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ASSESSMENT OF STRIPED MARLIN IN THE EASTERN PACIFIC OCEAN IN 2008 AND OUTLOOK FOR THE FUTURE

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1. SUMMARY

This report presents an assessment of the stock of striped marlin [*Kajakia audax*[1] (Philippi, 1887)] in the northeastern Pacific Ocean (EPO), conducted using Stock Synthesis (Version 3.10b). The assessment is based on the assumption that there is limited exchange of fish between the northern EPO and the western and central Pacific Ocean.

Striped marlin occur throughout the Pacific Ocean between about 45°N and 45°S. They are caught mostly by the longline fisheries of Far East and Western Hemisphere nations. Lesser amounts are caught by recreational, gillnet, and other fisheries. During recent years the greatest catches by commercial fisheries in the eastern Pacific Ocean (EPO) have been taken by Chinese Taipei, French Polynesia, and Japan.

There have been a number of studies of the stock structure of striped marlin in the Pacific Ocean. Hinton (2009) concluded that there is a single stock of striped marlin in the northern EPO, with a seasonal presence of juveniles in low abundance from the Hawaii/Japan stock(s) (Purcell 2009).

Hinton (2009) presents summary reviews of previous stock assessments and analyses of stock structure, and a discussion of the distribution of fishing effort in the northern EPO from the 1960s to the present, noting that "there is no indication of increasing fishing effort or catches of striped marlin in the EPO. During the period from 1965 to 2001, about 75 percent of the total longline fishing effort was north of 10ºS. Since then only about 65 percent has been north of 10ºS. A disproportionate amount of the overall drop in fishing effort has occurred in the principal portions of the stock distribution." This trend has

[1] Formerly *Tetrapturus audax*

continued, and it not expected that there will be increases in directed fishing effort or catch in the next few years.

Key results

1. The results of the assessment indicate that the northern EPO stock of striped marlin is not overfished or being overfished.
2. Stock biomass is increasing from a low of about 750 t in 2003, and is estimated to be about 3,600 t in 2009
3. The spawning biomass ratio (the ratio of observed spawning biomass to spawning biomass in the unexploited stock: SBR) in 2003 is estimated to have been about 0.16. The SBR estimate for 2009 is about 0.31
4. The estimated ratio of spawning biomass (S) in 2009 to that expected to provide MSY catch, $S(2009)/S_{\mathrm{MSY}}$, is 1.2, which indicates that the spawning biomass is above the level expected to support harvests at the estimated maximum sustainable yield (MSY) of slightly more than 2,000 t.
5. The results of the assessment (F_{mult} = 6.4) indicate that levels of fishing effort are below those which would be expected to harvest striped marlin at MSY. Recent catches, estimated at about 750 to 850 t, are about 40 percent of MSY. If harvests continue at this level, it is expected that the biomass of the stock will continue to increase over the near term.
6. Fishing mortality rate (F) estimates for the recreational fishery from the base case assessment have been on an increasing trend since 1990, although they have declined from a peak of about 1.6 in 2007 to about 0.8 in 2009. The average for 2007-2009 was 1.26.

   Estimates from the sensitivity analysis that assumes that 75 percent of fish caught and released by the recreational fishery survive (Domeier *et al.* 2003) show that fishing mortality rates for this fishery peaked in 2008 at about 0.6 and dropped to about 0.3 in 2009. The average for 2007-2009 obtained from the sensitivity analysis was about 0.45.

   These high estimates are due in part to a lack of detailed size-frequency data from this catch, and a vital key to improving the assessment is to obtain detailed size-frequency data for this fishery.

2. DATA

This assessment was conducted for the northeast Pacific Ocean (northern EPO) stock of striped marlin (Hinton 2009) in the region north of 5°S and east of 145°W. Data compiled for this region included (1) total annual catch, in metric tons (t), by fishery; (2) catch and effort data for longline fisheries during 1954-2009; (3) catch data for the recreational fisheries of Mexico during 1990-2008 (Fleischer *et al.* 2009); (4) size frequency, by length and by weight, for the longline fisheries of Japan for various years within the 1970-2008 period; and (4) size-frequency data from the EPO purse-seine fishery during 1991-2008.

2.1. Definitions of the fisheries

The stock assessment was conducted using Stock Synthesis Ver. 3.10b (Methot 2010). Six fisheries were defined on the basis of gear type (longline, purse seine, and recreational) and subareas of the northern EPO. Regression-tree analyses (TIBCO Spotfire S+ Ver. 8.1: http://spotfire.tibco.com) of size-frequency data were used to examine spatial distributions of size frequencies. The subarea boundaries in the northern EPO stock area that were suggested by the results were, though not in exact agreement, similar to those that have been used in the past in various analyses of Japanese longline fisheries (*e.g.* Okamoto and Bayliff 2003, Figures 1 and 2). Considering the results of the stock structure analyses (Hinton 2009) in concert with these various analyses, three subareas of the northern EPO were used in this assessment: (1) the region north of 5°S and south of 10°N between the coast of the Americas and 145°W (A1); (2) the region north of 10°N between 120°W and 145°W (A2); and (3) the region north of 10°N between the coast of the Americas and 120°W (A3) (Figure 2.1).

Fisheries 1, 2, and 3 were defined as the Japanese longline fisheries operating in areas A1, A2, and A3, respectively; Fishery 4 as all other longline fisheries operating in the EPO; Fishery 5 as the recreational fishery of Mexico; and Fishery 6 as the EPO purse-seine fishery (Table 2.1).

2.2. Catch

The catch and effort data were stratified in accordance with the fishery definitions described in Sec. 2.1, and the catch by fishery in this model is presented in Table 2.2.1.

Landings of billfish are fairly well known, due to the value of these fish in commerce. However, there remain unreported landings from artisanal and recreational fisheries, and from components of the commercial longline fisheries operating in the region.

Most of the commercially-landed striped marlin are taken by the longline fisheries of Far East and Western Hemisphere nations. Lesser amounts of striped marlin are, or have been, landed by the other fisheries described in Hinton and Bayliff (2002, Section 2.1). Data on the distribution of effort and total hooks fished by the principal longline fisheries are presented in Document SAC-01-05, *The fishery for tunas and billfishes in the eastern Pacific Ocean in 2009*[2].

The principal recreational fisheries for striped marlin in the EPO operate within about 50 to 100 miles of the shores of Mexico, and they may be characterized as catch-and-release for all marlin species. Fleischer *et al*. (2009) reported sport-fishing trips increasing from about 32,500 in the early 1990s to a record high catch of about 58,000 individuals taken in 2007. The preliminary estimate available for 2008 is of the same magnitude. Fleischer *et al.* (2009) report an average release rate (determined by the Instituto Nacional de Pesca and the Centro Regional de Investigación Pesquera of La Paz, Mexico) for the 1999-2007 period of about 77.4 percent (range: 72.4 to 82.5). Assuming (1) the average release rate for the 1990-2007 period, (2) 100 percent mortality of fish released, and (3) the annual median weight of fish sampled reported by Fleischer *et al.* (2009), the estimated average annual mortality caused by the recreational fishery during 1990-2006 was about 195 t (range: 115 to 310), and the mortality associated with the record high catch in 2007 was about 545 t. At a mortality rate of about 25 percent (Domeier *et al.*, 2003), the mortality in 2007 was about 140 t. The estimate of average annual mortality assuming 100-percent mortality of fish released was used in the assessment (Table 2.2.1), and a sensitivity analysis assuming the 25 percent mortality rate estimate of Domeier *et al.* (2003) was conducted.

A small number of striped marlin are captured in purse-seine fisheries targeting tuna in the EPO. During the 1998-2007 period, the average annual catch of striped marlin by the large (> 363 t carrying capacity) vessels in this fishery was about 370 fish (range: 161 to 566). This catch was orders of magnitude less than the catches made by either the commercial longline fishery or the recreational fishery.

2.2.1. Discards

There was no information on discards of striped marlin from commercial fisheries to include in the assessment. Discards from recreational fisheries were discussed in the previous section.

2.3. Indices of abundance

Indices of abundance (standardized catch rates: CPUE) were derived from Japanese longline catch and effort data for fisheries F1 – F3 (operating in areas A1 – A3) using delta-lognormal general linear models. Data used in these standardizations were restricted to those from years with three or more months of operation in the area. The CPUE series used in the assessment are provided in Table 2.3.1.

[2] http://www.iattc.org/Meetings2010/PDF/Aug/SAC-01-05-The-fishery-in-th-EPO-2009.pdf.

2.4. Size composition data

Size-frequency data for longline fisheries of Japan were available as total numbers of individuals aggregated in length-size intervals of 1 cm, 2 cm, and 5 cm. Annual size-frequency distributions in 2-cm intervals were compiled by combining the 1-cm and 2-cm data, and these, along with the 5-cm data, were used in the assessment (2 cm) and sensitivity analyses (2 cm and 5 cm). Data were compiled for each area in the model, and only data for those years with (O)100 or more measurements in the year were included in the assessment (Table 2.4.1).

Size-frequency data from these longline fisheries were also available as numbers of individuals in 1-kg and 2-kg weight intervals. These data were compiled into 2-kg intervals over the range of 4 to 60 kg, and into 4-kg intervals over the range of 60 to 172 kg. These data were used in sensitivity analyses.

Size-frequency data from purse-seine catches were available as measurements of individual fish during 1991-2008. These measurements were aggregated into 2-cm intervals for use in the assessment.

2.5. Age-at-length data

There were no age-at-length data available to include in the assessment.

3. ASSUMPTIONS AND PARAMETERS

3.1. Biological and demographic information

3.1.1. Growth

Striped marlin have very high growth rates during their first year, reaching about 50 percent of their asymptotic length, and have decreasing rates of about 10 percent in the second year, decreasing to about 4 percent thereafter (Melo-Barrera *et al*. 2003). There have been a number of growth studies on striped marlin in the Pacific Ocean (Table 3.1.1.1), and the maximum ages observed in these studies range from 8 to 11 years (Kopf *et al*. 2005). Estimates of the asymptotic maximum length (*L* infinity: L_{inf}) from von Bertalanffy growth models ranged from about 186 to 275 cm eye-fork length (EFL), and the estimates of the annual von Bertalanffy *K* from about 0.25 to 0.70. For this assessment, *K* was fixed at 0.25. The L_{inf} parameter may be estimated or specified, and in the assessment it was fixed at 275 cm (which relates to 269 cm at age 15, the maximum age in the model). Part of the reason for including this large value is because of the high proportion of large fish seen in the purse-seine length-composition data. In addition, fish of up to 296 cm have been measured in the catch of longline fisheries in the EPO, and they are included in the data used in this assessment.

The following weight-length relationship (Wares and Sakagawa 1972) was used to convert lengths to weights in the current stock assessment:

$$w = 6.9663 \times 10^{-6} \cdot l^{3.071}$$

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

Several weight-length relationships are available, and they differ substantially, particularly for older individuals. The weight-length relationship is important for calculating biomass, making catch recorded in numbers and weights compatible, and making length and weight compositions compatible.

3.1.2. Natural mortality

A constant annual instantaneous natural mortality rate (*M*) was assumed in the assessment (*M* = 0.5).

3.1.3. Recruitment and reproduction

Information on reproduction and recruitment of striped marlin was summarized by Hinton and Bayliff (2002). Since then, studies of striped marlin in the region of the Gulf of California found that fish in reproductive condition were present during the period from May to December (Gonzalez-Armas *et al*.

2006). Based on the results of these studies, it was assumed for this assessment that striped marlin are recruited to the fishery throughout the year.

In general, it is believed that environmental conditions provide the principal influence on recruitment levels, and that there is no biomass-mediated decrease in recruitment at high spawning stock biomass. Therefore, a Beverton-Holt (1957) stock-recruitment relationship was used in the assessment. In the Stock Synthesis model, the Beverton-Holt curve is parameterized to include steepness (h), which controls how quickly recruitment decreases when the spawning biomass is reduced. Steepness is defined as that fraction of the recruitment (R_0) produced by the spawning biomass of the unexploited stock (S_0) when the stock spawning biomass has been reduced to 20 percent of the unexploited spawning biomass ($0.2S_0$). 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. Simulation analyses have shown that estimation of steepness is problematic, with large uncertainty and frequent estimates equal to one even if the true steepness is moderately less than one (Conn *et al*. 2010).

There is no evidence that recruitment is related to spawning stock size for striped marlin in the EPO, and in the current assessment recruitment is assumed to be independent of stock size (h = 1).

A sensitivity analysis with h = 0.75 was conducted as part of the assessment.

Estimates of size at first maturity are on the order of 145 to 155 cm eye-fork length (Kume and Joseph 1969; Eldridge and Wares 1972; Kopf *et al*. 2005), although females in reproductive condition are not regularly encountered at eye-fork lengths under about 160 cm (Kume and Joseph 1969). Considering this information, in the assessment it was assumed that 50 percent of the females were mature at age 2, and that all were mature after that age.

3.1.4. Movement

The current assessment does not consider movement explicitly. It is assumed that the population is randomly mixed at the beginning of each year, and that the spatial definition of the fisheries accommodates some forms of movement by means of different selectivity and catchability.

3.1.5. Stock structure

There have been a number of analyses of stock structure of striped marlin in the Pacific Ocean, all of them essentially showing that there are multiple stocks in this ocean. This assessment was conducted assuming a single stock of striped marlin (Hinton 2009) in the northern EPO. A portion of the fish in area A2 may be from the central Pacific, and we provide a sensitivity analysis to investigate the effect of assuming that all fish from area A2 are not part of the EPO population.

3.2. Environmental influences

No environmental index was incorporated into this assessment.

4. STOCK ASSESSMENT

The Stock Synthesis method (SS - Version 3.10b; Methot 2005, 2009) was used to assess the status of striped marlin in the EPO. It consists of a size-based, age-structured, integrated (fitted to many different types of data) statistical stock assessment model. The model is fitted to the observed data, which include indices of relative abundance and size composition of the catch and, in sensitivity analyses, also to weight composition, by finding a set of population dynamics and fishing parameter estimates that maximize a penalized likelihood, given the amount of catch taken by each fishery. A number of aspects of the underlying assumptions of the assessment model are described in Section 3.

The assessment model is a gender-specific model in which both females and males share the same parameter values. The model starts in 1975, with M = 0.5, h = 1, K = 0.25, and L_2 = 275 cm. The initial conditions included a recruitment offset, fishing mortalities for Fisheries 1 and 2, and deviates for the five youngest ages. It also includes the following important assumptions:

1. The coefficients of variation (CVs) of the CPUE series for Fishery 1, which was used as an index of abundance, were fixed at 0.2; the CVs of the CPUE series for Fisheries 2 and 3 were estimated.
2. The catchability coefficients (used to scale the CPUE indices of abundance) for Fisheries 1-3 were estimated.
3. Selectivity curves for Fisheries 1-3 were estimated with a double normal distribution function, which allows for dome-shaped selectivity curves. Fishery 4 (other longline fleets) was assumed to have the same selectivity curve as Fishery 1.
4. The selectivity curve for Fishery 6, the purse-seine fishery, which catches on average larger fish than the longline fisheries, was modeled with asymptotic selectivity. The selectivity was parameterized by using the double normal distribution with fixed parameters other than (1) that estimating the selectivity for the first size interval, (2) that estimating the rate of increase at the inflection point, and (3) that estimating the age when selectivity reaches 1. Fishery 5, the recreational fishery, also tends to catch fish with average and maximum sizes greater than those of the longline fisheries, so it was assumed to have the same asymptotic selectivity as Fishery 6.
5. The longline fisheries of Japan first reported catch from the stock in 1954, so it was assumed that until then the stock was in an unfished equilibrium. The portion of the stock area that was being fished increased during the next decade, until finally, in about 1968, fishing operations extended throughout the EPO (Joseph *et al*. 1974; Figure 1). During this period of initial exploitation of the unfished stock biomass, the catch and catch rates of striped marlin increased rapidly, but they were then followed by a drastic drop in the early 1970s. The approach taken to address the problems presented when data such as these are included in an assessment model, and to provide a comparative reference for these data based on the results of the assessment, was to start the assessment model in 1975. To provide a measure of model fit to the period prior to 1975, the recruitment deviates for the 1969-1974 period were included in the model likelihood. This approach is consistent with that taken in stock assessments of yellowfin and bigeye tunas in the EPO.

The estimates of management quantities were based on the 3-year average fishing mortality rates for Fisheries 1-6 for 2007-2009.

Uncertainty arises in the model results due to sample and process errors. In the first instance, the observed data cannot perfectly represent the population parameters of striped marlin in the northern EPO, or more generally, those of any other stock. In the second, the structure of the assessment model provides only an approximation to the dynamics of the stock and the fisheries that harvest them. These uncertainties are expressed in approximate confidence intervals and CVs. These 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. The model structure uncertainty is investigated in several sensitivity analyses.

The following summarizes the important aspects of the base case assessment and the sensitivity analyses.

1. The model starts in 1975; steepness of the stock-recruitment relationship = 1 (no relationship between stock and recruitment); average size of the (theoretical) oldest fish is fixed at L_{inf} = 275 cm eye-fork length, and the CV of length-at-age is estimated; the model is fitted to CPUE time series for Fisheries 1-3; the CV of the CPUE likelihood function is fixed for Fishery 1, and is estimated for Fisheries 2 and 3; selectivity for Fisheries 1-3 are estimated using a double normal

distribution that allows dome-shaped selectivity; Fishery 4 shares selectivity with Fishery 1; asymptotic selectivity is estimated for Fishery 6 (purse-seine fishery); selectivity for Fishery 5, which tends to catch larger fish, shares selectivity with Fishery 6.

2. Several sensitivity analyses were conducted to investigate the uncertainties in the stock assessment. These included:

    a. Fixing natural mortality (*M*) at 0.3 and at 0.7;

    b. Fixing growth rate (*K*) at 0.1 and 0.4;

    c. Fixing steepness of the stock recruitment (*h*) at 0.75;

    d. Fixing maximum length (L_{inf}) at 265 cm;

    e. Removing area A2 from the assessment;

    f. Including other size composition data (weight, 5-cm length, and both);

    g. Starting the model in 1970 in combination with including other size composition data (2-kg weight, 5-cm length);

    h. Reducing the recreational catch by 75%;

    i. Starting the model from a virgin population in 1954;

    j. Estimating L_{inf} and starting individual area CPUE after the expansion of the fishery was estimated to have fully expanded to cover the area (1962 in A1; 1963 in A2; and 1966 in A3);

    k. Estimating L_{inf} and starting recruitment residuals in 1954;

    l. Estimating L_{inf}, starting recruitment residuals in 1954, and removing CPUE before 1973;

    m. Repeating the above three with L_{inf} = 275 cm (as in the base case).

4.1. Assessment results

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

Trends in fishing mortality (*F*) by fishery are shown in Figure 4.1.1. The estimated *F*s for Fisheries 1, 2, and 3 have been on a declining trend since about 1992-1993, and that of Fishery 4 since about 1995. The average *F*s for the most recent three-year period for Fisheries 1-3 were between 1.0×10^{-4} and 2.4×10^{-2}, while that of Fishery 4 was 1.2×10^{-1}. The base case estimates of *F* for Fishery 5 have been trended up over the entire period in the model, though it has decreased from a peak of 1.6 in 2007 to 0.81 in 2009. The average for the three-year period was 1.26.

The purse-seine and recreational fisheries both tend to catch fish which are on average larger than those taken in longline fisheries. In the base case and the sensitivity analyses, the selectivity of the recreational fishery (Fishery 5) is estimated by the selectivity of the purse-seine fishery. Part of the reason why *F* is high for the recreational fishery is that only five percent of the fish survive to age 5 or older in the unfished population, which is the age at full selection for the purse-seine fishery.

Access to size-frequency data from the recreational fishery in 1- or 2-cm size intervals is vital for improving the assessment.

4.1.2. Recruitment

The estimated spawning biomass at the beginning of each year, and the associated recruitment, are presented in Table 4.1.2. There is no indication that recruitment is related to spawning biomass ($F = 0.83$, $P = 0.37$).

4.1.3. Biomass

The spawning biomass ratio (SBR) estimate for 2009 from the base case is estimated to be about 0.32. The trend in the estimated SBR for the base case is shown in Figure 4.1.3. The estimate of total stock biomass has followed a trend very similar to that of the spawning biomass, decreasing from about 7,500 t in 1975 to about 4,350 t in 1984. Biomass then increased to a peak of about 8,100 t in 1987, before beginning a general decline to about 1,850 t in 2003. Since then the estimated total biomass has been steadily increasing, reaching about 3,600 t in 2009. It is considered that the recent increases in biomass are a result of the decrease in fishing effort in the northern EPO (Hinton 2009).

4.2. Comparisons to external data sources

No comparisons to external data were made in this assessment.

4.3. Diagnostics

4.3.1. Residual analysis

The model fits to the CPUE data from different fisheries are shown in Figure 4.2.1. The model was fitted to CPUEs of Fisheries 1, 2 and 3. The model fits these observed CPUE series only moderately well. The fit to Fishery 5, the recreational fishery (not used to estimate the model parameters but shown for comparison), does not reflect the increasing CPUEs seen in the last two observations.

Pearson residual plots are presented for the model fits to the length-composition data (Figure4.2.2). There are several notable characteristics of the residuals. The model underestimates the proportions of larger fish in Fishery 1 in the mid- to late 1970s, in 1987-1989, and again in 2000-2003. This underestimation is also seen in Fishery 2 in 1999, and in Fishery 3 in 1976. The model also underestimates the proportions of larger fish in Fishery 6 in the early 1990s, and periodically thereafter. It is noted that the underestimations in the late 1980s and early 2000s correspond to periods of higher spawning and population biomass.

4.3.2. Retrospective analysis

No retrospective analysis was conducted with this assessment.

4.4. Sensitivity analyses

The stability of the results obtained from the base case assessment model was examined with sensitivity analyses conducted by changing values of parameters which were fixed in the base case, by changing model structure, and by including additional size- and weight-frequency data. Results of sensitivity analyses are presented in Table 4.4 in terms of commonly-cited model output and MSY-based parameters used to provide management advice.

4.5. Comparison to previous assessments

This is the first assessment of the northern EPO stock of striped marlin carried out using Stock Synthesis. The absolute biomass levels estimated in the three most recent previous assessments (Hinton and Bayliff 2002; Hinton and Maunder 2004; Hinton 2009) were higher than those from the base case. However, in general the results of these assessments were that the stock biomass levels were at or above levels that are expected to provide catches at MSY levels and that, with continued decline in the observed fishing effort, increases in stock biomass were to be expected. The results of this assessment are consistent with those three previous assessments.

4.6. Summary of results from the assessment model

The estimated MSY from the base case assessment was relatively insensitive to changes in parameters, data, or model structure, generally falling within a range of about 1,800 to 2,075 t. The maximum estimate of MSY, about 3,900 t, was obtained from the model with $M = 0.7$.

The SBR in the final year of the model [SBR(2009)] was estimated to be 0.31, and the ratio of S/S_{MSY} to be 1.19. The SBR exhibited sensitivity to changes in M and K, but was less sensitive to other changes in parameter estimates, data, and model structure.

The estimated value from the base case for the F multiplier (F_{mult}), the multiplier applied to the recent average of F in order to achieve F_{MSY}, was about 6.4. F_{mult} was extremely sensitive to changes in M, with estimates of F_{mult} of about 1.2 for $M = 0.3$, and 50 for $M = 0.7$. The estimates of F_{mult} obtained from the other sensitivity analyses ranged from about 2 to 14, with seven estimates below the value from the base case, and two above.

The estimated average F of recreational fisheries during 2007-2009 was estimated to be about 0.8. Part of the reason for this high estimate is that, in the model, only five percent of the fish survive to age 5 or older in the unfished population, which is the age at full selection for the purse-seine fishery. Access to detailed size-frequency data from the recreational fishery is vital for improving the assessment.

5. STOCK STATUS

The results of the assessment indicate that the northern EPO stock of striped marlin is not being overfished [C(2009)/MSY = 0.36, $F_{mult} = 6.4$], and that the stock biomass is increasing from the low biomass (about 750 t) and SBR (about 0.16) observed in 2003. The estimates of biomass and SBR for 2009 were about 3,600 t and 0.31, respectively.

The results of the base case assessment indicate that at present the SBR for the stock is about 0.31, and that $S(2009)/S_{\mathrm{MSY}} = 1.2$, which indicates that the spawning biomass is above the level expected to support harvests at the estimated MSY of 2,000 t.

The results of the assessment ($F_{mult} = 6.4$) also indicate that levels of fishing effort are below those which would be expected to harvest striped marlin at the MSY level. Recent catches, which are estimated to be about 750 to 850 t, are about 40 percent of MSY. If harvests continue at this level, then it is expected that the biomass of the northern EPO stock of striped marlin will continue to increase over the near term.

6. SIMULATED EFFECTS OF CONSERVATION RESOLUTIONS AND FUTURE FISHING OPERATIONS

No simulations to examine the effects of future fishing operations were conducted.

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 striped marlin in the EPO. Updated and new data will be incorporated into the next stock assessment.

Efforts will be made to obtain size-frequency data from recreational fisheries, which are vital to improving the assessment.

7.2. Refinements to the assessment model and methods

The IATTC staff will continue developing the Stock Synthesis (Version 3) assessment for striped marlin. Much of the progress will depend on how the Stock Synthesis software is modified in the future. The following changes would be desirable for future assessments:

1. Determine appropriate weighting of the different data sets;
2. Include available tagging data (conventional and satellite tracking) in the assessment;
3. Explore alternative assumptions on stock structure (spatial analysis).

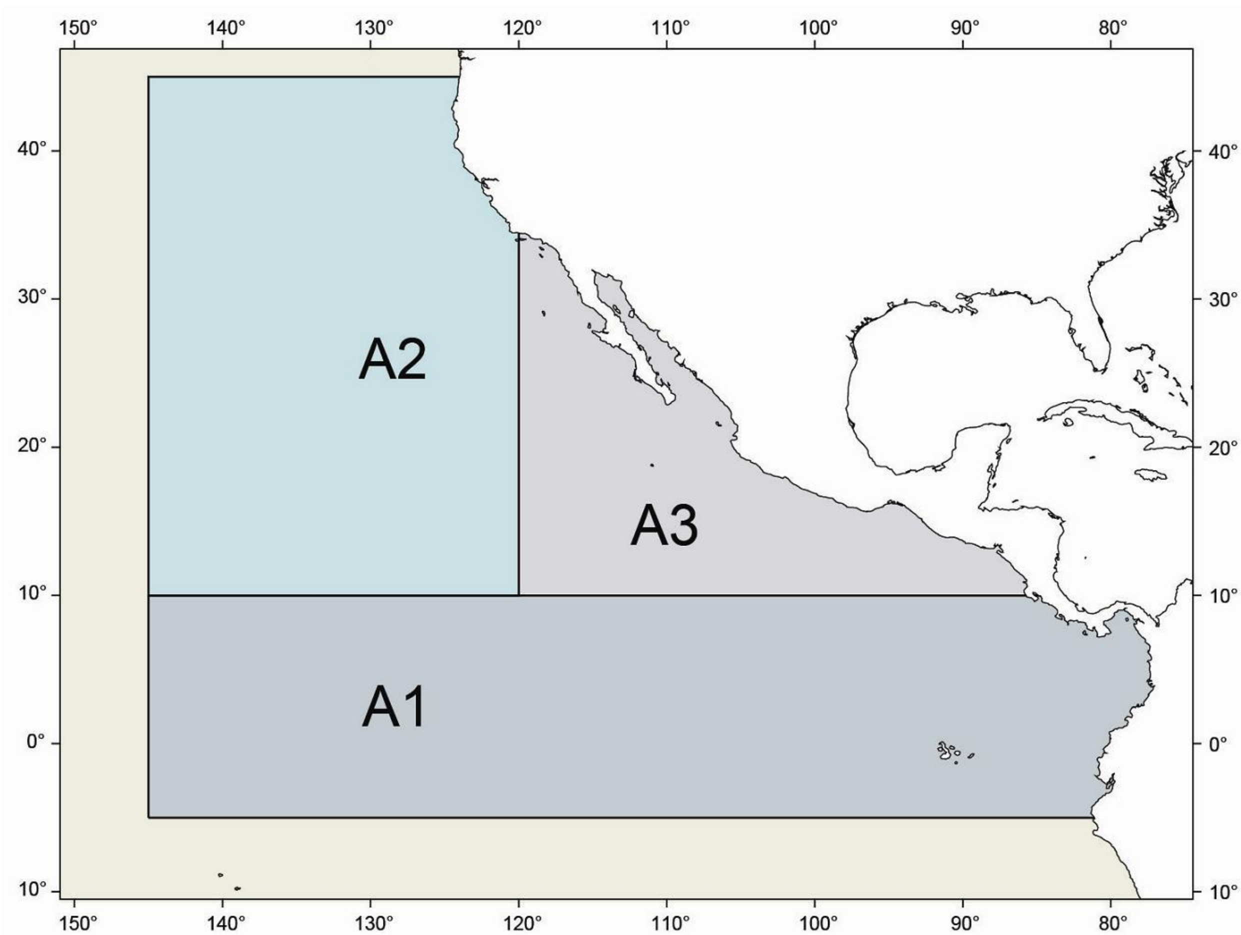

FIGURE 2.1. Areas designated for the assessment of the striped marlin stock in the northern EPO. See Table 2.1 for definitions of fisheries corresponding to these areas.
FIGURA 2.1. Zonas designadas para la evaluación de la población de marlín rayado en el OPO norte. Ver definiciones de las pesquerías correspondientes a estas zonas en la Tabla 2.1.

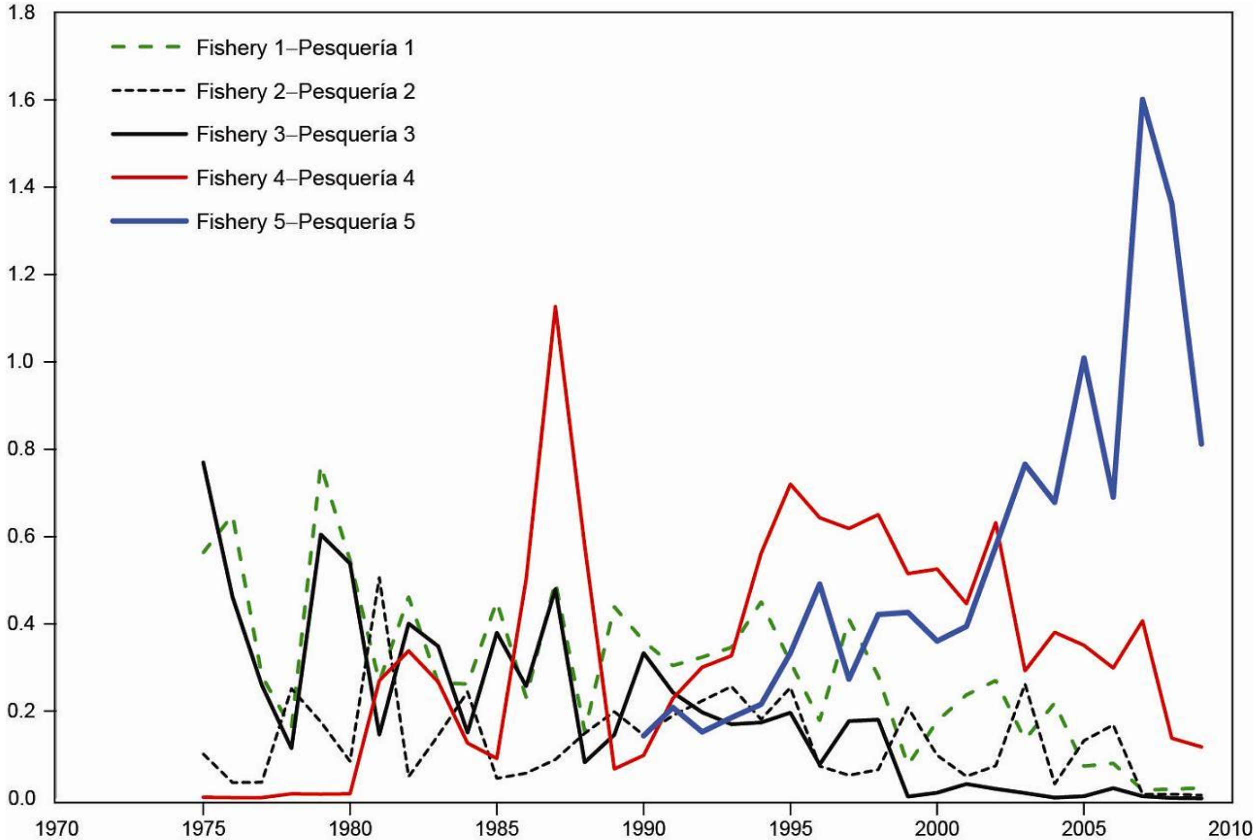

FIGURE 4.1.1. Estimated trends in fishing mortality (*F*) by fishery from the base case assessment of the northeastern Pacific Ocean stock of striped marlin. The fisheries are described in Table 2.1.

FIGURA 4.1.1. Tendencias estimadas de la mortalidad por pesca (*F*), por pesquería, de la evaluación de caso base de la población de marlín rayado en el Océano Pacífico nororiental. En la Tabla 2.1 se describen las pesquerías.

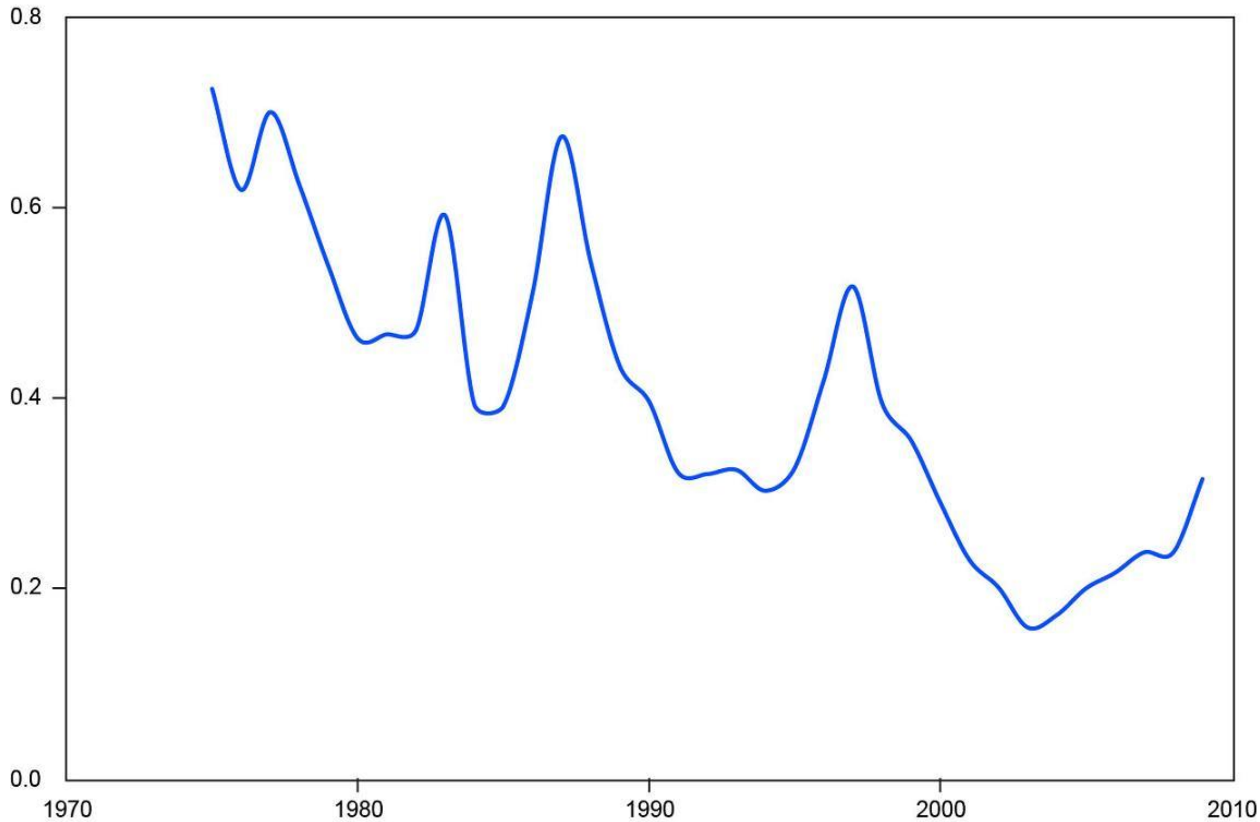

FIGURE 4.1.3. Estimated spawning biomass ratio (SBR) from the base case assessment of the northeastern Pacific Ocean stock of striped marlin. The fisheries are described in Table 2.1.
FIGURA 4.1.3. Cociente de biomasa reproductora (SBR) estimado de la evaluación de caso base de la población de marlín rayado en el Océano Pacífico nororiental. En la Tabla 2.1 se describen las pesquerías.

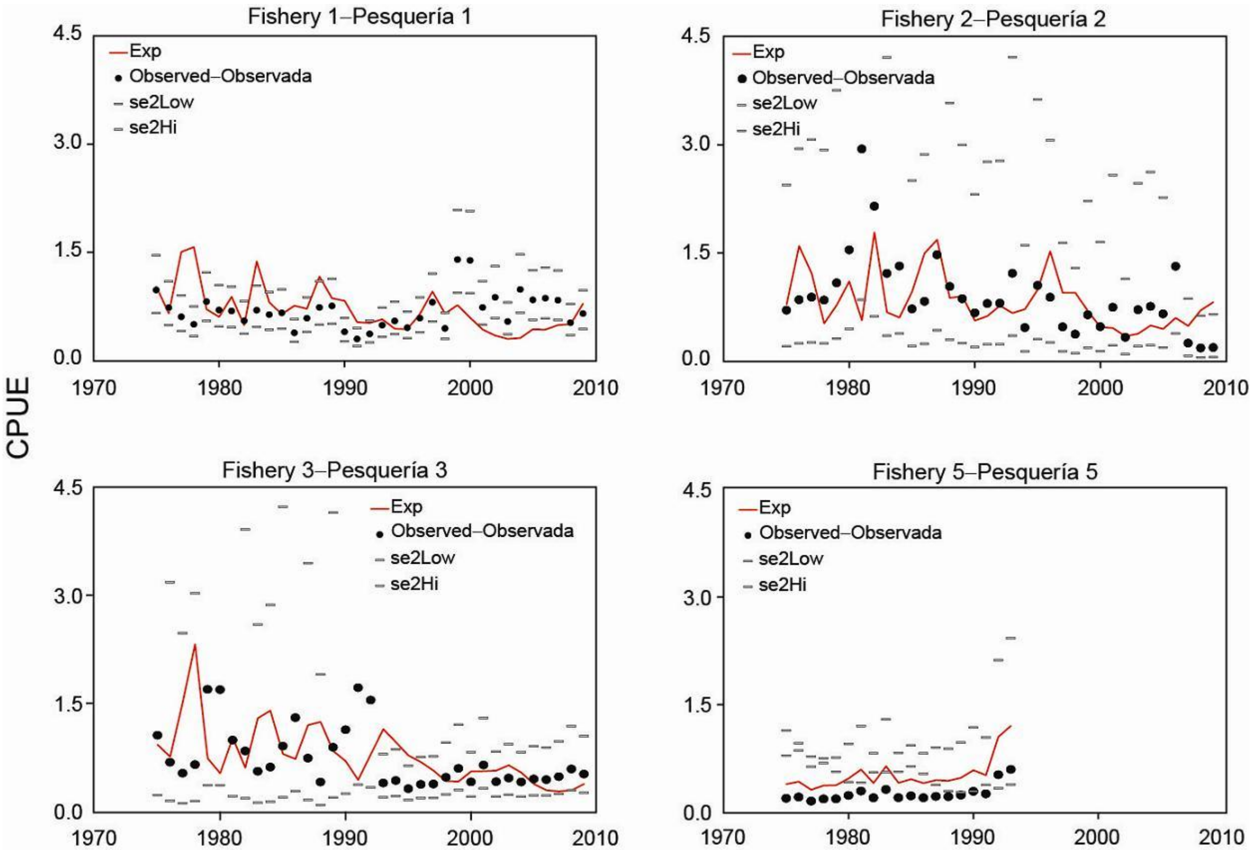

FIGURE 4.2.1. Fits of the assessment model for the northeastern Pacific stock of striped marlin to the observed catch rate (CPUE) for Fisheries 1, 2, and 3. Fishery 5 was not used to fit the model.

FIGURA 4.2.1. Ajustes del modelo de evaluación de la población de marlín rayado del Océano Pacífico nororiental a tasa de captura (CPUE) observada en las Pesquerías 1, 2, y 3. No se usó la Pesquería 5 para ajustar el modelo.

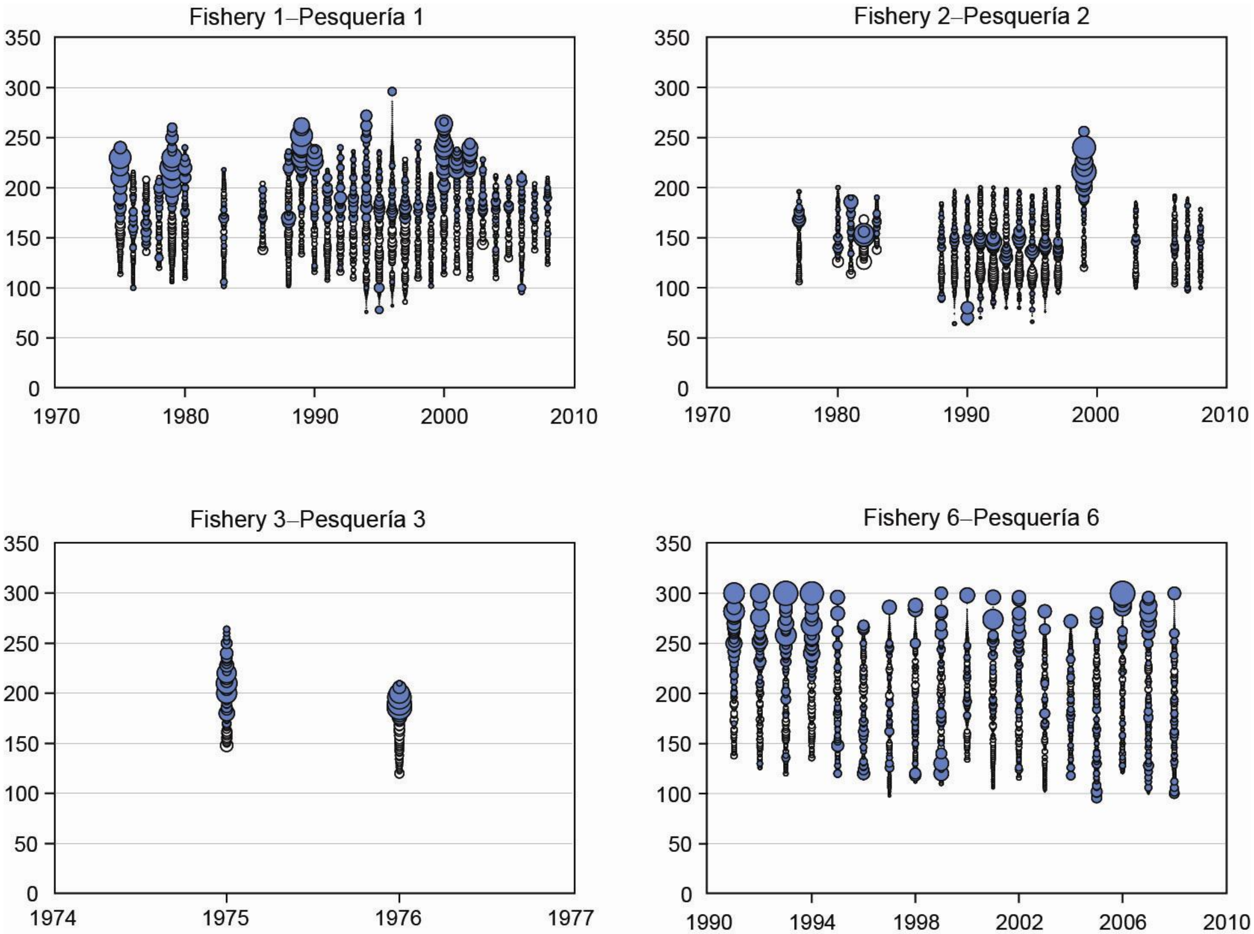

FIGURE 4.2.2. Pearson residual plots for the model fits to the length-composition data for Fisheries 1, 2, 3, and 6. The solid circles represent observations that are lower than the model predictions. The areas of the circles are proportional to the absolute values of the residuals. The numbers in the panels correspond to the numbers designating the fisheries in Table 2.1.

FIGURA 4.2.2. Gráficas de residuales de Pearson para los ajustes del modelo a los datos de composición por talla de las pesquerías 1, 2, 3, y 6. Los círculos sólidos representan observaciones que son inferiores a las predicciones del modelo. El área de los círculos es proporcional al valor absoluto de los residuales. El número en cada panel corresponde a los números que designan las pesquerías en la Tabla 2.1.

TABLE 2.1. Fisheries defined for the stock assessment of striped marlin in the northern EPO. Gears: RG = recreational; PS = purse seine; LL = longline. The fishery areas are shown in Figure 2.1.
TABLA 2.1. Pesquerías definidas para la evaluación de la población de marlín rayado en el OPO norte. Artes: RG = recreacional; PS = red de cerco; LL = palangre. En la Figura 2.1 se ilustran las zonas de las pesquerías.

Fishery	**Gear**	**Years**	**Sampling areas**	**Catch data**
Pesquería	**Arte**	**Años**	**Zonas de muestreo**	**Datos de captura**
1	LL	1954-2009	1	Catch (t) –captura (t)
2	LL	1956-2009	2	
3	LL	1962-2009	3	
4	LL	1975-2009	1	
5	RG	1990-2008	3	catch –captura
6	PS	1990-2009	3	catch –captura

TABLE 2.4.1. Numbers of size-frequency measurements used in the assessment, by type (intervals: 2 cm and 5 cm length, 2 kg weight), area, and year. There are no observations from Area 3 after 1988.
TABLA 2.4.1. Número de mediciones de frecuencia de tamaño usadas en la evaluación, por tipo (intervalos: 2 cm y 5 cm de talla, 2 kg en peso), área, y año. No hay observaciones del Área 3 después de 1988.

	A1			**A2**			**A3**				**A1**			**A2**		
	2 cm	5 cm	kg	2 cm	5 cm	kg	2 cm	5 cm	kg		2 cm	5 cm	kg	2 cm	5 cm	kg
1970		3057	3113		2627	6587		480	3834	1990	252		969	170		222
1971		4034	10691		286	4876			6642	1991	519		631	2667		749
1972		912	4638			1460			3168	1992	761	120	676	3519		117
1973		286	1169			3686			4334	1993	1177		202	1563		640
1974			322			1276			1086	1994	1935	405	334	1165		899
1975	1204	513	96		181	1206	2026		1570	1995	2395	219	278	2336		
1976	434		132		214	538	3108	621		1996	1697	105	270	2160		
1977	224	470		100		639				1997	3043		127	524		
1978	144	166	38			228				1998	534					
1979	502		464			253				1999	163		130	92		
1980	247	160	417	172		180				2000	326					
1981			510	108		493				2001	848	124				
1982			1638	1200		1989			1934	2002	481	115				
1983			2430	90		1254			102	2003	292	138		264		
1984			1780		558	1876				2004	442					
1985	228		2823			899				2005	307	191				
1986	282		1011		176	1751			906	2006	142			685		
1987			2016		455	1988			9982	2007	143			177		
1988	575		1185	297		391			116	2008	145			121		
1989	108		3444	661		283										

TABLE 3.1.1a. A representative selection of estimated growth parameters and natural mortality rates (estimated by Boggs (1989) and Hinton and Bayliff (2002) by the method of Pauly (1980)) for striped marlin in the Pacific Ocean.

TABLA 3.1.1a. Selección representativa de parámetros de crecimiento y tasas de mortalidad natural estimados (estimados por Boggs (1989) y Hinton y Bayliff (2002) con el método de Pauly (1980)) para el marlín rayado en el Océano Pacífico.

Gender-Sexo	L_{inf} **(cm)**	***K*** **(annual-anual)**	t_0 **(years-años)**	**Reference-Referencia**	**Natural mortality rate Tasa de mortalidad natural**	
					Boggs	**Pauly**
	275	0.264		Koto, 1963	0.49	0.389
M	206	0.417	-0.521	Skillman and Yong, 1976	0.79	0.569
F	186	0.696	0.136	Skillman and Yong, 1976	1.33	0.818
	221[1]	0.23	-1.6	Melo-Barrera *et al*., 2003		
	301[1]	0.22	-0.04	Kopf *et al*. 2005		

1. Lower jaw-fork length – Talla mandibula inferior-furca caudal

TABLE 4.1.2. Estimated spawning biomass (SB, t), resulting recruitment [R(0), t], and spawning biomass ratio (SBR) for the striped marlin assessment base case by year.

TABLA 4.1.2. Estimaciones de biomasa reproductora (SB, t), el reclutamiento resultante [R(0), t], y el cociente de biomasa reproductora (SBR) para la evaluación de caso base del marlín rayado, por año

	SB	**R(0)**	**SBR**		**SB**	**R(0)**	**SBR**
1975	7,451	224	0.725	1993	3,693	275	0.324
1976	7,447	82	0.619	1994	3,572	398	0.302
1977	7,476	219	0.700	1995	4,123	195	0.326
1978	6,210	279	0.624	1996	5,454	235	0.419
1979	5,912	106	0.538	1997	5,629	155	0.517
1980	5,429	514	0.463	1998	4,621	105	0.394
1981	4,818	72	0.467	1999	3,946	108	0.355
1982	6,369	166	0.471	2000	3,140	75	0.290
1983	5,868	236	0.592	2001	2,579	98	0.230
1984	4,348	369	0.394	2002	2,183	121	0.201
1985	4,590	450	0.391	2003	1,870	96	0.159
1986	6,221	157	0.510	2004	2,080	156	0.172
1987	8,090	240	0.675	2005	2,254	99	0.200
1988	5,727	112	0.543	2006	2,633	164	0.216
1989	5,001	162	0.433	2007	2,621	172	0.238
1990	4,169	203	0.396	2008	2,872	204	0.238
1991	3,651	166	0.321	2009	3,628	204	0.315
1992	3,792	189	0.320				

TABLE 4.4. Parameter estimates from the base case and from representative sensitivity analyses of the assessment model for the northern EPO stock of striped marlin. RG = recreational gear.

TABLA 4.4. Estimaciones de los parámetros del caso base y de análisis de sensibilidad representativos del modelo de evaluación para la población de marlín rayado del OPO norte. RG = arte recreacional

Changes in fixed parameters to values different from base case – Cambios en los parámetros fijos a valores diferentes al caso base								
Estimate – Estimación	Base case	M = 0.3	M=0.7	K=0.1	K=0.4	h=0.75	L_{inf}= 265	L_{inf}= 275
$S(0)$	4728	7321	4473	n/a	3878	5693	3691	4706
$S(2009)$	1488	959	3323	n/a	283	1512	775	1132
SBR(2009)	0.31	0.13	0.74	n/a	0.07	0.27	0.21	0.24
$S_{MSY} – S_{RMS}$	1246	1569	631	n/a	456	1618	819	1185
F_{mult}	6.36	1.15	49.97	n/a	2.04	2.45	2.80	4.58
MSY – RMS	2031	1835	3904	n/a	1981	1889	1856	1996
C(2009)	730	732	732	n/a	732	732	732	732
C(2009)/MSY – RMS	0.36	0.40	0.19	n/a	0.37	0.39	0.39	0.37
$S(2009)/ S_{MSY} – S_{RMS}$	1.19	0.61	5.26	n/a	0.62	0.93	0.95	0.96
$S_{MSY}/S(0)$	0.26	0.21	0.14	n/a	0.12	0.28	0.22	0.25
-LN(Likelihood – Verosimilitud)	3387.7	3460.5	3991.5	n/a	4674.2	3396.6	4000.5	3376.2

		Change – Cambio					
		Area	Data and structure – Datos y estructura				
Estimate – Estimación	Base case Caso base	Without – Sin A2	+ WF 2 kg	+ LF 5 cm	+WF & LF 5 cm	+WF & +LF; start - comienzo 1970	25% mort., RG fishery-pesquería
$S(0)$	4728	2634	4495	4804	4495	4871	4215
$S(2009)$	1488	328	940	1525	940	1075	1374
SBR(2009)	0.31	0.12	0.21	0.32	0.21	0.22	0.33
$S_{MSY} – S_{RMS}$	1246	395	1402	1201	1483	1307	955
F_{mult}	6.36	1.70	2.11	7.83	2.04	4.33	14.30
MSY – RMS	2031	1516	1863	2083	1873	2077	1872
C(2009)	730	717	732	732	732	732	403
C(2009)/MSY – RMS	0.36	0.47	0.39	0.35	0.39	0.35	0.22
$S(2009)/ S_{MSY} – S_{RMS}$	1.19	0.83	0.67	1.27	0.63	0.82	1.44
$S_{MSY}/S(0)$	0.26	0.15	0.31	0.25	0.33	0.27	0.23
-LN(Likelihood – Verosimilitud)	3387.7	n/a	n/a	n/a	n/a	n/a	3442.46

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