interactions would result in even less weight given to the CPUE abundance indices. Further interactions were not conducted since the fit to the southern longline data, which is the main index of abundance in the assessment, was not satisfactory (Figure E.4).

Two time blocks were considered for selectivity and catchability of the southern longline fishery (Fishery 9). As expected, the fit to the CPUE data from the southern fishery has improved (Figure F.4., Table 4.4). The time series of biomass is similar to that estimated by the base case, with the largest differences occurring during the early part of the time series for which the time block analysis estimated a lower biomass (Figure F.1). The model fits closely to the CPUE data for the southern longline fishery during the two time blocks considered (Figure F.4). When iterative reweighting was applied, the differences in biomass during the the early part of the time period were greater and the biomass levels were lower that those estimated by the base case in the most recent years. Again, there was more weight put on the length frequency data and the fit to the CPUE data has degraded (Figure F.4). However, the fit to the southern longline fishery is still better that when iterative reweight was applied to the base case with no time blocking.

Other presentations of sensitivity analysis, including investigation of growth estimation, environmental effects on recruitment and catchability, and natural mortality were conducted by Watters and Maunder (2002), Harley and Maunder (2004, 2005), and Maunder and Hoyle (2007).

4.5. Comparison to previous assessments

4.5.1. Comparisons to A-SCALA

The current assessment employs a new assessment model (SS2). This model differs from the A-SCALA model used in previous assessments (see section 4). Therefore, it is useful to compare results from the new model with those from A-SCALA. The estimated biomass trends are generally the same for both models, except that A-SCALA estimates that the biomass has increased rapidly in the few most recent years (Figures 4.13 to 4.15). This increase in abundance is partly due to the catch and effort data for Fishery 4 which are left out of the current assessment model. It should be noted that the current estimates of abundance are usually the most uncertain and subject to retrospective bias. This is apparent in the retrospective analysis with the 2006 data removed, which produces results closer to those of A-SCALA (see section 4.3.2). There is a greater difference in the estimates of absolute biomass, spawning biomass, and the SBR. The current assessment estimates greater values than does A-SCALA which is partly due to the differences in the growth curves used in the two models.

The recruitment trends are very similar between the two models (Figures 4.16). A major difference is that A-SCALA estimates two much larger recent recruitments, which probably drive the recent rapid increase in abundance.

4.5.2. Comparisons to previous assessments

The A-SCALA assessment using the most recent data is similar to the previous assessment, which also used A-SCALA. Therefore, the comparisons from this assessment using SS2 to the assessment of Maunder and Hoyle (2007) are similar to that described in the previous section.

4.5.3. 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 15 quarters old has increased substantially since 1993, and that on fish more than about 15 quarters old has increased slightly since then. The increase in fishing mortality on the younger fish was caused by the expansion of the fisheries that catch bigeye in association with floating objects.

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

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

The biomass of 3+-quarter-old bigeye increased during 1983-1984, and reached its peak level of about 614,898 t in 1986, after which it decreased to an historic low of about 278,962 t at the beginning of 2005.

Spawning biomass has generally followed a trend similar to that for the biomass of 3+-quarter-olds, but lagged by 1-2 years. There is uncertainty in the estimated biomasses of both 3+-quarter-old bigeye and spawners. Nevertheless, it is apparent that fishing has reduced the total biomass of bigeye in the EPO. The biomasses of both 3+-quarter-old fish and spawners were estimated to have increased in recent years.

The estimates of recruitment and biomass are only moderately sensitive to the steepness of the stock-recruitment relationship. The estimates of recruitment and biomass are very sensitive to the assumed value of the asymptotic length parameter in the von Bertalanffy growth equation. A lesser value gave greater biomasses and recruitments. When only the CPUE for the southern longline fishery was used the biomass was estimated to decline in the most recent years as a result of lower estimated recruiment.

When interative reweighting of the standard deviations and effective sample sizes of the likelihood functions was applied, more weight was given to the length frequency data and the biomass was estimated to be lower in the early and later segments of the time series, when compared to the base case.

When time blocks were applied to the selectivity and catchability of the southern logline fishery, the residual pattern of the model fit to the size composition data for this fishery was improved (Figure F.5 and F.6). Unlike when applying iterative reweighting to the base case without considering time blocking, the model fit to the southern longline CPUE index of abundance very closely (Figure F.6). Biomass was similar to that estimated in the base case using iterative reweighting.

5. STOCK STATUS

The status of the stock of bigeye tuna in the EPO is assessed by considering calculations based on the spawning biomass 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. Maintaining tuna stocks at levels that permit the AMSY to be taken is the management objective specified by the IATTC Convention. 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 subsections.

5.1. Assessment of stock status based on spawning biomass

The spawning biomass ratio (the ratio of the spawning biomass at that time to that of the unfished stock; SBR), described by Watters and Maunder (2001), has been used to define reference points in many fisheries. It has a lower bound of zero. If it is near zero, the population has been severely depleted, and is probably overexploited. If the SBR is one, or slightly less than that, the fishery has probably not reduced the spawning stock. If the SBR is greater than one, it is possible that the stock has entered a regime of increased production.

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

Estimates of SBR for bigeye tuna in the EPO have been computed from the base case assessment. Estimates of the spawning biomass during the period of harvest are presented in Section 4.2.3. The SBR corresponding to the AMSY (SBR_{AMSY}) is estimated to be about 0.22.

At the beginning of January 2007, the spawning biomass of bigeye tuna in the EPO was near the historical low level (Figure 5.1). At that time the SBR was about 0.20, 10% less than the level corresponding to the AMSY.

At the beginning of 1975, the SBR was about 0.39 (Figure 5.1), which is consistent with the fact that bigeye was being fished by longliners in the EPO for a long period prior to 1975 and that the spawning biomass is made up of older individuals that are vulnerable to longline gear. The SBR increased, particularly during 1984-1986, and by the beginning of 1987 was 0.51. This increase can be attributed to the above-average recruitment during 1982 and 1983 (Figure 4.5) and to the relatively small catches that were taken by the surface fisheries during that time (Figure 2.2, Fisheries 1 and 6). This peak in spawning biomass was soon followed by a peak in the longline catch (Figure 2.2, Fishery 9). After 1987 the SBR decreased to a level of about 0.21 by mid-1999. This depletion can be attributed mostly to a long period (1984-1993) during which recruitment was low. Also, it should be noted that the southern longline fishery took relatively large catches during 1985-1994 (Figure 2.2, Fishery 9). In 1999 the SBR began to increase, and reached about 0.37 in 2002. This increase can be attributed to the relatively high levels of recruitment that are estimated to have occurred during 1994-1998 (Figure 4.5). During the latter part of 2002 through 2003, the SBR decreased rapidly, due to the weak year classes in 1999 and 2005 and the large catches from surface fisheries and increased longline catches.

The SBR over time shows a trend similar to that of the previous assessment (Figure 4.15).

5.2. Assessment of stock status based on AMSY

Maintaining tuna stocks at levels that permit the AMSY to be taken is the management objective specified by the IATTC Convention. One definition of the AMSY is the maximum long-term yield that can be achieved under average conditions, using the current, age-specific selectivity pattern of all fisheries combined. Watters and Maunder (2001) describe how the AMSY and its related quantities are calculated. These calculations have, however, been modified to include, where applicable, the Beverton-Holt (1957) stock-recruitment relationship (see Maunder and Watters (2003) for details). It is important to note that estimates of the AMSY and its associated quantities are sensitive to the steepness of the stock-recruitment relationship (Section 5.4), and, for the base case assessment, steepness was fixed at 1 (an assumption that recruitment is independent of stock size); however, a sensitivity analysis (steepness = 0.75) is provided to investigate the effect of a stock-recruitment relationship.

The AMSY-based estimates were computed with the parameter estimates from the base case assessment and estimated fishing mortality patterns averaged over 2004 and 2005. Therefore, while these AMSY-based results are currently presented as point estimates, there are uncertainties in the results. While analyses to present uncertainty in the base case estimates were not undertaken as in a previous assessment (Maunder and Harley 2002), additional analyses were conducted to present the uncertainty in these quantities in relation to the periods assumed to represent catchability and fishing mortality.

At the beginning of January 2007, the spawning biomass of bigeye tuna in the EPO appears to have been about 10% less than S_{AMSY}, and the recent catches are estimated to have been greater than the AMSY (Table 5.1).

If fishing mortality is proportional to fishing effort, and the current patterns of age-specific selectivity (Figure 4.5) are maintained, F_{AMSY} is about 77% of the current level of effort.

The AMSY-based quantities are estimated by assuming that the stock is at equilibrium with fishing, but during 1995-1998 that was not the case. This has potentially important implications for the surface fisheries, as it suggests that the catch of bigeye by the surface fleet may be determined largely by the strength of recruiting cohorts. For example, the catches of bigeye taken by the surface fleet declined when the large cohorts recruited during 1995-1998 were no longer vulnerable to those fisheries.

Estimates of the AMSY, and its associated quantities, are sensitive to the age-specific pattern of selectivity that is used in the calculations. The AMSY-based quantities described previously were based on an average selectivity pattern for all fisheries combined (calculated from the current allocation of effort among fisheries). Different allocations of fishing effort among fisheries would change this combined selectivity pattern. To illustrate how the AMSY might change if the effort is reallocated among the various fisheries that catch bigeye in the EPO, the previously-described calculations were repeated, using the age-specific selectivity pattern estimated for each group of fisheries (Table 5.2). If only the purse-seine fishery were operating the AMSY would be about 33% less. If bigeye were caught only by the longline fishery the AMSY would about 89% greater than that estimated for all gears combined. To achieve this AMSY level longline effort would need to be increased by 320%.

The AMSY-related quantities vary as the size composition of the catch varies. The evolution of four of these over the course of 1975-1995 is shown in Figure 5.2 Before the expansion of the floating-object fishery that began in 1993, AMSY was greater than the current AMSY and the fishing mortality was less than that corresponding to AMSY (Figure 5.2).

When AMSY is estimated using the average fishing mortality rates for 2003-2004, it is 9% greater than the base case. When AMSY is estimated using the average fishing mortality rates for 2005-2006, it is 7% less than the base case.

Figure 5.3. shows the historical time series of exploitation rates and spawning biomass relative to the AMSY reference points. Overall, the reference points have not been exceeded until recent years.

5.3. Sensitivity to alternative parameterizations and data

Yields and reference points are moderately sensitive to alternative model assumptions, input data, and the periods assumed for fishing mortality (Tables 5.1 and 5.2).

The sensitivity analysis that included a stock-recruitment model with a steepness of 0.75 estimated the SBR required to support AMSY to be at 0.31, compared to 0.22 for the base case assessment (Table 5.1). The sensitivity analysis for steepness estimates an *F* multiplier considerably less than that for the base case assessment (0.55). The *F* multiplier is considerably greater for the reduced asymptotic length, indicating that effort should be increased, but considerably less for the increased asymptotic length (Table 5.1). All analyses, except the case that estimates growth and the case that assumes a greater asymptotic length, estimate the current SBR to be less than SBR_{AMSY}.

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

5.4. Summary of stock status

At the beginning of January 2007, the spawning biomass of bigeye tuna in the EPO was near the historic low level (Figure 5.1). At that time the SBR was about 0.20, about 10% less than the level corresponding to the AMSY.

Recent catches are estimated to have been about the AMSY level (Table 5.1). If fishing mortality is proportional to fishing effort, and the current patterns of age-specific selectivity are maintained, the level of fishing effort corresponding to the AMSY is about 77% of the current (2004-2005) level of effort. The AMSY of bigeye in the EPO could be maximized if the age-specific selectivity pattern were similar to that for the longline fishery that operates south of 15°N because it catches larger individuals that are close to the critical weight. Before the expansion of the floating-object fishery that began in 1993, the AMSY was greater than the current AMSY and the fishing mortality was less than F_{AMSY} (Figure 5.2).

All analyses, except that incorporating the low assumed value for the asymptotic length parameter of the von Bertalanffy growth curve, suggest that at the beginning of 2007 the spawning biomass was below S_{AMSY} (Tables 5.1 and 5.2). AMSY and the *F* multiplier are sensitive to how the assessment model is parameterized, the data that are included in the assessment, and the periods assumed to represent average fishing mortality, but under all scenarios considered, except that incorporating the time blocks for the selectivity and catchability for the southern longline fishery witout iterative reweighting or low assumed value for the asymptotic length, fishing mortality is well above F_{AMSY}.

6. SIMULATED EFFECTS OF FUTURE FISHING OPERATIONS

A simulation study was conducted to gain further understanding as to how, in the future, hypothetical changes in the amount of fishing effort exerted by the surface fleet might simultaneously affect the stock of bigeye tuna in the EPO and the catches of bigeye by the various fisheries. Several scenarios were constructed to define how the various fisheries that take bigeye in the EPO would operate in the future and also to define the future dynamics of the bigeye stock. The assumptions that underlie these scenarios are outlined in Sections 6.1 and 6.2.

A method based on the normal approximation to the likelihood profile has been applied (Maunder *et al*. 2006). Unfortunately, the appropriate methods are not often applicable to models as large and computationally intense as the bigeye stock assessment model. Therefore, we have used a normal approximation to the likelihood profile that allows for the inclusion of both parameter uncertainty and uncertainty about future recruitment. This method is implemented by extending the assessment model an additional five years with exploitation rates equal to the average for 2004 and 2005. No catch or length-frequency data are included for these years. The recruitments for the five years are estimated as in the assessment model, with a lognormal penalty with a standard deviation of 0.6.

6.1. Assumptions about fishing operations

6.1.1. Fishing effort

Future projection studies were carried out to investigate the influence of different levels of fishing effort (harvest rates) on the stock biomass and catch.

The scenarios investigated were:

1. Quarterly harvest rates for each year in the future was set equal to the average harvest rates for 2004 and 2005, which reflects the reduced effort due to the conservation measures of IATTC Resolution C-04-09;
2. An additional analysis was implemented that estimates the population status if the resolution was not implemented. For 2004-2006, purse-seine catch in the third quarter was increased by 86% and the catch in the southern longline fishery was increased by 39% in all quarters. For 2007-2011, the purse-seine harvest rate was increased by 13% for all quarters and the harvest rate in the southern longline fishery was increased by 39% in all quarters.

6.2. Simulation results

The simulations were used to predict future levels of the SBR, total biomass, the total catch taken by the primary surface fisheries that would presumably continue to operate in the EPO (Fisheries 2-5 and 7), and the total catch taken by the longline fleet (Fisheries 8 and 9). There is probably more uncertainty in the future levels of these outcome variables than suggested by the results presented in Figures 6.1-6.4. The amount of uncertainty is probably underestimated, because the simulations were conducted under the assumption that the stock assessment model accurately describes the dynamics of the system and with no account taken of variation in catchability.

6.2.1. Current effort levels

Projections were undertaken, assuming that harvest rates would remain at the average 2004 and 2005 levels (including the effort and catch restrictions in IATTC Resolution C-04-09).

SBR is estimated to have been increasing in recent years (Figure 5.1). This increase is attributed to two spikes in recent recruitment. If recent levels of effort and catchability continue, SBR is predicted to increase to about the level that would support AMSY in 2009, and then decline (Figure 6.1a). The total biomass is estimated to be currently at its peak, and it will probably decline in the future (Figure 6.2).

Purse-seine catches are predicted to decline during the projection period (Figure 6.3, left panels). Longline catches are predicted to increase moderately in 2007, but start declining by 2010 under current effort (Figure 6.3, right panels). The catches would decline slighlty further if a stock-recruitment relationship was included, due to reductions in the levels of recruitment that contribute to purse-seine catches.

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

6.2.2. No management restrictions

IATTC Resolution C-04-09 calls for restrictions on purse-seine effort and longline catches for 2004: a 6-week closure during the third *or* fourth quarter of the year for purse-seine fisheries, and longline catches not to exceed 2001 levels. To assess the utility of these management actions, we projected the population forward 5 years, assuming that these conservation measures were not implemented. Projected catches are would be less if the resosolution wound not have been adopted (Figure 6.3, lower panels)

Comparison of the SBR predicted with and without the restrictions from the resolution show some difference (Figure 6.4). Without the restrictions, SBR would increase only slightly and then decline to lower levels.

Clearly, the reductions in fishing mortality that could occur as result of IATTC Resolution C-04-09 are insufficient to allow the population to maintain levels corresponding to the AMSY.

6.2.3. Sensitivity analysis

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

6.3. Summary of the simulation results

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

The effects of IATTC Resolution C-04-09 are estimated to be insufficient to allow the stock to remain at levels that would support AMSY.

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

7. FUTURE DIRECTIONS

7.1. Collection of new and updated information

The IATTC staff intends to continue its collection of catch, effort, and size-composition data from the fisheries that catch bigeye tuna in the EPO. Updated and new data will be incorporated into the next stock assessment.

The IATTC staff will continue to compile longline catch and effort data for fisheries operating in the EPO. In particular, it will attempt to obtain data for recently-developed and growing fisheries.

7.2. Refinements to the assessment model and methods

The IATTC staff will continue developing the Stock Synthesis II assessment for bigeye tuna in EPO.

Much of the progress will depend on how the Stock Synthesis II software is modified in the future. The following is a list of desirable changes for future assessments

1) Model a separate longline fishery for catch that is reported in weight and share the selectivity to the longlinine fishery for which catch is reported in numbers. This will make the conversion from weight to numbers consistent with the length-frequency data and the population dynamics.
2) Use a seasonal model so that projections can be done on a quarterly basis.
3) Input a age-specific vector of natural mortality so that increased natural mortality for young bigeye can be incorporated.
4) Use a more flexible growth curve (e.g. the Richards growth curve) or input a vector of length-at-age so that the growth curve better represents that used in previous assessments using A-SCALA.
5) Make it easier to run projections with fixed harvest rates.
6) Re-evaluate the definitions of fisheries
7) Determine appropriate weighting of the different data sets

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

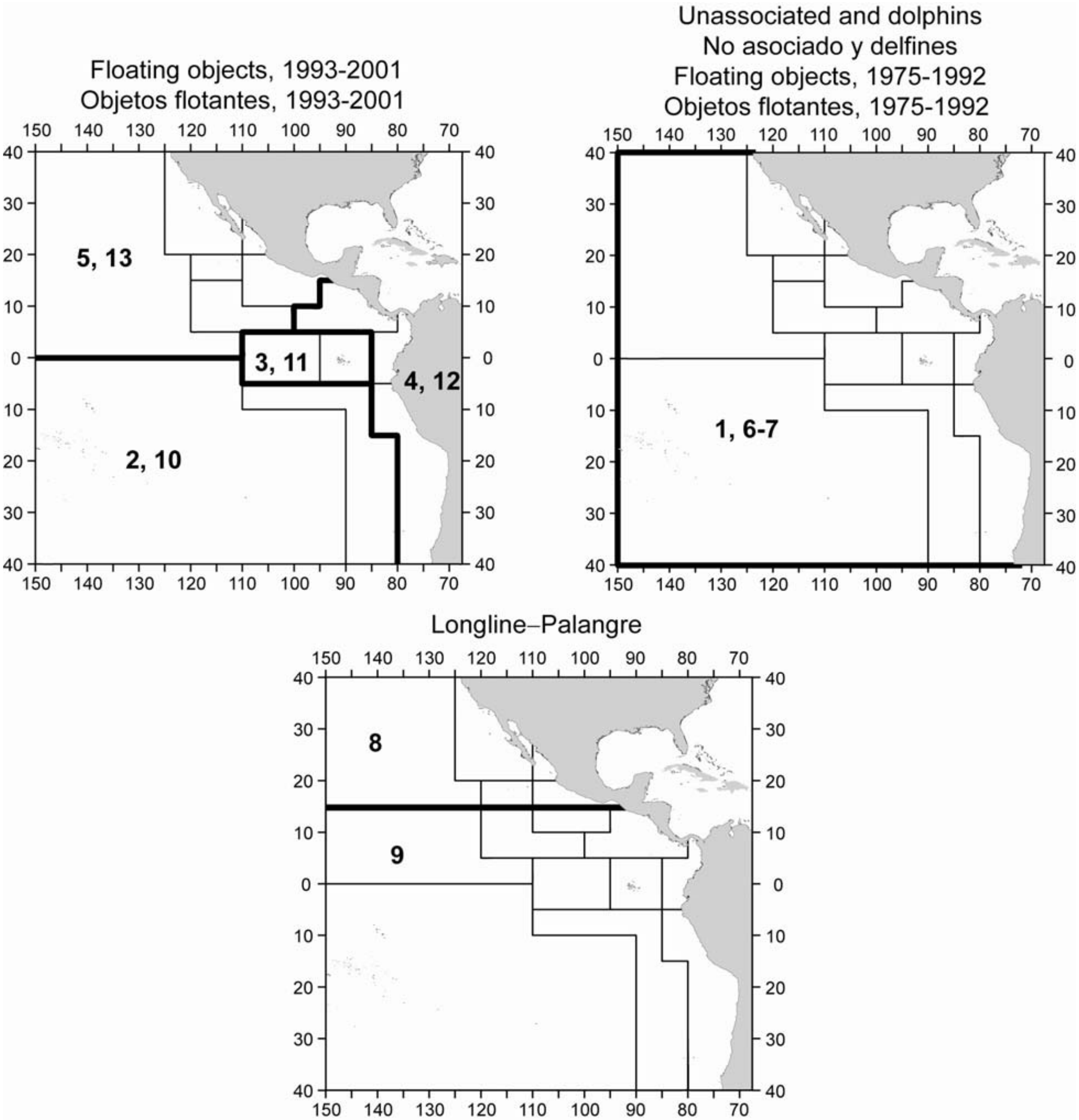


FIGURE 2.1. Spatial extents of the fisheries defined for the stock assessment of bigeye tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the bold numbers the fisheries to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

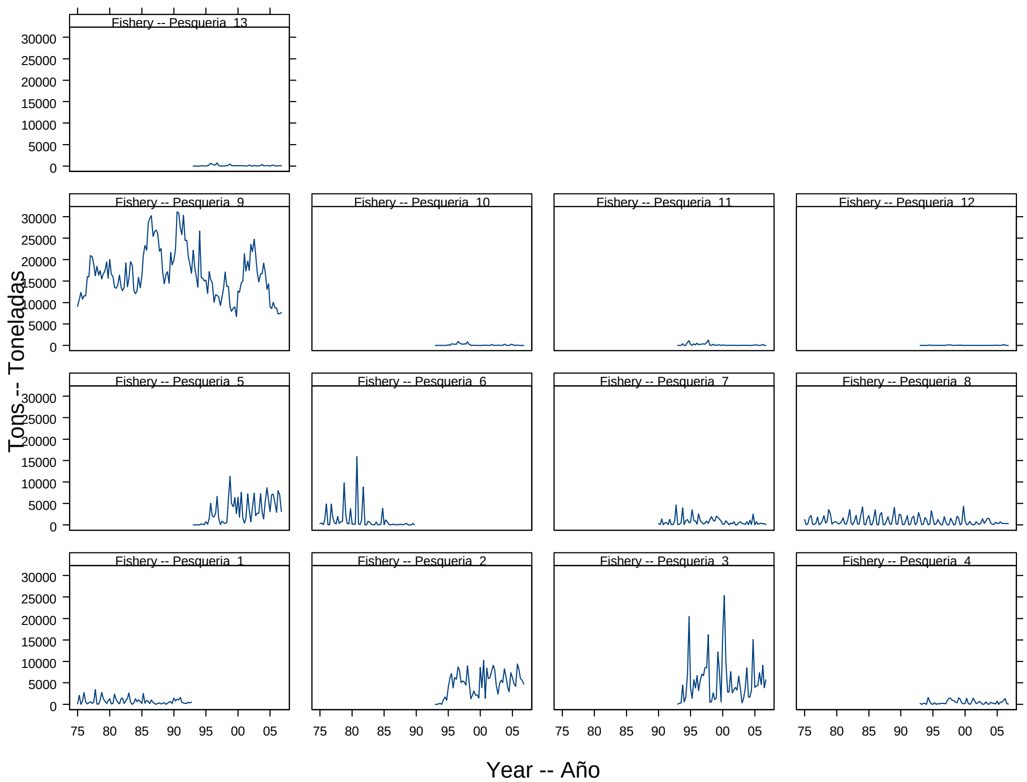


FIGURE 2.2. Catches of bigeye tuna taken by the fisheries defined for the stock assessment of that species in the EPO (Table 2.1). Since the data were analyzed on a quarterly basis, there are four observations of catch for each year. Although all the catches are displayed as weights, the stock assessment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

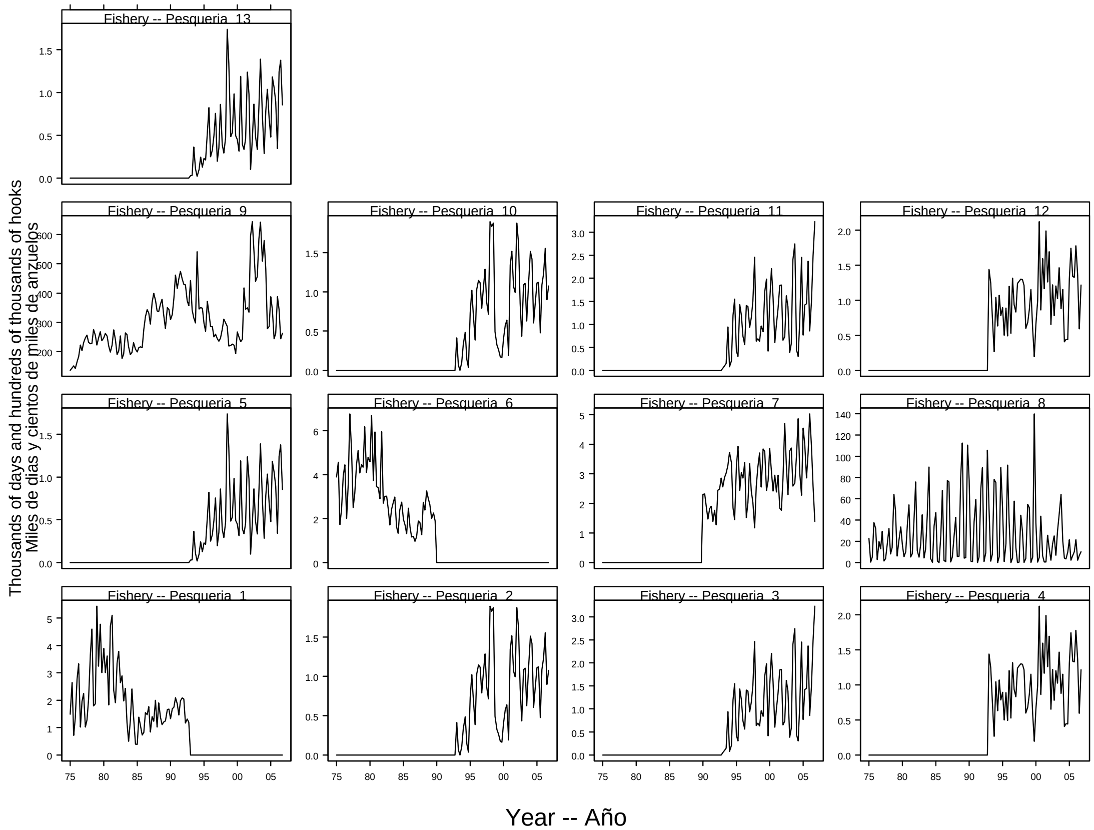


FIGURE 2.3. Fishing effort exerted by the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of effort for each year. The effort for Fisheries 1-7 and 10-13 is in days fished, and that for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

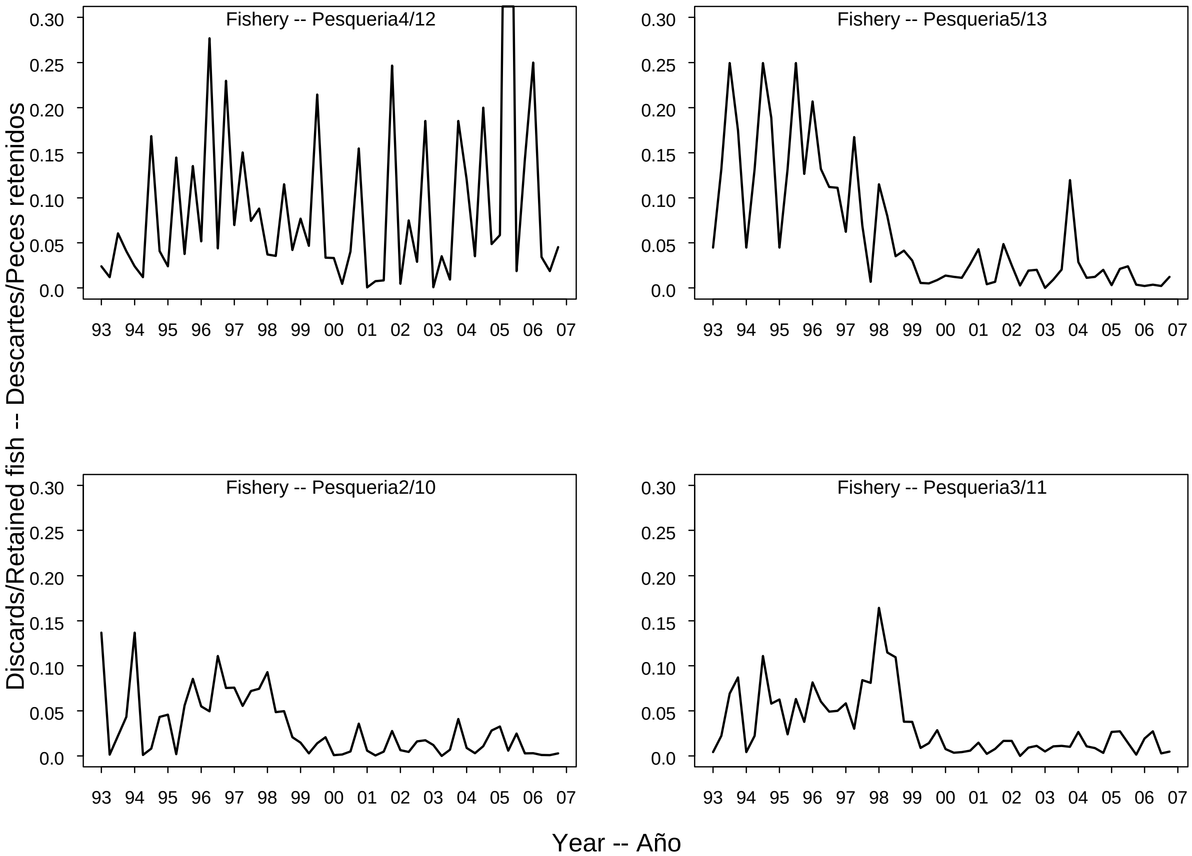


FIGURE 2.4. Weights of discarded bigeye tuna as proportions of the retained quarterly catches for the four floating-object fisheries. Fisheries 2, 3, 4, and 5 are the "real" fisheries, and Fisheries 10, 11, 12, and 13 are the corresponding discard fisheries.

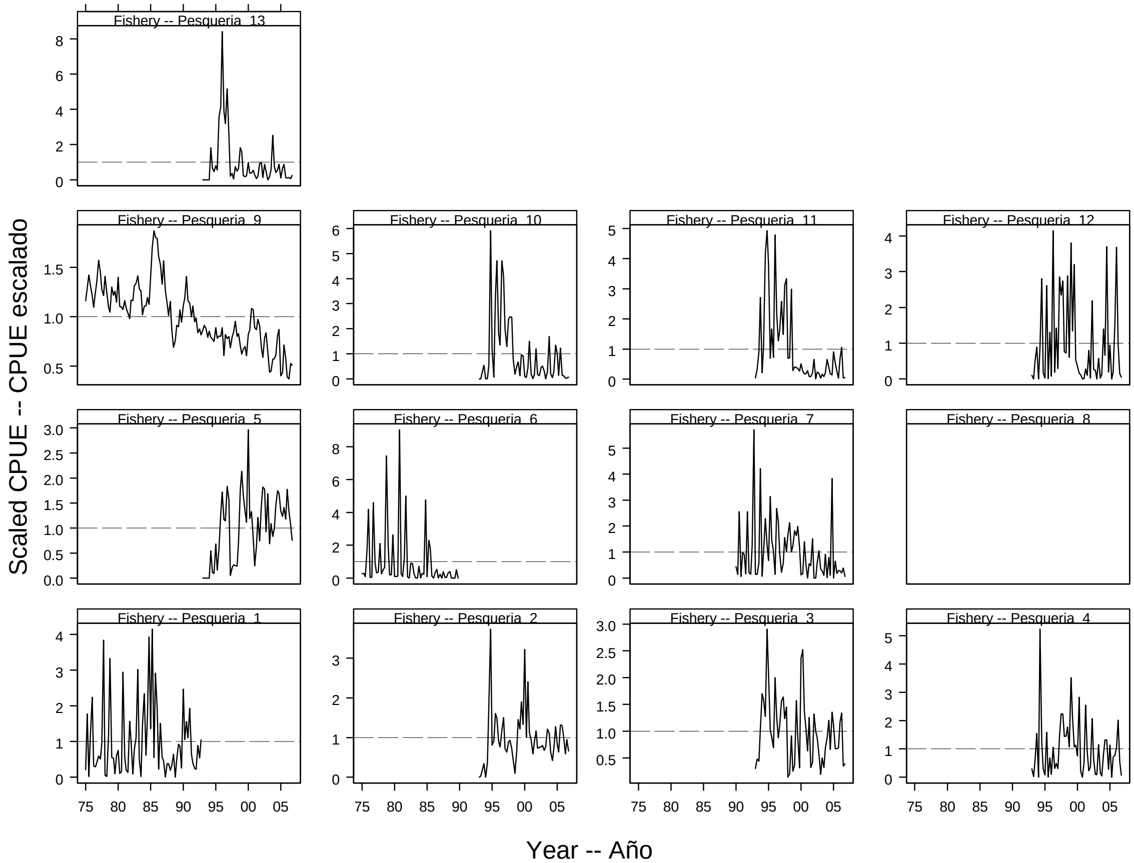


FIGURE 2.5. CPUEs of the fisheries defined for the stock assessment of bigeye tuna in the EPO (Table 2.1). Since the data were summarized on a quarterly basis, there are four observations of CPUE for each year. The CPUEs for Fisheries 1-7 and 10-13 are in kilograms per day fished, and those for Fisheries 8 and 9 in numbers of fish caught per standardized number of hooks. The data are adjusted so that the mean of each time series is equal to 1.0. Note that the vertical scales of the panels are different.

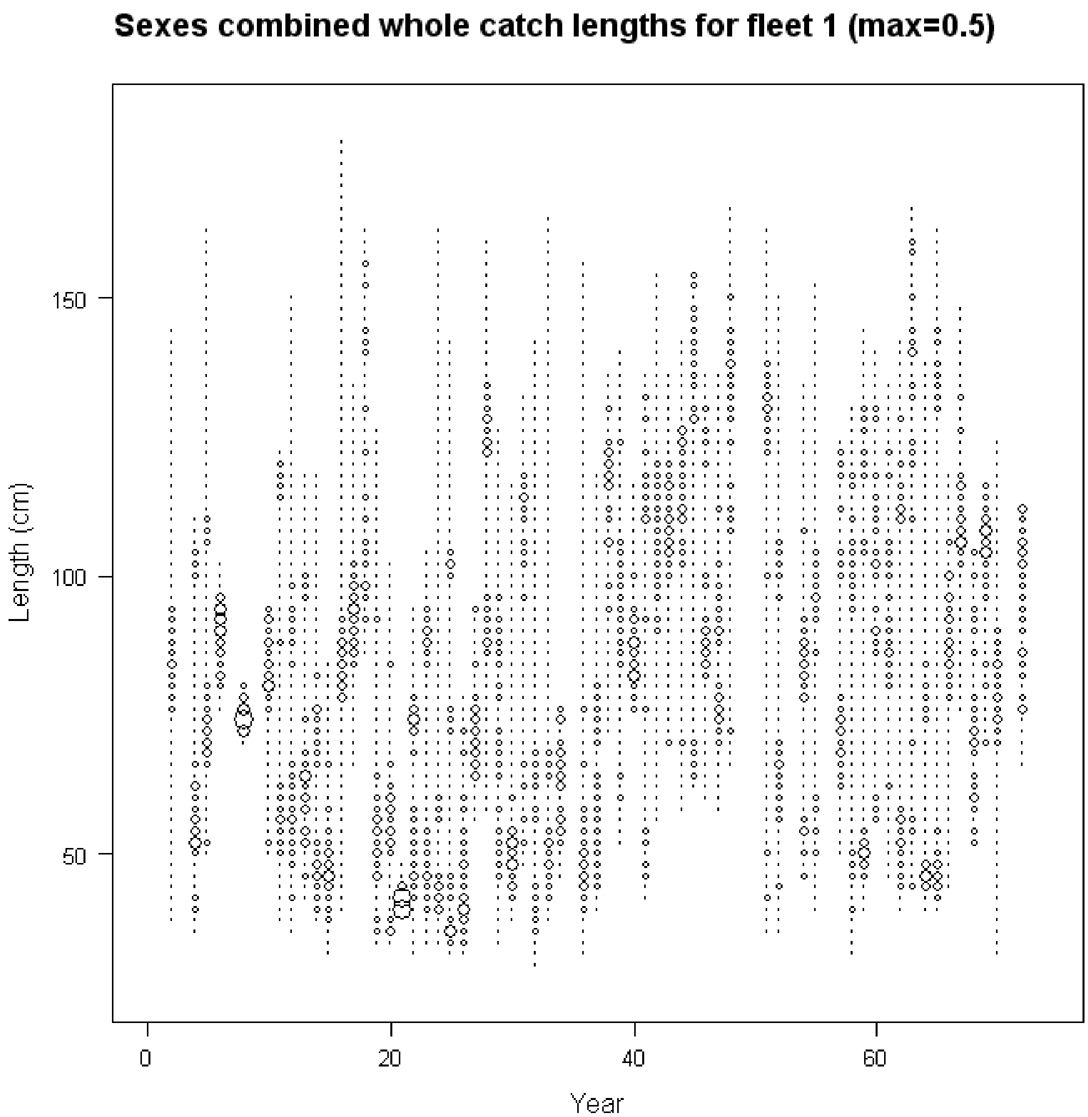


FIGURE 2.6a. Size compositions of the catches of bigeye tuna taken by Fishery 1 over time (quarterly). The area of the circles is proportional to catch.

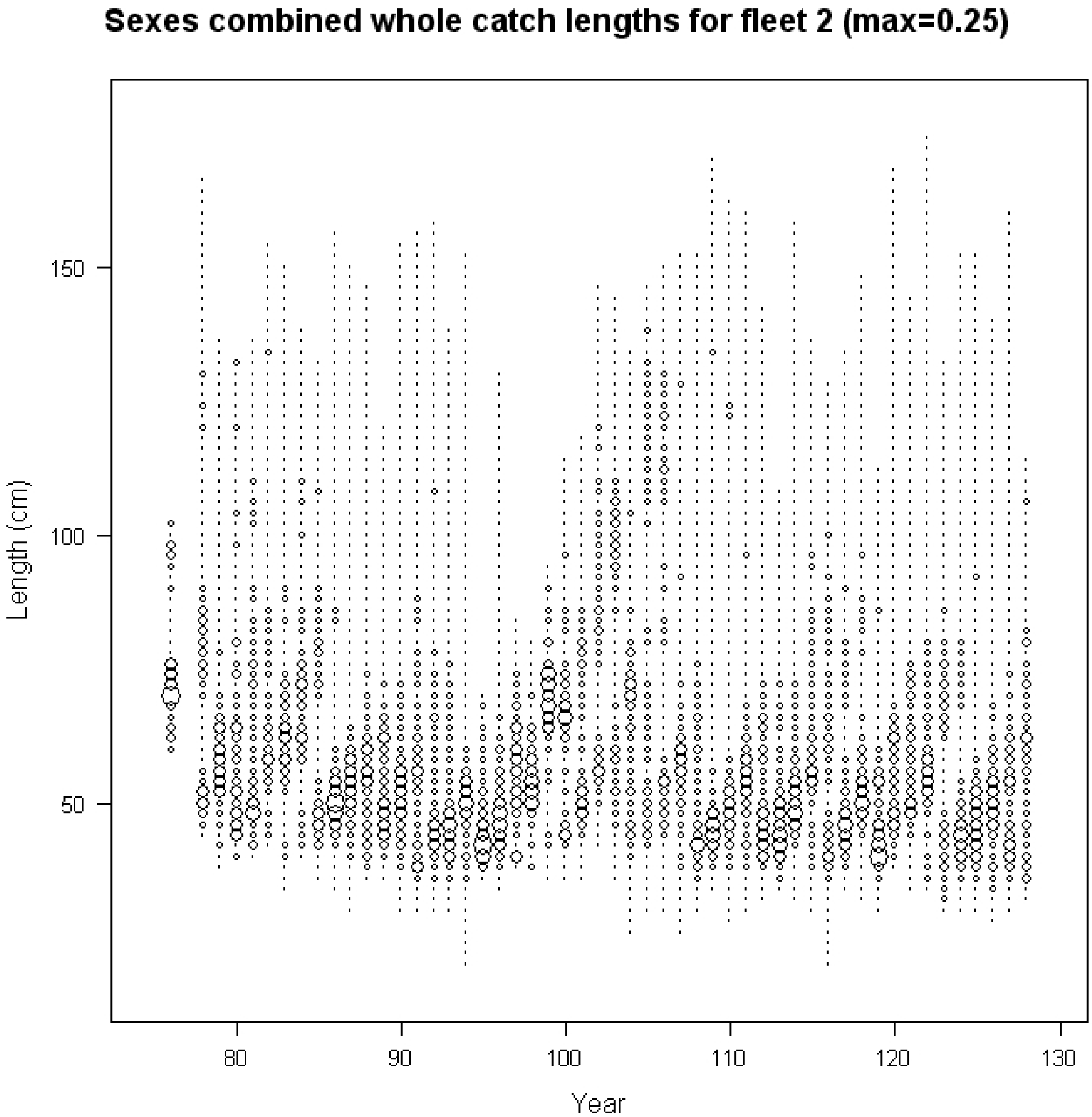


FIGURE 2.6b. Size compositions of the catches of bigeye tuna taken by Fishery 2 over time (quarterly). The area of the circles is proportional to catch.

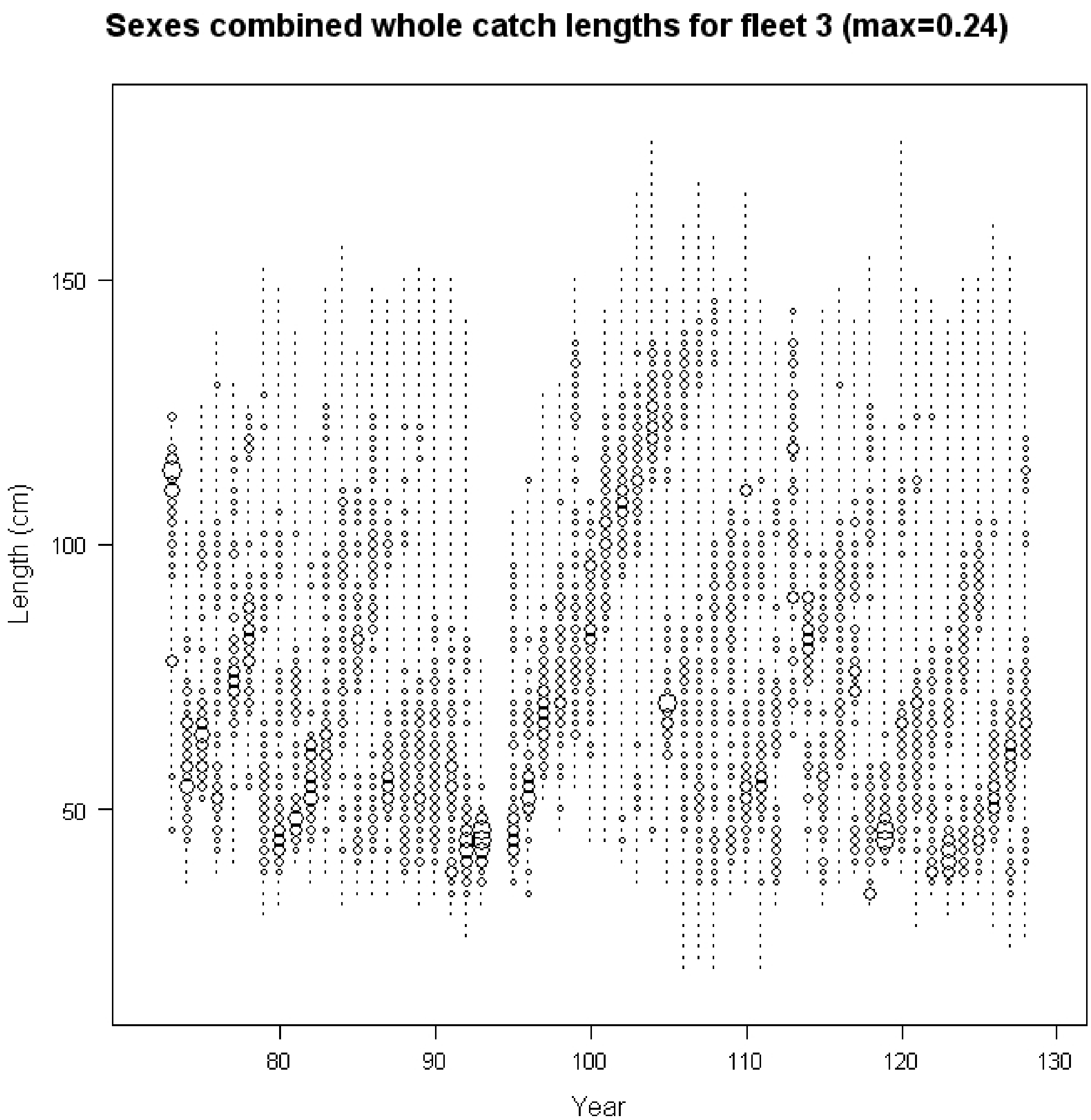


FIGURE 2.6c. Size compositions of the catches of bigeye tuna taken by Fishery 3 over time (quarterly). The area of the circles is proportional to catch.

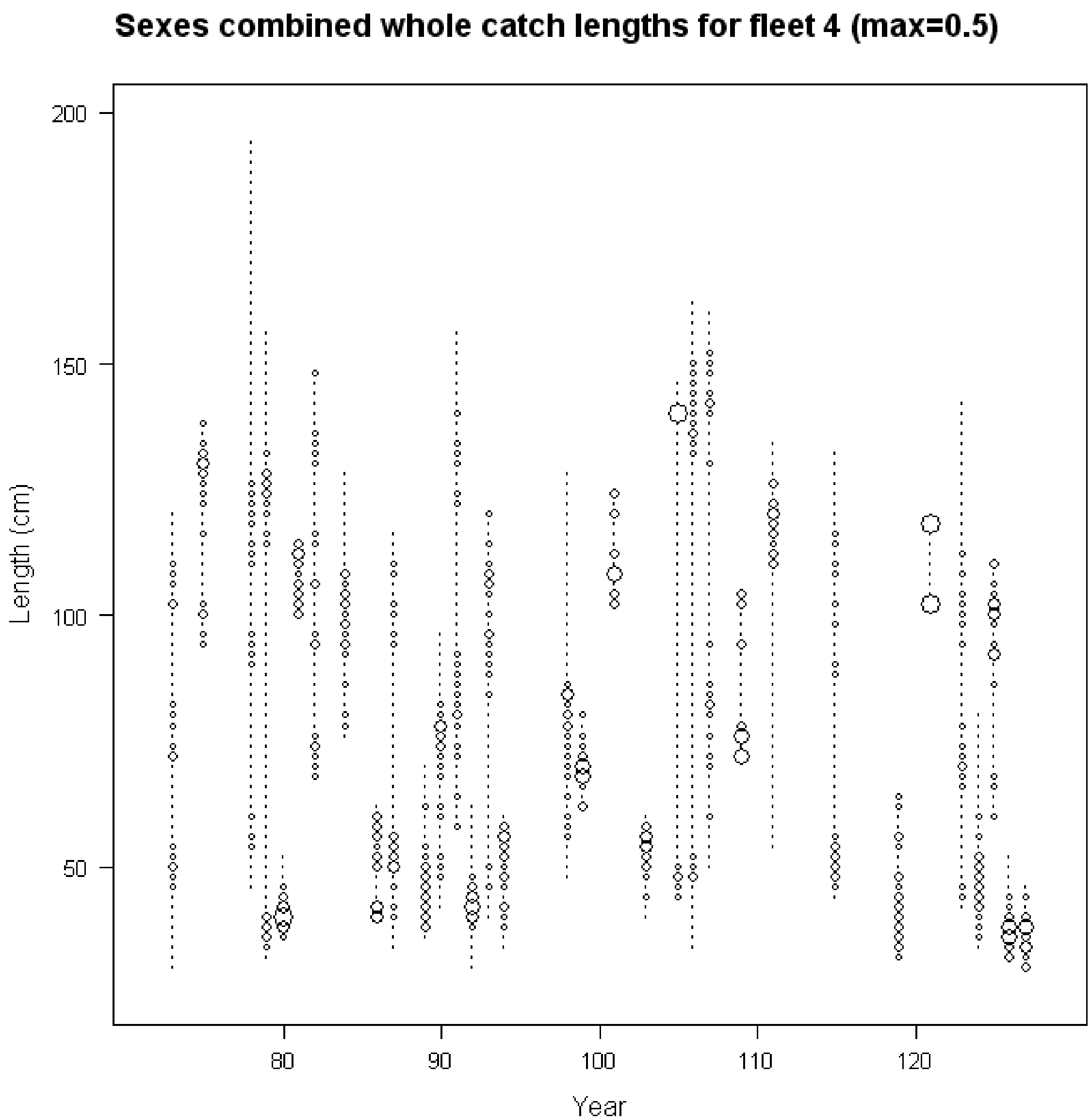


FIGURE 2.6d. Size compositions of the catches of bigeye tuna taken by Fishery 4 over time (quarterly). The area of the circles is proportional to catch.

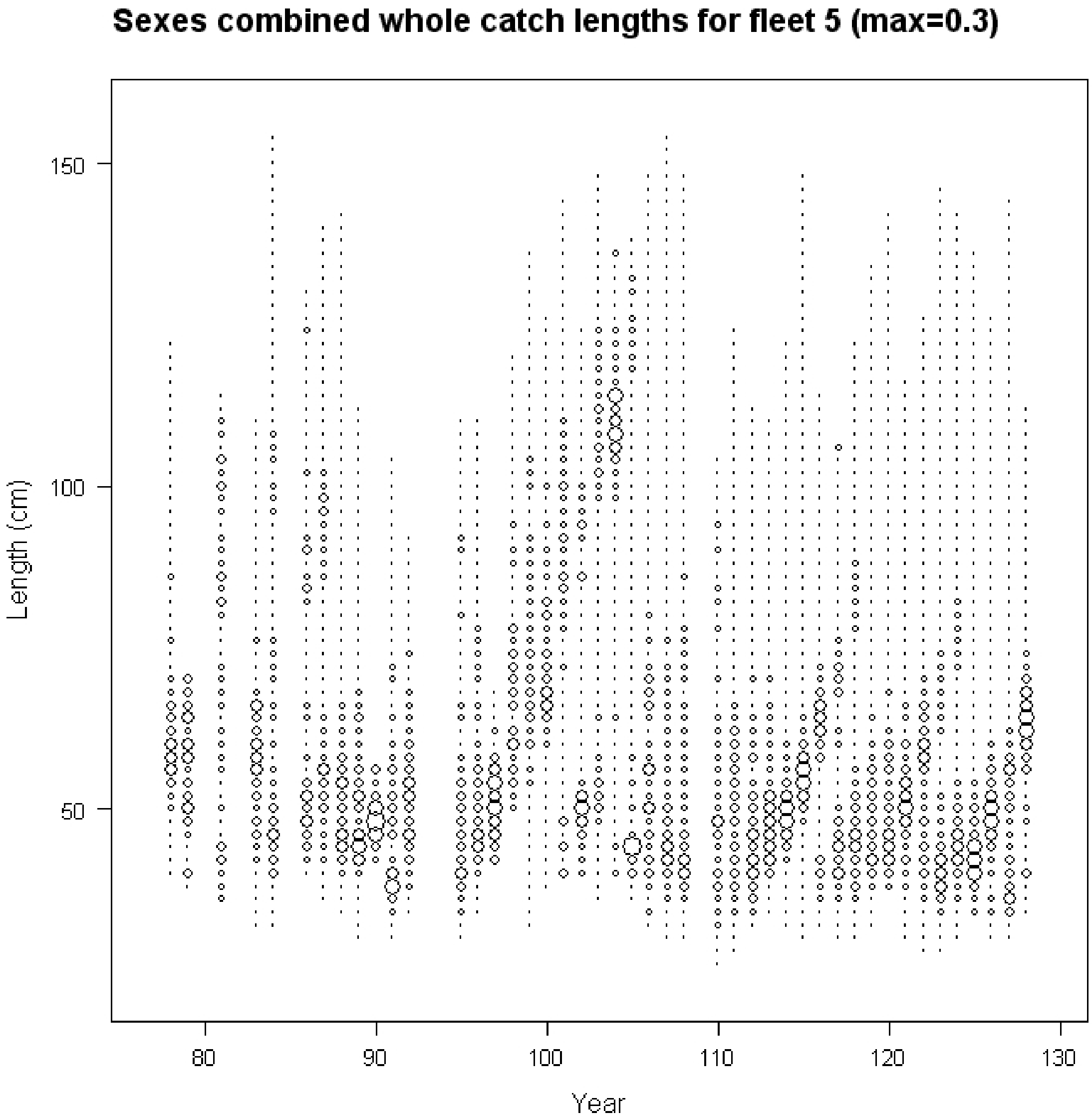


FIGURE 2.6e Size compositions of the catches of bigeye tuna taken by Fishery 5 over time (quarterly). The area of the circles is proportional to catch.

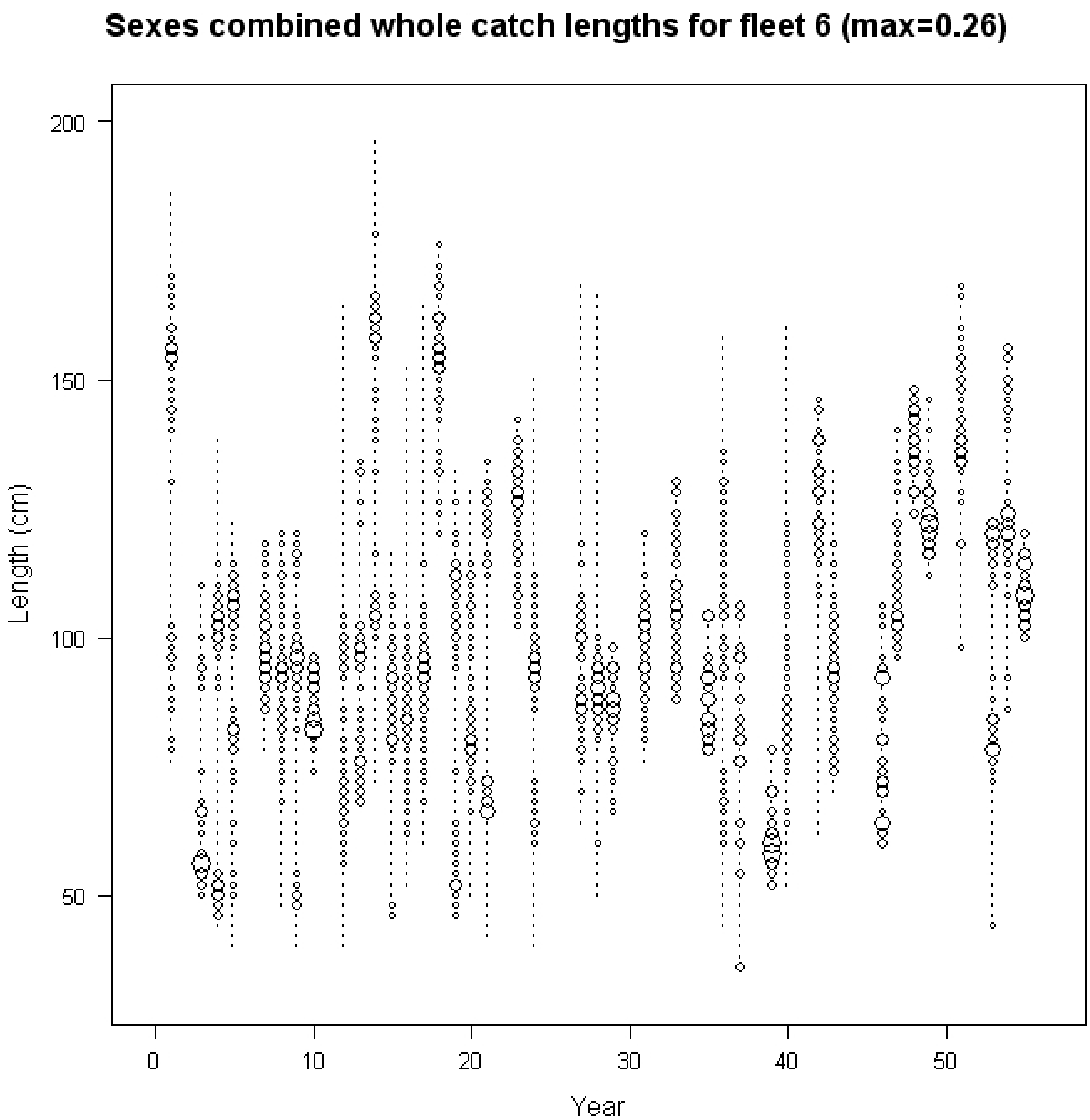


FIGURE 2.6f. Size compositions of the catches of bigeye tuna taken by Fishery 6 over time (quarterly). The area of the circles is proportional to catch.

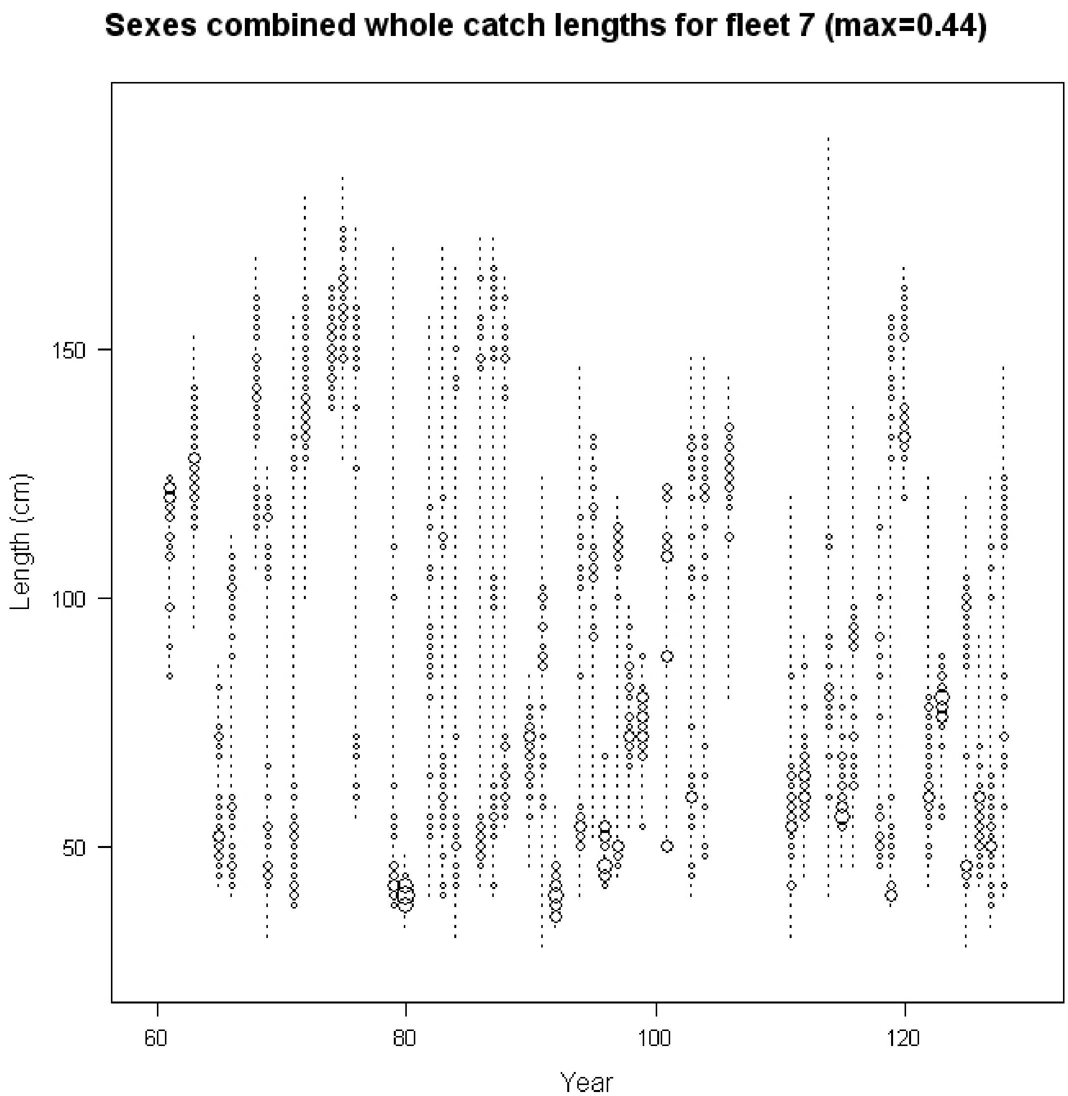


FIGURE 2.6g. Size compositions of the catches of bigeye tuna taken by Fishery 7 over time (quarterly). The area of the circles is proportional to catch.

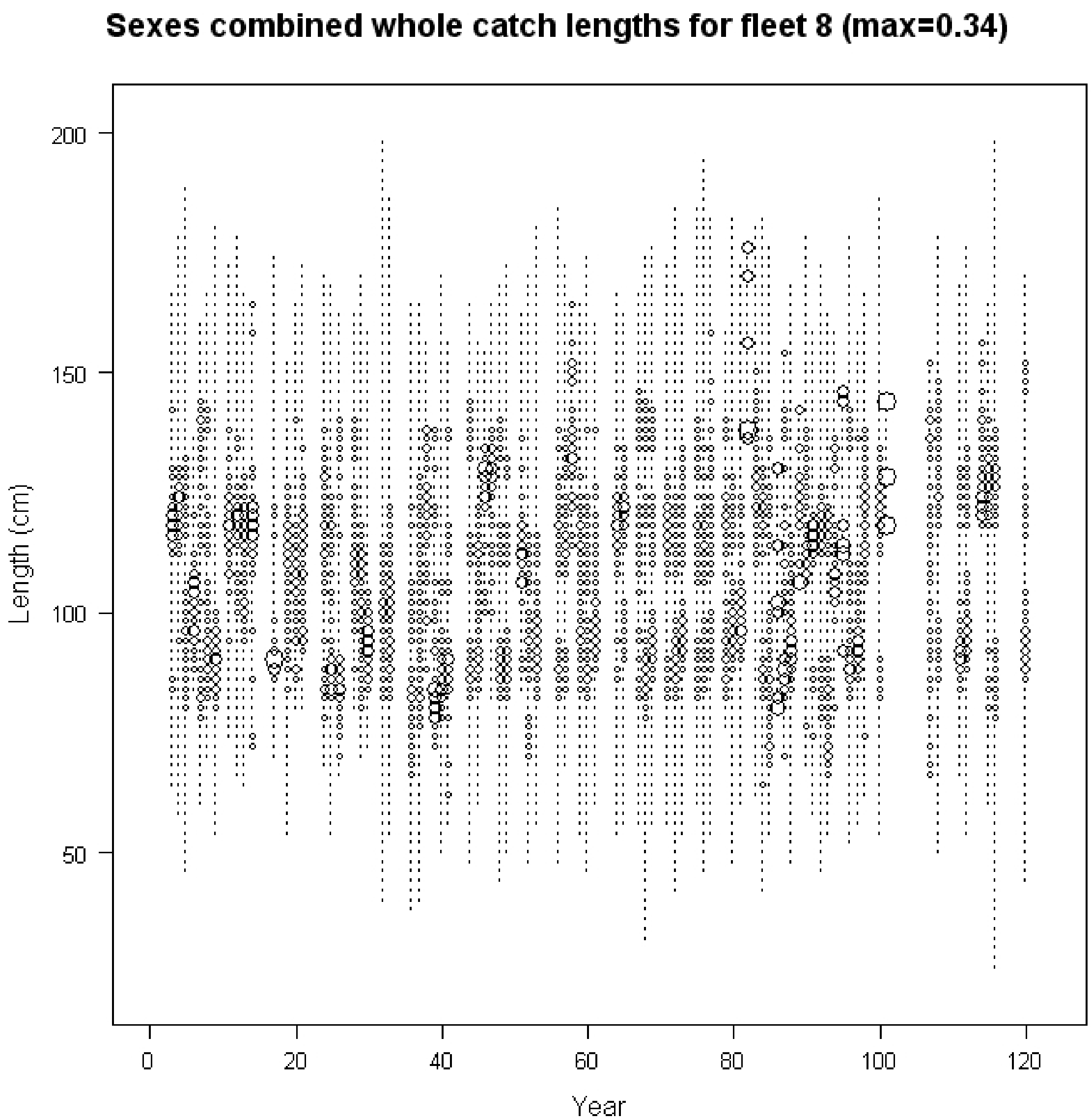


FIGURE 2.6h. Size compositions of the catches of bigeye tuna taken by Fishery 8 over time (quarterly). The area of the circles is proportional to catch.

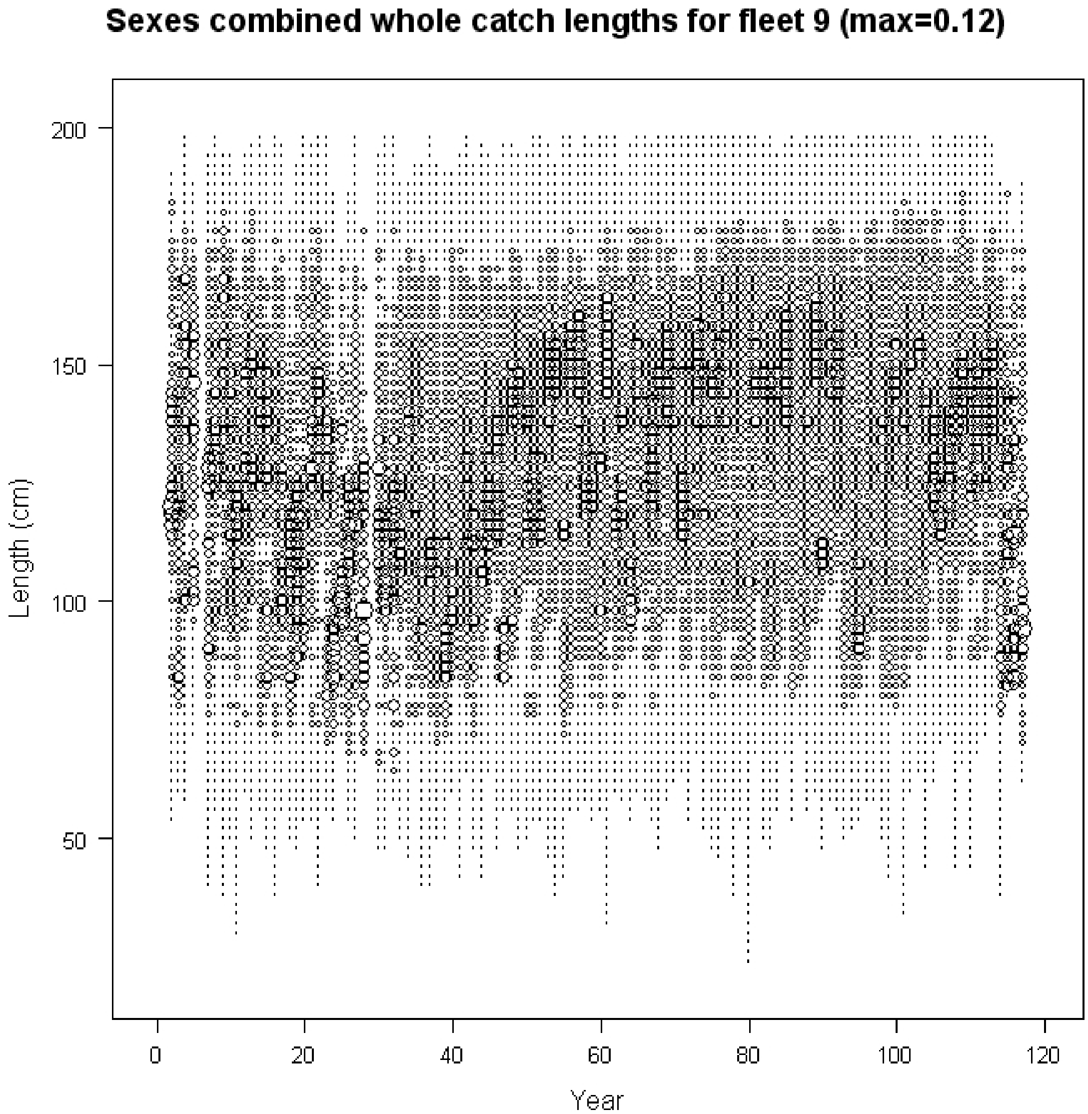


FIGURE 2.6i. Size compositions of the catches of bigeye tuna taken by Fishery 9 over time (quarterly). The area of the circles is proportional to catch.

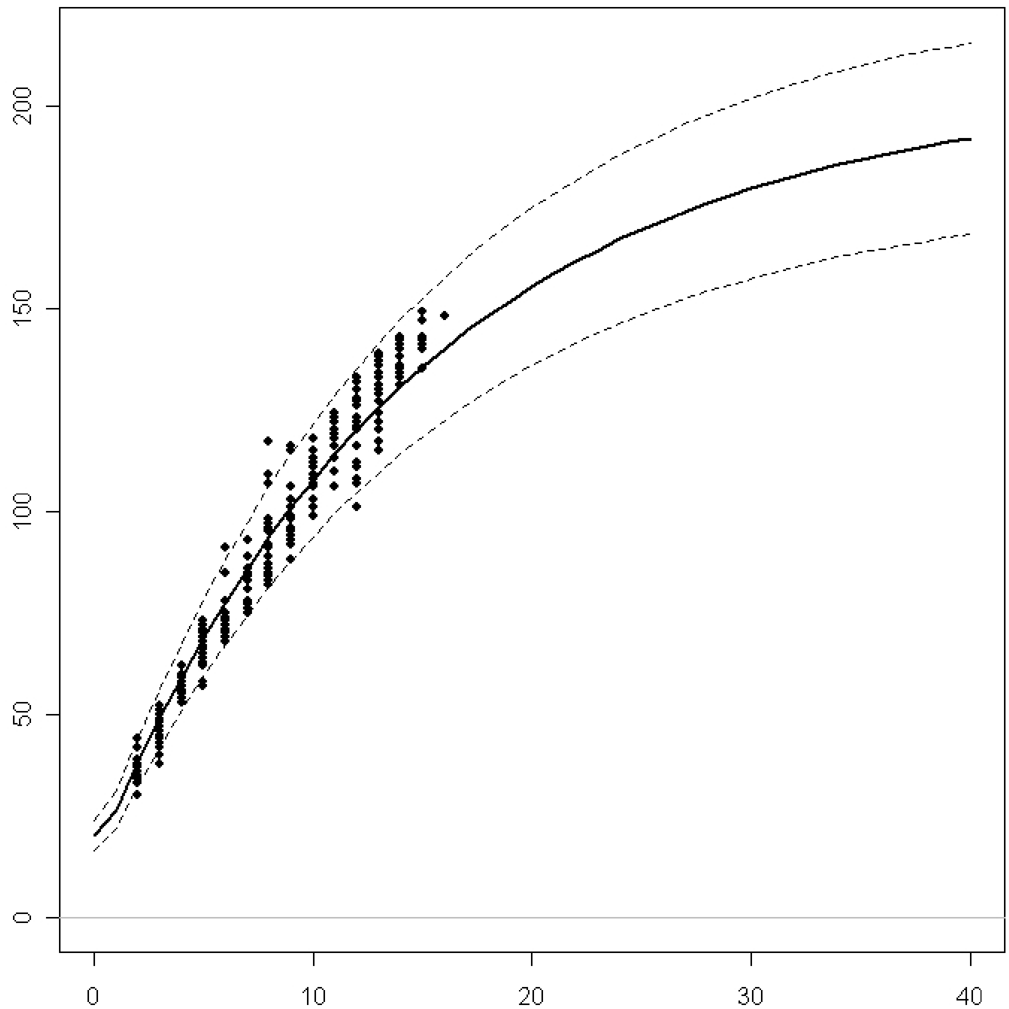


FIGURE 3.1. Estimated average lengths at age for bigeye tuna in the EPO. The crosses represent the otolith age-length data from Schaefer and Fuller (2006), and the circles represent the prior. The shaded area indicates the range of lengths estimated to be covered by two standard deviations of the length at age.

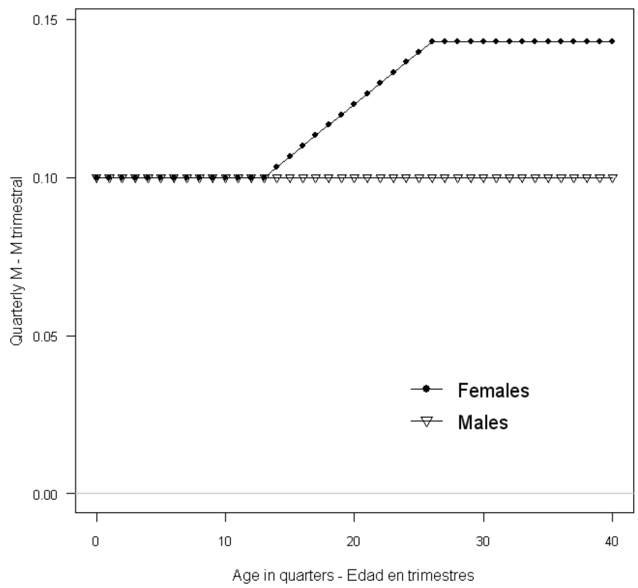


FIGURE 3.2. Quarterly natural mortality (*M*) rates used for the base case assessment of bigeye tuna in the EPO.

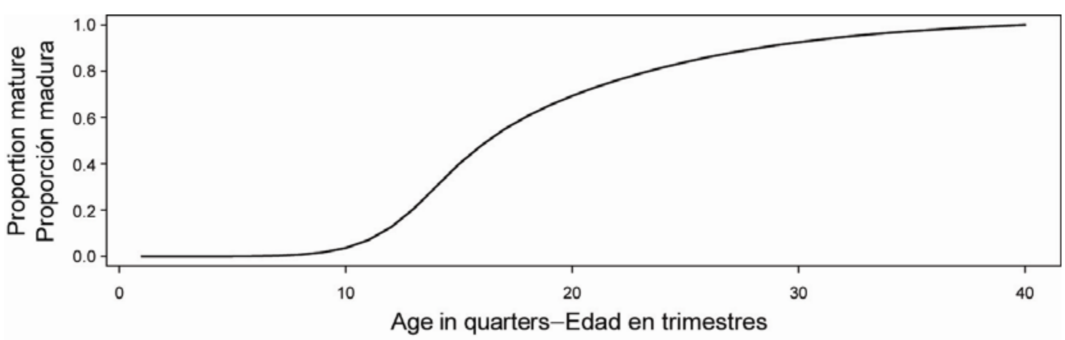


FIGURE 3.3. Age-specific index of fecundity of bigeye tuna as assumed in the base case model and in the estimation of natural mortality.

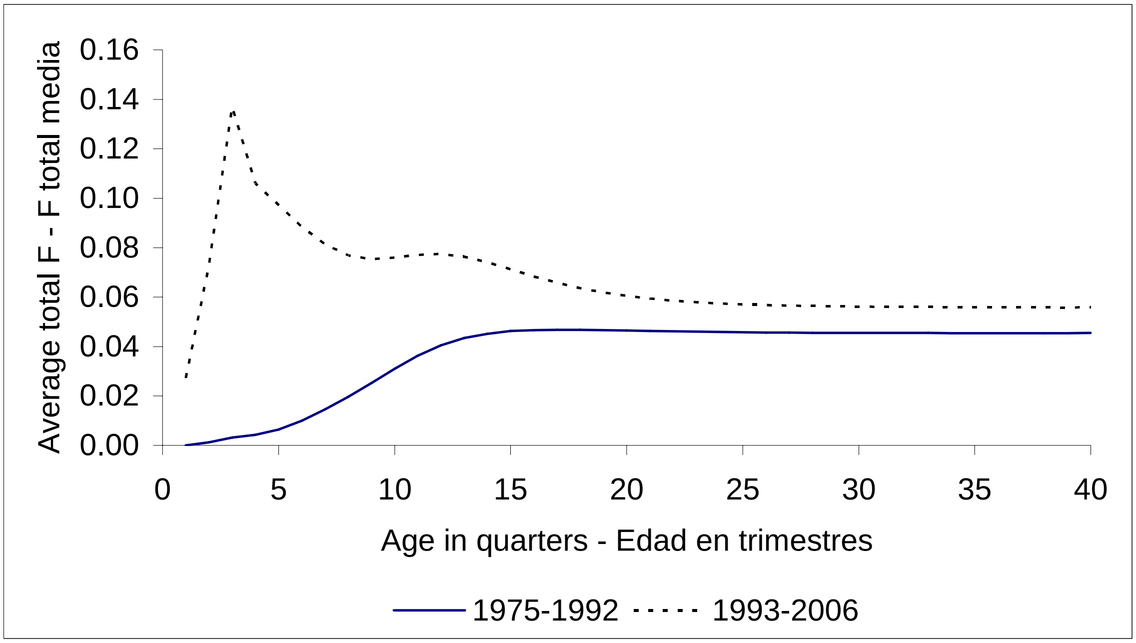


FIGURE 4.1. Average quarterly fishing mortality (approximated by exploitation rate) at age of bigeye tuna, by all gears, in the EPO. The curve for 1975-1992 displays averages for the period prior to the expansion of the floating-object fisheries, and that for 1993-2005 averages for the period since that expansion.

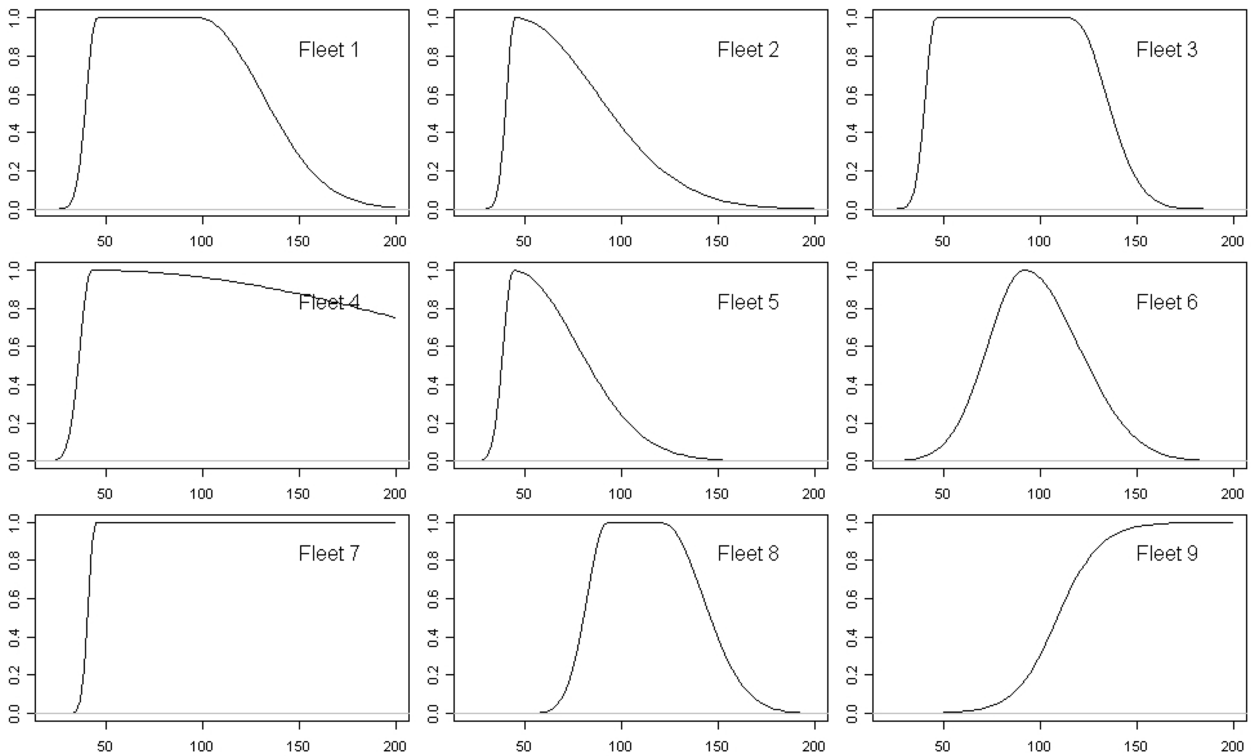


FIGURE 4.2. Selectivity curves for the 13 fisheries that take bigeye tuna in the EPO. The selectivity curves for Fisheries 1 through 9 were estimated with the A-SCALA method, and those for Fisheries 10-13 are based on assumptions.

FIGURA 4.2. 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.

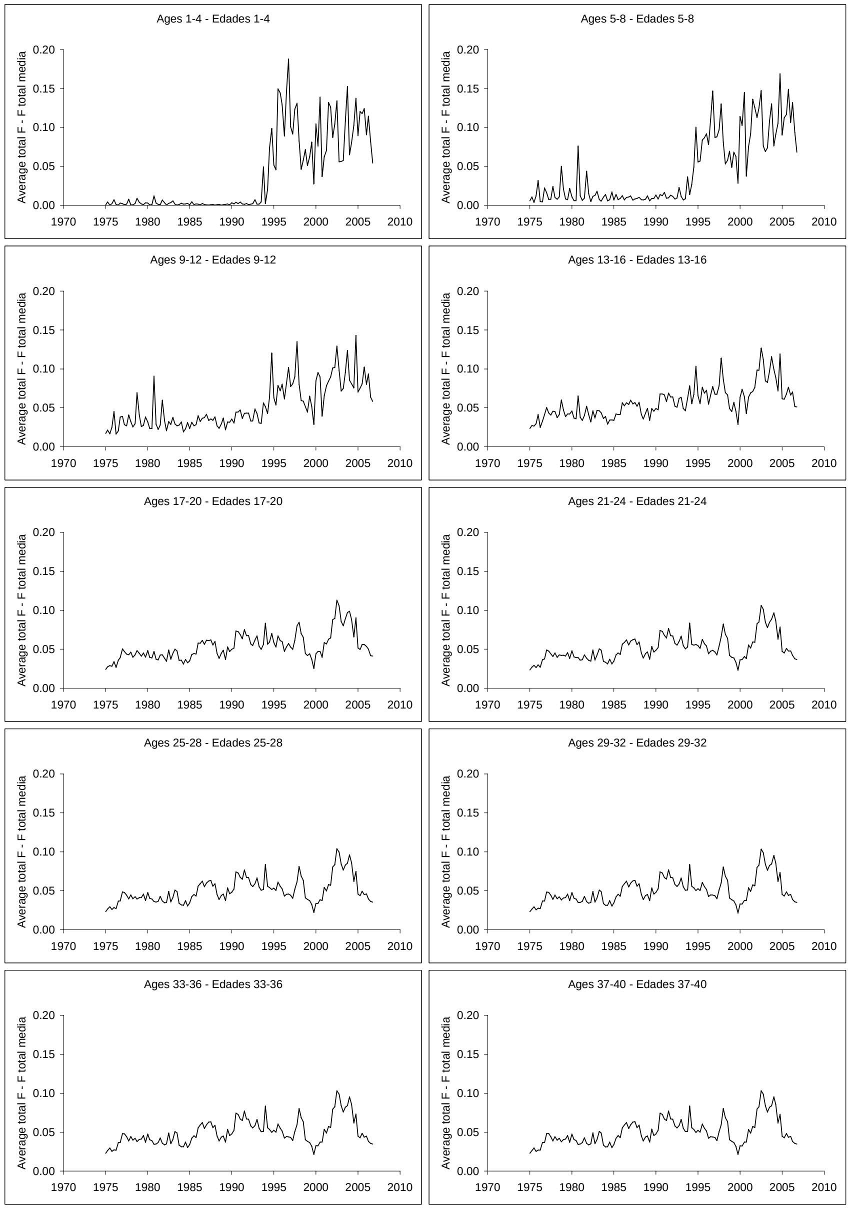


FIGURE 4.3. Average quarterly fishing mortality, by all gears, on bigeye tuna recruited to the fisheries of the EPO. Each panel illustrates an average of four quarterly fishing mortality vectors that affected the fish within the range of ages indicated in the title of each panel. For example, the trend illustrated in the upper-left panel is an average of the fishing mortalities that affected the fish that were 1-4 quarters old.

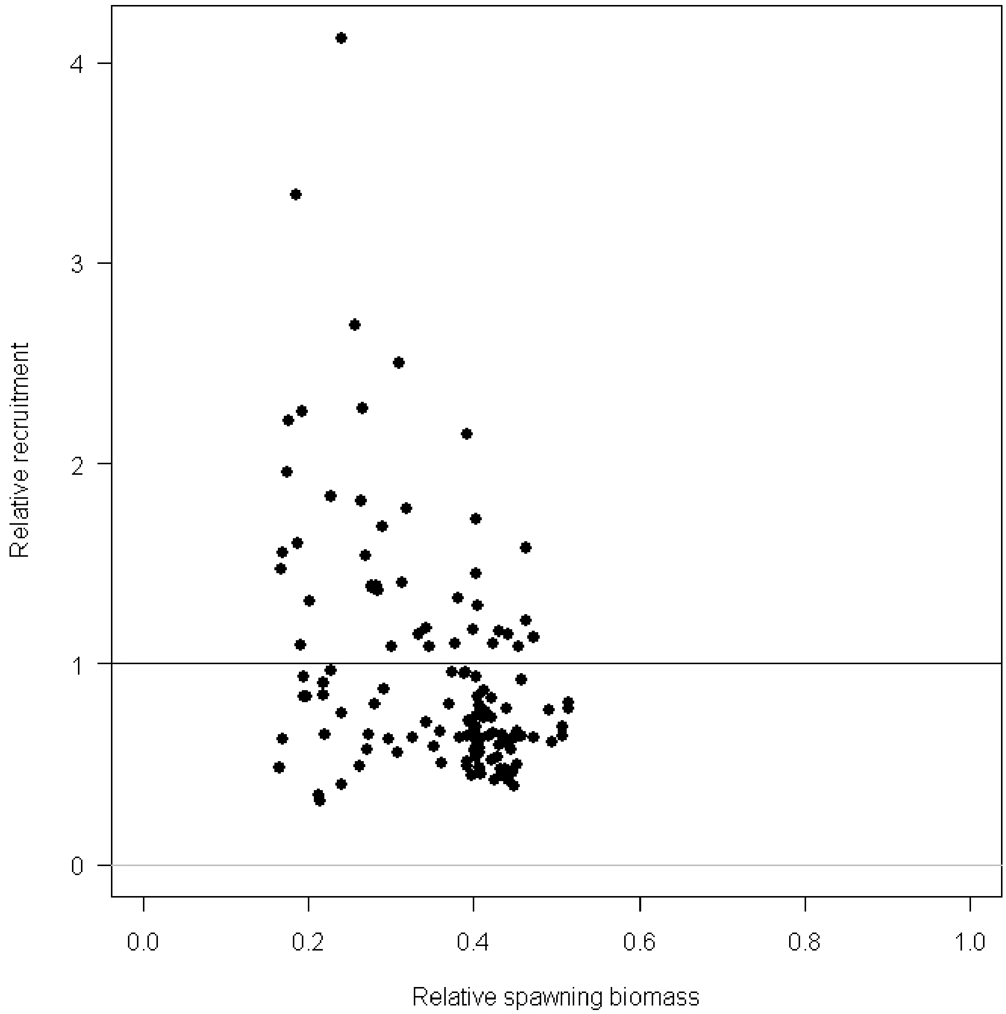


FIGURE 4.4. Estimated relationship between the recruitment of bigeye tuna and spawning biomass. The recruitment is scaled so that the estimate of virgin recruitment is equal to 1.0. Likewise, the spawning biomass is scaled so that the estimate of virgin spawning biomass is equal to 1.0. The horizontal line represents the assumed stock-recruitment relationship.

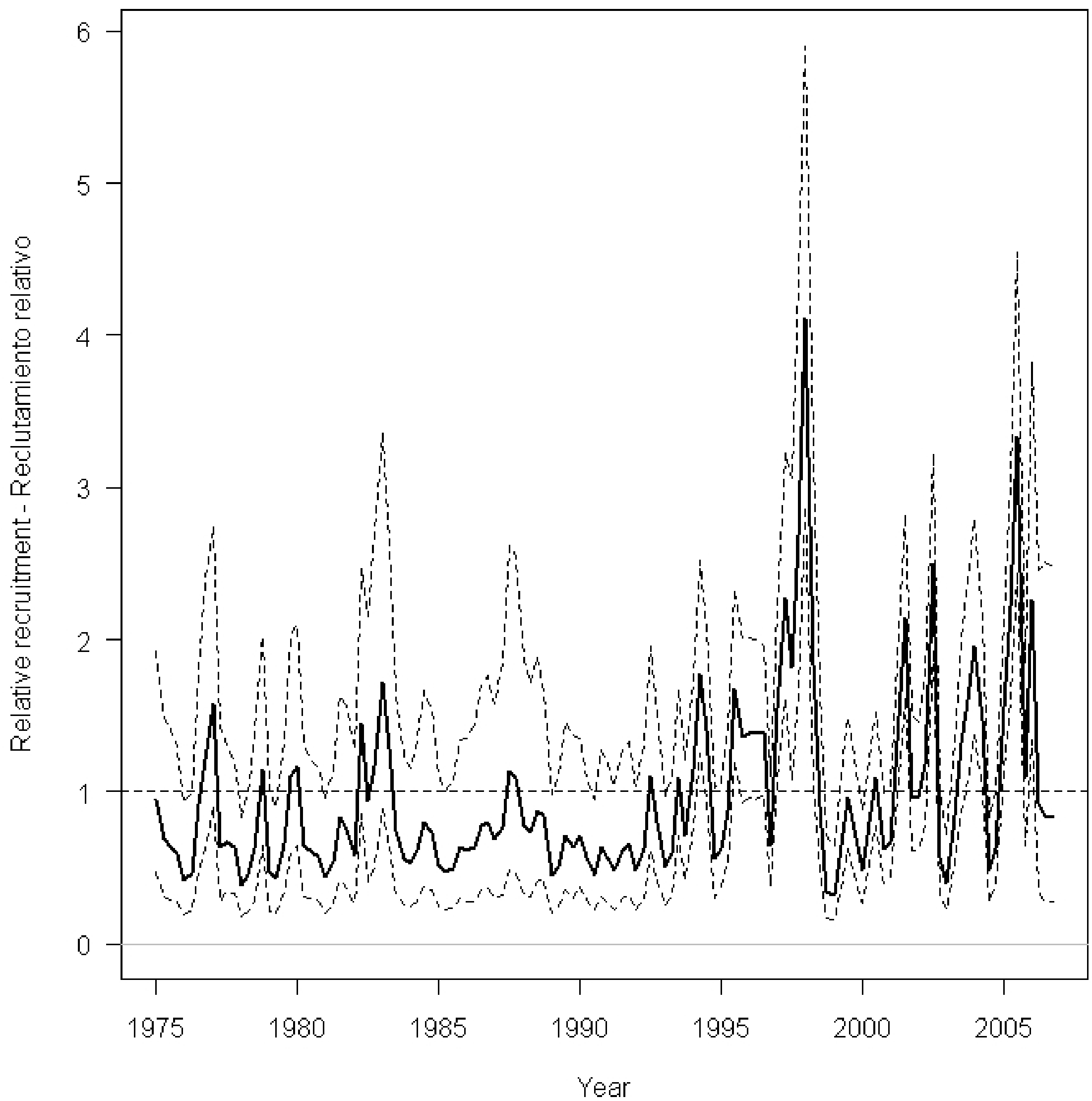


FIGURE 4.5. Estimated recruitment of bigeye tuna to the fisheries of the EPO. The estimates are scaled so that the estimate of virgin recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the thin dashed lines the confidence intervals (±2 standard deviations) around those estimates. The labels on the time axis are drawn at the beginning of each year, but, since the assessment model represents time on a quarterly basis, there are four estimates of recruitment for each year.

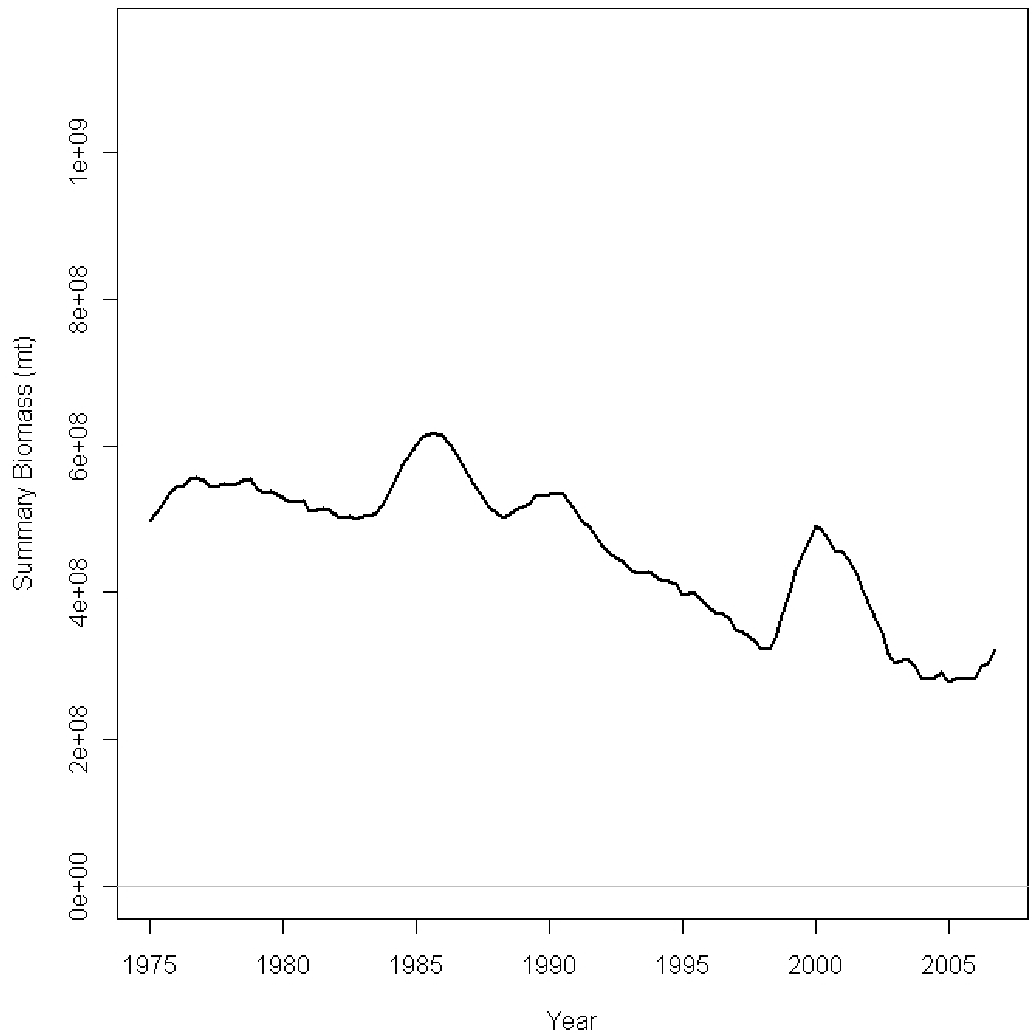


FIGURE 4.6. Estimated biomass of bigeye tuna 3+ quarters old in the EPO. The bold line illustrates the maximum likelihood estimates of the biomasses, and the thin dashed lines the confidence intervals (±2 standard deviations) around those estimates. Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year. t = metric tons.

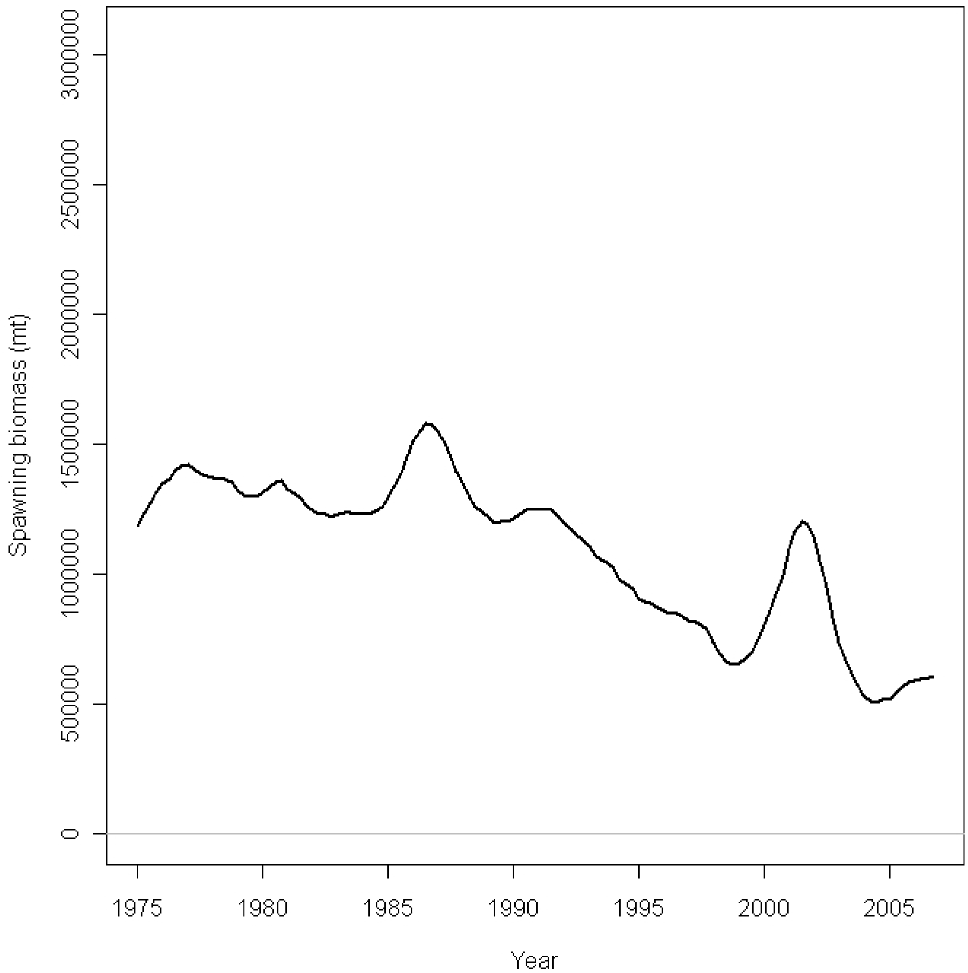


FIGURE 4.7 Estimated spawning biomass (see Section 3.1.2) of bigeye tuna in the EPO. The bold line illustrates the maximum likelihood estimates of the biomasses, and the thin dashed lines the confidence intervals (±2 standard deviations) around those estimates. Since the assessment model represents time on a quarterly basis, there are four estimates of biomass for each year. t = metric tons.

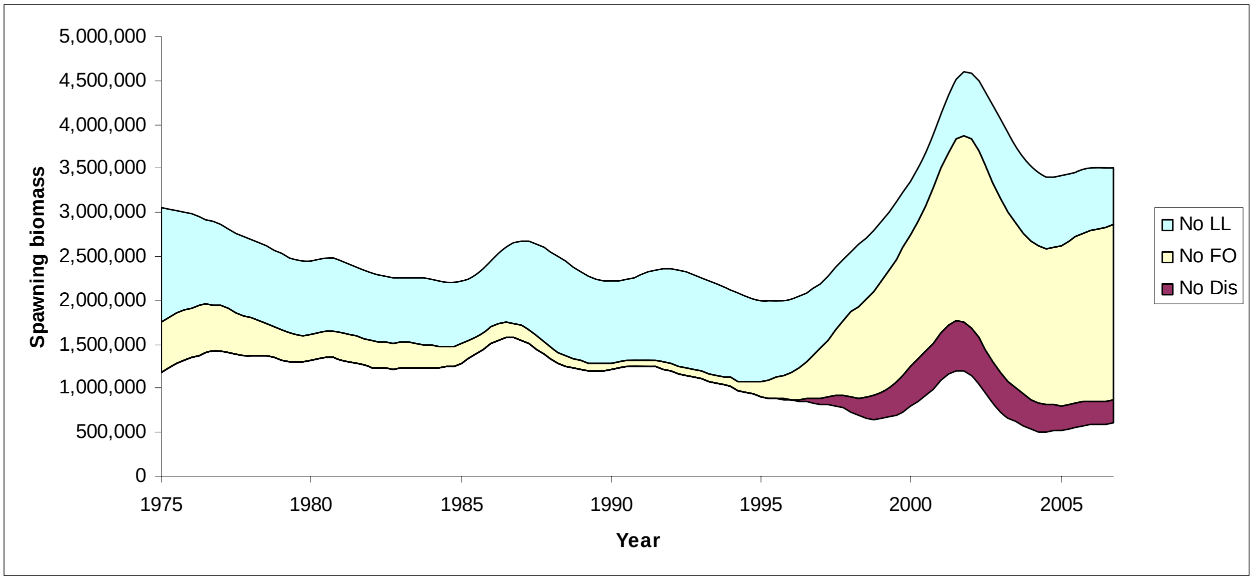


FIGURE 4.8. Biomass trajectory of a simulated population of bigeye tuna that was not exploited (dashed line) and that predicted by the stock assessment model (solid line). The shaded areas between the two lines show the portions of the impact attributed to each fishing method. t = metric tons.

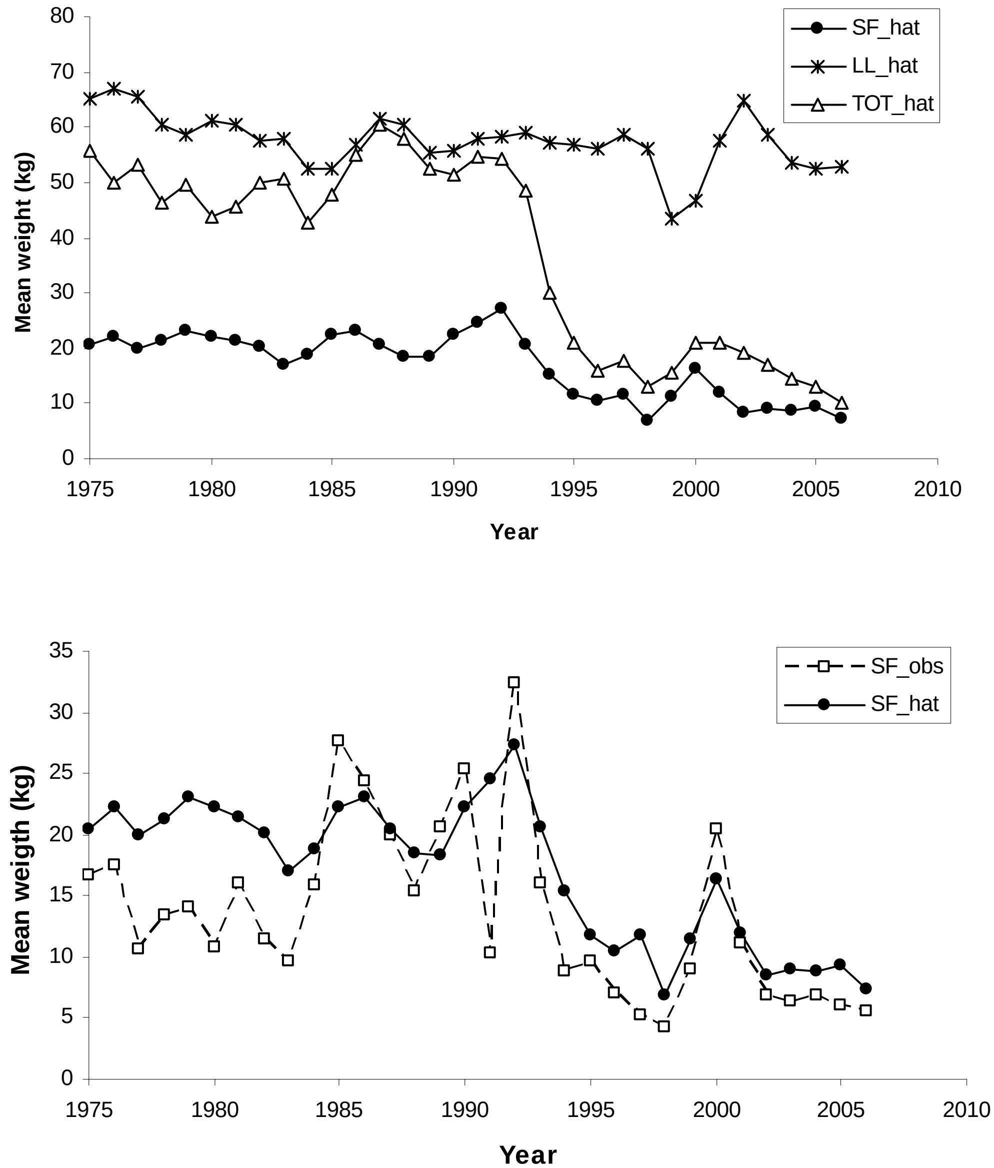


FIGURE 4.9. Estimated average weights of bigeye tuna caught by fisheries of the EPO. Time series of mean weights are presented for the surface fisheries (SF, Fisheries 1-5), longine fisheries (LL, Fisheries 8 and 9), and all fisheries combined (TOT, total). Top – predicted average weights, bottom – predicted and observed average weights for the surface fisheries.

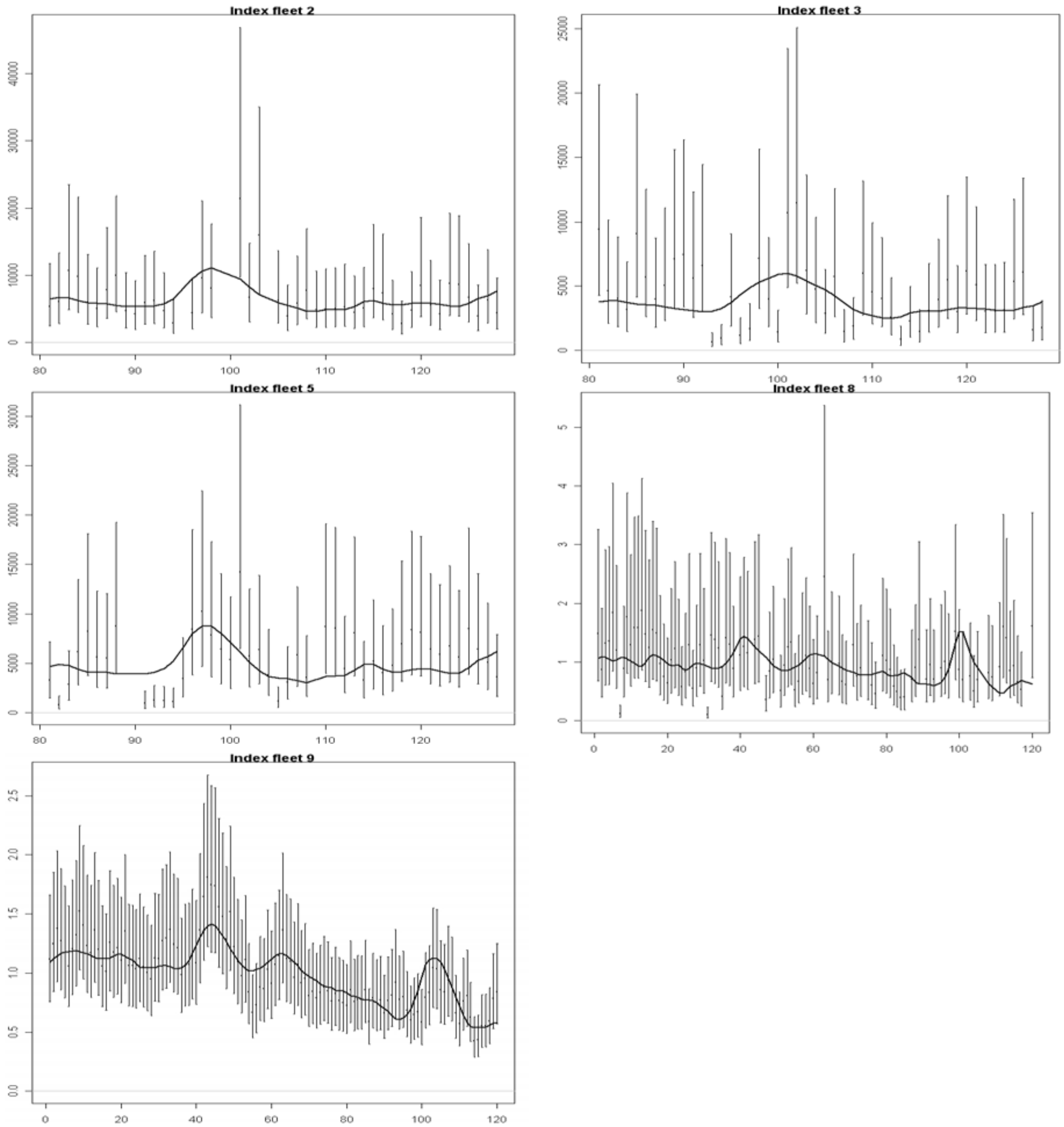


FIGURE 4.10. Model fit to the CPUE data from different fisheries.

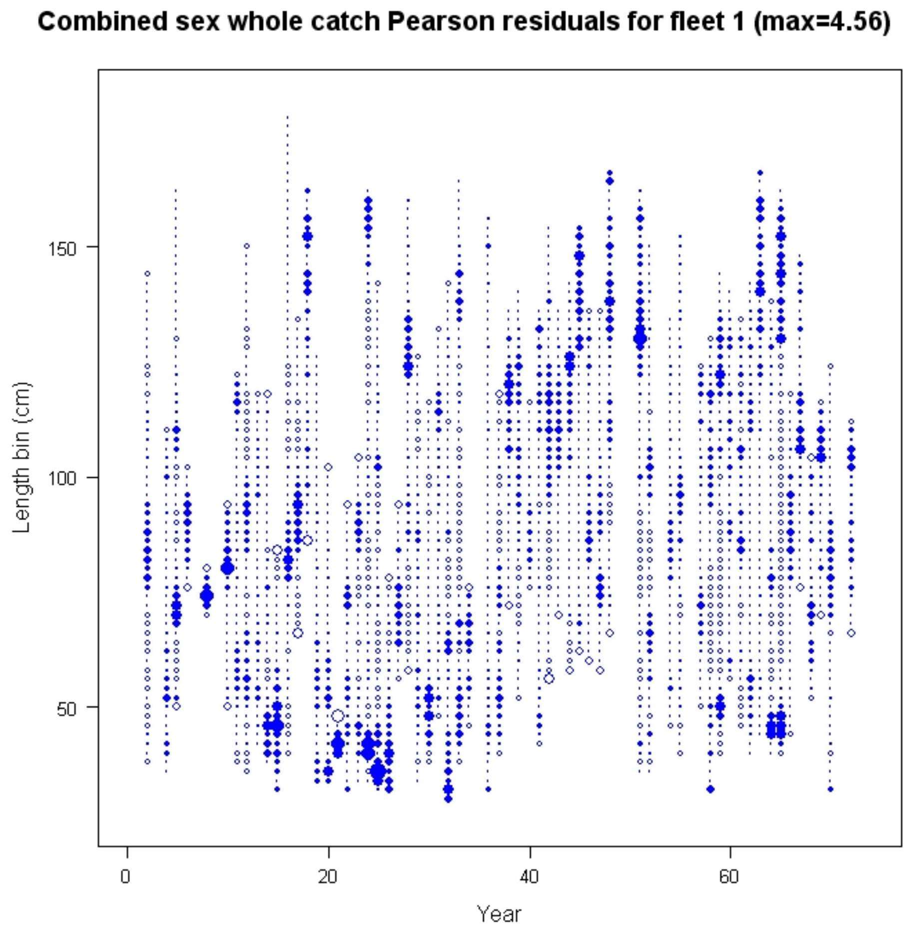


FIGURE 4.11a. Pearson residual plots for the model fits to the length composition data for Fishery 1. Solid circles represent observations that are less than the model predictions; open circles correspond to observations that are higher than model predictions. The area of the circles is proportional to the absolute value of residuals.

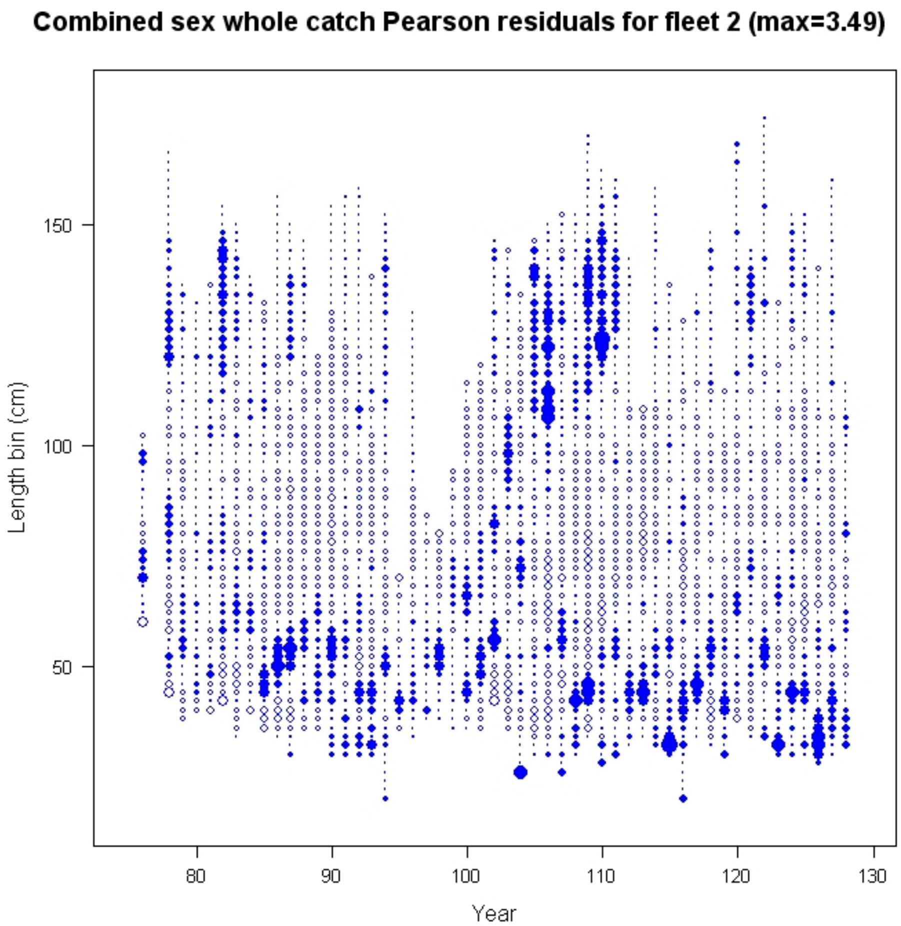


FIGURE 4.11b. Pearson residual plots for the model fits to the length composition data for Fishery 2. Solid circles represent observations that are less than the model predictions; open circles correspond to observations that are higher than model predictions. The area of the circles is proportional to the absolute value of residuals.

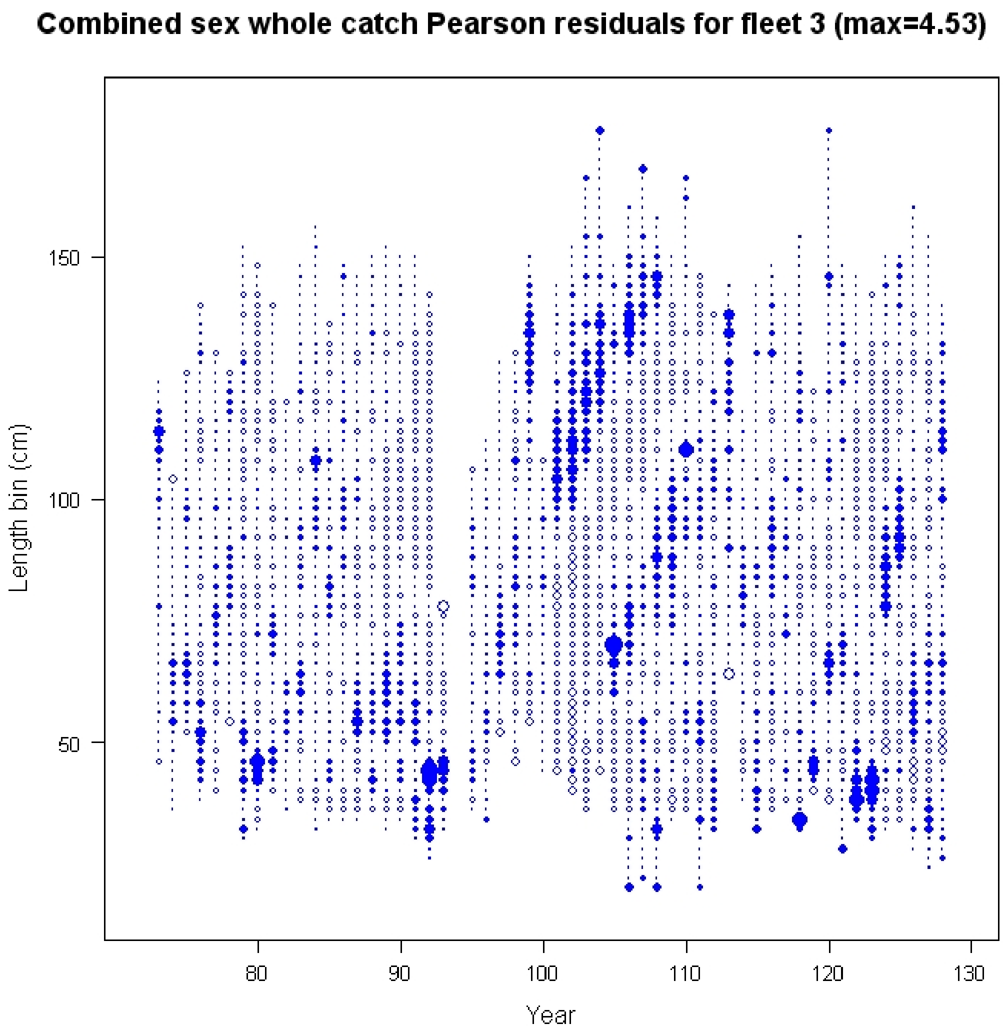


FIGURE 4.11c. Pearson residual plots for the model fits to the length composition data for Fishery 3. Solid circles represent observations that are less than the model predictions; open circles correspond to observations that are higher than model predictions. The area of the circles is proportional to the absolute value of residuals.

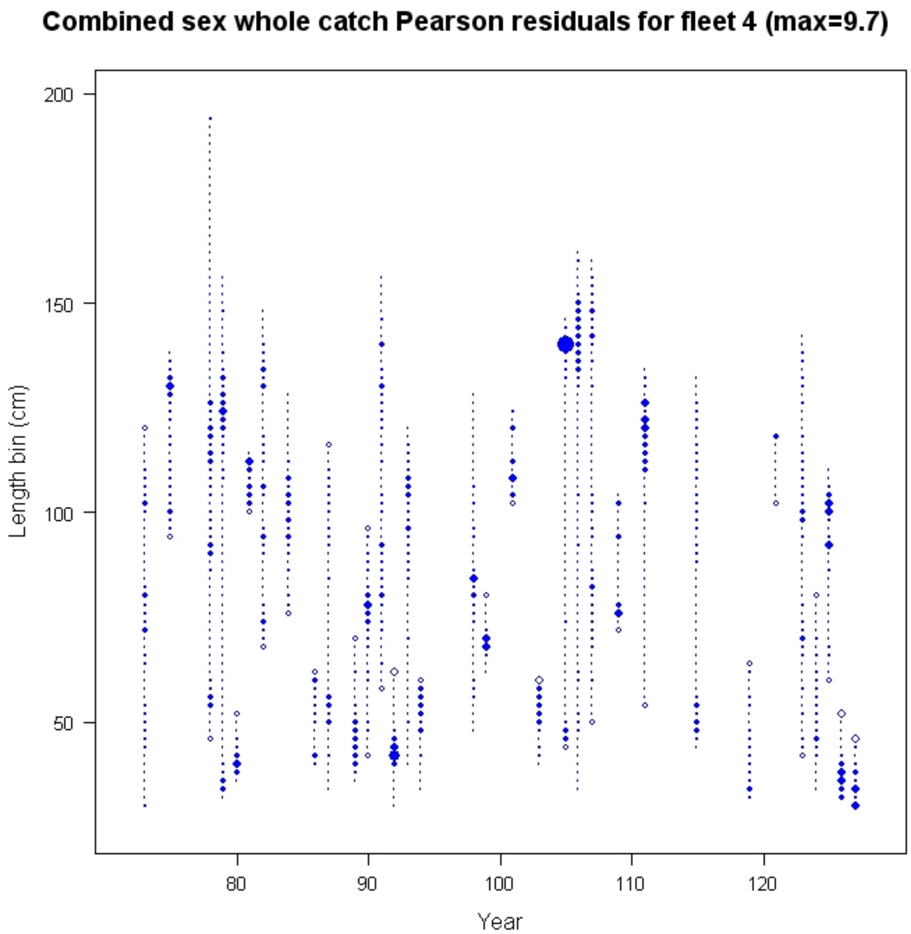


FIGURE 4.11d Pearson residual plots for the model fits to the length composition data for Fishery 4. Solid circles represent observations that are less than the model predictions; open circles correspond to observations that are higher than model predictions. The area of the circles is proportional to the absolute value of residuals.

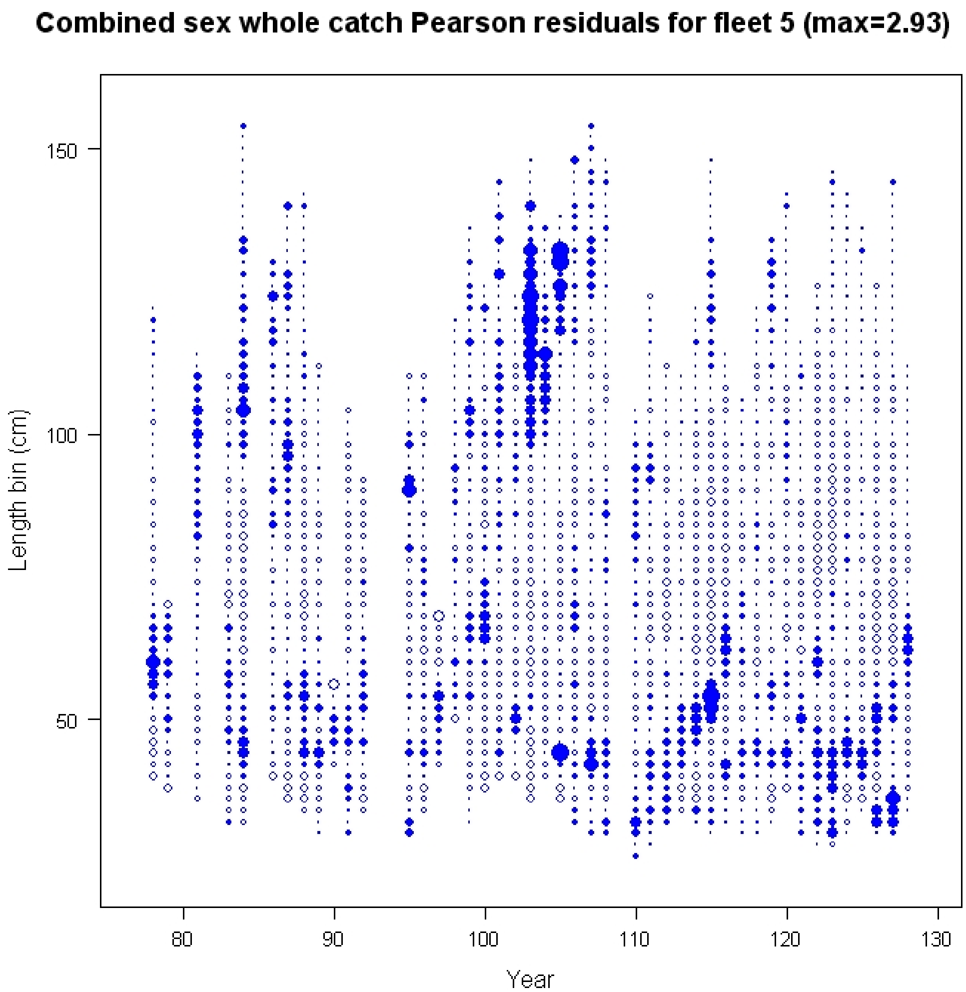


FIGURE 4.11e. Pearson residual plots for the model fits to the length composition data for Fishery 5. Solid circles represent observations that are less than the model predictions; open circles correspond to observations that are higher than model predictions. The area of the circles is proportional to the absolute value of residuals.

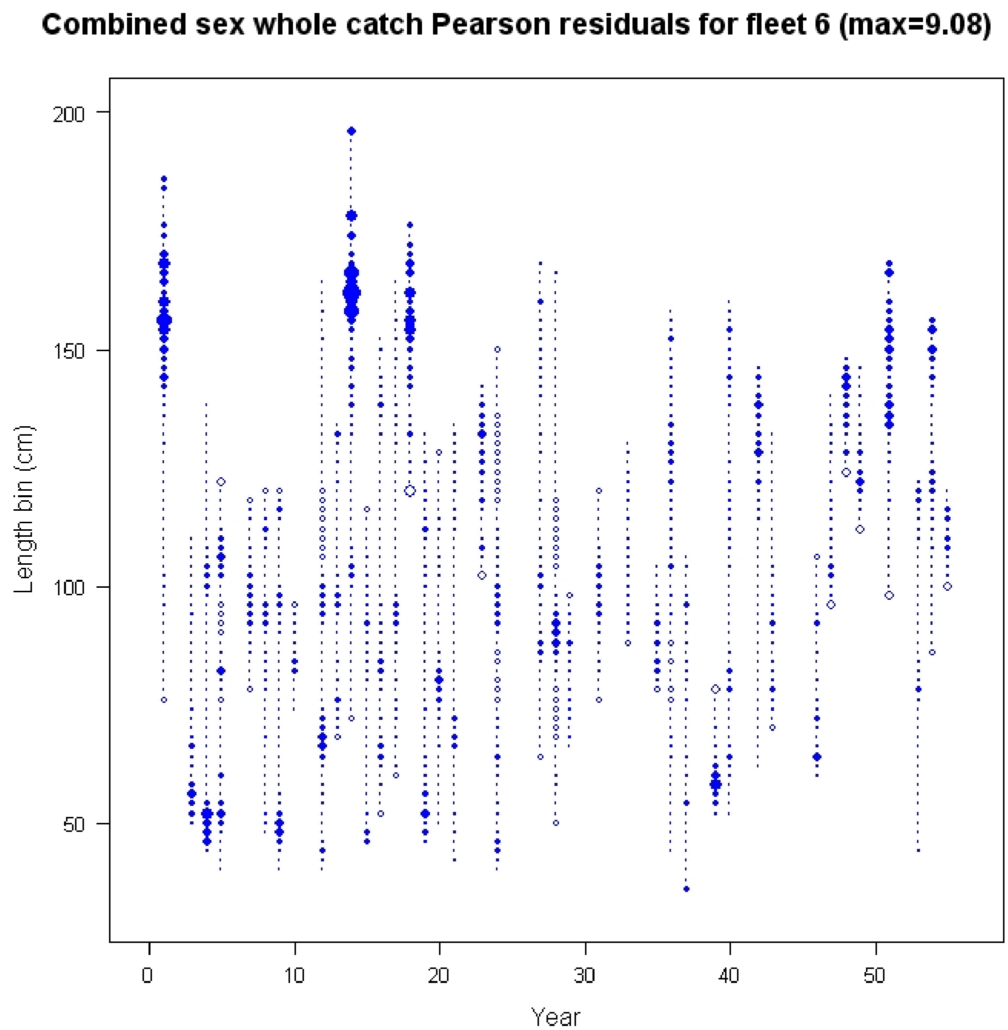


FIGURE 4.11f. Pearson residual plots for the model fits to the length composition data for Fishery 6. Solid circles represent observations that are less than the model predictions; open circles correspond to observations that are higher than model predictions. The area of the circles is proportional to the absolute value of residuals.

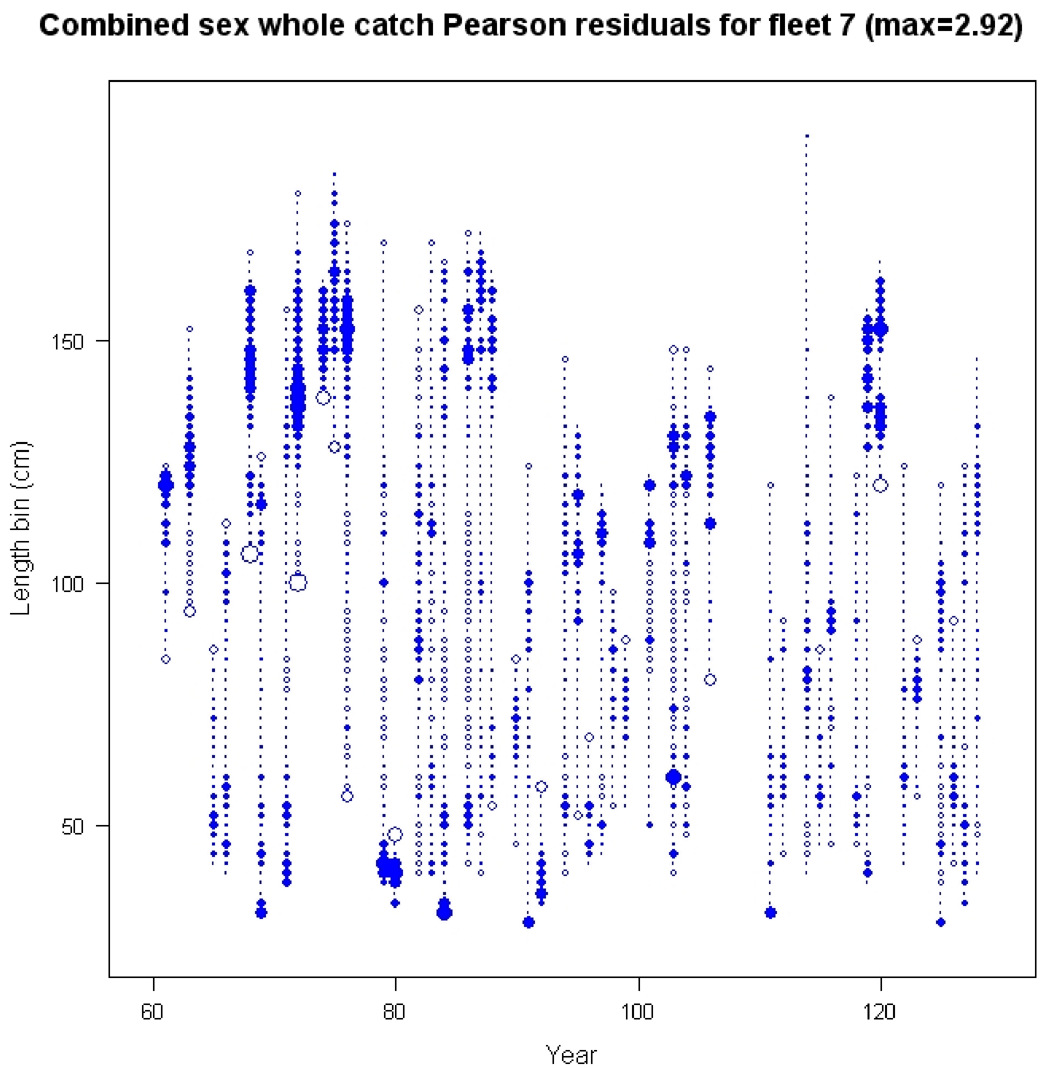


FIGURE 4.11g. Pearson residual plots for the model fits to the length composition data for Fishery 7. Solid circles represent observations that are less than the model predictions; open circles correspond to observations that are higher than model predictions. The area of the circles is proportional to the absolute value of residuals.

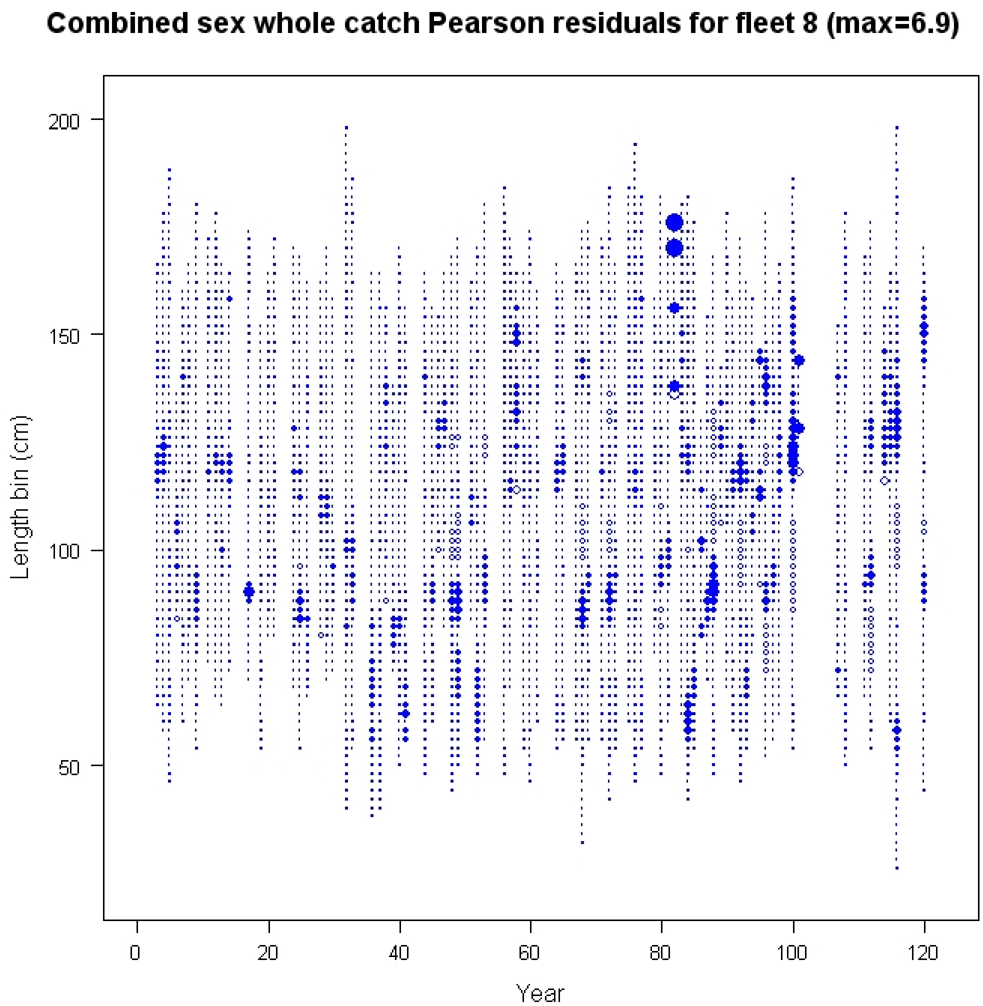


FIGURE 4.11h Pearson residual plots for the model fits to the length composition data for Fishery 8. Solid circles represent observations that are less than the model predictions; open circles correspond to observations that are higher than model predictions. The area of the circles is proportional to the absolute value of residuals.

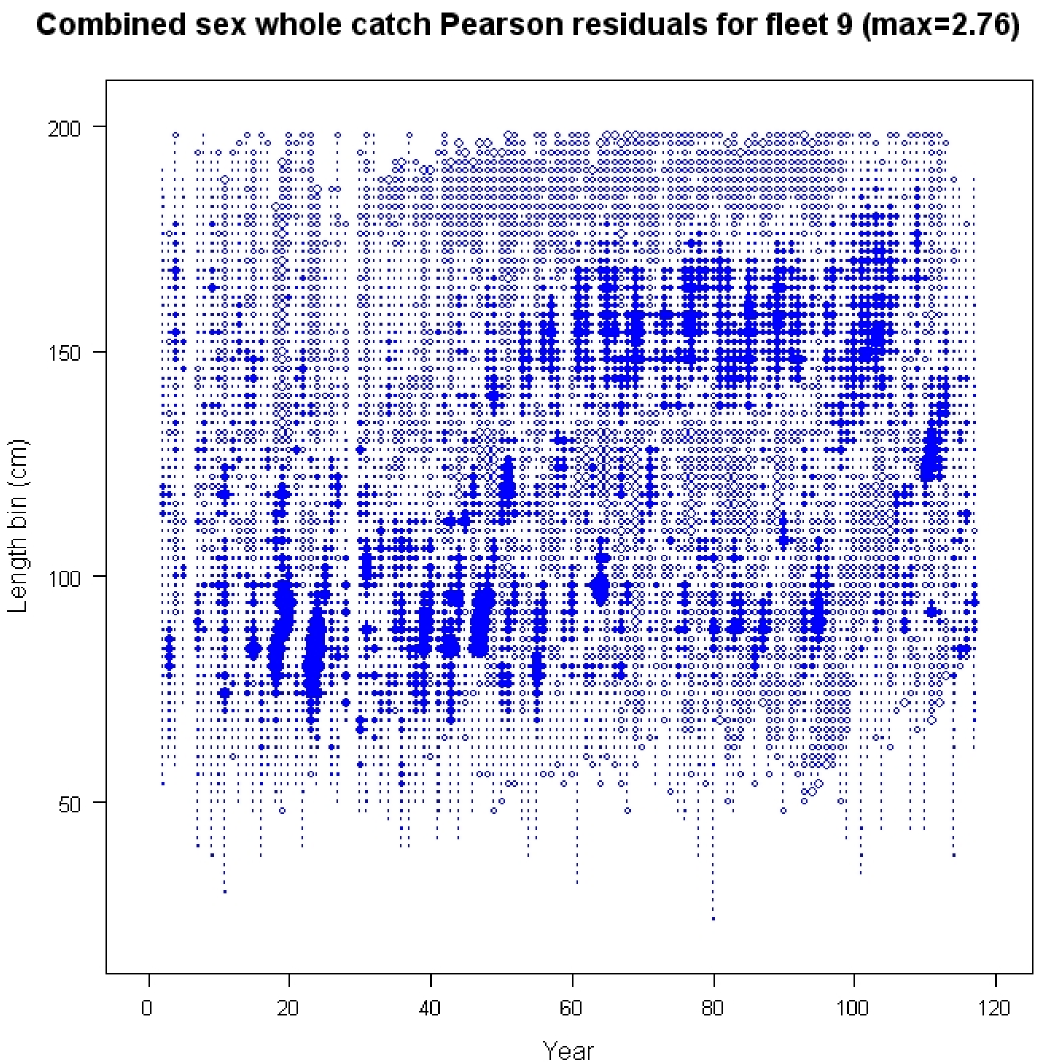


FIGURE 4.11i Pearson residual plots for the model fits to the length composition data for Fishery 9. Solid circles represent observations that are less than the model predictions; open circles correspond to observations that are higher than model predictions. The area of the circles is proportional to the absolute value of residuals.

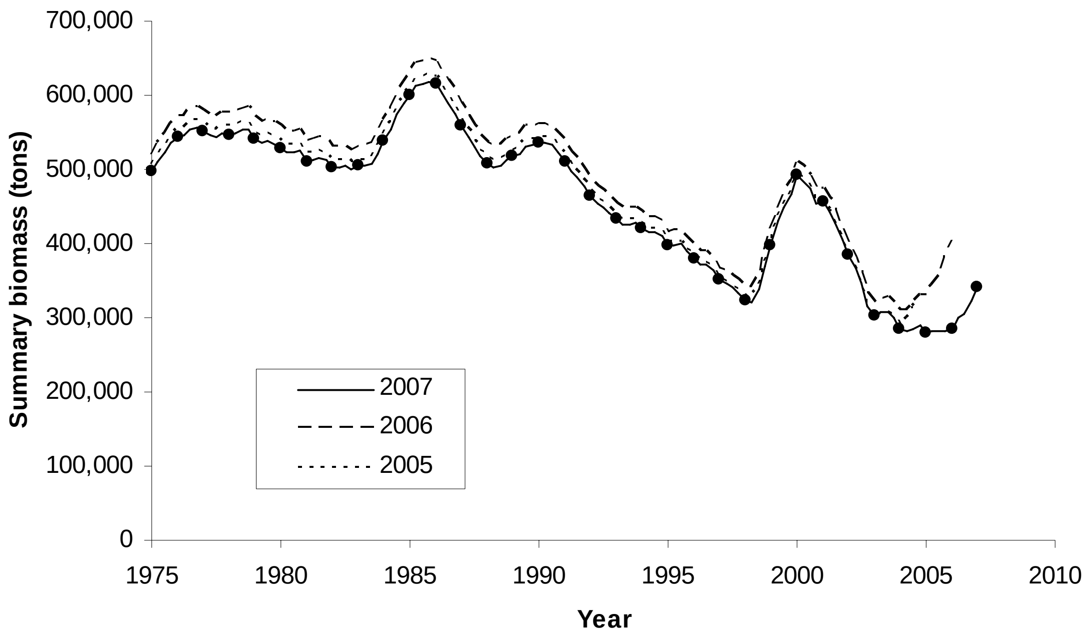


FIGURE 4.12. Retrospective comparisons of estimates of the summary biomass (fish of age 3 quarters and older) of bigeye tuna. The estimates from the basecase model are compared with the estimates obtained when the most recent year (2006) or two years of data (2005) were excluded.

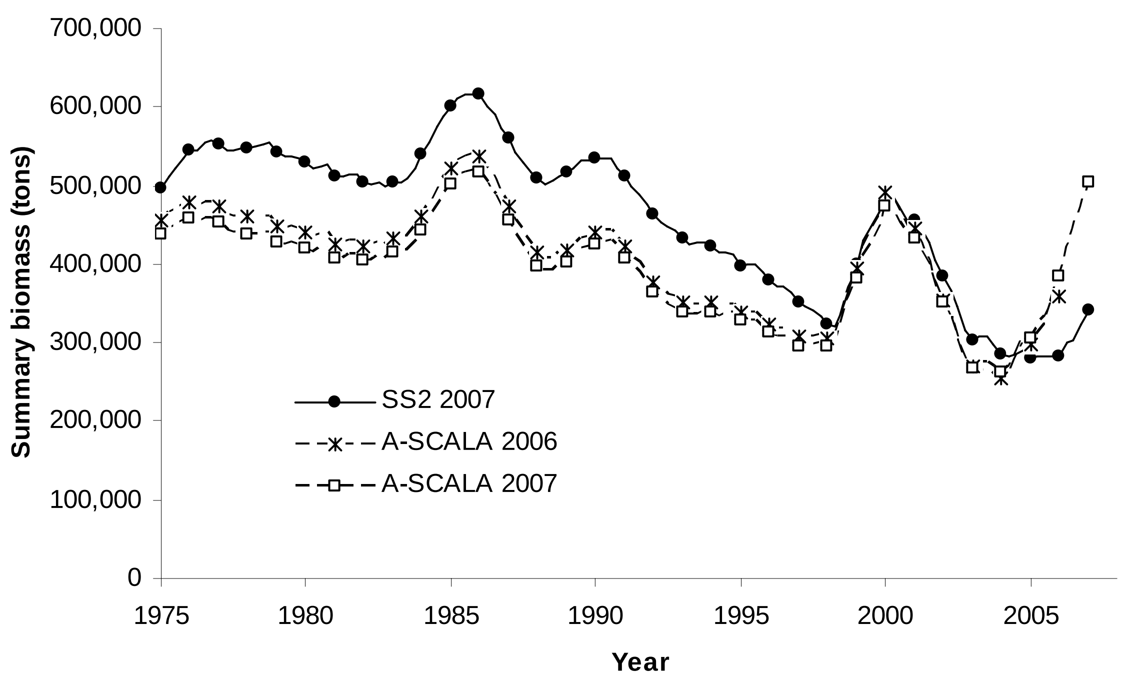


FIGURE 4.13. Comparison of estimates of the summary biomass (fish of age 3 quarters and older) of bigeye tuna from the A-SCALA most recent assessments (2007 and 2006) and the current assessment (SS2). t = metric tons.

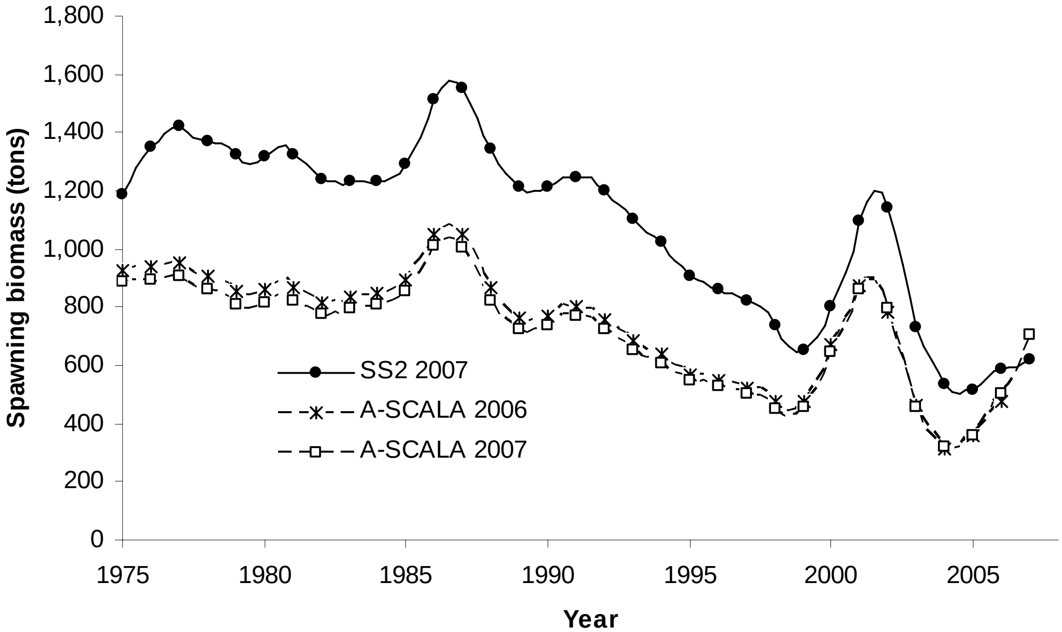


FIGURE 4.14. Comparison of estimated spawning biomass for bigeye tuna in the EPO from the A-SCALA most recent assessments (2007 and 2006) and the current assessment (SS2). The horizontal lines (at about 0.22 and 0.21) indicate the SBRs at AMSY.

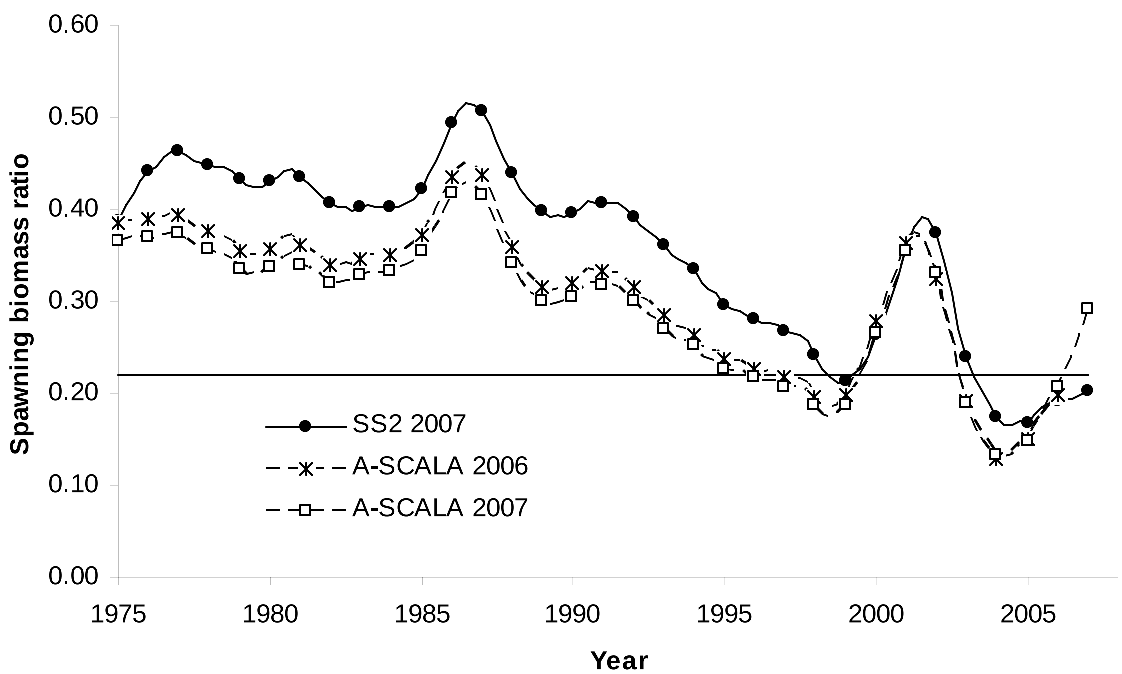


FIGURE 4.15. Comparison of estimated spawning biomass ratios (SBRs) for bigeye tuna in the EPO from the A-SCALA most recent assessments (2007 and 2006) and the current assessment (SS2). The horizontal lines (at about 0.22) indicate the SBRs at AMSY.

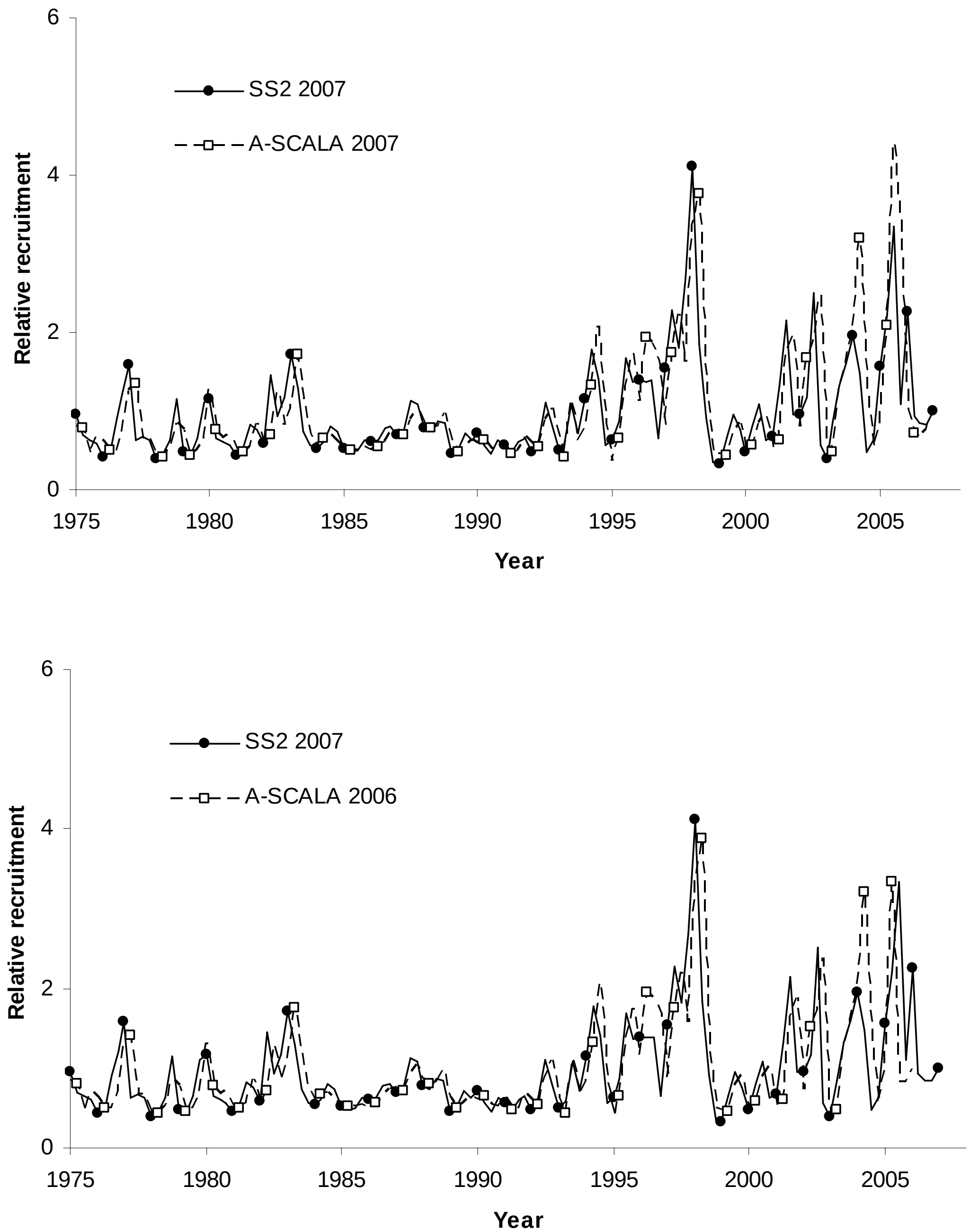


FIGURE 4.16. Comparison of estimated relative recrutiment for bigeye tuna in the EPO from the A-SCALA most recent assessments (2007 and 2006) and the current assessment (SS2).

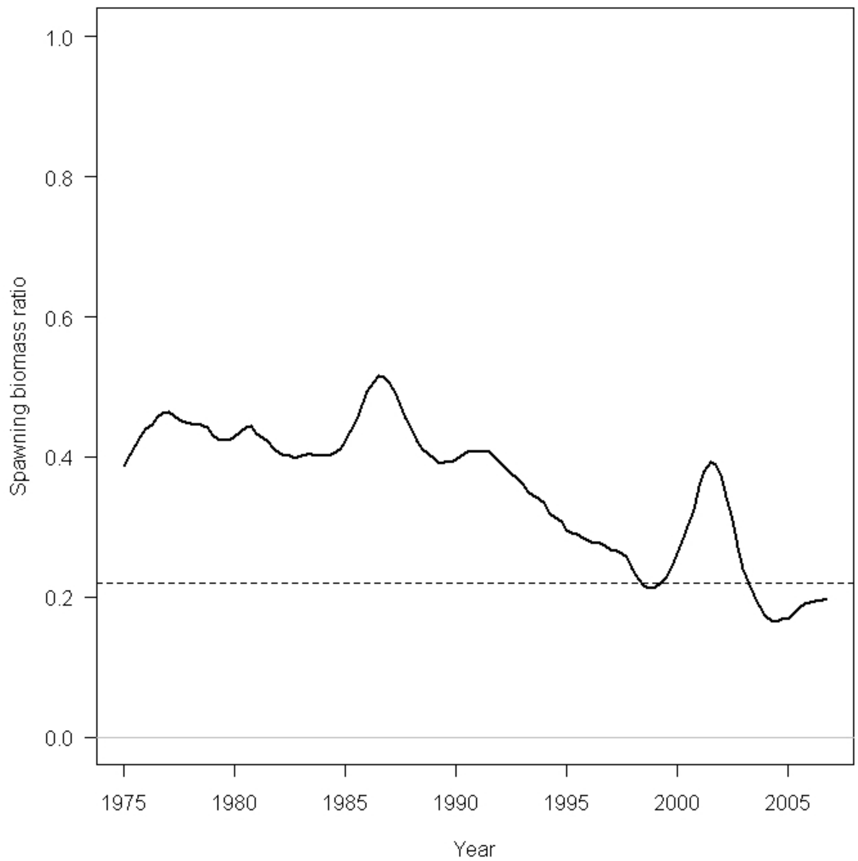


FIGURE 5.1. Estimated spawning biomass ratios (SBRs) for bigeye tuna in the EPO. The dashed horizontal line (at about 0.22) identifies the SBR at AMSY. The solid lines illustrate the maximum likelihood estimates, and the thin dashed lines the confidence intervals (±2 standard deviations) around those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

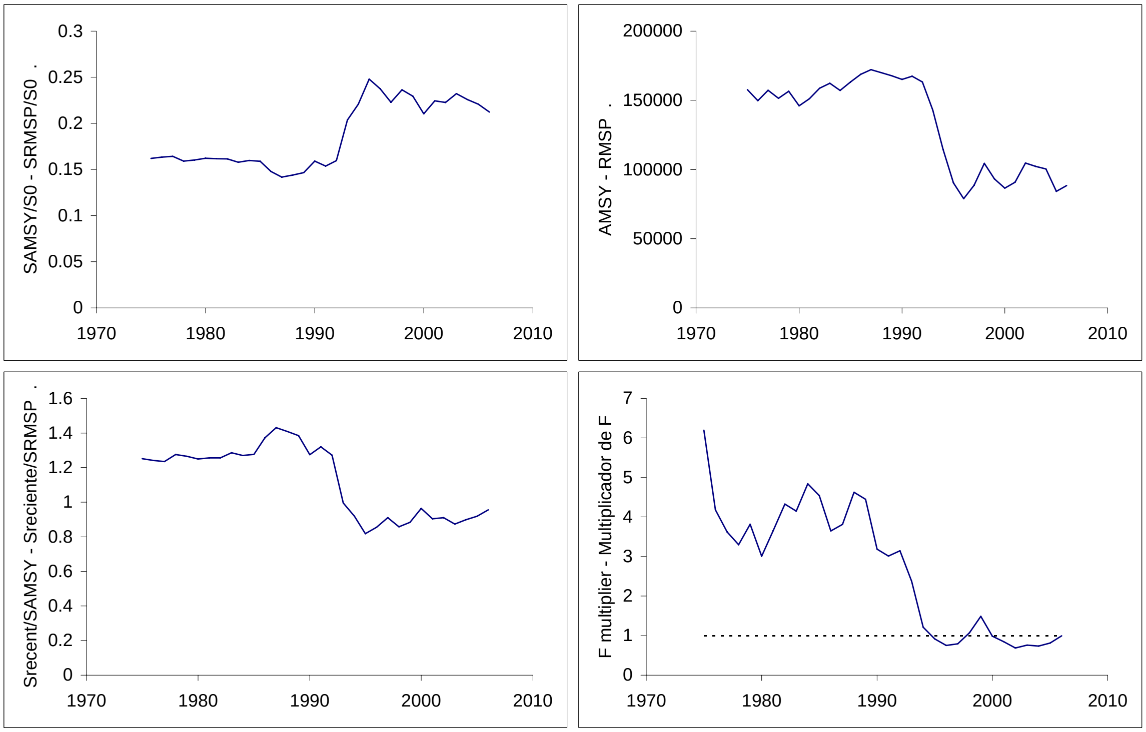


FIGURE 5.2. Estimates of AMSY-related quantities calculated using the average age-specific fishing mortality for each year. (S_{recent} is the spawning biomass at the beginning of 2006.)

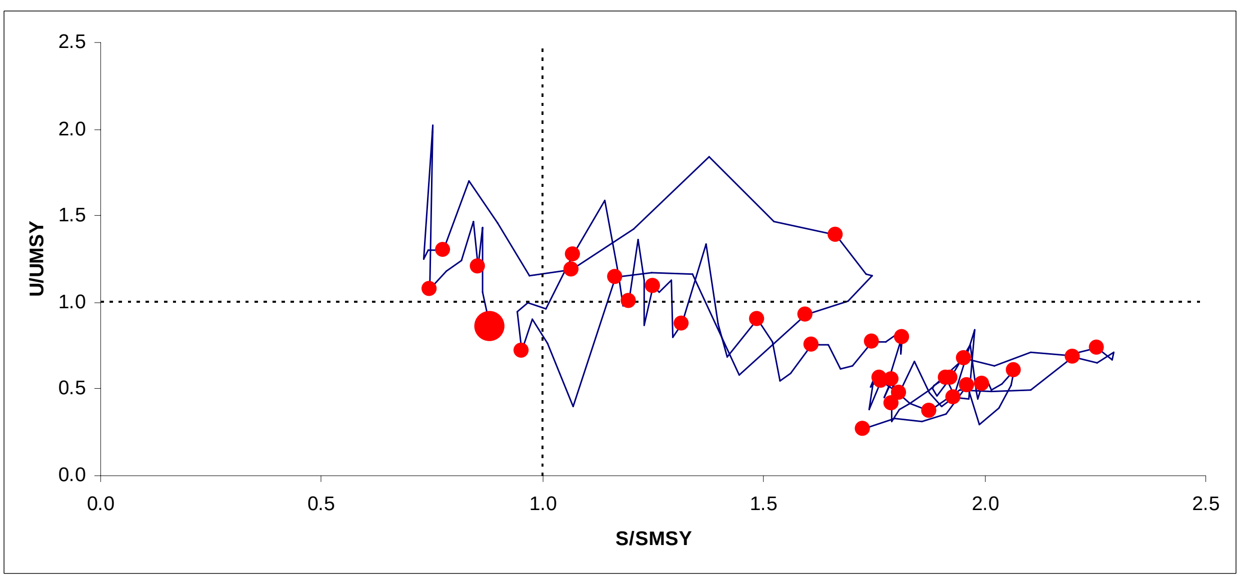


FIGURE 5.3. Historical time series of exploitation rate and spawning biomass relative to the MSY reference points

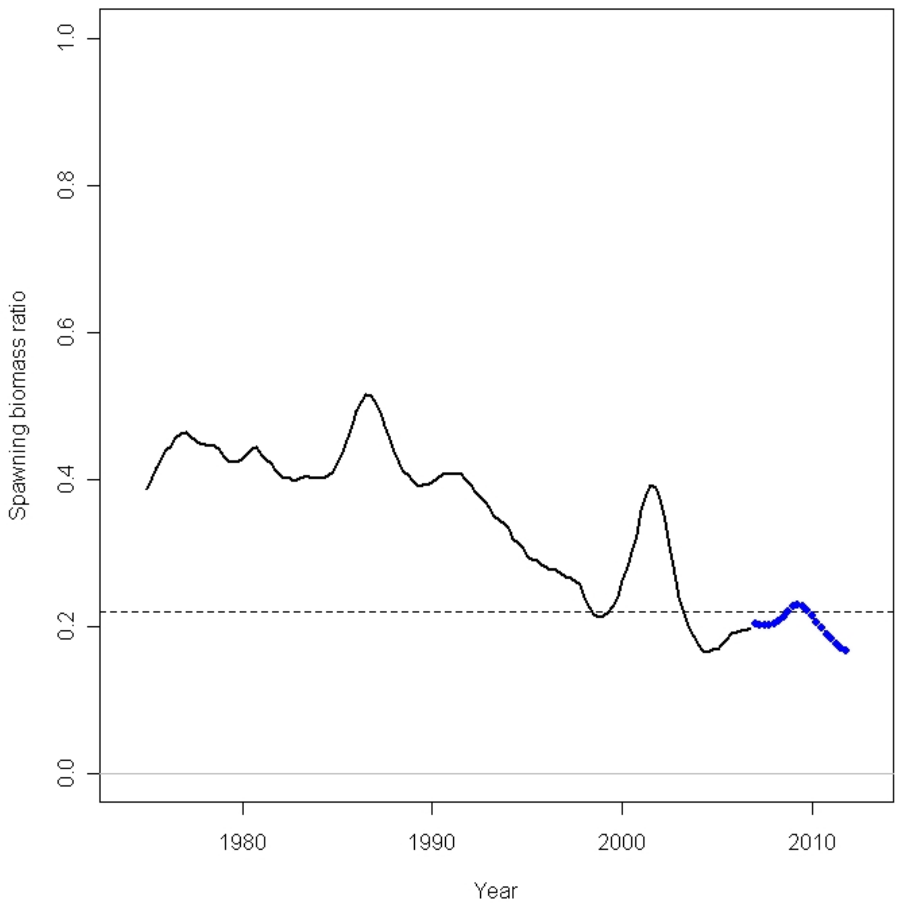


FIGURE 6.1. Spawning biomass ratios (SBRs) of bigeye tuna in the EPO. The dashed horizontal line (at about 0.22) identifies the SBR at AMSY. The solid line illustrates the maximum likelihood estimates and the thin dashed lines the 95% confidence intervals around these estimates. The estimates after 2006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

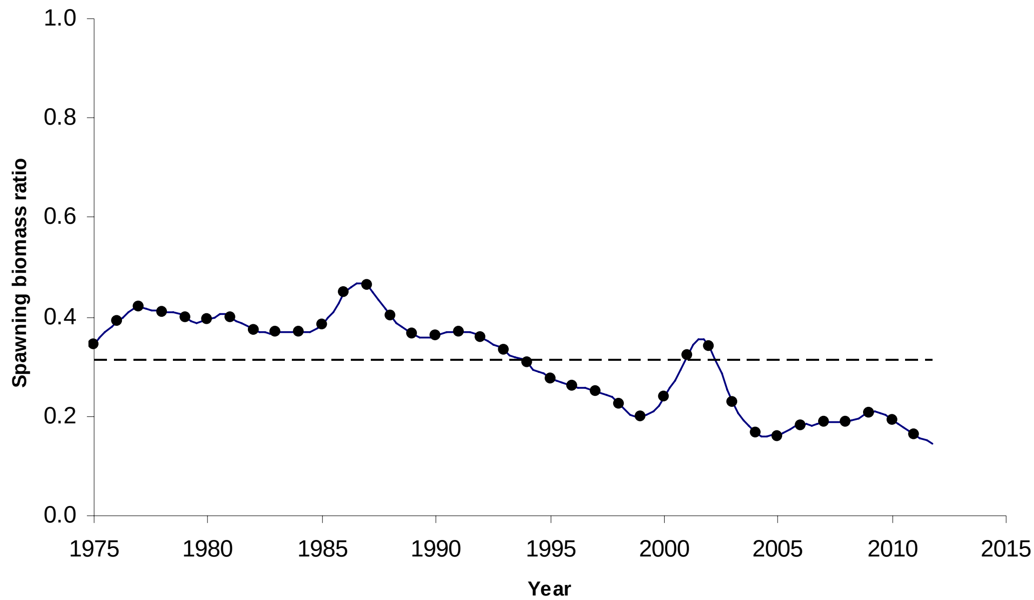


FIGURE 6.1b. Spawning biomass ratios (SBRs) of bigeye tuna in the EPO from the stock-recruitment sensitivity analysis. The dashed horizontal line (at about 0.31) identifies the SBR at AMSY.

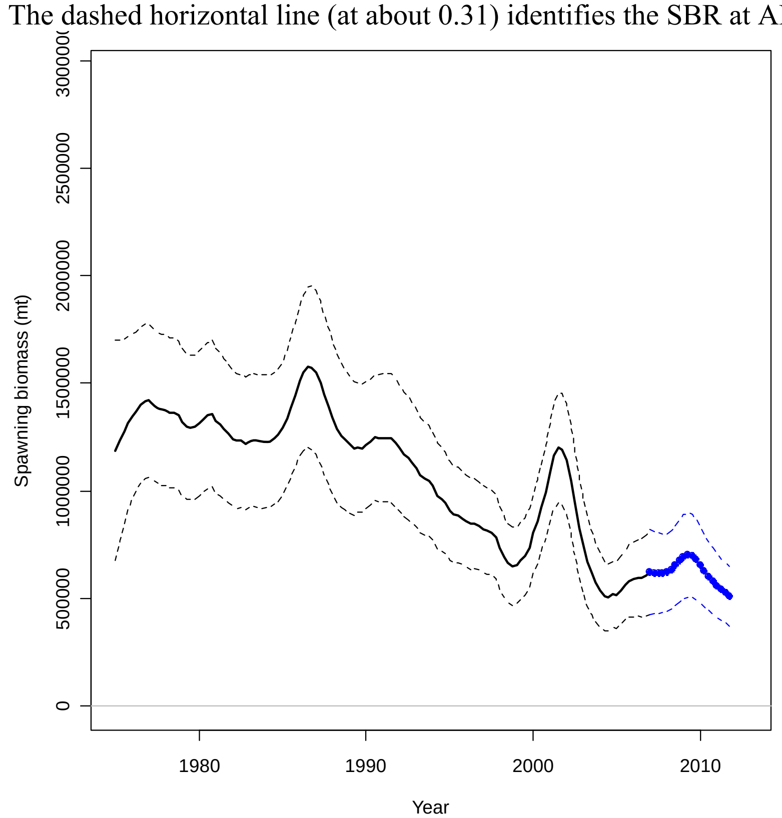


FIGURE 6.2. Estimated biomass of bigeye tuna of age three quarters and older, including projections for 2006-2010 with effort for 2005. These calculations include parameter estimation uncertainty and uncertainty about future recruitment. The areas between the dashed curves indicate the 95% confidence intervals, and the large dot indicates the estimate for the first quarter of 2006. t = metric tons.

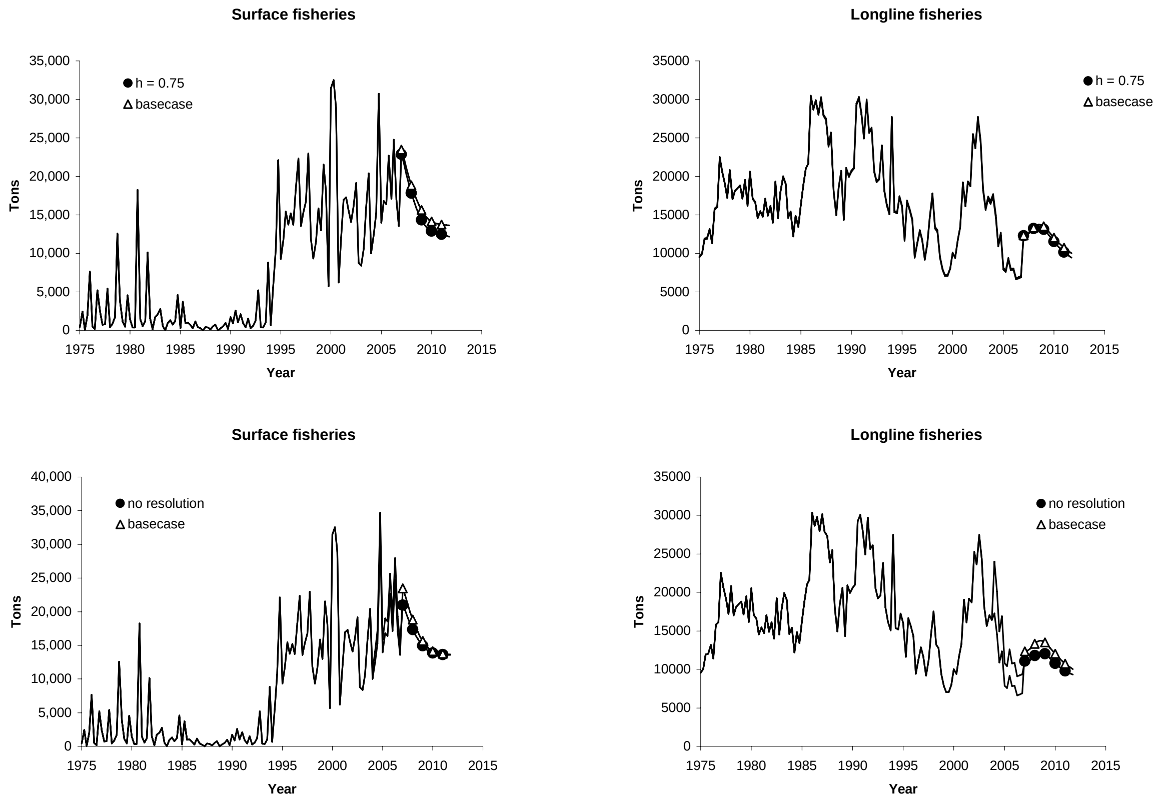


FIGURE 6.3. Predicted quarterly catches of bigeye tuna for the purse-seine and pole-and-line (left panels) and longline fisheries (right panels), based on harvest rates for 2004 and 2005. Predicted catches are compared between the base case and the analysis in which a stock recruitment curve was used (upper panels), and the analysis assuming no resolution (lower panels)**.**

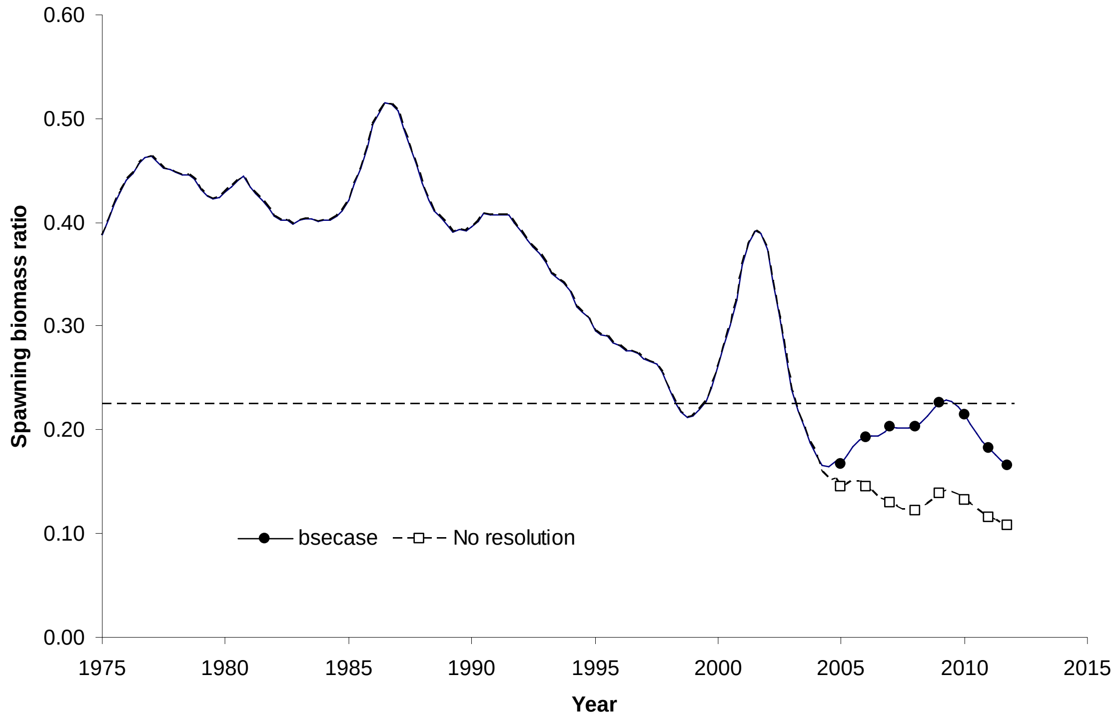


FIGURE 6.4. Predicted spawning biomass ratio (SBR) with and without restriction from IATTC Resolution C-04-09.

TABLE 2.1. Fishery definitions used for the stock assessment of bigeye tuna in the EPO. PS = purse-seine; LP = pole and line; LL = longline; OBJ = sets on floating objects; NOA = sets on unassociated fish; DEL = sets on dolphins. The sampling areas are shown in Figure 2.1, and descriptions of the discards are provided in Section 2.2.2.

TABLA 2.1. Pesquerías definidas para la evaluación del stock de atún patudo en el OPO. PS = red de cerco; LP = caña; LL = palangre; OBJ = lances sobre objeto flotante; NOA = lances sobre atunes no asociados; DEL = lances sobre delfines. En la Figura 2.1 se ilustran las zonas de muestreo, y en la Sección 2.2.2 se describen los descartes.

Fishery	Gear	Set type	Years	Sampling areas	Catch data
Pesquería	**Arte**	**Tipo de lance**	**Años**	**Zonas de muestreo**	**Datos de captura**
1	PS	OBJ	1980-1992	1-13	retained catch only–captura retenida solamente
2	PS	OBJ	1993-2005	11-12	retained catch + discards from inefficiencies in fishing process–captura retenida + descartes de ineficacias en el proceso de pesca
3	PS	OBJ	1993-2005	7, 9	
4	PS	OBJ	1993-2005	5-6, 13	
5	PS	OBJ	1993-2005	1-4, 8, 10	
6	PS LP	NOA DEL	1980-1989	1-13	retained catch only–captura retenida solamente
7	PS LP	NOA DEL	1990-2005	1-13	retained catch + discards from inefficiencies in fishing process–captura retenida + descartes de ineficacias en el proceso de pesca
8	LL		1980-2005	N of 15°N–N de 15°N	retained catch only–captura retenida solamente
9	LL		1980-2005	S of 15°N–S de 15°N	retained catch only–captura retenida solamente
10	PS	OBJ	1993-2005	11-12	discards of small fish from size-sorting the catch by Fishery 2–descartes de peces pequeños de clasificación por tamaño en la Pesquería 2
11	PS	OBJ	1993-2005	7, 9	discards of small fish from size-sorting the catch by Fishery 3–descartes de peces pequeños de clasificación por tamaño en la Pesquería 3
12	PS	OBJ	1993-2005	5-6, 13	discards of small fish from size-sorting the catch by Fishery 4–descartes de peces pequeños de clasificación por tamaño en la Pesquería 4
13	PS	OBJ	1993-2005	1-4, 8, 10	discards of small fish from size-sorting the catch by Fishery 5–descartes de peces pequeños de clasificación por tamaño en la Pesquería 5

TABLE 3.1. Age-specific fecundity indices used to define the spawning biomass.

Age in quarters	Index of fecundity	Age in quarters	Index of fecundity
Edad en trimestres	**Índice de fecundidad**	**Edad en trimestres**	**Índice de fecundidad**
1	0	21	0.73
2	0	22	0.76
3	0	23	0.79
4	0	24	0.82
5	0	25	0.84
6	0	26	0.86
7	0	27	0.88
8	0.01	28	0.9
9	0.02	29	0.91
10	0.04	30	0.93
11	0.07	31	0.94
12	0.13	32	0.95
13	0.21	33	0.96
14	0.3	34	0.97
15	0.4	35	0.97
16	0.48	36	0.98
17	0.55	37	0.99
18	0.61	38	0.99
19	0.65	39	1
20	0.69	40	1

TABLE 4.1. 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 4.1. 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	Summary biomass	Spawning biomass	SB ratio
1975	11,542	497,486	1,186	0.39
1976	12,147	544,798	1,349	0.44
1977	14,127	552,340	1,420	0.46
1978	10,522	547,308	1,372	0.45
1979	10,647	541,521	1,321	0.43
1980	11,961	528,965	1,315	0.43
1981	10,330	511,498	1,327	0.43
1982	16,627	503,633	1,241	0.41
1983	17,326	504,037	1,231	0.40
1984	10,739	538,402	1,230	0.40
1985	8,536	600,474	1,290	0.42
1986	11,354	614,898	1,513	0.49
1987	14,751	559,017	1,551	0.51
1988	12,934	508,807	1,342	0.44
1989	9,295	516,981	1,215	0.40
1990	9,486	534,748	1,211	0.40
1991	9,302	510,734	1,246	0.41
1992	12,127	464,271	1,199	0.39
1993	11,627	432,241	1,105	0.36
1994	19,623	421,717	1,022	0.33
1995	18,264	397,421	905	0.30
1996	19,298	379,756	859	0.28
1997	33,434	350,584	821	0.27
1998	28,941	322,620	736	0.24
1999	10,793	398,374	654	0.21
2000	12,064	491,831	802	0.26
2001	20,470	455,736	1,096	0.36
2002	20,920	385,589	1,145	0.37
2003	16,696	303,264	733	0.24
2004	18,210	285,230	533	0.17
2005	32,956	278,962	513	0.17
2006	19,564	283,503	588	0.19
2007		340,059	621	0.20

TABLE 4.3. Estimates of the average sizes of bigeye tuna. The ages are quarters after hatching.
TABLA 4.3. Estimaciones del tamaño medio del atún patudo. La edad es en trimestres desde la cría.

Age (quarters)	Average length (cm)	Average weight (kg)	Age (quarters)	Average length (cm)	Average weight (kg)
Edad (trimestres)	**Talla media (cm)**	**Peso medio (kg)**	**Edad (trimestres)**	**Talla media (cm)**	**Peso medio (kg)**
1	26.61	0.51	21	158.52	89.67
2	38.25	1.46	22	161.52	94.69
3	49.12	3.01	23	164.33	99.54
4	59.29	5.18	24	166.96	104.22
5	68.79	7.97	25	169.41	108.71
6	77.67	11.33	26	171.70	113.00
7	85.97	15.21	27	173.84	117.09
8	93.72	19.54	28	175.85	120.96
9	100.97	24.25	29	177.72	124.61
10	107.74	29.27	30	179.47	128.03
11	114.07	34.53	31	181.10	131.22
12	119.99	39.99	32	182.63	134.17
13	125.51	45.57	33	184.06	136.89
14	130.68	51.22	34	185.39	139.40
15	135.51	56.90	35	186.64	141.69
16	140.02	62.57	36	187.80	143.78
17	144.24	68.19	37	188.89	145.68
18	148.18	73.74	38	189.91	147.41
19	151.86	79.18	39	190.86	148.97
20	155.30	84.49	40	191.75	150.40

TABLE 4.4. Likelihood components obtained for the base case and sensitivity analyses.

Data	Basecase	h = 0.75	cpue 9	Growth estimation			Fit init. catch	Iter. reweight	t. blocks	t_blocks (iter. rw)
				All params	Lmax = 171.5	Lmax = 201.5				
CPUE										
2	-20.72	-20.59	-	-20.16	-19.04	-22.13	-20.24	-13.60	-20.79	-16.8392
3	23.61	23.53	-	23.87	25.01	22.41	23.86	10.76	23.69	8.9456
5	21.41	21.82	-	22.56	23.83	18.99	22.93	12.56	21.20	10.7926
8	-5.60	-5.83	-	-7.15	-6.49	-7.42	-5.22	9.95	-5.15	0.0755354
9	-153.53	-154.17	-138.23	-156.17	-156.97	-151.35	-154.22	14.02	-160.81	-107.21
Size comps.										
1	166.84	166.73	166.11	165.71	165.29	167.37	166.79	984.33	166.70	958.902
2	195.64	196.72	186.15	205.48	211.91	196.34	196.88	962.80	197.08	945.143
3	246.40	246.55	236.11	251.42	258.01	243.94	246.64	1229.45	245.82	1277.03
4	70.93	75.51	73.64	72.02	70.70	70.10	71.93	268.08	75.36	256.279
5	136.75	137.08	129.47	144.17	148.92	136.10	137.49	724.54	137.23	688.79
6	132.05	132.21	131.48	133.66	134.39	132.97	130.95	655.15	131.98	621.809
7	129.59	129.00	128.32	129.50	122.77	136.08	128.03	714.51	129.65	713.554
8	124.17	123.89	123.66	119.90	119.22	123.74	123.49	1631.91	123.36	1469.02
9	272.40	274.77	276.30	244.80	222.73	289.84	286.84	3695.10	236.49	3417.48
Age at length	-	-	-	103.72	112.73	81.44	-	-	-	-
Recruitment	-24.72	-20.69	-26.70	-30.02	-32.91	-19.84	-21.23	17.30	-20.16	18.9462
Total	**1315.22**	**1326.52**	**1286.32**	**1403.29**	**1400.07**	**1418.58**	**1334.92**	**10916.86**	**1281.65**	**10262.72**

TABLE 5.1. Estimates of the AMSY and its associated quantities for bigeye tuna for the base case assessment and sensitivity analyses. All analyses are based on average fishing mortality for 2004 and 2005. B_{recent} and B_{AMSY} are defined as the biomass of fish 3+ quarters old at the beginning of 2006 and at AMSY, respectively, and S_{recent} and S_{AMSY} are defined as indices of spawning biomass (therefore, they are not in metric tons). C_{recent} is the estimated total catch in 2006.

	Basecase	h = 0.75	cpue9	growth est.	Lmax = 171.5	Lmax = 201.5	init catch	iter. rwt	t. blocks	t. blocks (iter. rwt)
AMSY	92,758	88,391	92,059	99,839	117,348	89,234	93,557	72,629	97,992	72,629
Bmsy	313,767	493,285	321,528	327,607	401,325	281,816	323,414	252,070	319,277	252,070
Smsy	688	1,182	710	660	815	579	713	559	695	559
Bmsy/B0	0.27	0.35	0.27	0.26	0.26	0.28	0.27	0.27	0.30	0.27
Smsy/S0	0.22	0.31	0.22	0.21	0.21	0.22	0.22	0.23	0.25	0.23
Crecent/AMSY	1.10	1.16	1.14	1.02	0.87	1.13	1.10	-	0.76	-
Brecent/Bmsy	1.08	0.76	0.61	1.36	1.71	0.83	1.19	0.55	1.00	0.55
Srecent/Smsy	0.90	0.61	0.50	1.19	1.58	0.60	1.03	0.26	0.82	0.26
Fmultiplier	0.77	0.55	0.61	0.98	1.34	0.57	0.85	0.79	1.11	0.79

TABLE 5.2. Estimates of the AMSY and its associated quantities for bigeye tuna, obtained by assuming that there is no stock-recruitment relationship (base case), that each fishery maintains its current pattern of age-specific selectivity (Figure 4.5), and that each fishery is the only fishery operating in the EPO. The estimates of the AMSY and B_{AMSY} are in metric tons. The *F* multiplier indicates how many times effort would have to be effectively increased to achieve the AMSY based on the average fishing mortality over 2003 and 2004. "only" means that only that gear is used and the fishing mortality for the other gears is set to zero. "scaled" means that only that gear is scaled and the other gears are left at their current fishing mortality rates.

	Basecase	**FO**	**Longline Only**	**2003-2004**	**2005-2006**
AMSY	92,758	62,566	175,340	101,316	86,134
Bmsy	313,767	230,786	312,126	325,300	300,779
Smsy	688	510	416	700	664
Bmsy/B0	0.27	0.2	0.27	0.28	0.26
Smsy/S0	0.22	0.17	0.14	0.23	0.22
Crecent/AMSY	0.00	0.00	0.00	0.00	0.00
Brecent/Bmsy	1.08	1.47	1.09	1.05	1.13
Srecent/Smsy	0.9	1.22	1.49	0.89	0.93
Fmultiplier	0.77	1.41	4.32	0.75	0.9

APPENDIX A: SENSITIVITY ANALYSIS FOR STEEPNESS
ANEXO A: ANÁLISIS DE SENSIBILIDAD A LA INCLINACIÓN

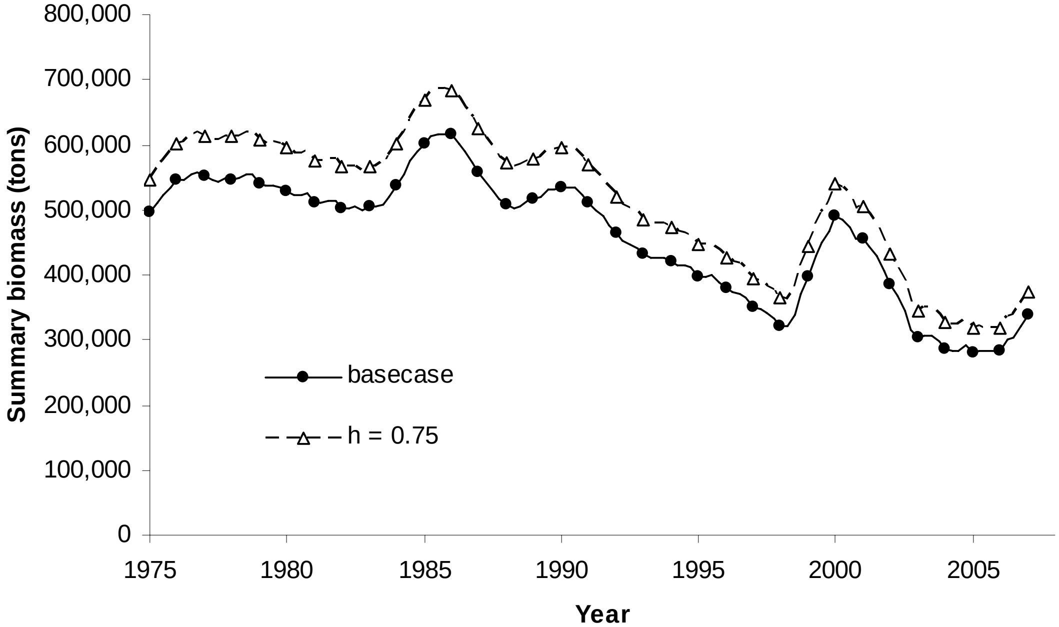


FIGURE A.1. Comparison of estimates of biomass of bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).

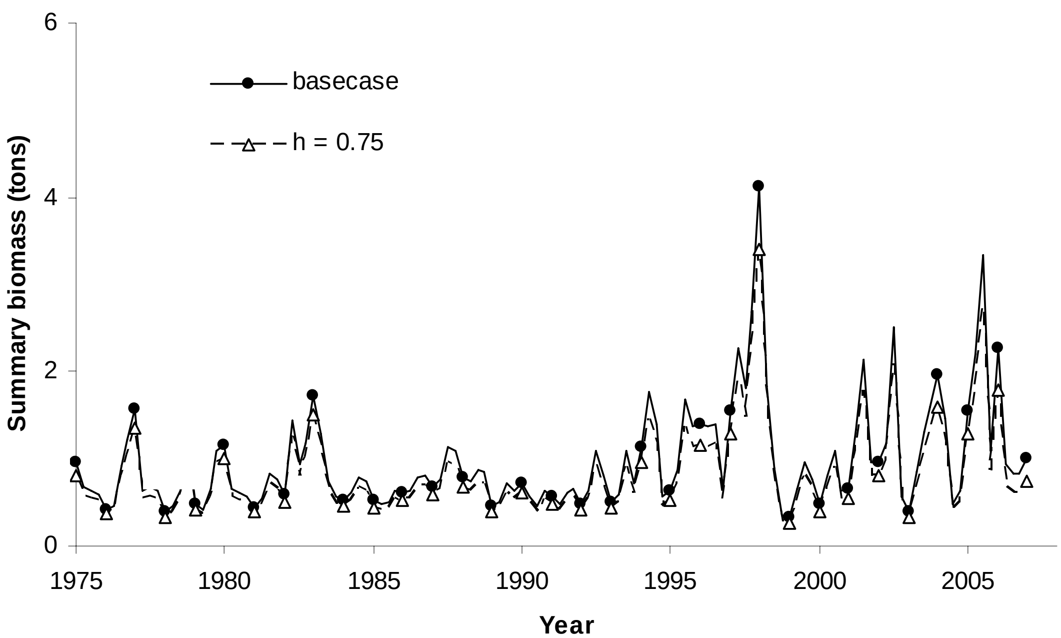


FIGURE A.2. Comparison of estimates of relative recruitment for bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75).

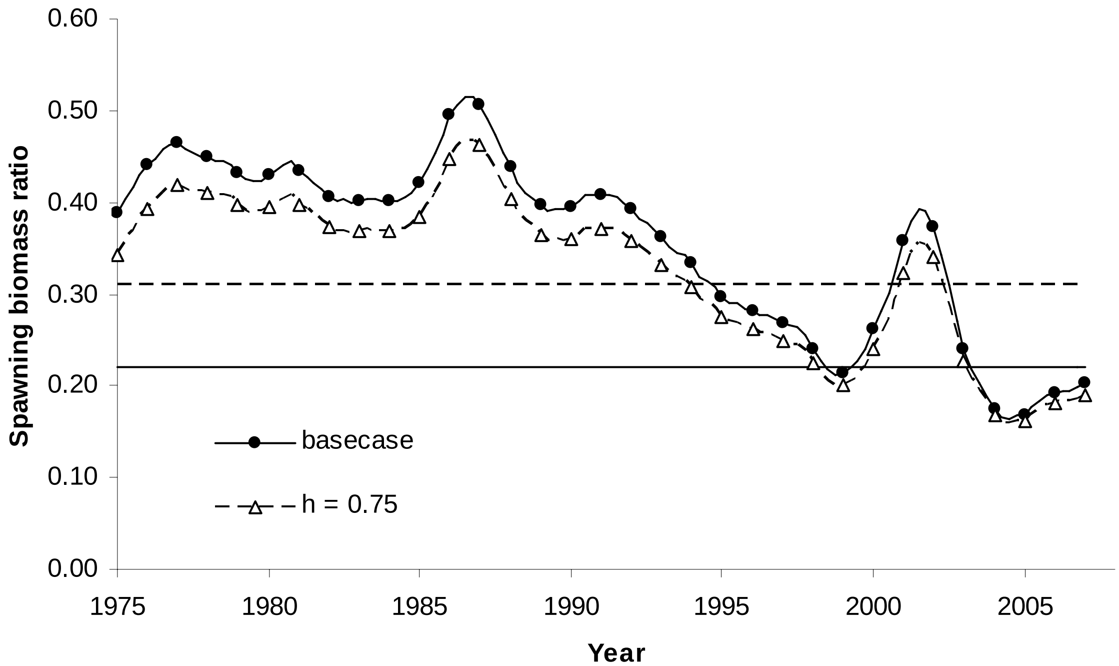


FIGURE A.3. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the analysis without a stock-recruitment relationship (base case) and with a stock-recruitment relationship (steepness = 0.75). The horizontal lines represent the SBRs associated with AMSY under the two scenarios.

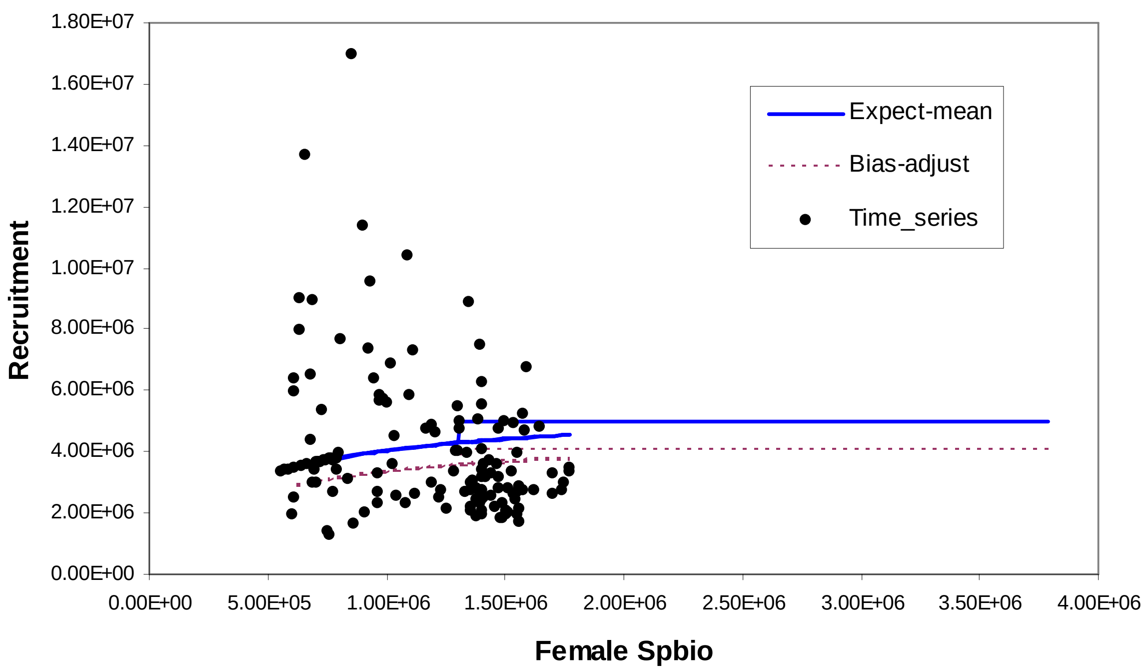


FIGURE A.4. Recruitment of bigeye tuna plotted against spawning biomass when the analysis has a stock-recruitment relationship (steepness = 0.75).

APPENDIX B: SENSITIVITY ANALYSIS USING CPUE DATA FOR SOUTHERN LONGLINE FISHERY ONLY

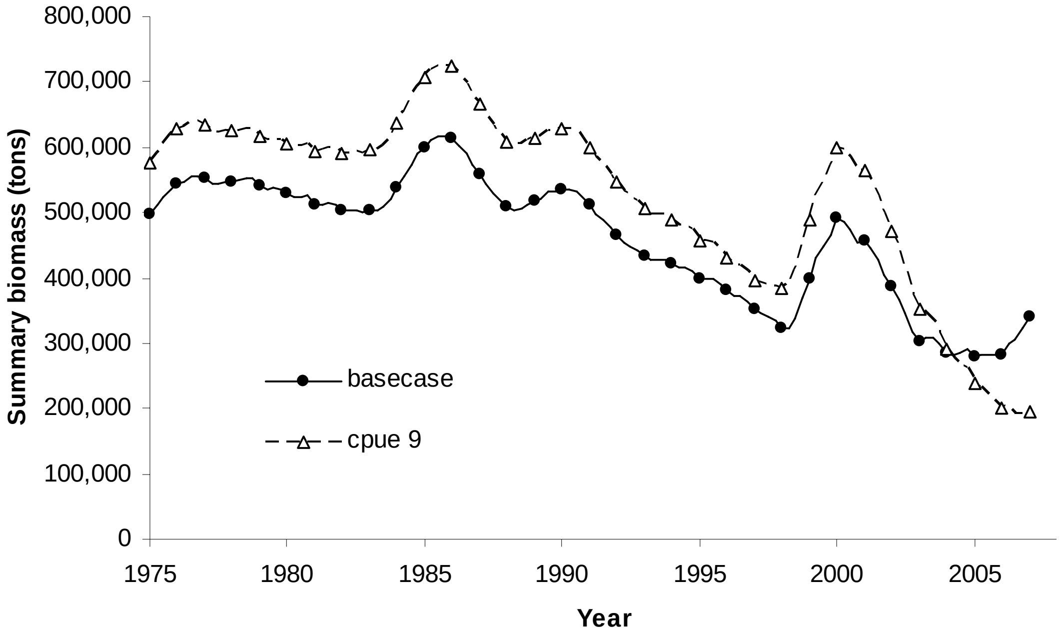


FIGURE B.1. Comparison of estimates of biomass of bigeye tuna from the basecase analysis with a model in which only the CPUE data for the southern longline fishery was used.

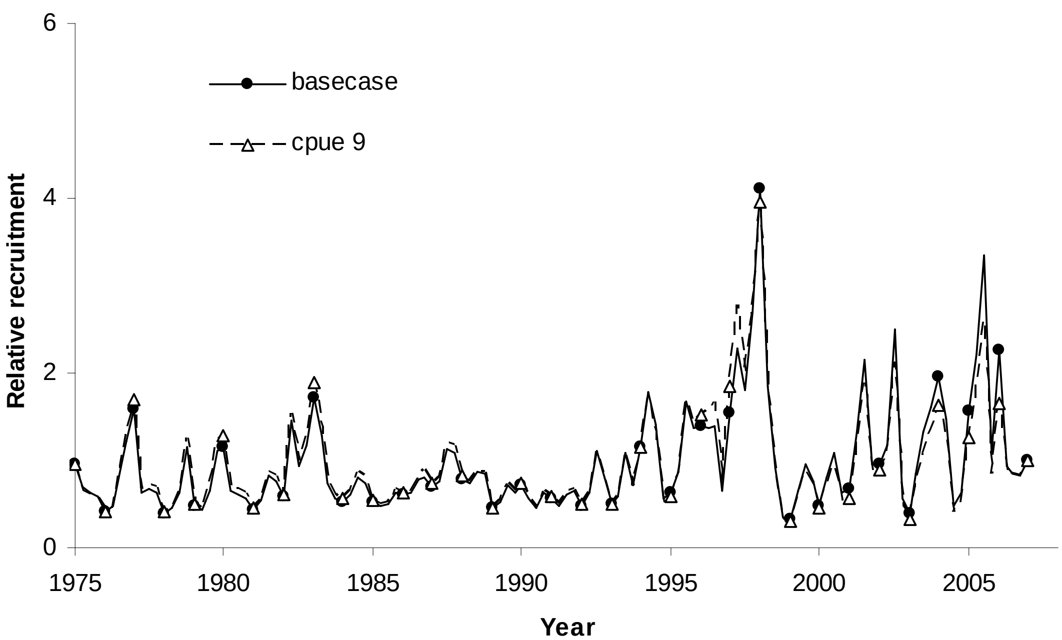


FIGURE B.1. Comparison of estimates of recruitment for bigeye tuna from the basecase analysis with a model in which only the CPUE data for the southern longline fishery was used.

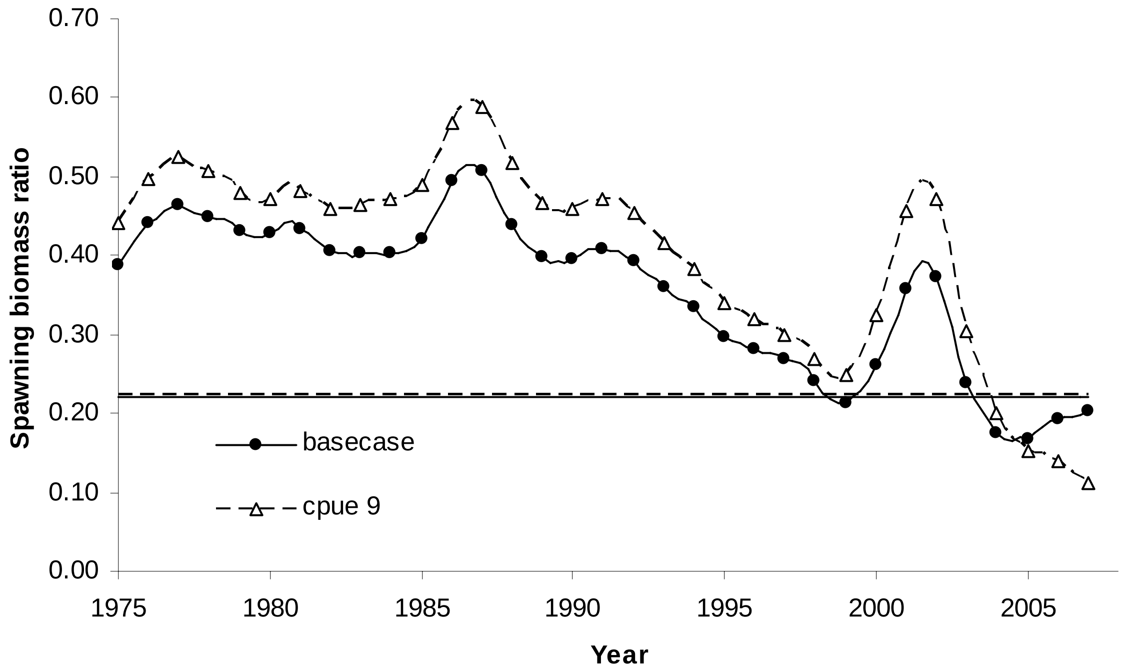


FIGURE B.2. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the basecase analysis with a model in which only the CPUE data for the southern longline fishery was used. The horizontal lines represent the SBRs associated with AMSY under the two scenarios.

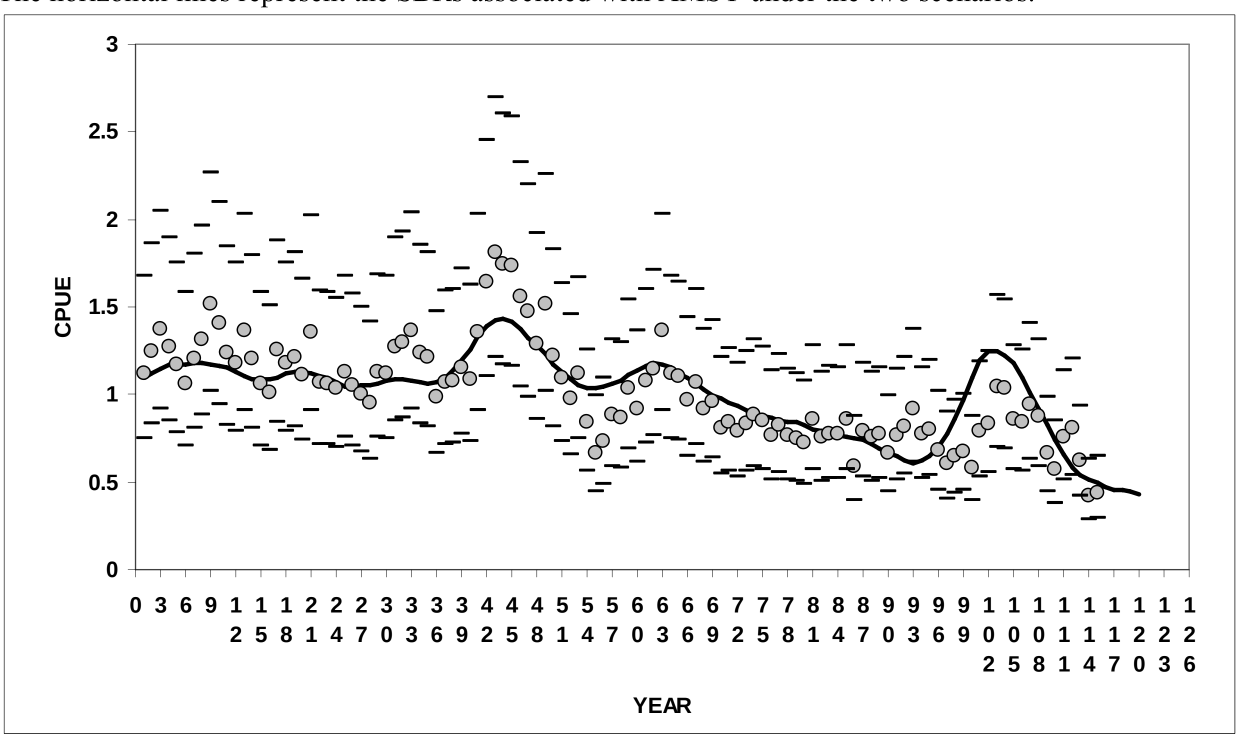


FIGURE B.3. Model fit to the CPUE data for the southern longline fishery.

APPENDIX C: SENSITIVITY ANALYSIS FOR GROWTH ESTIMATION USING OTOLITH DATA

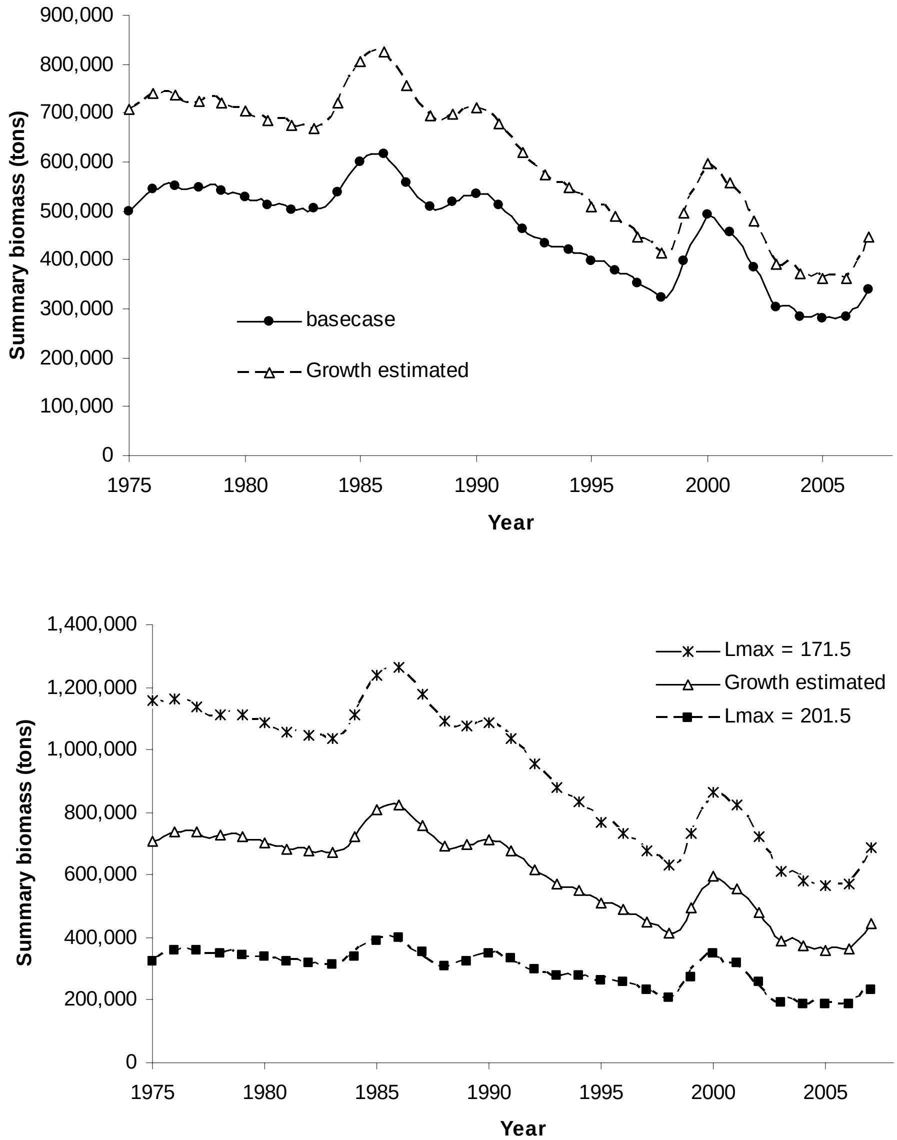
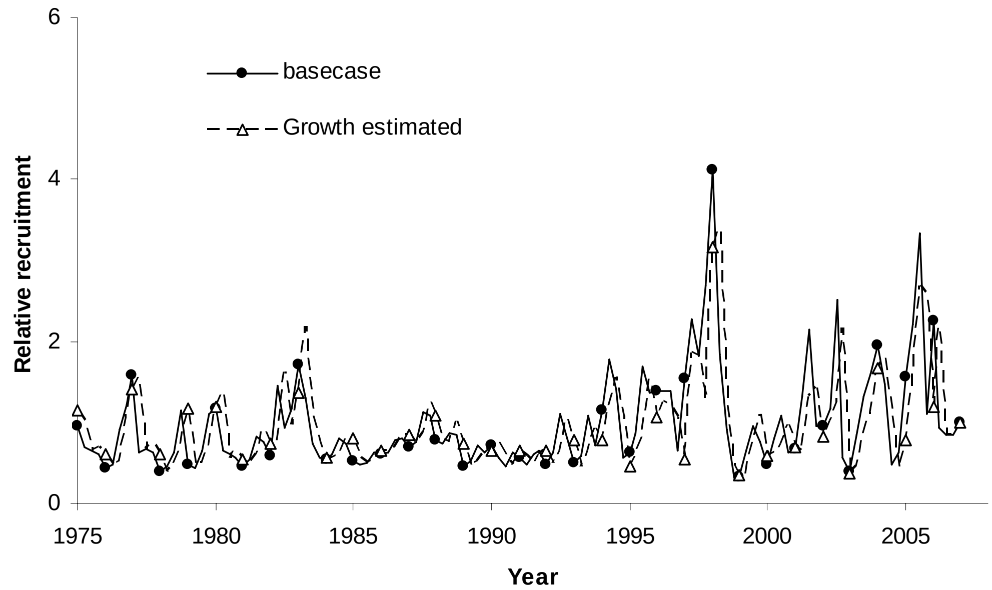


FIGURE C.1. Comparison of estimates of biomass of bigeye tuna from the basecase model with a model in which growth was estimated using the otolith data. Three sensitivities were conducted for growth estimation: 1) all growth parameters estimated, b) Lmax fixed at 171.5 and c) Lmax fixed at 201.5.



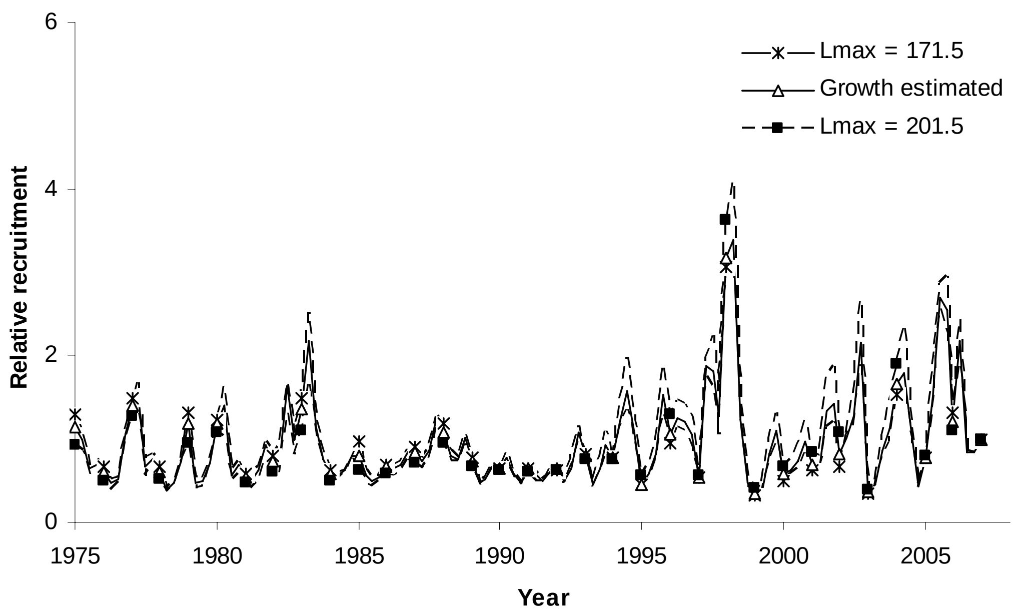


FIGURE C.2. Comparison of estimates of recruitment for bigeye tuna from the basecase model with a model in which growth was estimated using the otolith data. Three sensitivities were conducted for growth estimation: 1) all growth parameters estimated, b) Lmax fixed at 171.5 and c) Lmax fixed at 201.5.

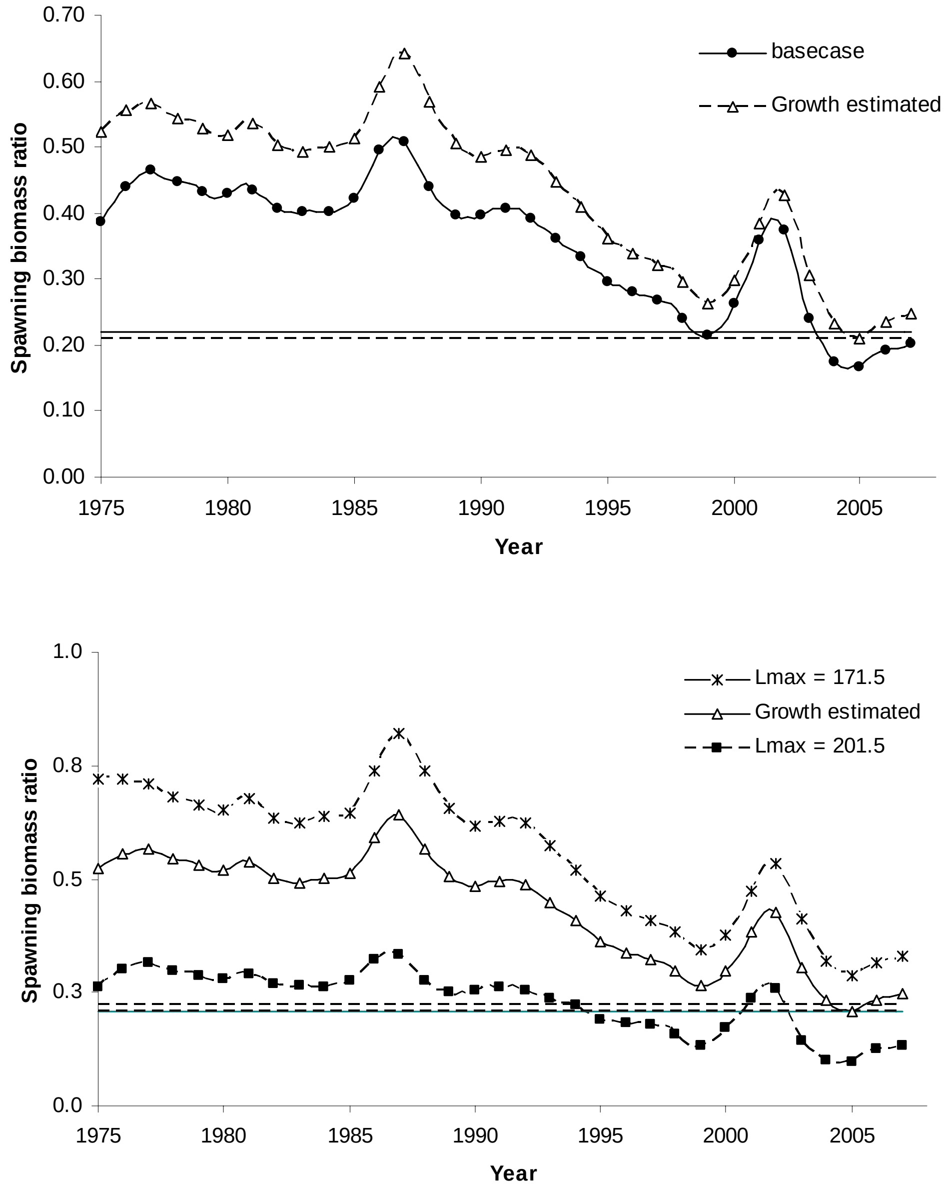


FIGURE C.3. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the basecase model with a model in which growth was estimated using the otolith data. Three sensitivities were conducted for growth estimation: 1) all growth parameters estimated, b) Lmax fixed at 171.5 and c) Lmax fixed at 201.5. The horizontal lines represent the SBRs associated with AMSY under the two scenarios.

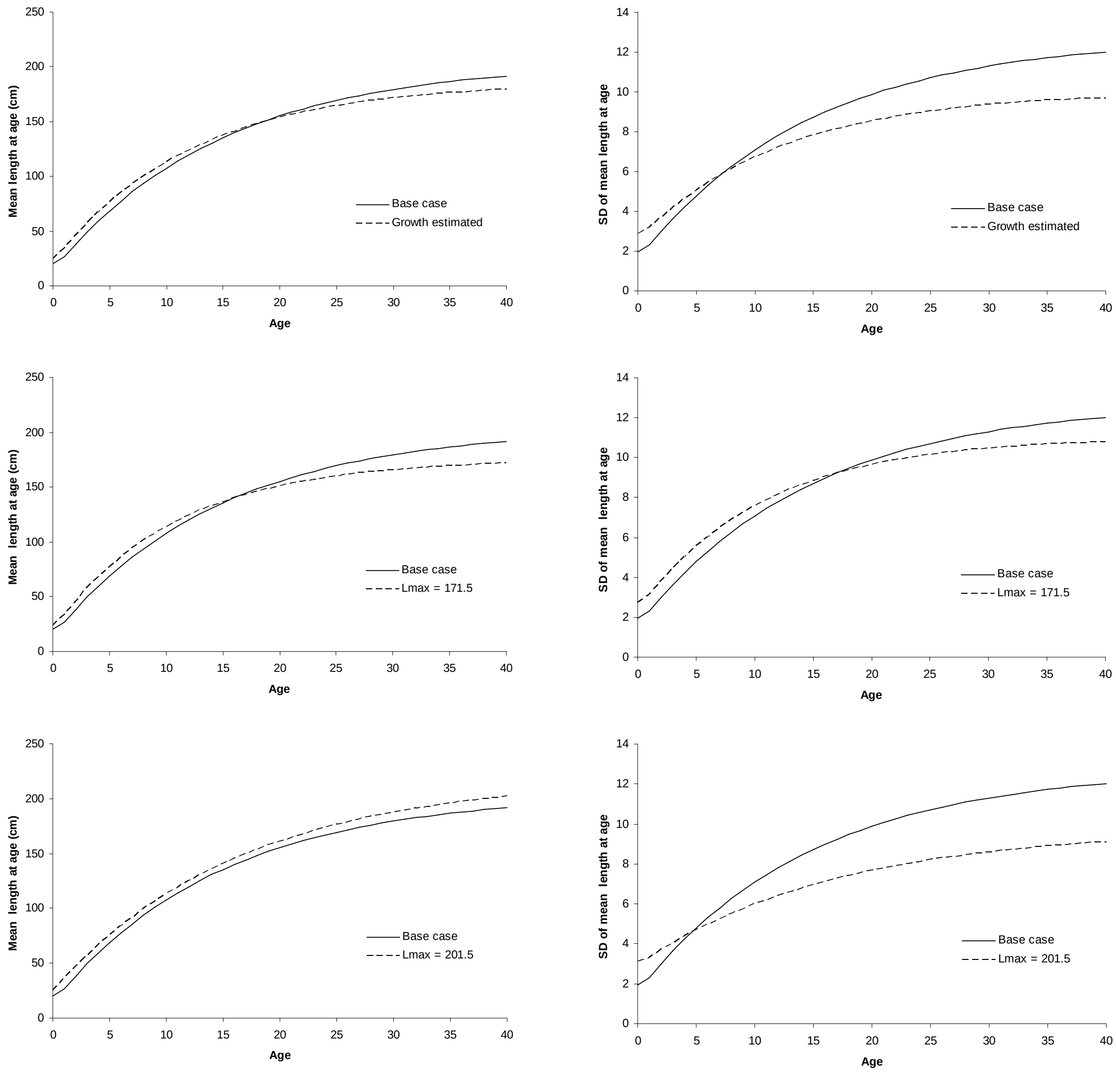


FIGURE C.4. Mean lengths at age and its standard deviations for the basecase analysis (growth parameters fixed) and models in which growth parameters were estimated or Lmax fixed (at 171.5 or 201.5 cm).

APPENDIX D: SENSITIVITY ANALYSIS FOR MODEL FITTING TO INITIAL CATCH

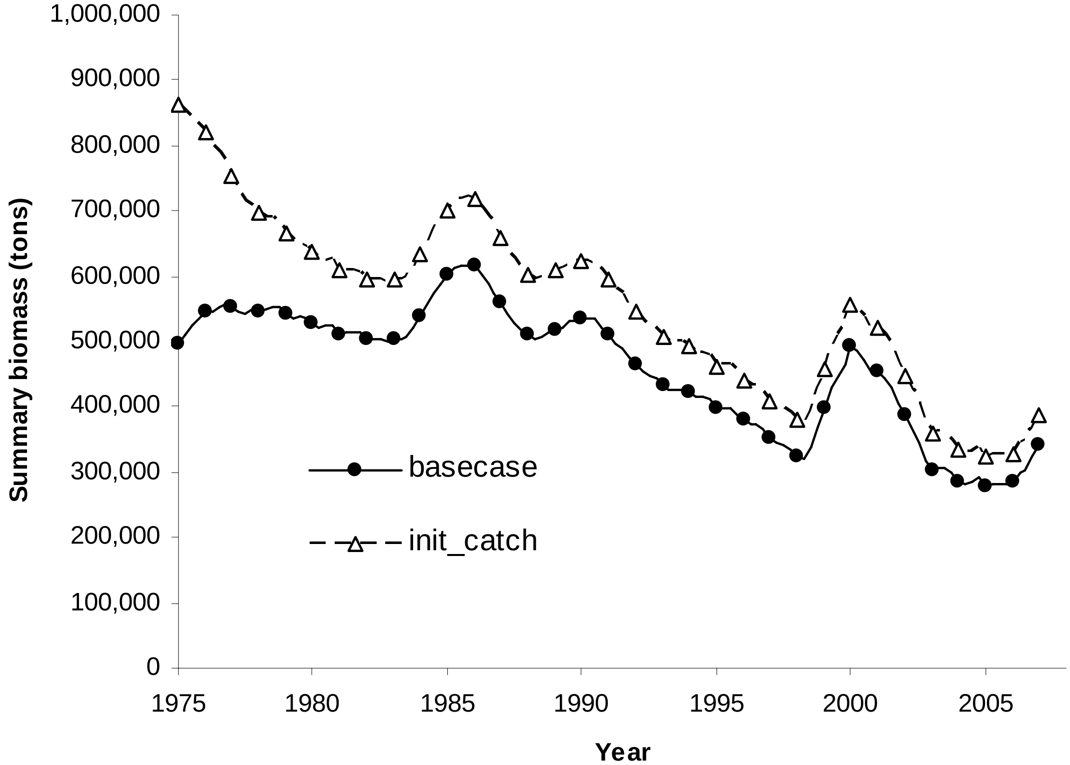


FIGURE D.1. Comparison of estimates of biomass of bigeye tuna from the basecase analysis with a model which was fit to initial catch.

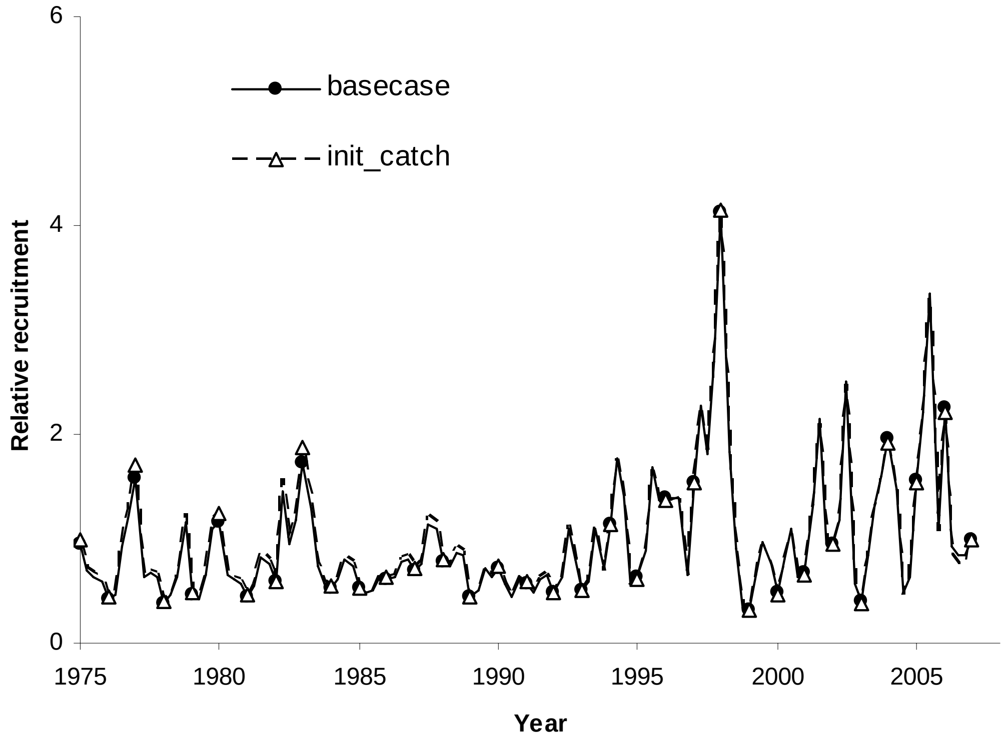


FIGURE D.2. Comparison of estimates of recruitment for bigeye tuna from the basecase analysis with a model which was fit to initial catch.

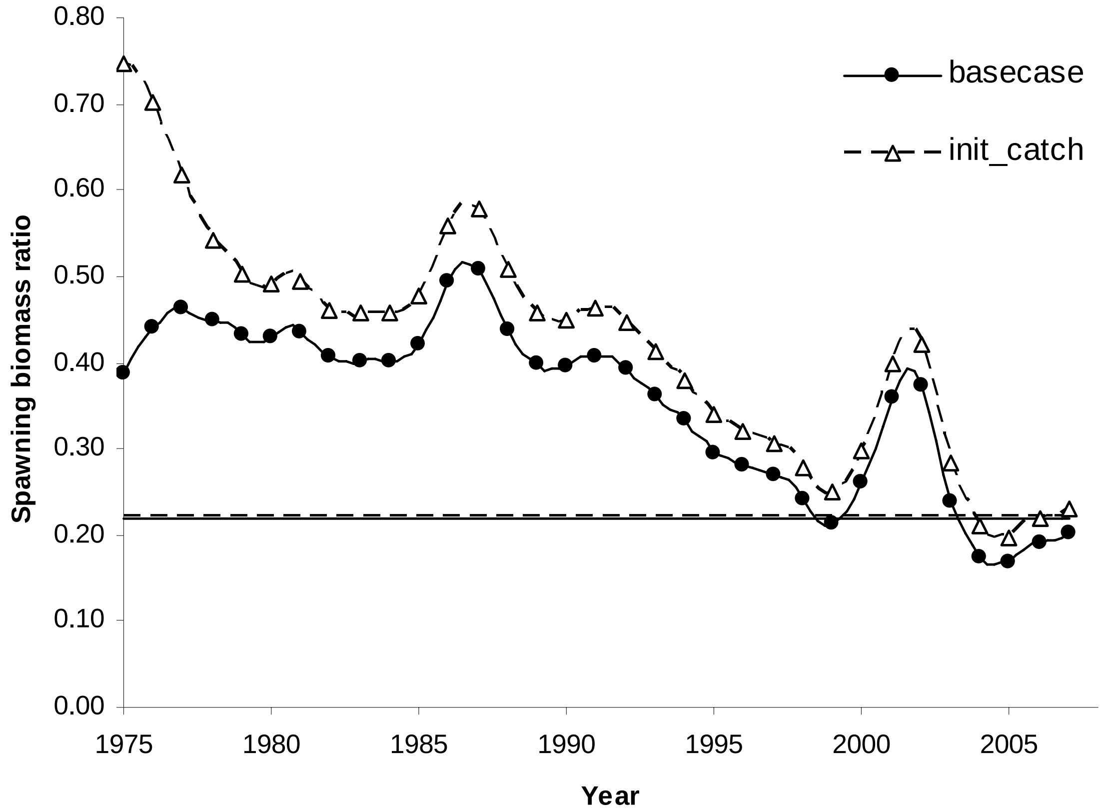


FIGURE D.3. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the basecase analysis with a model which was fit to initial catch. The horizontal lines represent the SBRs associated with AMSY under the two scenarios.

APPENDIX E: SENSITIVITY ANALYSIS FOR ITERATIVE REWEIGHTING

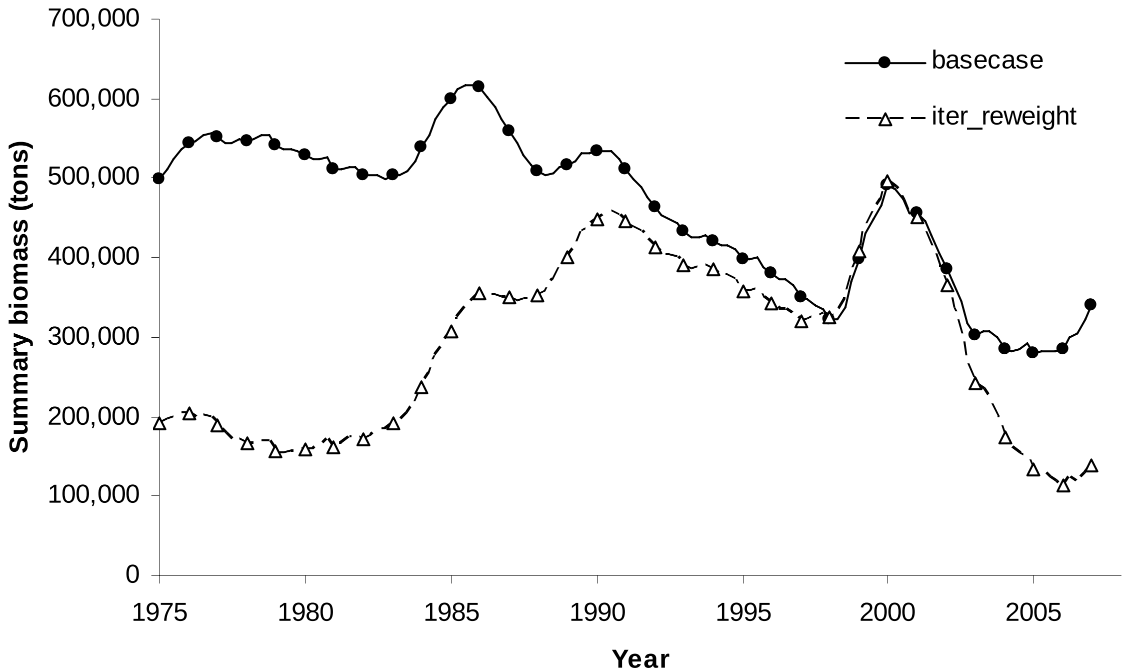


FIGURE E.1. Comparison of estimates of biomass of bigeye tuna from the basecase analysis with a model in which iterative reweighting was applied.

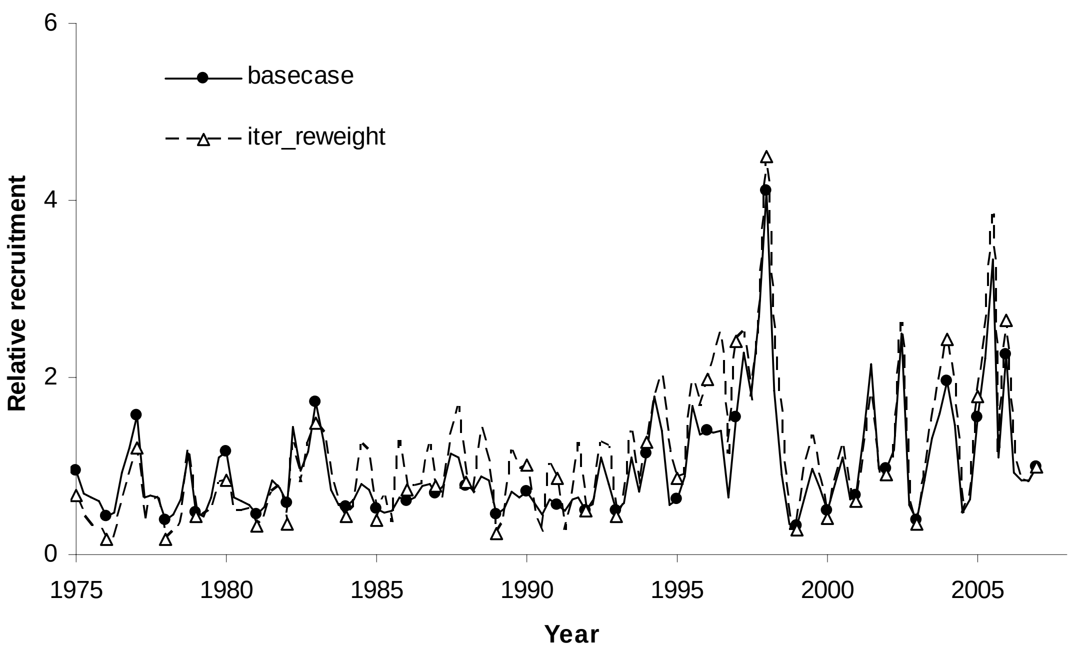


FIGURE E.2. Comparison of estimates of recruitment for bigeye tuna from the basecase analysis with a model in which iterative reweighting was applied.

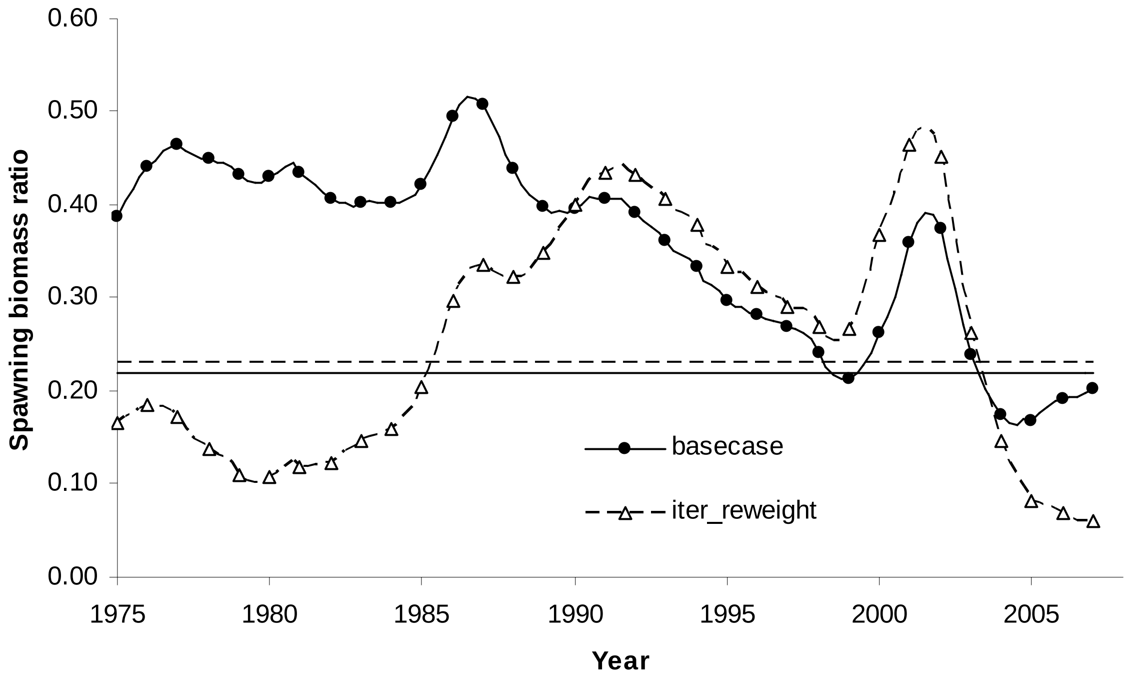


FIGURE E.3. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the basecase analysis with a model in which iterative reweighting was applied. The horizontal lines represent the SBRs associated with AMSY under the two scenarios.

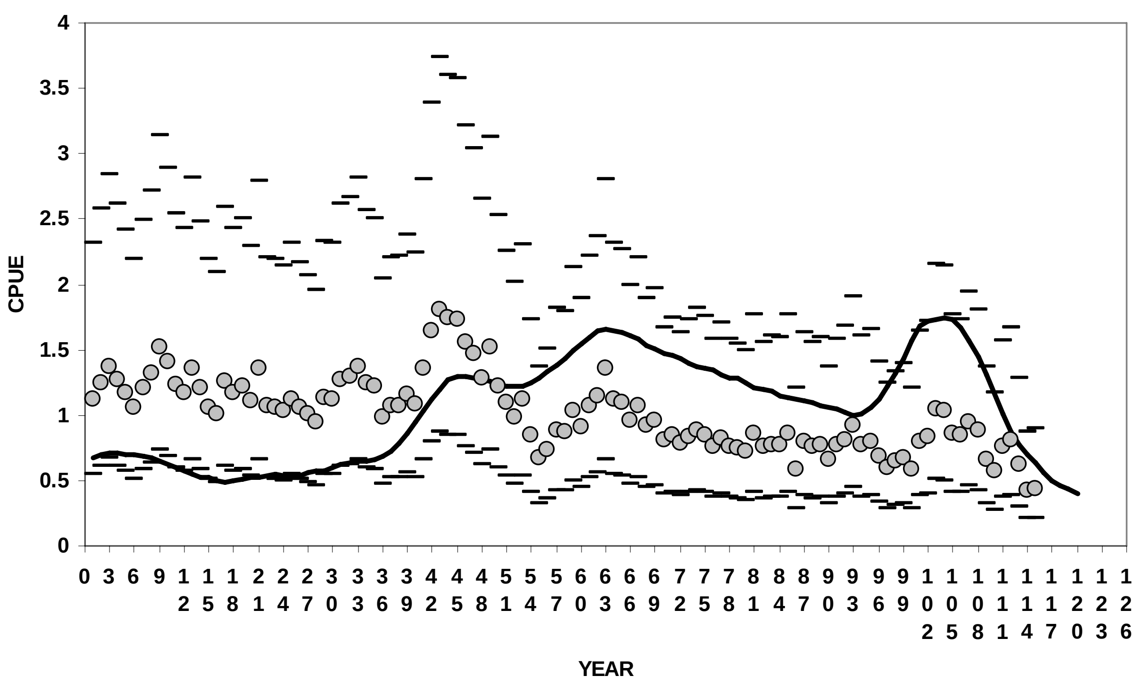


FIGURE E.4. Model fit to the southern longline data (Fishery 9) obtained when iterative reweighting was used.

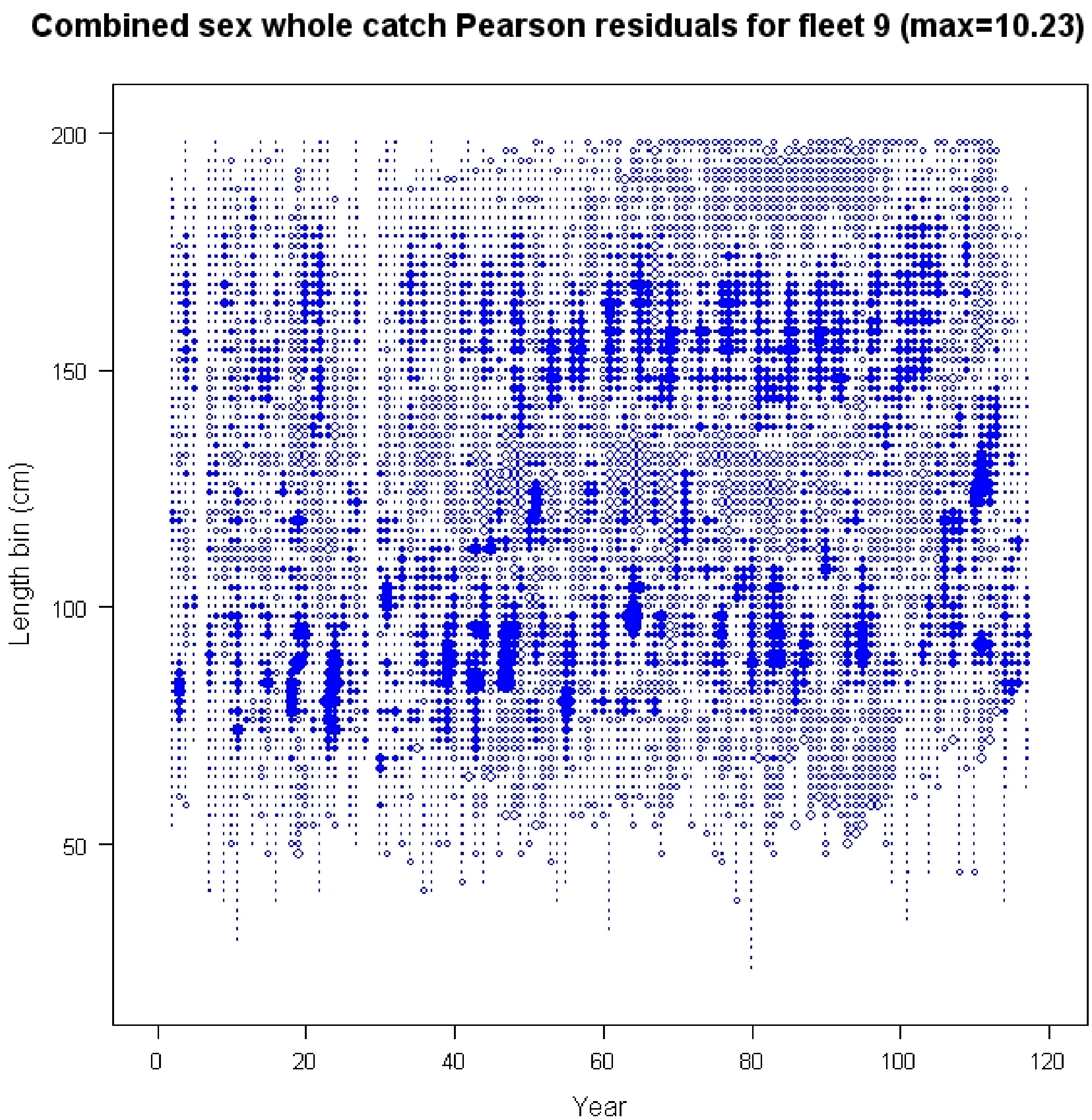


FIGURE E.5. Pearson residual plots for the model fits to the length composition data for the southern longline fishery (Fishery 9). Solid circles represent observations that are less than the model predictions; open circles correspond to observations that are higher than model predictions. The area of the circles is proportional to the absolute value of residuals.

TABLE E.1. Mean input standard error and effective sample sizes used in the iterative reweighing process. The estimated values are presented for the last iteration (iteration 2).

		Basecase	Iteration 1 used	Iteration 2 used	Iteration 2 mse
Rec		0.60	0.50	0.63	0.68
Mean input SE					
CPUE					
	2	0.40	0.38	0.41	0.44
	3	0.40	0.67	0.73	0.76
	5	0.40	0.67	0.76	0.80
	8	0.40	0.52	0.59	0.66
	9	0.20	0.16	0.36	0.54
Mean effective sample size					
LF					
	1	3.77	21.75	21.86	19.82
	2	15.02	73.04	74.78	74.33
	3	13.58	67.41	64.30	62.51
	4	1.88	7.28	7.05	7.43
	5	9.89	52.89	56.95	57.47
	6	6.45	30.25	31.62	31.63
	7	2.91	15.26	15.66	15.51
	8	4.22	63.96	72.83	73.66
	9	14.64	222.61	255.92	258.21

APPENDIX F: SENSITIVITY ANALYSIS FOR THE USE OF TWO TIME BLOCKS FOR SELECTIVITY AND CATCHABILITY OF THE SOUTHERN LONGLINE FISHERY, AND CORRESPONDING CPUE TIME SERIES

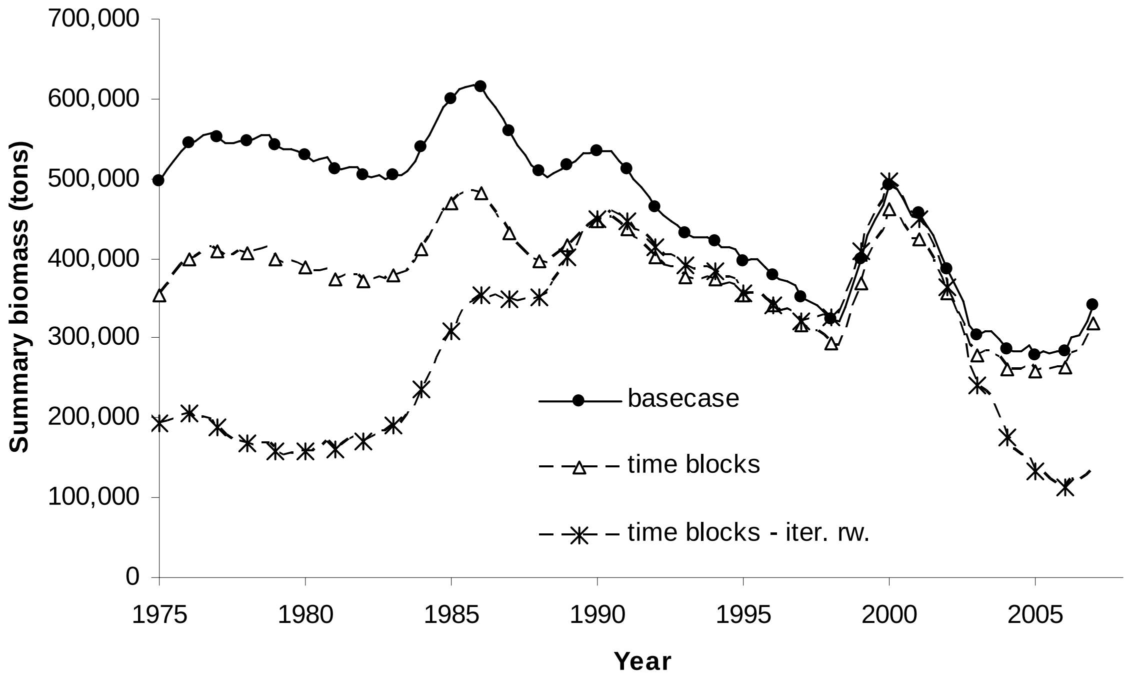


FIGURE F.1. Comparison of estimates of biomass of bigeye tuna from the base case analysis and two models in which two time blocks were considered for selectivity and catchability of the southern longline fishery (with and without use of iterative reweighting).

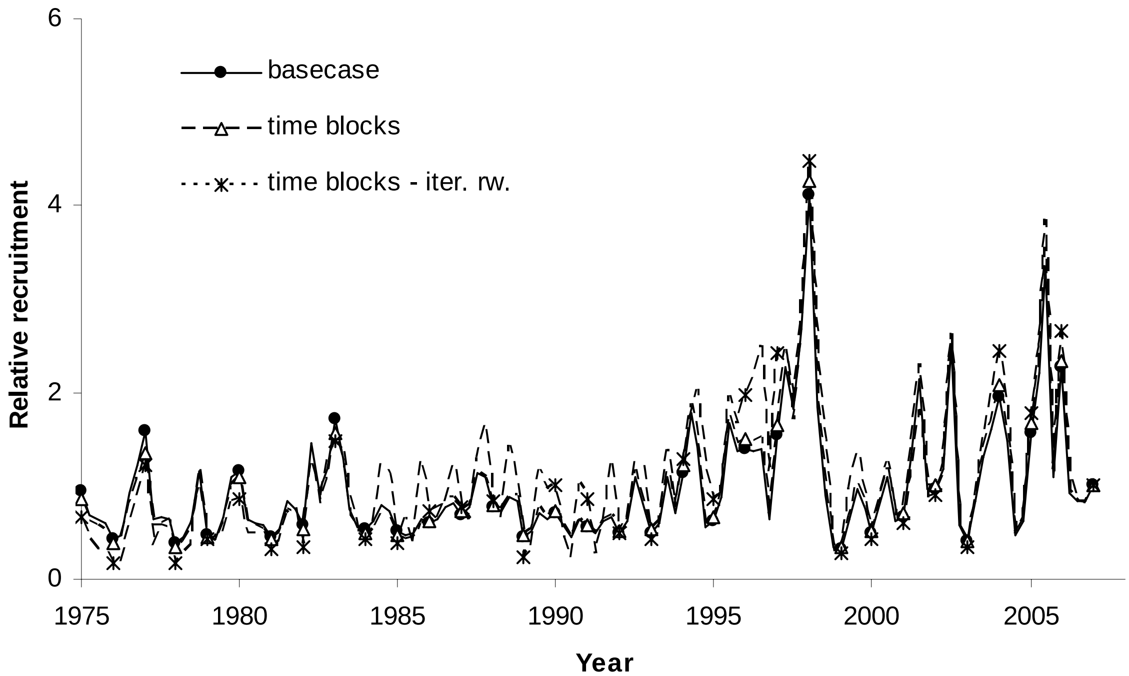


FIGURE F.2. Comparison of estimates of recruitment for bigeye tuna from the basecase analysis and two models in which two time blocks were considered for selectivity and catchability of the southern longline fishery (with and without use of iterative reweighting).

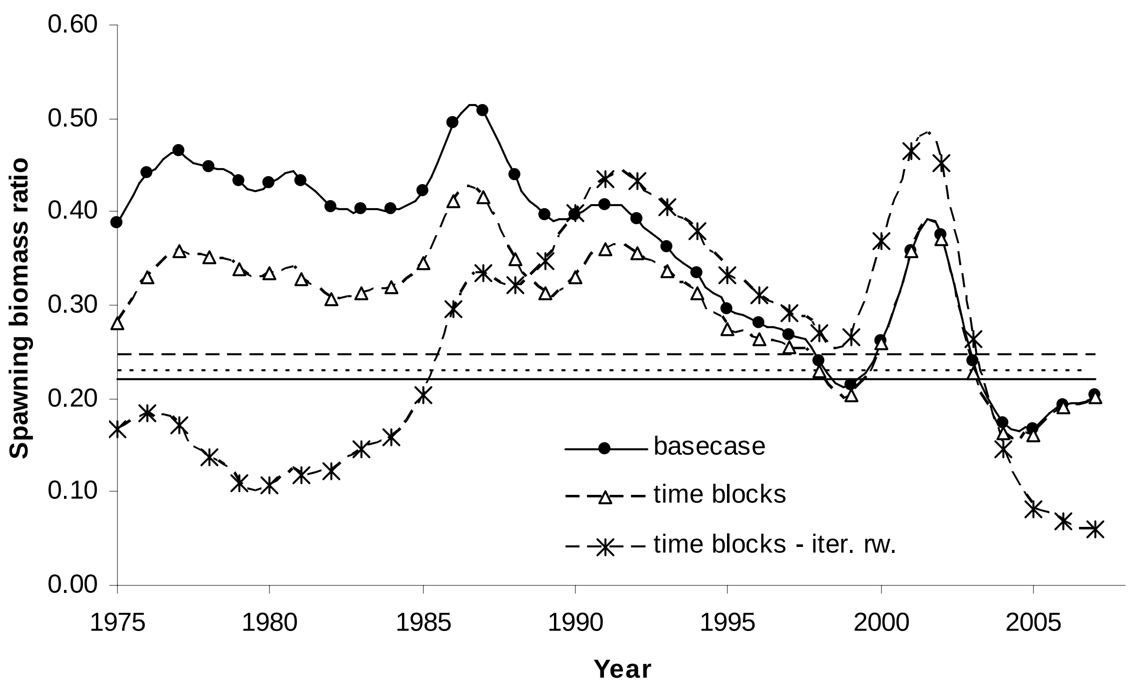
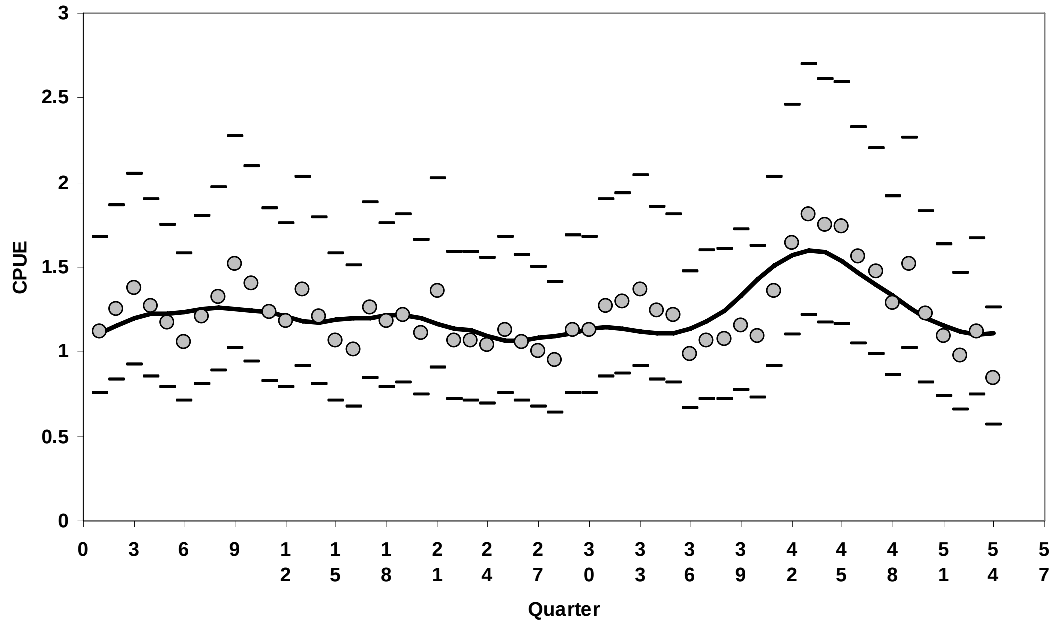


FIGURE F.3. Comparison of estimates of the spawning biomass ratio (SBR) of bigeye tuna from the basecase analysis and two models in which two time blocks were considered for selectivity and catchability of the southern longline fishery (with and without use of iterative reweighting).



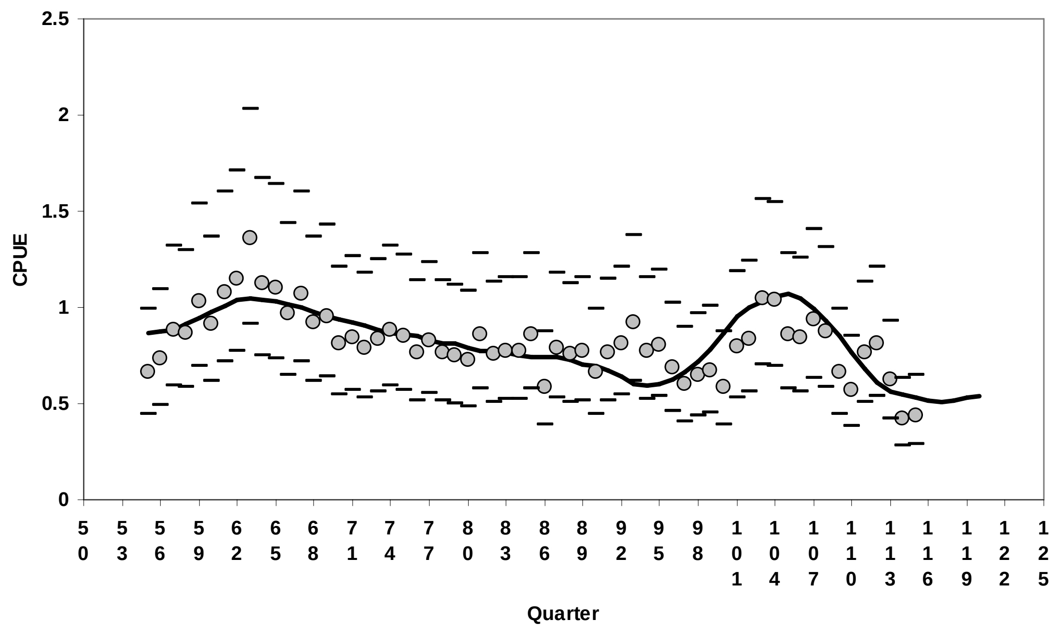


FIGURE F.4. Model fit to the southern longline CPUE data from for the analysis considering two time blocks for selectivity and catchability of the southern longline fishery (no iterative reweighting applied).

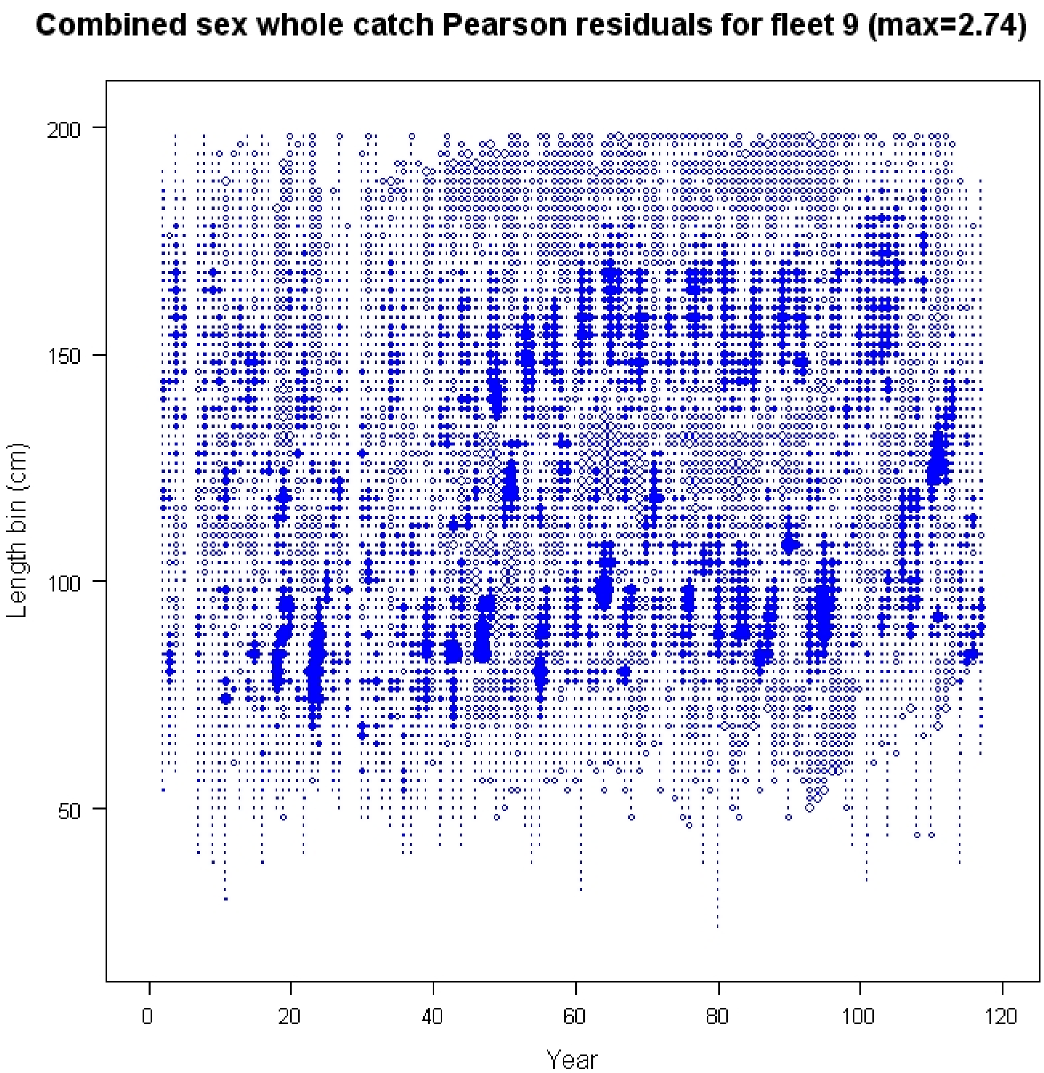
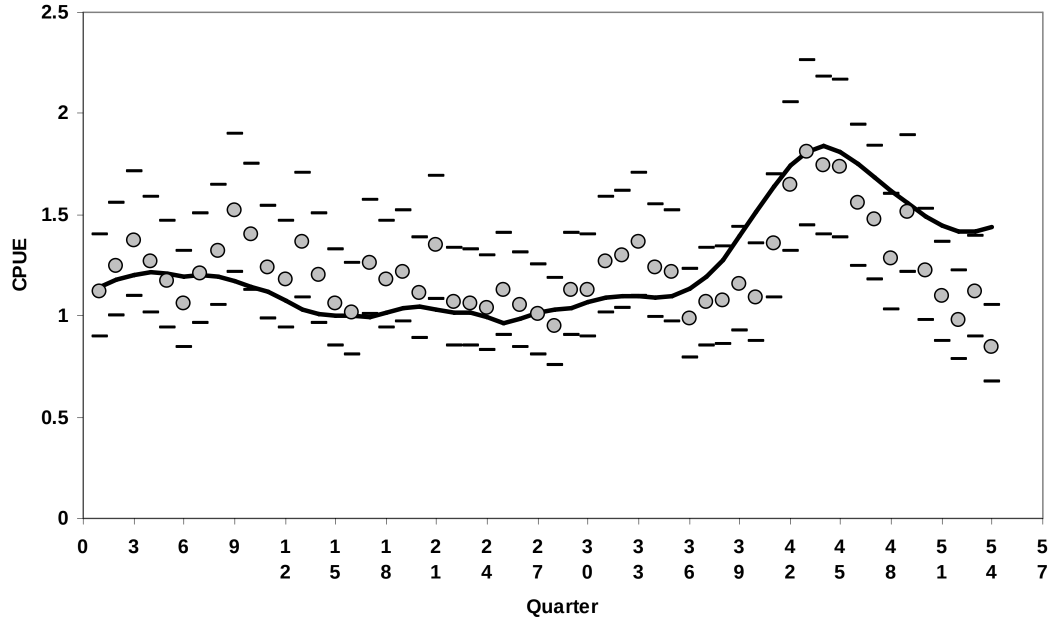


FIGURE F.5. Pearson residual plots for the model fits to the length composition data for the southern longline fishery (Fishery 9). Solid circles represent observations that are less than the model predictions; open circles correspond to observations that are higher than model predictions. The area of the circles is proportional to the absolute value of residuals.



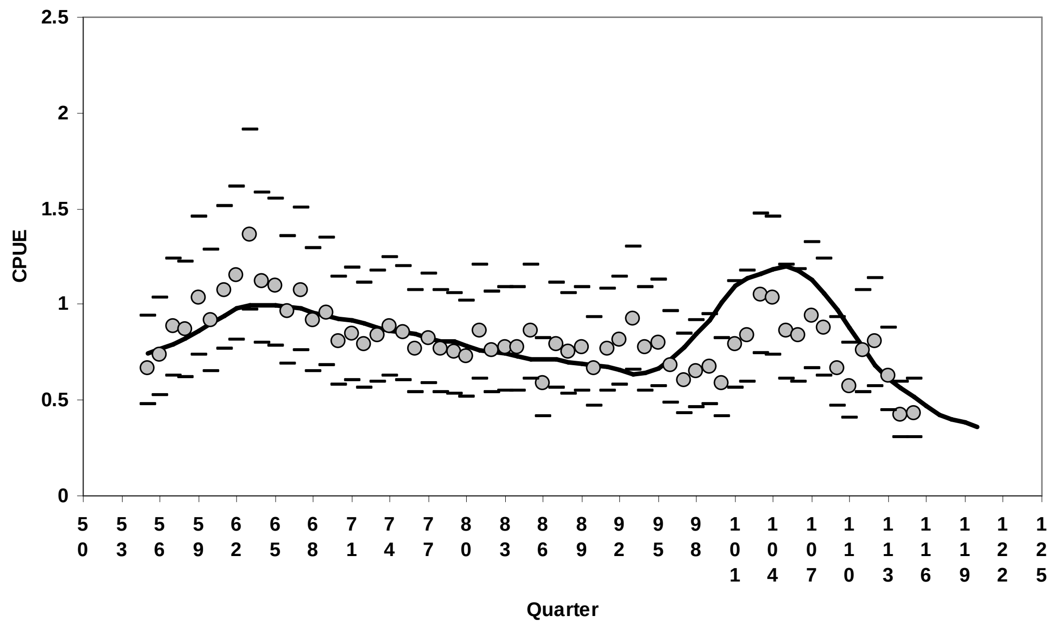


FIGURE F.6. Model fit to the southern longline CPUE data from for the analysis considering two time blocks for selectivity and catchability of the southern longline fishery (iterative reweighting was applied).

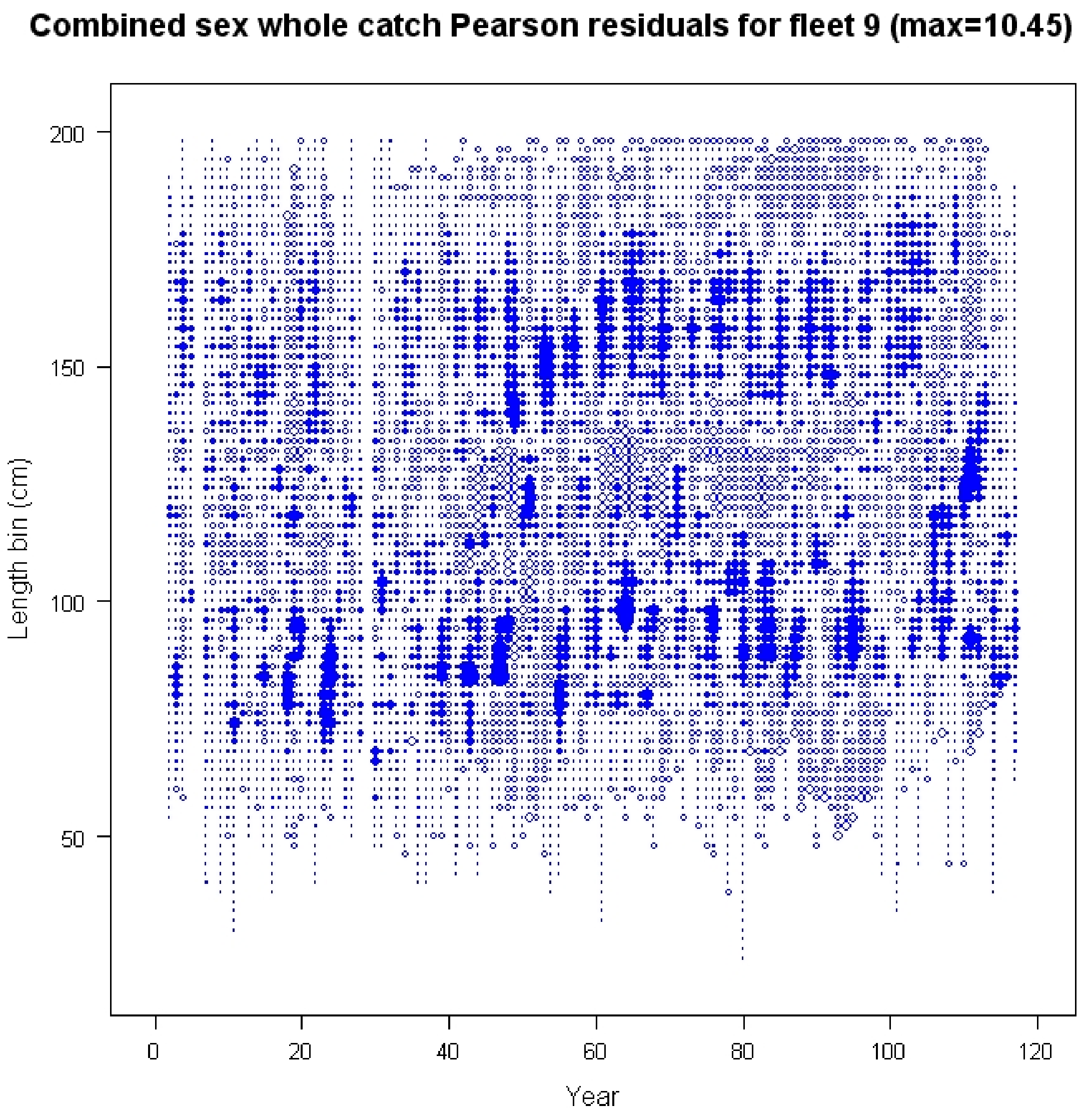


FIGURE F.7. Pearson residual plots for the model fits to the length composition data for the southern longline fishery (Fishery 9). Iterative reweighting was used. Solid circles represent observations that are less than the model predictions; open circles correspond to observations that are higher than model predictions. The area of the circles is proportional to the absolute value of residuals.

APPENDIX G: ADDITIONAL RESULTS FROM THE BASE CASE ASSESSMENT

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

ANEXO G: RESULTADOS ADICIONALES DE LA EVALUACIÓN DEL CASO BASE

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

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

					Age					
Year	**1-4**	**5-8**	**9-12**	**13-16**	**17-20**	**21-24**	**25-28**	**29-32**	**33-36**	**37-40**
1975	0.01	0.03	0.08	0.11	0.11	0.11	0.10	0.10	0.10	0.10
1976	0.01	0.06	0.12	0.14	0.14	0.13	0.13	0.13	0.13	0.13
1977	0.01	0.06	0.13	0.18	0.18	0.18	0.18	0.18	0.18	0.18
1978	0.01	0.08	0.16	0.18	0.18	0.17	0.17	0.16	0.16	0.16
1979	0.01	0.06	0.13	0.17	0.17	0.17	0.17	0.16	0.16	0.16
1980	0.02	0.10	0.17	0.18	0.17	0.17	0.16	0.16	0.16	0.16
1981	0.01	0.07	0.14	0.16	0.16	0.15	0.15	0.15	0.15	0.15
1982	0.01	0.04	0.11	0.16	0.16	0.16	0.15	0.15	0.15	0.15
1983	0.01	0.04	0.12	0.17	0.18	0.18	0.17	0.17	0.17	0.17
1984	0.01	0.04	0.10	0.14	0.14	0.13	0.13	0.13	0.13	0.13
1985	0.01	0.04	0.11	0.16	0.17	0.17	0.17	0.16	0.16	0.16
1986	0.01	0.04	0.15	0.22	0.23	0.23	0.23	0.23	0.23	0.23
1987	0.00	0.04	0.14	0.22	0.24	0.24	0.24	0.24	0.24	0.24
1988	0.00	0.03	0.12	0.18	0.19	0.19	0.19	0.19	0.19	0.19
1989	0.00	0.04	0.12	0.18	0.19	0.18	0.18	0.18	0.18	0.18
1990	0.01	0.05	0.15	0.23	0.25	0.25	0.25	0.25	0.25	0.25
1991	0.01	0.05	0.17	0.26	0.28	0.28	0.28	0.28	0.28	0.28
1992	0.01	0.05	0.16	0.23	0.24	0.24	0.24	0.24	0.24	0.24
1993	0.06	0.06	0.16	0.22	0.23	0.22	0.22	0.22	0.22	0.22
1994	0.19	0.19	0.28	0.30	0.27	0.25	0.24	0.24	0.24	0.24
1995	0.39	0.28	0.27	0.27	0.24	0.23	0.22	0.22	0.22	0.22
1996	0.55	0.43	0.32	0.27	0.22	0.19	0.19	0.18	0.18	0.18
1997	0.45	0.40	0.38	0.33	0.24	0.21	0.20	0.19	0.19	0.19
1998	0.26	0.26	0.25	0.27	0.26	0.26	0.25	0.25	0.25	0.25
1999	0.22	0.21	0.19	0.18	0.15	0.13	0.13	0.13	0.13	0.13
2000	0.36	0.40	0.31	0.24	0.18	0.15	0.14	0.14	0.14	0.14
2001	0.39	0.43	0.32	0.28	0.24	0.23	0.22	0.22	0.22	0.22
2002	0.38	0.46	0.43	0.44	0.40	0.38	0.37	0.37	0.36	0.36
2003	0.37	0.38	0.37	0.38	0.35	0.34	0.33	0.33	0.33	0.33
2004	0.39	0.44	0.38	0.38	0.34	0.32	0.32	0.32	0.32	0.32
2005	0.45	0.47	0.33	0.27	0.21	0.19	0.18	0.18	0.18	0.18
2006	0.34	0.40	0.30	0.24	0.19	0.16	0.16	0.15	0.15	0.15

TABLE G.2. Number of days fished in the four floating-object fisheries that operated since 1993, by quarter, and totals for each year.
TABLA G.2. Número de días de pesca en las cuatro pesquerías sobre objetos flotantes que operaron desde 1993, por trimestre, y los totales de cada año.

	Quarter	Fishery--Pesquería				Total
	Trimestre	2	3	4	5	
1993	1	413	49	1439	30	1931
	2	67	98	1243	33	1440
	3	0	150	764	364	1279
	4	102	940	266	107	1415
	Total	581	1237	3712	534	6065
1994	1	336	76	1043	19	1474
	2	486	207	632	97	1421
	3	140	1200	1072	243	2655
	4	37	1549	782	128	2496
	Total	999	3031	3529	487	8046
1995	1	733	419	895	230	2277
	2	1021	305	500	212	2039
	3	666	1433	888	532	3519
	4	386	1203	492	822	2904
	Total	2806	3361	2775	1796	10738
1996	1	1035	741	1201	251	3228
	2	1145	558	528	327	2559
	3	1118	1410	1316	494	4338
	4	790	1388	936	756	3869
	Total	4087	4097	3980	1828	13993
1997	1	1063	936	831	197	3027
	2	1288	1143	1240	354	4026
	3	866	1505	1271	861	4502
	4	715	2461	1300	392	4868
	Total	3932	6046	4642	1803	16423
1998	1	1894	635	1294	292	4114
	2	1830	686	1211	473	4201
	3	1876	633	599	1737	4846
	4	492	962	682	1344	3480
	Total	6092	2916	3786	3847	16641
1999	1	322	837	866	486	2512
	2	264	1710	1152	532	3658
	3	173	1980	582	984	3719
	4	163	418	196	493	1269
	Total	922	4945	2796	2495	11158
2000	1	401	1498	655	452	3005
	2	575	2208	991	314	4088
	3	640	1591	2122	1189	5543
	4	191	600	862	393	2046
	Total	1806	5897	4630	2348	14682
2001	1	1343	996	1596	337	4272
	2	1517	1332	1166	461	4475
	3	1064	1845	1991	1236	6136
	4	993	1855	1260	980	5088
	Total	4917	6028	6012	3014	19971
2002	1	1874	654	1692	100	4319
	2	1617	732	651	453	3453
	3	853	1617	1219	863	4553
	4	435	1390	780	484	3088
	Total	4779	4393	4341	1900	15413
2003	1	1061	362	1128	309	2861
	2	1094	542	962	772	3370
	3	622	2339	1361	1303	5624
	4	1104	2675	808	675	5261
	Total	3880	5918	4260	3059	17117
2004	1	1463	408	1124	270	3265
	2	1397	279	377	730	2783
	3	596	1053	421	979	3050
	4	854	2423	427	657	4360
	Total	4310	4164	2348	2636	13458
2005	1	1143	778	1376	517	3814
	2	1142	1458	1693	1264	5556
	3	495	1415	1319	1082	4311
	4	1048	2381	1224	900	5553
	Total	3828	6032	5611	3763	19234

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