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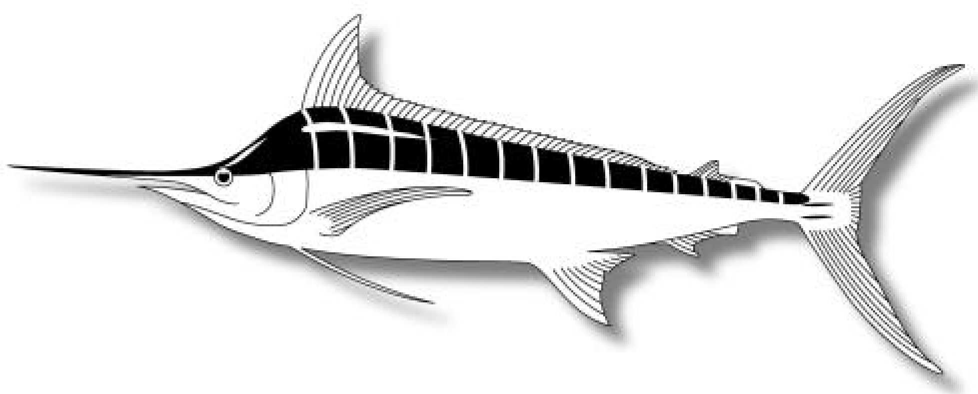
Status of striped marlin in the eastern Pacific Ocean in 2001 and outlook for 2002



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STATUS OF STRIPED MARLIN IN THE EASTERN PACIFIC OCEAN IN 2001 AND OUTLOOK FOR 2002

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The stock structure of striped marlin, *Tetrapturus audax*, is not well known in the Pacific. There are indications that there is only limited exchange of striped marlin between the eastern Pacific Ocean (EPO) and the central and western Pacific Ocean, so it is considered herein that examinations of local depletions and independent assessments of the striped marlin of the EPO are meaningful. Accordingly, most of the data presented in this report are for the EPO. Nevertheless, for various reasons, some data for the central and western Pacific Ocean are also presented.

1. EXECUTIVE SUMMARY

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 and by recreational fishermen. Lesser amounts are caught by gillnet and other fisheries. During recent years the greatest catches in the EPO have been taken by fisheries of Japan, Korea, and Costa Rica.

Striped marlin reach maturity when they are about 140 cm long, and spawning occurs in widely-scattered areas of the Pacific Ocean.

Some information on the movements of striped marlin is available. Tagged fish released off the tip of the Baja California peninsula have been recaptured mostly in the same general area, but some have been recaptured around the Revillagigedo Islands, a few around Hawaii, and one near Norfolk Island, Australia.

The catch rates of striped marlin off California and Baja California tend to be greater when the sea-surface temperatures are higher and when the thermocline is shallow. The catch rates are greater on the shallower hooks of longlines, especially when the thermocline is shallow.

The stock structure of striped marlin is uncertain. The trends for the catch rates of the northeastern and northwestern areas of the central-eastern Pacific are not significantly different. The same is the case for catch rates in the EPO north and south of 10°N. These results suggest that the fish in the EPO belong to one stock. Reexamination of published genetic data suggests that there is a stock located in the southwestern Pacific (Australia) but provided no clear resolution of separate stocks for the Ecuador-Hawaii-Mexico triad of sampling locations. The conclusions reached herein should be considered tentative, and collaborative research now in progress should help resolve the question of stock structure of striped marlin in the Pacific.

The current biomass of striped marlin in the EPO is apparently equal to that which would produce the average maximum sustainable yield of about 4,500 mt. Retained catch and standardized fishing effort for striped marlin decreased in the EPO from 1990-1991 through 1998, and preliminary estimates indicate that nominal fishing effort in the area has continued to decrease during the 1999-2001 period. This may result in a continued decrease in standardized fishing effort for striped marlin, with an associated continuing increase in their biomass in the EPO.

2. DATA

2.1. Definitions of the fisheries

2.1.1. Longline fisheries

Longlining for tunas and billfishes takes place in the Pacific Ocean from the Americas to Asia between about 50°N and 50°S.

2.1.1.1. Far East nations

Vessels of Indonesia, Japan, the Philipines the Republic of Korea, and Taiwan have fished for tunas and billfishes in the eastern Pacific Ocean (EPO) (Sakagawa, 1989; Ueyanagi *et al*., 1989; Uozumi and Uosaki, 1998; Uosaki and Bayliff, 1999). Currently those of Indonesia, Japan, Korea, and Taiwan are known or believed to be fishing in the EPO, and collectively they fish in nearly all of the range of striped marlin in the Pacific Ocean, which extends from about 45°N to 45°S (Bedford and Hagerman, 1983).

2.1.1.2. Western Hemisphere nations

Longline vessels of Western Hemisphere nations, most notably Chile (Barbieri *et al*., 1998), Mexico (Holts and Sosa-Nishikawa, 1998), and the United States (Holts and Sosa-Nishikawa, 1998; Ito *et al*., 1998; Vojkovich and Barsky, 1998), fish for tunas and billfishes in the eastern and central Pacific Ocean. Longline-caught billfishes, other than swordfish, cannot be unloaded in California ports, however.

2.1.2. Gillnet fisheries

Until the end of 1992 there was a high-seas fishery for tunas and billfishes with large-meshed gillnets carried out by vessels of Japan, the Republic of Korea, and Taiwan (McKinnell and Waddell, 1993; Nakano *et al*., 1993; Uosaki, 1998). Vessels of Chile (Barbieri *et al*., 1998), Mexico (Holts and Sosa-Nishikawa, 1998), and the United States (Hanan *et al*., 1993; Holts and Sosa-Nishikawa, 1998) fish or have fished for tunas, billfishes, and sharks with gillnets in the EPO. These latter fisheries generally operate in the coastal waters and Exclusive Economic Zones (EEZs) of the respective nations. Gillnet-caught billfishes, other than swordfish, cannot be unloaded in California ports, however.

2.1.3. Purse-seine fishery

Small amounts of striped marlin are caught by tuna purse seiners in the EPO (Anonymous, 2002: Table 11b). These are generally discarded at sea or retained by the vessel crews for their personal use.

2.1.4. Recreational fisheries

Striped marlin and other billfishes are the object of important recreational fisheries in the EPO (de Sylva, 1974; Talbot and Wares, 1975; Bedford and Hagerman, 1983; Holts, 2001).

2.2. Effort and retained catch data

Estimates of retained catch of billfish are fairly well known, due to the value of these fish in commerce. However there are unreported catches from artisanal and recreational fisheries and from some components of the commercial longline fisheries operating in the region.

2.2.1. Commercial fisheries

The distributions of fishing effort by major fleets have varied over the decades as a result of varying target species for the fisheries. The distribution of nominal fishing effort by longline fisheries by decade in the EPO are shown in Figure 2.2.1.

Most of the striped marlin caught by commercial fisheries are taken by the longline fisheries of Far East and Western Hemisphere nations. Lesser amounts of striped marlin are or have been caught by the other fisheries described in Section 2.1. Preliminary estimates of the retained catch of striped marlin in the EPO from north and south of 10°N are shown in Table 2.2.1a-b. The distribution of retained catches by longline fisheries by decade and subarea of the EPO are shown in Figure 2.2.2.

2.2.2. Recreational fisheries

No comprehensive data on the fishing effort for billfishes or the retained catch of striped marlin from recreational fisheries is available. However, fishing records of the principal fishing clubs in southern California have been compiled, providing an index of the retained catches of striped marlin by this component of the recreational fishery (Holts and Prescott, 2001).

2.3. Size-composition data

2.3.1. Longline fisheries

Length-frequency data for retained catches of striped marlin taken by longline gear in the EPO are given by Miyabe and Bayliff (1987: Figure 59), Nakano and Bayliff (1992: Figures 66-68), and Uosaki and Bayliff (1999: Figures 68-70). Eye-fork length-frequency histograms by subareas, north and south of 10°N, and for the EPO are shown in Figure 2.3.1. The distribution of lengths of fish from the northern area have shifted to smaller sizes over the decades. In the 1970s the mode was about 180 cm, and in the 1980s, about 155 cm. In the 1990s the distribution is bimodal, with modes at about 110 and about 145 cm. In the southern area the distribution was unimodal in all decades, with the mode at about 170-180 cm.

2.3.2. Recreational fisheries

Data on length and weight frequencies of striped marlin retained by recreational fishermen off Southern California are given by Squire (1983) and Holts and Prescott (2001; Figure 2).

3. ASSUMPTIONS AND PARAMETERS

3.1. Biological and demographic information

3.1.1. Growth

The parameters of the von Bertalanffy growth equation for striped marlin in the Pacific Ocean estimated by various investigators are listed in Table 3.1.1a. The estimated lengths of striped marlin at ages 1 through 10, calculated from the data in that table, are shown in Table 3.1.1b. It should be recognized that these estimates are crude because (1) the growth of striped marlin may not be well described by the von Bertalanffy curve and (2) even if it is well described by that curve, the estimates of its parameters may be erroneous.

Data on the weight-length relationships of striped marlin are listed in Table 3.1.1c.

3.1.2. Reproduction

The maturity of striped marlin in the EPO has been studied by Howard and Ueyanagi (1965), Shiohama (1969), Kume and Joseph (1969b), Eldridge and Wares (1974), Shingu *et al.* (1974), Miyabe and Bayliff (1987), Nakano and Bayliff (1992), and Uosaki and Bayliff (1999). Howard and Ueyanagi (1965) and Nishikawa *et al.* (1978 and 1985) have studied the distribution of striped marlin larvae and post-larvae. Hanamoto (1977b) stated that the minimum size of spawning fish in the southern Coral Sea was estimated to be 143 cm (eye to fork of caudal fin). Howard and Ueyanagi (1965) reported the occurrence of mature fish between 20°S and 30°S and 130°W and 140°W. Shiohama (1969) recorded high concentrations of mature fish between 15°N and 20°N and 110°W and 120°W and between 10°S and 25°S and 120°W and 130°W. Kume and Joseph (1969b) found mature fish to occur off Mexico during the second and third quarters, off Central America during the first and fourth quarters, and between 10°S and 25°S and 120°W and 130°W during the first, second, and fourth quarters. Eldridge and Wares (1974) stated that mature striped marlin occur near the Revillagigedo Islands during July. Shingu *et al.* (1974) recorded high concentrations of mature fish between 25°S and 30°S during the first and fourth quarters. Miyabe and Bayliff (1987) reported that the greatest concentrations of mature fish were encountered off Mexico during the second, third, and fourth quarters and south of 20°S during the first and fourth quarters. Nakano and Bayliff (1992) reported the captures of two mature fish at 11°S-131°W and 12°S-126°W during October, and Uosaki and Bayliff (1999) reported the capture of three mature fish offshore off Mexico during the first and fourth quarters. The mature fish studied by Kume and Joseph (1969b) were smaller in the north (140 to 180 cm) than in the south (160 to 220 cm). Howard and Ueyanagi (1965) and Nishikawa *et al*. (1978 and 1985) reported the occurrence of larvae and post-larvae at about 20°S-142°W. Matsumoto and Kazama (1974) remarked on the fact that they had found no striped marlin larvae in their surveys in the central Pacific Ocean, despite the fact that this is the predominant species of billfish taken commercially off Hawaii. Squire and Suzuki (1990) stated that "the major spawning area is in the western Pacific ... Some spawning may occur in the eastern Pacific but few larvae have been caught there." González Armas *et al*. (1999), however, reported the capture of 68 striped marlin larvae near the mouth of the Gulf of California.

3.1.3. Movement

Information on the horizontal movements of striped marlin in the Pacific, based on tagging experiments utilizing conventional tags, is given by Squire (1974b and 1987a), and a basic movement model incorporating tagging data is hypothesized by Squire and Suzuki (1990). Most of the fish were released off the tip of the Baja California peninsula, and most of the recaptures were made in the same area. Some fish were recaptured in the vicinity of the Revillagigedo Islands, a few near the Hawaiian Islands, and one near Norfolk Island, north of New Zealand. Hanamoto (1977a) stated that, "based on the movement of the fishing grounds, it can be surmised that the striped marlin occurring in the southern Coral Sea have their origin in the eastern Pacific Ocean."

3.1.4. Natural mortality

Boggs (1989) used the method of Murphy and Sakagawa (1977) and the growth parameter estimates of Koto (1963) and Skillman and Yong (1976) to estimate the natural mortality of striped marlin. For this report the method of Pauly (1980) was used with the growth parameter estimates of Koto (1963) and Skillman and Yong (1976) and a mean temperature estimate of 26°C (see Section 3.2) to calculate estimates of the natural mortality for this species, which appear in Table 3.1.1a.

3.2. Environmental influences

Information on the relationship of striped marlin to their environment is given by Squire (1974a, 1985, and 1987b), Hanamoto (1974, 1978, and 1979), Miyabe and Bayliff (1987), Holts and Bedford (1990), Nakano and Bayliff (1992), Brill *et al.* (1993) and Uosaki and Bayliff (1999).

Squire (1974a) examined the catch rates for San Diego-based recreational fishing vessels, and found that the catch rates per half-month period were 40.5 fish per period when the sea-surface temperatures (SSTs) were less the 20°C, 99.2 fish per period when the SSTs were between 20° and 21.1°C, and 122.7 fish per period when the SSTs were greater than 21.1°C. When the 21.1°C isotherm was continuous the catch rates were greater than when it was discontinuous. Squire (1985) found that the catches off Southern California were greatest when there were continuous isotherms of 22.2°C. He stated that "it is reasonable to assume that the ocean temperatures … never attain values that would result in a maximum catch … because catches appear to be increasing at the peak continuous isotherm recorded (… 22.2°C)." Squire (1987b) reported that the catches of striped marlin were distributed further to the north during the 1983 El Niño event than during "normal" years. Hanamoto (1974) reported that the catch rates of striped marlin for longliners are greater off Baja California when the thermocline is shallow and attributed this to more abundant supplies of food during such conditions.

Hanamoto (1978) reported that in the southern Coral Sea during September and October the catch rates of striped marlin are greater around submarine elevations than in the open sea. This was not the case during November and December, however. He attributed this difference to the fact that the most of the fish caught during the earlier period were immature, whereas most of them caught during the later period were mature.

Holts and Bedford (1990) described the vertical movements of 11 striped marlin that were tracked with ultrasonic tags off Southern California. The fish spent most of their time in the upper mixed layer, at temperatures of 19° to 20°C, but sometimes descended to depths where the temperatures were less than 12°C. Four of the fish occupied greater depths at night than during the day. The maximum depth to which a fish descended was about 90 m. Brill *et al.* (1993) tracked six striped marlin in the vicinity of Hawaii. The fish spent about 80 percent of their time in waters with temperatures between 25° and 27°C, and never occupied water with temperatures less than 18°C. The maximum depth to which a fish descended was about 170 m. Abitia *et al*. (1998) stated that in the vicinity of Cape San Lucas, Baja California Sur, striped marlin feed on pelagic fishes during the day and "occasionally migrate to deeper waters to consume prey which live near or on the sandy bottoms."

Hanamoto (1979) reported that when longlines with five hooks per basket are used in the Pacific Ocean the greatest catches of striped marlin are taken on the first and fifth hooks, which fish at depths of 60 to 90 m. Miyabe and Bayliff (1987) found that the catch rates for conventional (4 to 6 hooks per basket) and deep (more than 10 hooks per basket) longline gear were about the same in offshore areas, but greater for conventional longline gear in onshore areas. They attributed this to the fact that the thermocline is shallower in onshore areas. The results obtained by Nakano and Bayliff (1992) for deep and conventional longline gear and by Uosaki and Bayliff (1999) for deep and intermediate (7 to 10 hooks per basket) were mixed. Boggs (1992) used hook timers on longine gear deployed near Hawaii to determine the times at which fish were caught, which made it possible to eliminate the data for fish caught on sinking or rising hooks. Confirmed catches of striped marlin were made at depths of about 50 to 210 m, with most of them being made at depths of 50 to 140 m.

3.3. Stock structure

Striped marlin are distributed throughout the temperate and warmer waters of the Pacific (Nakamura, 1985). The stock structure of striped marlin in the Pacific has not been well determined, with essentially no further examination of hypotheses since Shomura (1980) stated:

> "The stock structure of the Pacific striped marlin is not clear. While many hypotheses may be advanced, considering the distributional patterns and other biological data, the two most likely hypotheses are:
>
> 1. A single-unit stock in the Pacific
>
> The single stock hypothesis is supported by the continuous distribution of striped marlin in a horseshoe-pattern.
>
> 2. A two-stock structure, where the stocks are separated roughly at the Equator into North Pacific and South Pacific stocks with some intermixing in the eastern Pacific.
>
> The two-stock hypothesis is supported by morphometric differences between adults from the north and south regions of the western Pacific (Kamimura and Honma 1958) and perhaps also in the eastern Pacific (Howard and Ueyanagi 1965). Honma and Kamimura (1958) noted that there is a zone of low longline catch rates along the Equator which suggests a separation of north and south stocks at the Equator. Larval distribution suggests two centers of spawning, one in the north and one in the south, although gonad index data (Kume and Joseph 1969a) suggest that spawning occurs through the eastern tropical Pacific, the supposed region of stock mixing."

Using analyses of genetic data Graves and McDowell (1994) suggested that there may be separate stocks in the western South Pacific (Australia region) and from the regions proximate to Hawaii, Ecuador, and

Mexico. However, the analyses presented were conducted with small sample sizes that were not collected synoptically. Samples from Mexico were collected in one month (June 1991), from Ecuador over seven months (April-October 1990), from Hawaii over six months (June-November 1991), and from Australia from one month in two years (February 1991 and 1992). The authors noted that "examination of the temporal stability of the genotypic distributions will require larger sample sizes over a much longer period." Unfortunately Graves and McDowell (1994) did not show the data for Australia as individual samples, which limited a reexamination of the results. In addition, the authors detected significant heterogeneity in the frequency distribution of genotypes for the entire sample; however, they did not test the differentiation between the localities sampled. When the data were reexamined with the necessary correction (Dr. Jaime Alvarado-Bremer, Texas A & M Univ., Galveston, TX, pers. comm., May 2002), there were no significant differences between samples from Ecuador and Hawaii. As a result, Alvarado-Bremer concluded that when the necessary correction is applied, and, among other things, the sample sizes and collection periods are taken into consideration, there is no clear resolution of separate stocks for the Ecuador-Hawaii-Mexico triad.

The changing modal length of fish in the northern subarea, without a comparable change in the southern subarea, might suggest that there are separate northern and southern stocks of striped marlin in the EPO. However, this the northern subarea has been identified as a mixing region (Shomura, 1980; Yoshida, 1981) and a good feeding region for striped marlin (Hanamoto, 1974). Thus, it would be expected that if the northern subarea is a growth and rearing area, then the length-frequency distribution for this subarea may be shifted to smaller sizes as the numbers of larger fish in the population are reduced.

If subareas contain individual stocks, then it is expected that the trends in catch rates among the subareas would be significantly different, as a result of differences in exploitation histories and population parameters. This would be particularly true for a comparison of trends from hypothesized subareas in which one was assumed to have been fished heavily enough to produce a significant shift in length-frequency distribution over time, while the other showed no shift in pattern. Analyses of trends in catch per unit standardized effort (CPUSE: see Sec. 4.2) were conducted for potential subareas of the EPO to see if the indications of stock structure suggested by Graves and McDowell (1994), and which might be hypothesized based on the decadal-length-frequency distributions, were supported. To compare hypothesized stocks for subareas proximate to Hawaii and to Mexico, trends in CPUSE for the region lying north of 14°N and east of 125°W and that north of 14°N between 140°W and 180° during the 1964-1998 period were examined, and no significant difference was found (Figure 3.3.1). Additionally, to compare hypothesized northern and southern stocks, trends of CPUSE east of 150°W and north and south of 10°N during the 1964-1998 period were examined, and again no significant difference was found (Figure 3.3.1).

Considering (1) that the hypotheses that striped marlin in the EPO are from a single stock was not rejected based on analyses of catch rates, (2) that the difference in the length-frequency distributions for the north and south are likely resulted from movement of smaller fish to the area for feeding and growth (Hanamoto, 1974), (3) that the indicator of recruitment to the population in the length-frequency distribution coincides in time with an indication of increasing abundance from trends in CPUSE for the EPO, (4) that the tagging data and the movement model (Squire and Suzuki, 1990) for striped marlin in the Pacific indicate that individuals mix freely in the EPO, moving long distances from near-coastal to offshore waters and that they cross the hypothesized (Shomura, 1980) north-south stock boundary, and (5) that there is a lack of clear information on stock structure in the EPO based on genetic analyses, analyses of the status of striped marlin stocks in the EPO presented herein are based on the hypothesis that they are from a single stock.

4. STOCK ASSESSMENT

4.1. Indices of abundance and previous assessments

Trends in catch rates of striped marlin in the EPO have previously been calculated, using data from longline fisheries, as catch per unit of nominal effort (CPUE: Kume and Schaefer, 1966; Kume and Joseph, 1969a; Joseph *et al*., 1974; Shingu *et al*., 1974; Miyabe and Bayliff, 1987; Skillman, 1989; Suzuki, 1989; Nakano and Bayliff, 1992; Uosaki and Bayliff, 1999). Skillman (1989) considered that there was a single Pacific population, and, using data for 1952-1984 in stock production modeling, concluded that "the Pacific fishery for striped marlin is apparently still in the development stage, and the MSY [maximum sustainable yield] level has not yet been approached by the fishery." Suzuki (1989) used catch-rate-based boundaries for northern and southern stocks at the equator west of 130°W and at 10°N east of 130°W. He found that for the northern stock there were sustained catches over a wide range of fishing effort, and there was no trend in CPUE. From this he "inferred that the fishing impact on the north stock may not be high enough to be a dominant factor in changing stock size." For the southern stock, Suzuki (1989) used data for 1952-1985 and production modeling to estimate that the MSY of this stock was on the order of 6,000 to 9,000 mt and that the fishery was exploiting the stock at near optimum levels.

Holts and Prescott (2001; Figure 1b) show the catch rates of striped marlin by recreational fishermen off Baja California. There was no significant trend in these catch rates ($F = 0.7$, $p = 0.4$), which varied between about 0.3 and 0.8 fish per angler day from 1969 to 2000. They also show that the rates for recreational fishermen off Southern California also remained nearly constant, at less than 0.2 fish per angler day, except for rates of about 0.3 fish per angler day in 1985, and that the catch rates for fishermen in Hawaii have increased steadily from 1969 until about 1986 and that they since have remained relatively constant at about 0.1 fish per angler day.

4.2. Assessment

Obtaining a measure of standardized effort that accounts for variability in habitat is problematic. The most commonly-used approach is limited to including location, time, and environmental indices as model parameters in general linear or additive models. However, the spatial and temporal scales on which such indices are frequently available are at long-period-ocean-basin scales, which well exceed the decorrelation scales of oceanographic conditions important to the fishing event, which occurs in the case of longline fisheries over about 100 km and 1 day. Obtaining a satisfactory standardization becomes a particular problem when, as is the norm, fishermen modify their gear and operations over time. Hinton and Nakano (1996) developed a general method to standardize effort using information on the distributions of habitat, species and fishing gear. The method provides a direct accounting for variation in distributions in space and time, thus directly addressing the problems created by the normal condition of the data obtained from commercial and recreational fisheries. The method has since been applied to bigeye (Hampton *et al.*, 1998; Bigelow *et al.*, 2002) and yellowfin (Bigelow *et al.*, 1999) tuna, to blue marlin (Hinton, 2001; Kleiber *et al.*, In Press), and to swordfish (Hinton and Deriso, 1998). A brief description of the method follows; however, readers are referred to the noted applications and references therein, and to Hinton and Nakano (1996) for more detailed information and equations.

The effectiveness of longline effort with respect to striped marlin is strongly affected by the fishing depth of the gear, which is generally configured with large numbers of hooks and long lengths of line between floats in order to fish deep in the water column to target and increase catch rates of highly-valued bigeye tuna. Therefore, it is important that standardized longline effort, which is used with catch to provide information on abundance, take into consideration the depth of the longline and the relationship between this depth and the habitat preference of striped marlin. Habitat preferences are species-specific. The habitat preference of striped marlin, in terms of gradients in ambient temperature, was estimated (Brill *et al*., 1993) by coupling acoustic tracking information with temperature data for the associated area, and recognizing that the relationship was conserved in fish of the same species across the extremely different oceanic environments of Hawaii and Baja California. The distribution of the hooks in the water column was estimated using a modified catenary curve to represent the shape of the longline (Suzuki *et al.*, 1977). Though under conditions of high vertical current shear this approximation may be improved (*c.f.* Mizuno *et al.*, 1997; Mizuno *et al.*, 1998), it is believed to be a fairly good approximation for the majority of the fishing effort of longliners (pers. comm. Dr. Keisuke Mizuno, Senior Research Coordinator, Resources Development Department, Fisheries Agency of Japan, May, 2002). The relative fishing power of each hook is calculated as the proportion of time spent by the average individual in water of a temperature at or below the mixed-layer temperature. The effective effort is then calculated as the sum of the relative fishing power of all the hooks in a stratum. Only Japanese- and Mexican-flag effort data are used in the standardization model, because these include information on the number of hooks per basket, and only data from Japanese fisheries provide consistent large-area coverage of the distribution of striped marlin; as well, it represents the majority of the total effort in most regions.

Herein standardized effort for striped marlin was obtained at 2° latitude by 5° longitude by bimonthly resolution for the 1955-1998 period, using the habitat-based method of Hinton and Nakano (1996).

Catch per unit of standardized effort (CPUSE) is generally assumed to provide a relative index of abundance. However, since there are a significant number of bimonthly period-areas with fishing effort but no retained catch of striped marlin (Table 4.2.1), a Δ-distribution model (Pennington, 1996), fit using general linear models (GLMs), was used to obtain the series of annual abundance indices (AAI):

$$\ln(\text{CPUSE}) = \text{Year} + \text{Bimonth} + \text{Latitude} + \text{Longitude} + \text{Environment Indices} + \text{Interactions}$$

and,

$$\text{CIndex} = \text{Year} + \text{Bimonth} + \text{Latitude} + \text{Longitude} + \text{Environment Indices} + \text{Interactions}$$

where CIndex ~ Binomial(0: no retained catch of striped marlin; 1: retained catch of striped marlin). Environmental indices were the bimonthly averages of the monthly observations of the Southern Oscillation Index (SOI), and the Northern and Southern Extratropical Oscillation Indices (NOI and SOI*, Schwing *et al.* In Press). Interaction terms were considered in the fitting of the models only for significant main effects. Year was not included in the interaction terms, its coefficients thus providing a direct measure of AAI as the product of predicted annual CPUSE and CIndex. An approximate 90-percent confidence level on AAI was estimated as the product of the upper 95-percent confidence levels on the annual CPUSE and the CIndex for the upper bound, and the product of the lower limits for the lower bound. The models were fit in S-PLUS 6 (MathSoft, Inc., Cambridge, MA, USA) by first fitting to the mean, using the procedure "glm," and then using function "step" to perform a stepwise fitting procedure for main effects, followed by fittings for interaction terms if indicated.

For comparison, the results of standardizing CPUSE and of standardizing CPUE using a Δ-distribution model are both presented in Figure 4.2.1. In the CPUE standardization the fishing effort was categorized into four levels based on the number of hooks per basket (HPB): Level 1: $3 < \text{HPB} < 8$; Level 2: $8 \leq \text{HPB} < 12$; Level 3: $12 \leq \text{HPB} < 16$; and Level 4: $\text{HPB} \geq 16$. For the period prior to 1975, which brought the introduction of deep longlines to the EPO, all effort was considered to be Level 1 (Hinton and Nakano, 1996). Catch and effort data used were at 5° latitude by 5° longitude by bimonthly period resolution, and large-scale environmental parameters SOI, NOI, and SOI* were included.

The Deriso-Schnute delay-difference population model (Quinn and Deriso, 1999) was used with catch and effort data for 1955-1998 from the area east of 150°W to investigate the dynamics of striped marlin stocks in the EPO. Recruitment was modeled with a Beverton-Holt recruitment curve (Ricker, 1975). The model was fit using natural survival rates bounding the range of observed estimates (0.32, 0.74) obtained as described in Section 3.1.4. The Brody growth coefficient was estimated, using the data for striped marlin from Skillman and Yong (1974), to be 0.73. Catchability was assumed constant during the entire period. Parameters estimated were those for the recruitment curve, catchability, and process errors on recruitment. The stock was assumed to be at or near virgin-biomass levels before and during the first year for which catches were recorded (1954). Model fits (Figures 4.2.2a-c) were obtained, using Solver [Microsoft Excel 2000 (9.0 SR-1)].

Results of model fitting (Figure 4.2.2) indicate that the average maximum sustainable yield (AMSY) is about 4,500 mt (range: 4,300 to 4,700 mt) and that the 1998 stock biomass was about that expected at AMSY (B/B_{AMSY} ratio = 1). During the 1991-1998 period the average annual retained catch were about 3,100 mt (range: 2,600 to 3,900 mt). Preliminary estimates of this catch in 1999-2000 of about 1,800 to 2,000 are on the order of one-half the estimated AMSY. During this period (1998 was the last year for which standardized effort data were available for this analysis), the ratio of observed standardized effort to that effort expected to yield AMSY at B_{AMSY} (F_{msy}: about 1.8 million standardized hooks) steadily decreased from about 1.4 to 0.7. During this period the ratio of the estimated annual biomass to the biomass that would support the AMSY (B/B_{AMSY}) increased at an average annual rate of about 0.064 from about 0.62 to 1.07. Preliminary estimates of nominal fishing effort for 2000-2001 show continuing decreases in nominal hooks fished in the EPO, which may lead to continuing decreases in striped-marlin-standardized effort in the region and continuing increases in the B/B_{AMSY} ratio. Due to the large amount of information on stock dynamics contained in the standardized trend of annual abundance, sensitivity analyses indicated that these results were stable to perturbations across the entire range of natural survival rates (0.2 to 0.8) and Brody growth coefficients (0.40 to 0.95) tested.

5. STOCK STATUS

The results cited indicate that the stock(s) of striped marlin in the EPO are at or near the level expected to produce AMSY. The decreasing trend in standardized fishing effort from about 1990-1991 to 1998 is expected to have continued during 1999-2000, resulting in increased B/B_{AMSY} ratios in those years.

6. FUTURE DIRECTIONS

6.1. Collection of new and/or updated information

There remain questions about the stock structure of striped marlin in the Pacific. A collaborative research project has been established in which scientists of the IATTC, the U.S. National Marine Fisheries Service (NMFS) and the National Research Institute of Far Seas Fisheries (NRIFSF) of Japan are examining this question: results are expected to be available in late 2002 or 2003. Catch-rate, distributional, and morphometric data suggest that there are one or two stocks. Analyses of genetic data that have been published suggest a stock in the southwest Pacific (Australia) but do not reveal the stock structure in the central-eastern Pacific region. Tagging data suggest that there is some movement of individuals into and out of the EPO. Analysis of standardized catch rates for potential stock subareas of the EPO based on the simplest approach, that of stationary demarcation of stock boundaries, indicates similar trends throughout the region, which supports the single-stock hypothesis used herein.

Assessment analyses would benefit significantly from improved information on the growth rates and natural mortality rates of striped marlin. This species exhibits sexual dimorphic growth, and improved estimates of sex-specific size at age, with estimates of the retained catch by sex, would be likely to increase confidence in the results. These improvements would require increased on-board sampling for biological data, and improvements in techniques for aging of striped marlin.

Estimates of total removals of fish from a population are critical to stock assessment. There remain undocumented and unreported catches of striped marlin from the EPO. Efforts have been undertaken to increase reporting of retained catch made by artisanal and small-scale commercial fisheries, and attempts are being made to obtain estimates from components of the large-scale longline fisheries for which data are not now available. These efforts should be pursued with diligence. Also, better data for the recreational fisheries should be collected. An unknown portion of the fish caught by recreational fisheries is released, and an unknown portion of those released die.

6.2. Assessment model development

The habitat-based model used in assessments of tunas and billfishes requires information on the distribution of the population in the habitat. A collaborative research project has been established involving scientists of the IATTC, Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), NMFS, and NRIFSF to examine the possibility for use of time-depth-recorder and hook timing data in conjunction with environmental data to estimate the distribution of populations of striped and blue marlin, and of yellowfin and bigeye tuna, for use in habitat-based models for standardizing fishing effort. The results may provide alternatives to the use of physiological-based models for species distributions in the standardizations. When available, analyses of stock status that incorporate information from temperature-depth-recorder (TDR)-based models will be examined.

Preliminary results from a fully-integrated model for standardization of catch rates and estimation of population dynamics are consistent with the results presented herein. This integrated model incorporates effort standardization using the habitat-based model of Hinton and Nakano (1996). However in contrast to the application of the Hinton and Nakano (1996) model, the gear model in the integrated model incorporates effects of oceanographic currents and shear and for retrieval of the hooks through the water column. The model makes it possible to treat distributions of species, gear, and habitat as priors, which would allow testing of the sensitivity of the standardization to the various component model inputs. As well, the integrated model may be set to allow for incorporation of spatially- and temporally-stratified biological data on stocks, and for dimorphic growth parameters. Development and testing of this model is continuing, and it is expected that application to striped marlin and other species will follow.

Following completion of the collaborative research projects investigating the use of TDR-based habitat preference distributions and stock structure of striped marlin, a collaborative research project involving the IATTC, NMFS, and NRIFSF will examine the status of striped marlin using MULTIFAN-CL.

6.3. General

As more data become available, these analyses should be updated to ensure that, if there develop indications that the condition of the stock(s) of striped marlin has deteriorated, action could be considered and taken in a timely manner.

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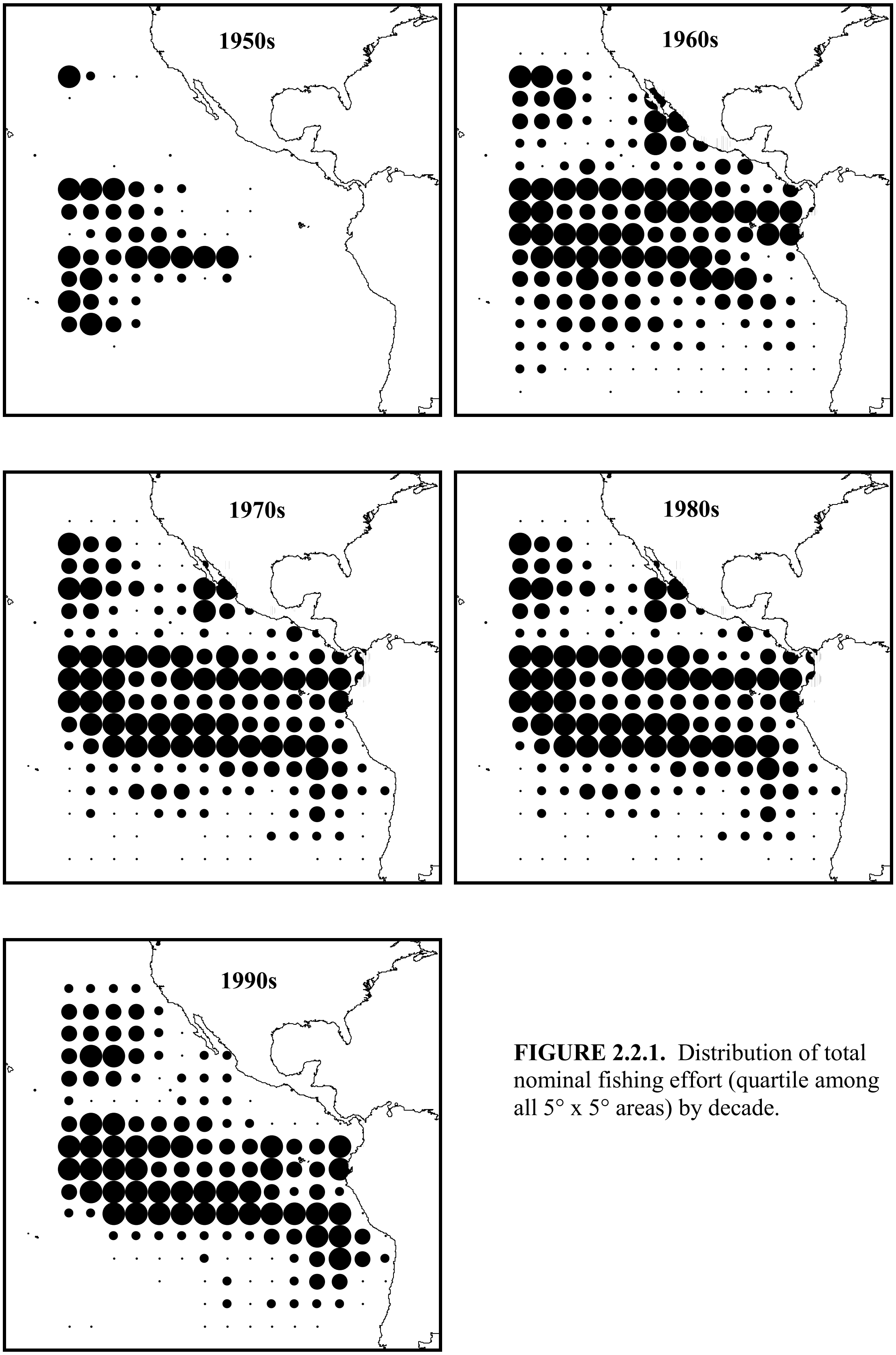

FIGURE 2.2.1. Distribution of total nominal fishing effort (quartile among all 5° x 5° areas) by decade.

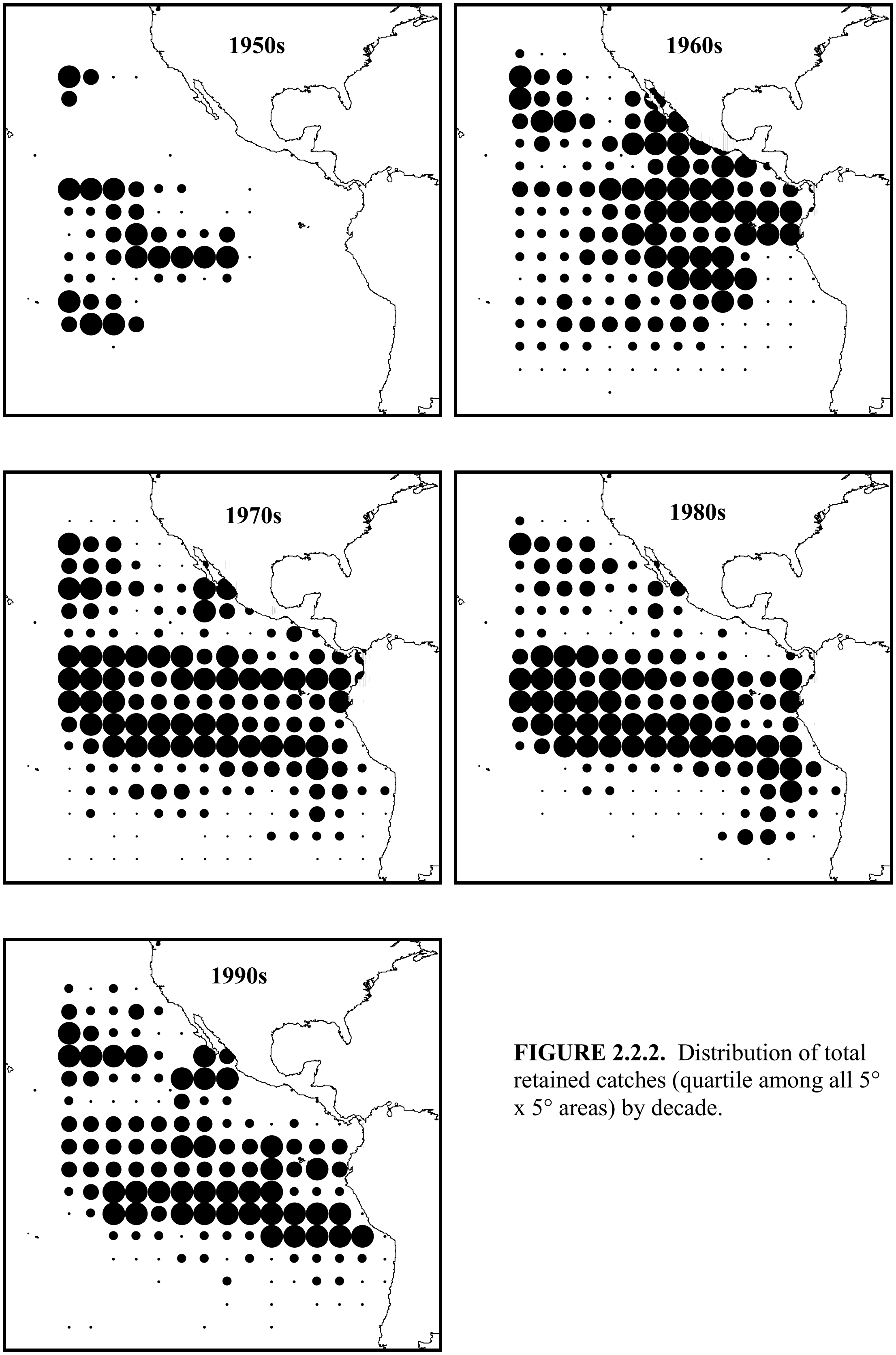

FIGURE 2.2.2. Distribution of total retained catches (quartile among all 5° x 5° areas) by decade.

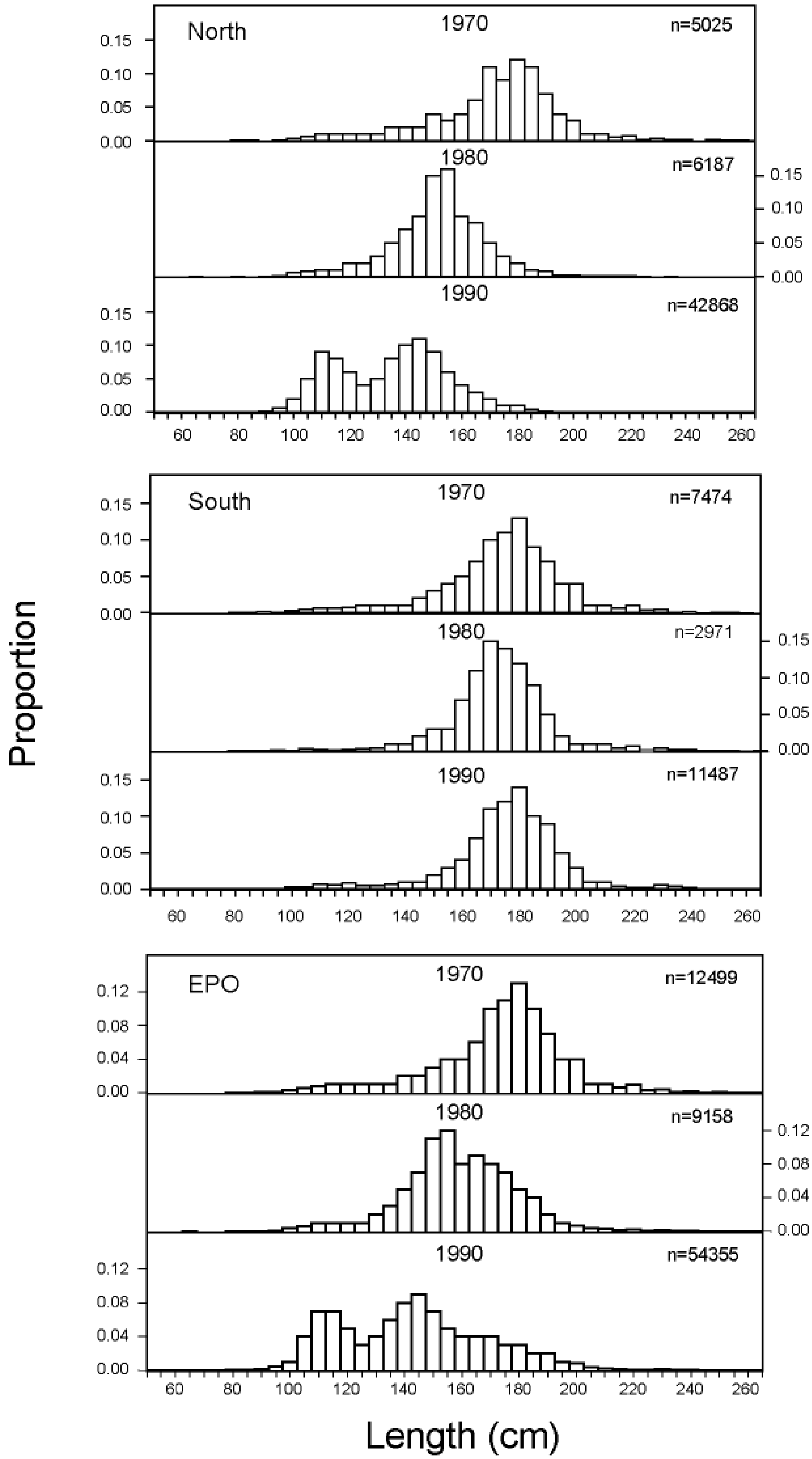

FIGURE 2.3.1. Frequency of eye-fork lengths (cm) of retained catches of striped marlin by Japanese longline fisheries from the EPO and sub-areas north and south of 10°N.

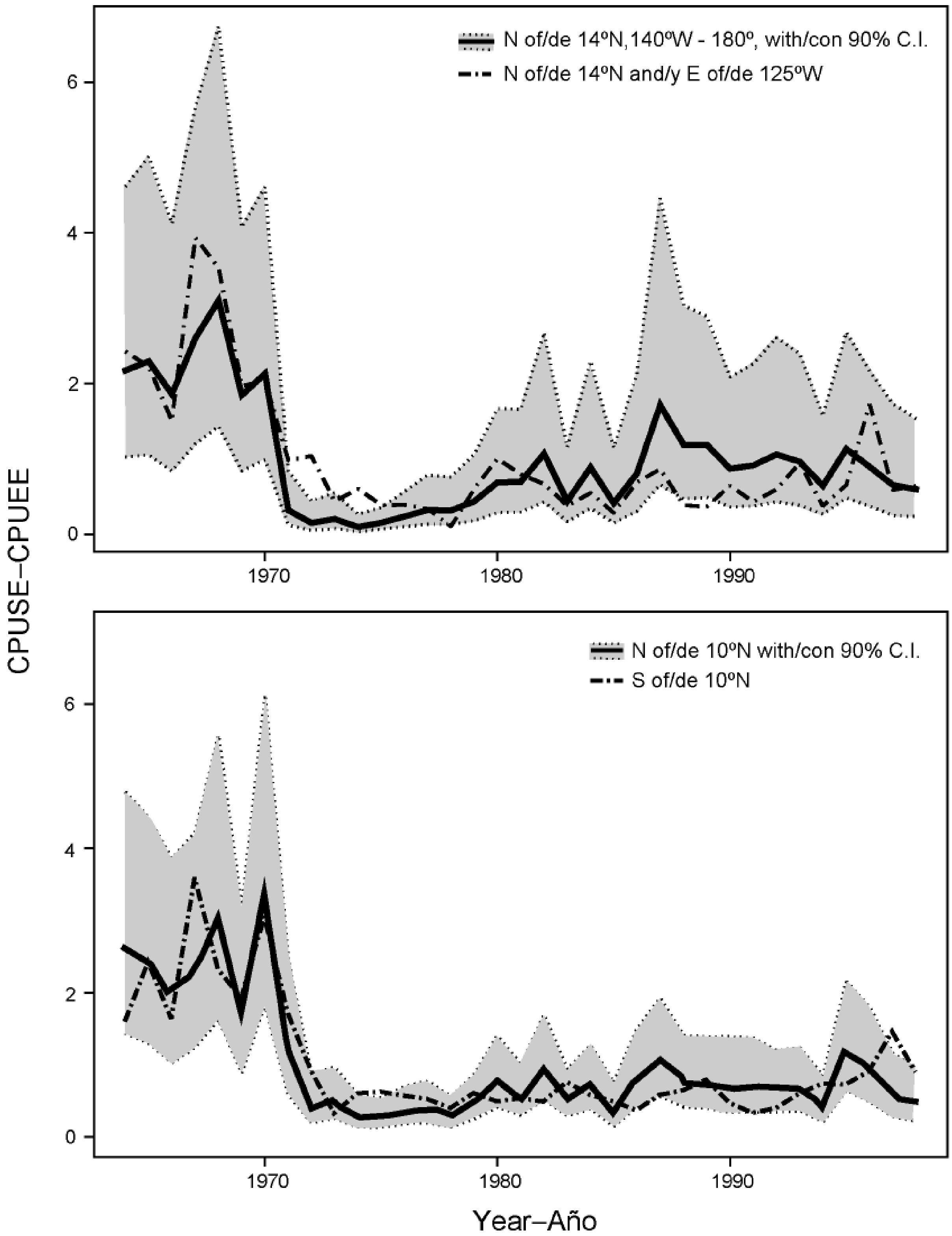

FIGURE 3.3.1. Comparison of trends in CPUSE between northeast and northwest (upper panel) and between north and south (lower panel) subareas of the EPO.

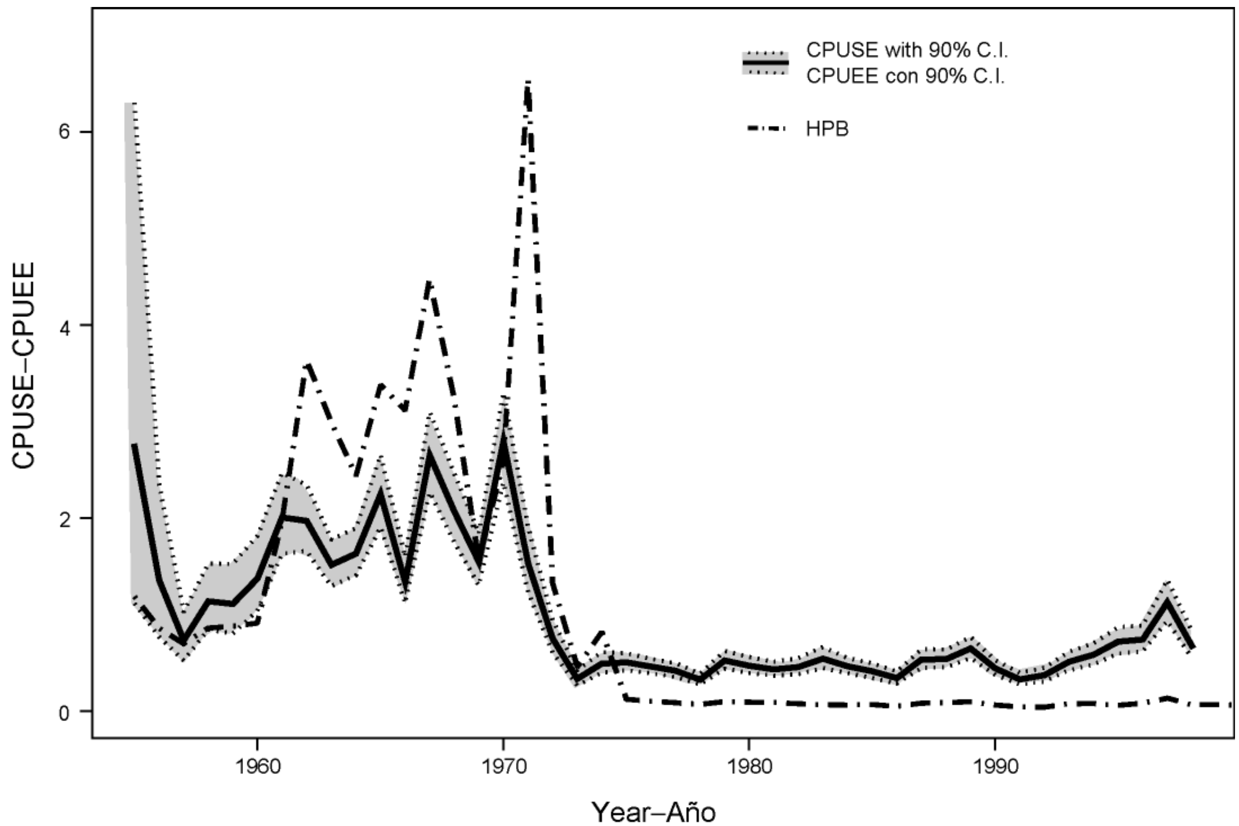

FIGURE 4.2.1. Trends in relative abundance of striped marlin in the EPO and 90-percent confidence limits (CPUSE model) from the fitted Δ-distribution model and the hooks-per-basket (HPB) model.

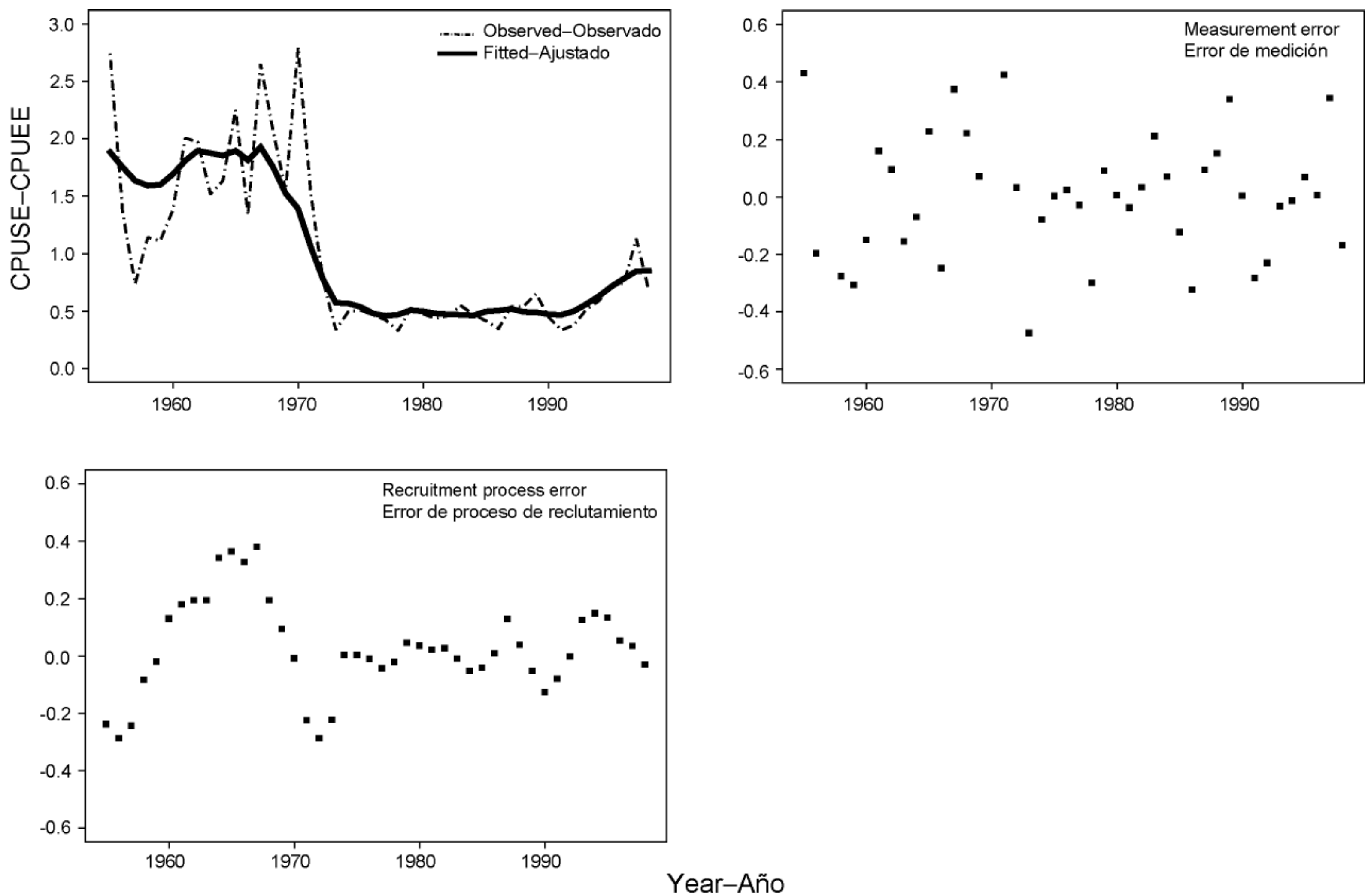

FIGURE 4.2.2. Results of fitting Deriso-Schnute delay-difference model, with survival rate = 0.60 and Brody-growth coefficient = 0.73, to striped marlin in the EPO.

TABLE 2.2.1a. Preliminary estimates of retained catch (mt) of striped marlin from the eastern Pacific Ocean north of 10°N. 0 = More than zero but less than 0.5 mt; .... = Data not available; unobtainable; data not separately available but included in another category.

Year	CRI	JPN	KOR	MEX	TWN	USA	Total
1954	...	0	...	...	...	...	0
1955	...	1	...	...	...	...	1
1956	...	49	...	...	...	...	49
1957	...	18	...	...	...	...	18
1958	...	94	...	...	...	...	94
1959	...	141	...	...	...	...	141
1960	...	257	...	...	...	...	257
1961	...	147	...	...	...	...	147
1962	...	190	...	...	...	...	190
1963	...	712	...	...	...	...	712
1964	...	7369	...	...	...	...	7369
1965	...	5702	...	...	...	...	5702
1966	...	4034	...	...	...	...	4034
1967	...	5365	...	...	...	...	5365
1968	...	9602	...	...	...	...	9602
1969	...	4375	...	...	...	...	4375
1970	...	6991	...	...	...	...	6991
1971	...	5545	...	...	...	...	5545
1972	...	3630	...	...	...	...	3630
1973	...	3088	...	...	...	...	3088
1974	...	3250	...	...	...	...	3250
1975	...	2748	0	...	...	...	2748
1976	...	3273	1	...	...	...	3274
1977	...	565	2	...	...	...	567
1978	...	398	21	...	...	...	419
1979	...	877	10	...	...	...	887
1980	...	2250	16	0	3	...	2269
1981	...	1558	570	...	...	...	2128
1982	...	2293	383	...	...	...	2676
1983	...	1436	671	192	...	...	2299
1984	...	1104	240	...	...	...	1344
1985	...	167	5	93	...	...	265
1986	...	1100	0	969	...	...	2069
1987	...	2416	4	3038	...	...	5458
1988	...	1472	1	1615	...	...	3088
1989	...	1032	0	59	0	...	1091
1990	...	523	0	...	1	...	524
1991	179	636	313	...	...	4	1141
1992	135	498	140	...	...	12	797
1993	221	475	0	...	...	14	732
1994	245	394	12	...	...	3	679
1995	197	1006	48	...	...	17	1377
1996	3	370	39	...	8	10	664
1997	252	219	38	...	...	7	536
1998	210	402	...	...	0	16	699
1999	250	467	...	...	8	25	834
2000	104	81	...	30	...	3	...

TABLE 2.2.1b. Preliminary estimates of retained catch (mt) of striped marlin from the eastern Pacific Ocean south of 10°N. 0 = More than zero but less than 0.5 mt; .... = Data not available; unobtainable; data not separately available but included in another category.

Year	CRI	JPN	KOR	MEX	PYF	TWN	Total
1954	...	23	...	...	...	...	23
1955	...	16	...	...	...	...	16
1956	...	18	...	...	...	...	18
1957	...	132	...	...	...	...	132
1958	...	232	...	...	...	...	232
1959	...	231	...	...	...	...	231
1960	...	273	...	...	...	...	273
1961	...	1887	...	...	...	...	1887
1962	...	3529	...	...	...	...	3529
1963	...	6533	...	...	...	...	6533
1964	...	4098	...	...	...	...	4098
1965	...	4234	...	...	...	...	4234
1966	...	5031	...	...	...	...	5031
1967	...	5004	...	...	...	144	5148
1968	...	4535	...	...	...	55	4590
1969	...	4636	...	...	...	12	4648
1970	...	3964	...	...	...	27	3991
1971	...	4504	...	...	...	69	4573
1972	...	3351	...	...	...	124	3475
1973	...	2028	...	...	...	161	2189
1974	...	1979	...	...	...	174	2153
1975	...	2613	10	...	...	59	2682
1976	...	3137	13	...	...	49	3199
1977	...	2454	17	...	...	47	2518
1978	...	1772	270	...	...	34	2076
1979	...	3179	32	...	...	23	3234
1980	...	2521	7	...	...	82	2610
1981	...	2537	163	...	...	41	2741
1982	...	1869	98	...	...	38	2005
1983	...	2021	119	0	...	16	2156
1984	...	1202	100	...	...	7	1309
1985	...	1162	160	...	...	5	1327
1986	...	1435	...	...	...	24	1459
1987	...	2627	50	12	...	56	2745
1988	...	1940	57	16	...	28	2041
1989	...	2121	105	...	...	48	2274
1990	...	2289	77	...	...	10	2376
1991	9	1685	72	...	...	8	1774
1992	12	1509	535	...	16	136	2208
1993	23	1762	...	...	1	160	1946
1994	25	1985	436	...	64	129	2639
1995	107	1205	413	...	80	11	1816
1996	156	1590	485	...	90	14	2335
1997	85	2398	846	...	88	67	3484
1998	71	1871	...	...	65	21	2028
1999	84	842	...	...	116	37	1079
2000	35	762	...	...	...	...	...

TABLE 3.1.1a. Estimated growth parameters and natural mortality rates (estimated by Boggs (1989) and estimated for this report by the method of Pauly (1980)) for striped marlin in the Pacific Ocean.
TABLA. 3.1.1a. Parámetros de crecimiento y tasas de mortalidad natural estimados (estimados por Boggs (1989) y estimados para este informe por el método de Pauly (1980)) para marlín rayado en el Océano Pacífico.

	Sex	L_∞ (cm)	K (annual)	t_0 (years)	Reference	Natural mortality rate	
						Boggs	Pauly
	Sexo	L_∞ (cm)	K (anual)	t_0 (años)	Referencia	Tasa de mortalidad natural	
						Boggs	Pauly
1		275	0.264		Koto, 1963	0.49	0.389
2	M	206	0.417	-0.521	Skillman and Yong, 1976	0.79	0.569
3	F	186	0.696	0.136	Skillman and Yong, 1976	1.33	0.818

TABLE 3.1.1b. Estimated lengths (cm) at age of striped marlin, calculated from the data in Table 3.3.1a.
TABLA 3.1.1b. Tallas estimadas (cm) a edad del marlín rayado, calculadas de los datos en la Tabla 3.3.1a.

	Age in years—Edad en años									
	1	2	3	4	5	6	7	8	9	10
1	64	113	150	179	202	219	232	242	249	255
2	97	134	159	175	185	192	197	200	202	203
3	84	135	161	173	180	183	184	185	186	186

TABLE 3.1.1c. Equations for converting lengths, in centimeters, to weights, in kilograms, for striped marlin. The abbreviations are as follows: EPO, eastern Pacific Ocean; CPO, central Pacific Ocean; EFL, posterior edge of orbit to fork of tail; SFL, anterior tip of bill to fork of tail; GG, gilled and gutted.
TABLA 3.1.1c. Ecuaciones para convertir tallas (*l*), en centímetros, a pesos (*w*), en kilogramos, para el marlín rayado. EPO, Océano Pacífico oriental; CPO, Océano Pacífico central; EFL: borde posterior de la órbita a la furca caudal; SFL, punta anterior de pico a la furca caudal; GG: desagallado y eviscerado; round: entero.

Area	Sample size	Length range (cm)	Length measurement	Weight measurement	Equations	Reference
Area	Tamaño de la muestra	Rango de tallas (cm)	Medida de talla	Medida de peso	Ecuaciones	Referencia
EPO	51	108-211	EFL	round	$\log w = -5.2552 + 3.0888\log l$ $w = (5.5565 \times 10^{-6})l^{3.0888}$	Kume and Joseph, 1969b
EPO	111	132-222	EFL	GG	$\log w = -4.9896 + 2.9749\log l$ $w = (1.0242 \times 10^{-5})l^{2.9749}$	Kume and Joseph, 1969b
EPO	1,982	110-215	EFL	round	$\log w = -5.157 + 3.071\log l$ $w = (6.9663 \times 10^{-6})l^{3.071}$	Wares and Sakagawa, 1974
EPO	535	153-271	SFL	round	$\log w = -5.34 + 2.982\log l$ $w = (4.5709 \times 10^{-6})l^{2.982}$	Wares and Sakagawa, 1974
EPO	1,748	107.5-225.5	EFL	not stated—no dicho	$\log w = -4.0120 + 2.5682\log l$ $w = (9.727 \times 10^{-5})l^{2.5682}$	Ponce Díaz *et al.*, 1991
CPO	53	142-310	SFL	round	$\log w = -6.24317 + 3.3756\log l$ $w = (5.7126 \times 10^{-7})l^{3.3756}$	Skillman and Yong, 1974

TABLE 4.2.1. Number and proportion of bimonthly period – areas of the EPO with standardized effort and with (without) catch of striped marlin by stock and year.

Year	Without	With	Proportion Without	Year	Without	With	Proportion Without
1955	299	1202	0.199	1980	218	821	0.210
1956	320	1149	0.218	1981	218	913	0.193
1957	376	1318	0.222	1982	207	796	0.206
1958	292	1553	0.158	1983	250	746	0.251
1959	359	1582	0.185	1984	220	799	0.216
1960	386	1618	0.193	1985	181	644	0.219
1961	504	1876	0.212	1986	189	698	0.213
1962	515	2340	0.180	1987	214	812	0.209
1963	469	2743	0.146	1988	177	720	0.197
1964	561	2581	0.179	1989	196	760	0.205
1965	568	2689	0.174	1990	166	731	0.185
1966	621	2501	0.199	1991	212	714	0.229
1967	619	2505	0.198	1992	201	776	0.206
1968	673	2357	0.222	1993	190	795	0.193
1969	605	2377	0.203	1994	186	701	0.210
1970	557	2400	0.188	1995	237	737	0.243
1971	96	329	0.226	1996	174	679	0.204
1972	120	353	0.254	1997	109	668	0.140
1973	144	353	0.290	1998	207	608	0.254
1974	85	370	0.187				
1975	236	703	0.251				
1976	273	911	0.231				
1977	265	844	0.239				
1978	284	861	0.248				
1979	231	880	0.208				

TABLE 4.2.2. Fitted GLMs for to obtain standardized estimates of CPUSE of striped marlin in the EPO using a Δ-distribution model. Terms shown in order of addition to the model (first to last). BIM = bi-monthly period; LAT = latitude; LON = longitude; NOI = Northern Oscillation Index; SOI = Southern Oscillation Index; DF = degrees of freedom.

a. ln(CPUSE): Gaussian component

Source	DF	Deviance	Residual DF	Residual Deviance	F_{obs}	Pr(F)
NULL	28442	165156				
LON	1	17284.4	28441	147871.7	5776.0	0.00E+00
LAT	1	22256.8	28440	125614.8	7437.7	0.00E+00
YEAR	43	15629.1	28397	109985.7	121.5	0.00E+00
BIM	5	3666.7	28392	106319.0	245.1	0.00E+00
NOI	1	61.7	28391	106257.3	20.6	5.67E-06
LAT:LON	1	10051.5	28390	96205.8	3359.0	0.00E+00
BIM:LAT	5	10256.7	28385	85949.1	685.5	0.00E+00
BIM:LON	5	1024.2	28380	84924.9	68.5	0.00E+00

b. CIndex: Binomial component

Source	DF	Deviance	Residual DF	Residual Deviance	F_{obs}	Pr(F)
NULL	35996	36987.6				
LON	1	3477.2	35995	33510.3	3098.4	0.00E+00
LAT	1	814.7	35994	32695.6	725.9	0.00E+00
BIM	5	524.6	35989	32171.0	93.5	0.00E+00
YEAR	43	209.4	35946	31961.7	4.3	0.00E+00
SOI	1	18.1	35945	31943.5	16.2	5.84E-05
LAT:LON	1	546.7	35944	31396.8	487.1	0.00E+00
BIM:LON	5	73.0	35939	31323.8	13.0	0.00E+00
BIM:LAT	5	61.0	35934	31262.8	10.9	1.80E-10