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STATUS OF SAILFISH IN THE EASTERN PACIFIC OCEAN IN 2011 AND OUTLOOK FOR THE FUTURE

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1. SUMMARY

This report describes the status and trends of sailfish (*Istiophorus platypterus*) in the eastern Pacific Ocean (EPO). The assessment was conducted using a surplus production model, after determining that the data available were insufficient to support an assessment using Stock Synthesis.Data used were updated as of 14 March 2013.

Sailfish are found in highest abundance in waters relatively near the continents and the Indo-Pacific land masses bordering the Pacific Ocean, and only infrequently in the high seas separating them. This separation by its very nature suggests that the regions of abundance in the EPO and in the western Pacific should be managed separately, and in this case, the separation has over time resulted in genetically distinct populations.

The centers of sailfish distribution along the coast of the Americas shift in response to seasonal changes in surface and mixed-layer water temperature. Sailfish are found most often in waters warmer than about 28°C, and are present in tropical waters nearer the equator in all months of the year. Spawning takes place off the coast of Mexico during the summer and fall, and off Costa Rica during winter, and perhaps year-round in areas with suitable conditions. The sex ratio is highly skewed towards males during spawning. The known shifts in sex ratios among spawning areas, and the spatial-temporal distributions of gonad indices and size-frequency distributions, which show smaller fish offshore, suggest that there may be maturity-dependent patterns in the distribution of the species in the EPO. Sailfish can reach an age of about 11 years in the EPO.

The principal fisheries that capture sailfish in the EPO include the large-vessel, distant-water tuna-targeting longline fisheries of Chinese Taipei, Costa Rica, Japan, and Korea; the smaller-vessel longline fisheries targeting tuna and non-tuna species, particularly those operating in waters off the coast of Central America; and the artisanal and recreational fisheries of Central and South America. Sailfish are also taken occasionally in the purse-seine fisheries targeting tropical tunas.

Key results

1. It is not possible to determine the status of the sailfish stock in the EPO with respect to specific management parameters, such as maximum sustained yield (MSY), because the parameter estimates used in making these determinations cannot be derived from the model results. This is because the results do not provide reliable information on stock productivity and the biomass level corresponding to MSY.
2. Sailfish abundance trended downward during 1994-2009, after which it has entered a period of relatively constant to slightly increasing abundance.
3. Recent levels of reported annual catch are on the order of 500 t. This is significantly less than the average of about 2,100 t during 1993-2007.
4. Model results suggest that there are significant levels of unreported catch. The actual catches prior to 1993 were probably on the order of or greater than those reported for 1993-2007. Assuming that this level of harvest has existed for many years, it is expected that the stock condition will not deteriorate if catches do not increase above current levels.
5. A precautionary approach that does not increase fishing effort directed at sailfish and that closely monitors catch until sufficient data are available to conduct another assessment is recommended.
6. It is unlikely that a reliable assessment of sailfish in the EPO can be made without reliable estimates of catch.
7. It is recommended that:
    a. historical data on catches of sailfish be obtained wherever possible;
    b. fisheries currently reporting sailfish catches commingled with other species be encouraged to report catches by species;
    c. existing data from small-scale fisheries, such as local longline fleets and artisanal fisheries, be compiled and that where necessary catch monitoring programs identifying catch to species be developed.

2. DATA

The data used in the assessment had been initially prepared for use in Stock Synthesis (Methot 2009), but were then aggregated into annual observations for all fisheries combined for use in the surplus production model used for the assessment. The size-frequency data were not incorporated in the production model, for which the data inputs are catch and indices of abundance.

2.1. Definitions of the fisheries

Twenty-two fisheries and two surveys were defined for this assessment. They were based on gear type, flag, units of reported catch (numbers or weight), and analyses of the spatial distribution of sailfish catch. Sailfish are generally most abundant along the coasts of Central and South America between about 20°N and 20°S, with latitudinal movement associated with warm water temperatures (Joseph *et al*. 1974). Sailfish are not found in great abundance on the high seas (Kume 1973; Joseph *et al*. 1974). This fact was exploited to develop estimates of the catch of sailfish by fisheries in which they are pooled with other billfish, particularly the short-billed spearfish (*Tetrapturus angustirostris*), in reported catch

Kume (1973) analyzed the spatial distribution of sailfish catch, using the data from the early years (1963-1970) following the full expansion of the Japanese longline fishery into the EPO. That analysis of catch and catch rates in waters proximate to Central and South America (Kume 1973: Research Area, Figure 2) showed that the abundance of sailfish dropped significantly as distance from the coast increased (Kume 1973: Table 2). Joseph *et al*. (1974) reported that “sailfish are extremely abundant within 600 miles” of the coast and that the catch of sailfish decreases rapidly beyond 1,000 miles

. The fisheries defined for this assessment are shown in Table A

TABLE A. Fisheries (F) and surveys (S) defined for this assessment. LL: longline; PS: purse seine; RG: recreational gear; nSFA: number of sailfish; nBIL: number of mixed sailfish and spearfish: tSFA: tons of sailfish. Purse-seine fisheries are associated with dolphins (DEL), floating objects (OBJ), and unassociated tunas (NOA).

Fishery	Description & area	Period	Catch units**
F1	Japanese LL coast	1964-1970	nSFA
F2	Japanese LL coast	1971-1993	nBIL
F3	Japanese LL coast	1994-2011	nSFA
F4	Japanese LL high seas	1964-1993	nBIL * 0.1
F5	Japanese LL high seas	1994-2011	nSFA
F6	Korean LL coast	1975-2011	nSFA
F7	Korean LL high seas	1975-2011	nSFA
F8	Korean LL coast	1992-1994 & 2003-2004	tSFA
F9	Korean LL high seas	1992-1994 & 2003-2005	tSFA
F10	Chinese Taipei LL coast	1964-2011	nBIL
F11	Chinese Taipei LL high seas	1964-2011	nBIL * 0.1
F12	EPO PS coast, DEL	1993-2011	nSFA
F13	EPO PS coast, NOA	1993-2011	nSFA
F14	EPO PS coast, OBJ	1993-2011	nSFA
F15	EPO PS high seas, DEL	1993-2011	nSFA
F16	EPO PS high seas, NOA	1993-2011	nSFA
F17	EPO PS high seas, OBJ	1993-2011	nSFA
F18	Mexican LL coast	1980-1989	nSFA
F19	Mexican LL high seas	1980-1989	nSFA
F20	Mexican RG	1990-2008	nSFA
F21	Mexican artisanal Gulf of Tehuantepec	2005-2008	nSFA
F22	Other industrial LL	1991-2011	tSFA
S1	Japanese LL N-Equatorial	1994-2011	nSFA
S2	Japanese LL S-Equatorial	1994-2011	nSFA

2.2. Catch[1]

The catch histories for a number of the fisheries in the assessment are problematic. The catch of sailfish by Japanese longline fisheries described by Kume (1973) is known to species, year, and small area, but in general, prior to about 1994, catches of sailfish were pooled with those of spearfish in reported catch by longline fisheries. This mixed-species reporting continues to be the norm for longline fisheries of Chinese Taipei. The tuna purse-seine fisheries of the EPO have operated for many decades, but the magnitude of catch of billfish is unknown prior to the early 1990s, when scientific observers initially placed on vessels to monitor marine mammal interactions began collection of these data. A similar situation is evidenced by the catch data of the recreational fisheries of Mexico, for which annual catch data have been reported by Fleischer *et al*. (2009) for the 1990-2008 period, and for the other recreational fisheries of Central and South America, for which we know of no reliable data on catches of sailfish. Finally, the catch estimates for the artisanal fisheries of the Gulf of Tehuantepec were developed from a published catch rate series and the associated effort, reported as sample size. These data are available for the short period, 2005-2008, during which a study on relative seasonal abundance and size frequency was conducted. The full

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[1] The catches used in the final assessment model are provided in Table 4.1

magnitude of the catches made by the smaller-vessel longline fisheries targeting tuna and non-tuna species, particularly those operating in waters off the coast Central America; and by the artisanal fisheries in Central and South America is not known.

Catches by the longline fisheries were compiled using reported monthly catches. This was not possible for the artisanal fishery operating in the Gulf of Tehuantepec or for the recreational fishery of Mexico, for which only annual catch data were available. The quarterly catch from these fisheries was estimated as follows.

Catch estimates for the artisanal fishery in the Gulf of Tehuantepec are considered minimums. Monthly estimates were obtained as the product of the monthly catch rate (number of fish per trip) and monthly number of trips (sample size *n*) obtained from Cerdenares-Ladrón *et al.* (2012; Figure 2), and were then totaled by quarter.

The annual reported catches of sailfish by the recreational fisheries of Mexico (Fleischer *et al.* 2009) for the 1999-2008 period were adjusted using the annual sampled release rates and an estimated post-release mortality rate of 25% (Hinton and Maunder 2011). Release rates prior to 1999 were lower than those observed in later years.[2] During 1999-2008, the average self-reported release rate for the Los Cabos fleet was 79%, while the sampled release rate was 68%. The Los Barriles fleet self-reported release rate over the same period was about 64%, 15% less than that of the Los Cabos fleet. Assuming the same reporting error rate for Los Barriles as observed for Los Cabos, the average reporting rate for the pooled fleets was adjusted using the ratio of the observed and self-reported release rates from Los Cabos. The reported catches for years prior to 1999 were decreased by 62% using this estimated release rate. However, not all fish released survive.

The most extensive study of billfish survival following capture by recreational gear was conducted on striped marlin (Domeier *et al.* 2003) and estimated an overall survival rate of about 25%; however, the mortality rate for fish released in good condition was about 10%. Kerstetter and Graves (2008) estimated a similar rate, 12%, for sailfish captured on longline gear; they reported that 69% (20 fish) survived from hooking until line retrieval. Of the 15 fish they tagged, 12 had fitness scores of eight or higher on a 10-point scale. These results suggest that the mortalities of sailfish that might have been in poor condition as a result of the capture event were not available for the tag and release survival study, as they had died by the time of longline retrieval. Given the similar estimates of survival of fish in good condition reported in both these studies, and the lack of sailfish in poor condition in the survival analysis of Kerstetter and Graves (2008), a post-release survival rate of 25% was used in estimates of total mortalities from recreational fisheries, which is consistent with previous assessments (Hinton and Maunder 2011).

In order to account for the seasonal presence and movement of sailfish along the coast of the Americas (Kume and Joseph 1969), the reported annual catches by the recreational fishery of Mexico and by the Japanese longline fishery (1964-1970) were apportioned to quarters based on the averages of the quarterly catch rates (Cerdenares-Ladrón *et al.* 2012) from the artisanal fishery. Proportions used were 0.15 for quarter 1; 0.28 for 2; 0.38 for 3; and 0.19 for quarter 4.

The catches of sailfish and spearfish were pooled in the reported catches of Japan until 1993, when a logbook and reporting system was instituted in which sailfish and spearfish were reported at the species level. Implementation of the reporting system was completed in 1994, since many Japanese longline vessels return to home ports only once each year or less. Analysis of the post-1993 catch of these species in the Research Area of Kume (1973) showed that 1,080 sailfish and 52 spearfish (4.6% of the pooled catch) were taken from the region. The low total catch numbers for sailfish in the area resulted from a westward shift in the spatial distribution of the fisheries following the adoption of Exclusive Economic Zones, but the distribution patterns described by Kume (1973) persist. Based on this analysis, the reported

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[2] L. Fleischer. 2010. Pers. comm. Release rates were lower in years prior to 1999. 3 September 2010. La Jolla, California.

catches of mixed sailfish and spearfish were used as the estimate of sailfish catch from the Research Area for reported catches of Chinese Taipei and Japan.

During 1993-2011, sailfish accounted for about 5% (14,250 of about 265,750 fish) of the reported catches by Japanese longline vessels of spearfish and sailfish combined from the waters west of the Research Area. However, the proportion has declined steadily, from about 13% in 1994 to less than 2% in recent years. Therefore, for years and fisheries in which catch was not reported by species, sailfish was assumed to have accounted for 10% of the reported catch of mixed sailfish and spearfish in the high-seas area.

2.3. Discards

Discard data, obtained by on-board observers, were available for the EPO tuna purse-seine fishery only. No discard data were available from other fisheries.

2.4. Indices of abundance

It is preferred to have a catch rate time series that covers the temporal and spatial extent of fisheries harvesting a resource. In this assessment, due to common practice in longline fisheries to report sailfish and spearfish in a single category and to the significant changes in the spatial distribution of the Japanese longline fisheries in the EPO over time (Hinton 2009), there is no single catch rate time series that extends over the area and time period of the fisheries taking sailfish in the EPO.

Abundance indices for a number of fisheries (F1, F5, F12, F12/13, F15/16, F18/19, F20 and F21) were considered for use in the assessment. Most were plagued by low numbers of observations, short temporal coverage, and lack of detailed data needed for modeling. Two indices which showed consistency, covered much of the same time period (including more recent years), and which were from geographically separated areas within the EPO were chosen for use in the assessment.

The first index was from the recreational fishery of Mexico during 1990-2008. It was estimated using the catch and effort series presented by Fleischer *et al*. (2009). The second was for the Japanese high-seas longline fishery in the region bounded by the equator and 10°N from 92°W to 150°W. This latter index was developed using a delta-lognormal model (Pennington 1983) fitted in TIBCO Spotfire S+ 8.2 . Initial identification of model parameters was made using functions “step.glm” and “stepAIC”. Final selection of model parameters was made by comparing the decrease in the Akaike Information Criterion (AIC) resulting from the addition of the individual parameters suggested by the initial fittings, and including only those that resulted in a decrease in AIC of O(100) (Burnham and Anderson 1998). Initial model scopes included parameters for position, in latitude and longitude and in distance from the nearest point on the American continents, and for oceanographic conditions that might be expected to be correlated with the presence and vulnerability of sailfish. The models selected, with parameters in order of selection, were:

$$\text{CPUE} = \text{Intercept} + \text{Month} + \text{Year} + \text{Latitude}$$

$$P(\text{sailfish catch recorded} \mid \text{fishing effort}) = \text{Intercept} + \text{Year} + \text{Latitude} + \text{Month}$$

2.5. Size-composition data

The few available size-frequency data for the principal fisheries were eye-fork length (EFL) measurements. Measurements were aggregated into 2-cm length intervals by quarter for the Japanese longline (F4 and F5) and for the purse-seine (F12 and F13) fisheries. The number of samples for the longline fisheries was extremely low, covering only 44 quarters with sample sizes ranging from one to 45 measurements per quarter. Sampling coverage of the purse-seine fishery was high, with 87 quarterly observations in the coastal (F12) and 79 in the high-seas (F13) fisheries. Numbers of sailfish measured in a quarter averaged about 125 in the coastal fishery, and about 15 in the high-seas fishery, where sailfish occur less frequently in the catch.

Annual size-frequency distributions for the artisanal fishery in the Gulf of Tehuantepec, taken from

Cerdenares-Ladrón *et al.* (2012: Figure 3), were digitized as numbers of fish in 5-cm intervals .

2.6. Age-composition data

No age-composition data were available.

3. ASSUMPTIONS AND PARAMETERS

3.1. Biological and demographic information

3.1.1. Growth

Sailfish grow rapidly, and by age two may be expected to reach or exceed 100 cm eye-fork length (EFL) (Cerdenares-Ladrón *et al.* 2011; Ramírez-Pérez *et al.* 2011).

Cerdenares-Ladrón *et al.* (2011) examined 477 sailfish captured in the artisanal fisheries of the Gulf of Tehuantepec and identified individuals of age 1 to 11 years and ranging in EFL from about 80 to 220 cm: only 7% of these individuals had EFL > 180 cm. The growth rates estimated in their study were consistent with high growth rates reported by others (see summary of studies and parameter estimates in Table III of Cerdenares-Ladrón *et al.* 2011).

Ramírez-Pérez *et al.* (2011) examined 572 sailfish captured in the recreational fishery in and near the Gulf of California. They identified sailfish of ages 1 to 9 years, and ranging in EFL from about 96 to 198 cm. They estimated that sailfish reached lengths of about 71 cm by age 1, 104 cm by age 2, 127 cm by age 3, and 160 cm by age 4. After age 4 they estimated that sailfish grew at a rate of about 13 cm per year. These results were consistent with those of Cerdenares-Ladrón *et al.* (2011) and the studies noted therein.

Ramírez *et al.* (2011) reported a statistically-significant difference in the growth curves of males and females. The average absolute value of the difference between the estimated length-at-age for males and females of ages 1-9 was less than 3 cm, which, in the context of the assessment model wherein size-frequency data have been compiled into length intervals of 2 and 5 cm, is an insignificant difference. Considering that the size-frequency data used in the assessment are not known by sex and that Cerdenares-Ladrón *et al.* (2011) included fish up to age 11 and sizes up to 22 cm greater in length than those of Ramírez *et al.* (2011), the pooled-sex von Bertalanffy growth model of Cerdenares-Ladrón *et al.* (2011) was selected for use in the assessment. Parameters and confidence intervals from Cerdenares-Ladrón *et al.* (2011) were *L*-infinity (L_{inf}) = 180.6 cm (176-186 cm); Brody growth coefficient (k) = 0.36 (0.34-0.39); and age at length zero (t_0) = -0.24 (-0.30 to -0.18). Length at age t is estimated as:

$$L(t) = 180.6(1 - e^{-0.36(t+0.24)})$$

The L_{inf} parameter may be estimated or specified in Stock Synthesis, and in the assessment it was fixed for males and females at 188 cm. The von Bertalanffy equation in Stock Synthesis does not use the standard t_0 parameterization and instead was parameterized with the length at age 1 equal to 65 cm for females and males.

Age	n	μ	σ	CV
2	5	104.0	17.46	16.8
3	16	146.6	12.74	8.7
4	67	160.0	12.49	7.8
5	154	160.4	9.80	6.1
6	115	166.4	12.42	7.5
7	58	167.4	11.13	6.6
8	26	171.9	12.58	7.3
9	21	176.4	15.66	8.9
10	6	168.3	15.06	8.9
11	7	188.6	15.74	8.3

The mean (μ), standard deviation (σ) and coefficient of variation (CV) of length-at-age for ages 2-11 years were estimated from data of Cerdenares-Ladrón *et al.* (2011; p. 493, Table 1). Due to the low sample sizes for some ages, a constant CV of 9% was used in the assessment.

In Stock Synthesis a weight-length relationship is used to calculate biomass and to enable converting data, which may be provided in units of weight or length, into common units for analysis. In this assessment round weight [RW(kg)] was estimated from EFL (cm) using the weight-length relationship of Cerdenares-Ladrón *et al.* (2011):

$$RW = 5.0\times10^{-5}(EFL)^{2.6}$$

This choice was consistent with the choice of the assessment growth model (Cerdenares-Ladrón *et al.* 2011).

3.1.2. Natural mortality

The instantaneous natural mortality rate (M) of sailfish is not known. Given that most sailfish apparently live no longer than about 11 years, in this assessment we used a constant annual M of 0.5 which is consistent with rates used in assessments of other billfish with similar life histories (*e.g.* Hinton and Maunder 2007; Hinton and Maunder 2011).

3.1.3. Recruitment and reproduction

Hernández and Ramírez (1998), using histological analyses of sailfish ovaries and values of gonad indices, found that the length-at-first-maturity of females was on the order of 150 cm and that the length at 50% maturity was about 175 cm. They found that these values were consistent with those of previous studies conducted in the EPO. The proportion of females that are mature by EFL (cm) (Hernández and Ramírez 1998: Figure 5) is given by:

$$P(mature\ females) = (1+e^{(34.3719\,-\,0.1962435\,\times\,EFL)})^{-1}$$

The maturity schedule in the assessment was set by evaluating the function for proportion of females that are mature at the estimated mean EFL by age (Cerdenares-Ladrón *et al.* 2011: p. 494, Table II). The vector of the proportion of females mature by age 0 to 11 =

[0.0, 0.0, 0.0, 0.0001, 0.0016, 0.0101, 0.0619, 0.1160, 0.2200, 0.3867, 0.4342, 0.9186].

In the Atlantic Ocean sailfish may spawn multiple times in a season (deSylva and Breder 1997), but this appears not to be the case in the EPO (McDowell 2002). In the EPO spawning occurs throughout the year at locations with suitable conditions (Kume and Joseph 1969; Hernández and Ramírez 1998; Ramírez *et al.* 2011), which results in a sequence of spawning locations extending from the equatorial region northward over the course of a year (McDowell 2002). Identified locations and times of spawning extend from Costa Rica [December-March] to Guatemala [January-April], and from southern to northern Mexico over a period of about seven months [May-November]. We assume that recruitment occurs in all seasons and that recruitment may vary among seasons.

It is generally considered that environmental conditions are the principal influence on recruitment levels of the pelagic tunas and tuna-like species, including sailfish, and that recruitment is not substantially reduced in response to changes in the level of spawning biomass. Therefore, a Beverton-Holt stock-recruitment relationship (Beverton and Holt 1957) was used in the assessment. In the Stock Synthesis model, the Beverton-Holt relationship has been parameterized to include steepness (h) (Francis 1992, Appendix 1). Steepness is that fraction of the recruitment to an unexploited stock (R_0) that would be produced by a spawning biomass that has been reduced to 20% of the unexploited spawning biomass (S0), *i.e.* $hR_0 = \Psi(0.2S_0)$, where Ψ is the Beverton-Holt stock-recruitment relationship. 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 observations of spawning biomass and because other factors (*e.g.* environmental) may cause extreme variability in recruitments from a given spawning biomass. Simulation analyses have shown that estimation of steepness is problematic, with large uncertainty and frequent estimates equal to 1, even when the true steepness is moderately less than 1 (Conn *et al.* 2010, Lee *et al.*

2012).

There was no information on relationships of recruitment and spawning stock size for sailfish in the EPO, so h = 0.90 was used in the assessment. Sensitivity analyses were carried out with h = [0.75, 1.0] to investigate the effect of various strengths of, and of no, stock-recruitment relationships.

3.1.4. Movement

The assessment did not include explicit parameters for movement within the EPO. There is very little information on the movements independent of changes in catch rates that have been associated with changes in the distribution of sea surface temperature. It was assumed that the population was randomly mixed at the beginning of each year (or season) and, though not explicitly modeled, some aspects of movement within the EPO, such as that suggested to lead to variations in the spatial distribution of size-frequency, were accommodated by differences in selectivity and catchability using a spatial definition of the fisheries.

3.1.5. Stock structure

The stock structure of sailfish is relatively well known in the Pacific. In comparison to the other billfish species, sailfish are found in highest abundance in waters relatively near the continents and the Indo-Pacific land masses bordering the Pacific Ocean (Howard and Ueyanagi 1965) and only infrequently in the high seas separating them. This separation led Kume and Joseph (1969) to suggest that, regardless of the genetic signatures in the population centers, the regions of abundance in the EPO and in the western Pacific should be managed separately.

Subsequent genetic analyses (McDowell 2002) found that the apparent population centers in the Pacific Ocean are centers of genetically differentiated stocks that result from their separation by distance. McDowell confirmed that the sailfish in the EPO were of a single genetic stock separated from the sailfish stock(s) of the Indo-west Pacific.

It is therefore considered that examinations of local depletions and assessments of the sailfish of the EPO are appropriate without including model parameters for transboundary movements of individuals.

3.2. Environmental influences

Environmental data were used in the catch-rate standardization (Section 2.4).

4. STOCK ASSESSMENT

The assessment was conducted using a surplus production model, after determining that the data available were insufficient to support an assessment using Stock Synthesis (Methot 2009), a sex-specific, age-structured, integrated (fitted to many different types of data) statistical stock assessment model. The data included in the assessment were those available on 14 March 2013, and determined, to a great degree, the structure of the assessment model.

Preparation for analysis using Stock Synthesis required compilation of estimates of a number of population characteristics, such as natural mortality rate, growth rates, and length at first maturity, were obtained from studies and were included in the assessment as assumed or fixed parameters. In the initial steps of the assessment, Stock Synthesis was fitted to a suite of scenarios, in seasonal and annual models, using the method of maximum likelihood. The value of the negative log-likelihood from each of the scenarios was used for evaluation and comparison of results.

It became apparent from estimates of stock productivity, biomass levels, and fishing mortality rates that either this stock had uncharacteristically low productivity (low natural mortality or low steepness of the stock-recruitment relationship) and high standing biomass or, most probably, that a large amount of catch was missing in the data compiled for the assessment. Attempts were made to estimate the catch for fisheries which have not reported sailfish catch by species (*e.g.*, Chinese Taipei and Japan in the period prior to 1994) due to the practice of longline vessels of reporting sailfish and spearfish together in landings statistics. In addition, there are small- and medium-scale longline fisheries and artisanal fisheries operating in Central America which are known to capture sailfish and for which data were not available. We were unable to identify a means to satisfactorily estimate this catch in order to obtain reliable estimates of stock status and trends using Stock Synthesis

The results obtained from the assessment conducted using the surplus production model suffer from these same limitations in data, and show results consistent with those obtained in analyses conducted using Stock Synthesis. The surplus production model was used to simplify the illustration of the issues in the stock assessment.

TABLE 4.1. Estimated total catch (t) and catch rate indices used in the surplus production model for sailfish in the EPO. LL = longline fishery; RG = recreational fishery.

Year	Catch (t)	JPN LL	MEX RG
1990	801.4		0.360
1991	1711.2		0.290
1992	5027.9		0.200
1993	3829.3		0.210
1994	2776.7	0.029	0.170
1995	2003.2	0.035	0.180
1996	1674.8	0.026	0.190
1997	2840.2	0.020	0.210
1998	2142.2	0.025	0.210
1999	1675.1	0.035	0.150
2000	2275.0	0.022	0.180
2001	2125.9	0.012	0.100
2002	2229.6	0.013	0.070
2003	1877.1	0.026	0.090
2004	1865.5	0.012	0.110
2005	1133.5	0.017	0.090
2006	1262.0	0.009	0.050
2007	1146.0	0.008	0.040
2008	543.4	0.011	0.070
2009	276.0	0.017	
2010	356.3	0.056	
2011	317.9	0.019	

4.1. Assessment model structure

The data included in the assessment were the reported catch for the 1990-2011 period and two abundance indices, the first from the recreational fisheries of Mexico (1990-2008) and the second from the Japanese longline fishery (1994-2011) in the region bounded by the equator and 10°N from 92°W to 150°W. The catch was converted from numbers to weight in the Stock Synthesis model to take into account fishery selectivity. The data used in the assessment are presented in Table 4.1.

Gilbert's (1992) version of the Pella-Tomlinson model was used (see the Appendix of Maunder 2001):

$$B_{t+1} + \frac{r}{\left[\frac{1}{m}-1\right]}\left[\frac{B_t^m}{B_0^{m-1}} - B_t\right] - C_t \qquad (1)$$

$$\frac{B_{MSY}}{B_0} = \frac{1}{\left[m^{\frac{1}{m-1}}\right]} \qquad (2)$$

$$r = \frac{MSY}{B_{MSY}} \qquad (3)$$

where MSY = maximum sustainable yield, *B* = biomass, and *m* = the shape parameter that determines the biomass level corresponding to MSY. The model was fitted to the indices of abundance using the method of maximum-likelihood estimation (MLE).

It was assumed that this species has a life history similar to related species. Therefore the shape parameter (m) was assumed to be 0.5, corresponding to a $B_{MSY}/B_0 = 0.25$, a level consistent with that for similar species.

Model dynamics were examined by fitting across a range of values of stock productivity r = [0.05, 0.1, 0.2, …, 0.5] and of initial model year (1990) stock depletion levels B_{1990}/B_0 = [0.25, 0.50, 0.75, 1.00]. In addition, the MLE estimate of stock productivity, r, was obtained at the stock depletion levels noted above.

4.2. Assessment results

The results of fitting the surplus production model across the range of values described above is presented in Figure 4.2.1 and Table 4.2. At all levels of initial stock depletion, the best model fits were obtained at unrealistically low levels of stock productivity ($r \approx 0.1$ to 0.2). This result would be expected if there were catch taken from the stock, particularly in the early part of the modeling time period, which was not included in the model. It follows that estimates of management parameters that would be obtained from the model, such as MSY or the current level of fishing effort relative to the level corresponding to MSY, would depend on the assumed productivity level or, in the context of the Stock Synthesis model, assumed steepness or natural mortality, *i.e*. based on information external to the model.

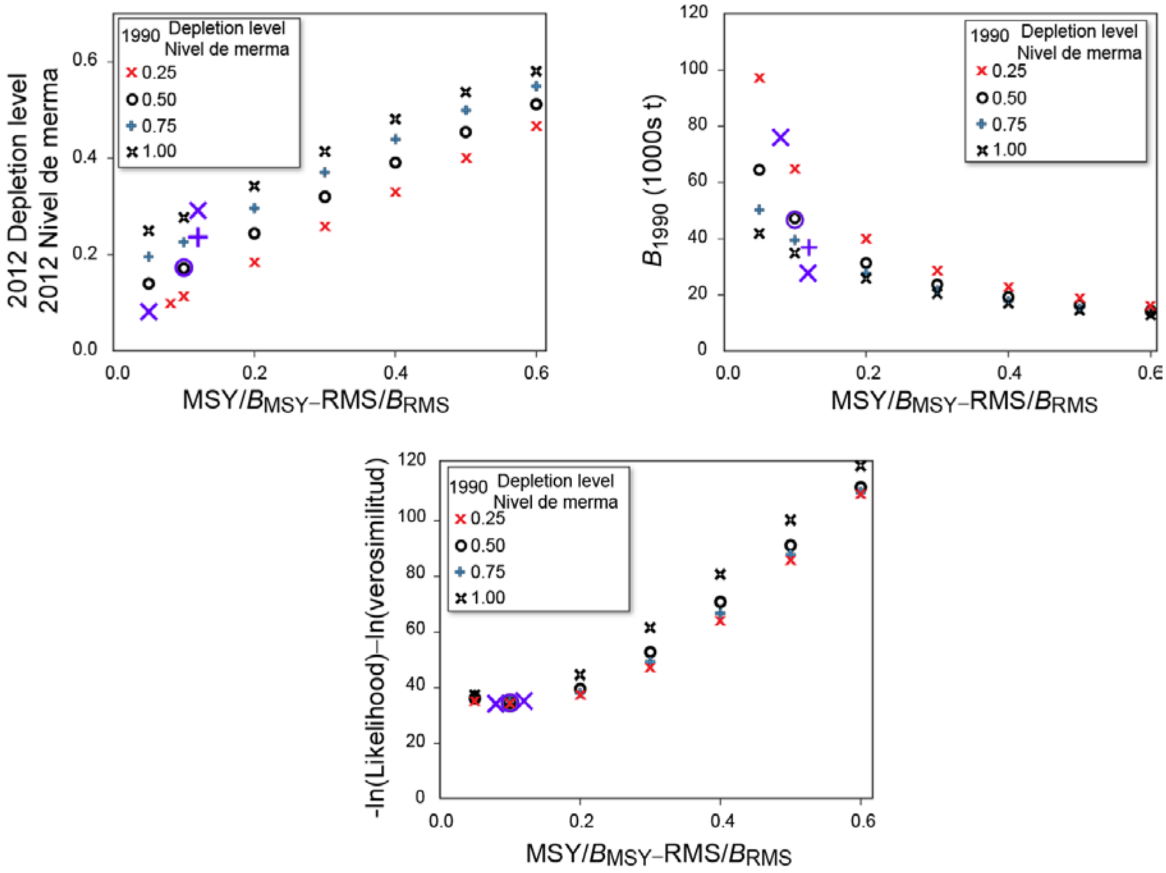

FIGURE 4.2.1. Estimates of sailfish stock biomass in the EPO in 1990 (B_{1990}; the first year in the stock production model) and level of biomass depletion in 2012; and the –ln(likelihood) from fitting the model at fixed values of stock depletion in 1990 and MSY/B_{MSY}. The maximum likelihood estimates for 1990 stock depletion, B_{1990}, and MSY/B_{MSY} are shown in purple.

TABLE 4.2. Parameter estimates and likelihood measures from fitting the surplus production model across a range of stock productivity (*r*), and depletion levels at MSY (B_{MSY}/B_0).

r	0.05	0.1	0.2	0.3	0.4	0.5	0.6	MLE
			B_{1990}/B_0 = 0.25					**r_{MLE} = 0.08**
-ln(Like)	34.95	34.62	44.63	61.53	80.68	100.25	119.70	34.18
B_{2012}/B_0	0.08	0.11	0.18	0.26	0.33	0.40	0.46	0.10
B_0	97,382	64,781	39,465	28,665	22,636	18,787	16,119	75,964
			B_{1990}/B_0 = 0.50					**r_{MLE} = 0.10**
-ln(Like)	36.13	34.46	39.49	52.76	70.85	91.09	111.95	34.46
B_{2012}/B_0	0.14	0.17	0.24	0.32	0.39	0.45	0.51	0.17
B_0	64,496	47,312	31,326	23,717	19,260	16,332	14,262	46,707
			B_{1990}/B_0 = 0.75					**r_{MLE} = 0.12**
-ln(Like)	36.86	34.94	37.98	49.22	66.64	87.75	110.25	34.82
B_{2012}/B_0	0.20	0.23	0.30	0.37	0.44	0.50	0.55	0.24
B_0	50,216	39,507	27,782	21,563	17,751	15,202	13,388	36,935
			B_{1990}/B_0 = 1.00					**r_{MLE} = 0.12**
-ln(Like)	37.36	35.44	37.46	47.33	64.07	85.80	109.95	35.19
B_{2012}/B_0	0.25	0.28	0.34	0.41	0.48	0.54	0.58	0.29
B_0	41,855	34,860	25,815	20,421	16,933	14,554	12,864	32,103

The trends in catch rate indices are assumed to be proportional to annual stock biomass. The observed and fitted estimates of annual catch rate indices used in the assessment are presented in Figure 4.2.2. Both indices show a decline in abundance over the period from 1990 to about 2005, after which the estimated catch rates levelled off. Data for the Mexican recreational fishery (MEX RG) were not available for years after 2009, during which there is an indication of stability to a slight increasing trend in the Japanese longline (JPN LL) index of abundance.

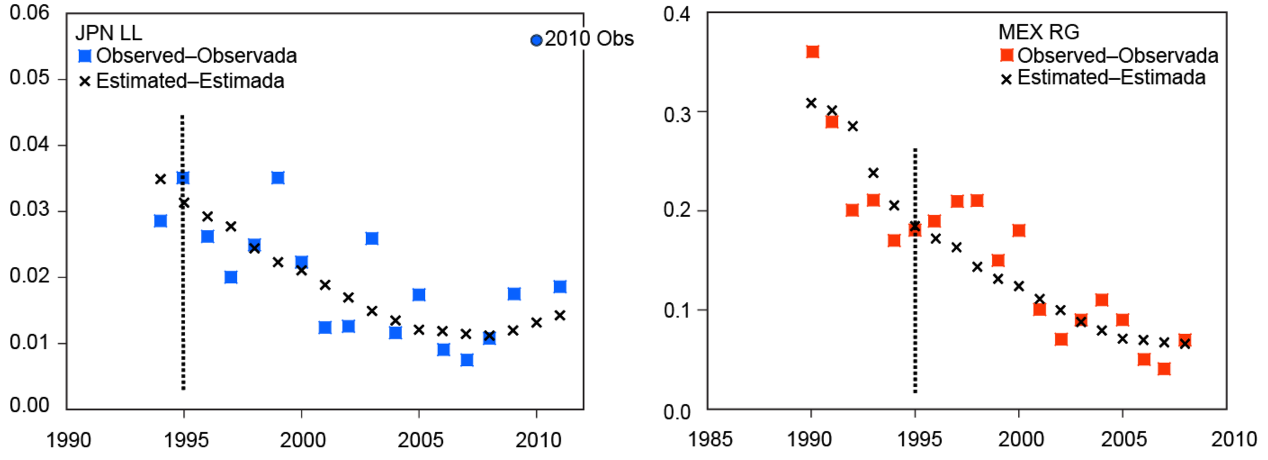

FIGURE 4.2.2. Observed and estimated catch rates for Japanese longline (JPN LL) and Mexican recreational (MEX RG) fisheries. The 2010 observation in the JPN LL series was not included in the analyses.

Nominal indices of abundance based on sailfish taken in dolphin-associated (DEL) and unassociated (NOA) purse-seine operations were estimated as the multiple of the probability that a sailfish would be observed in a set (a positive set) and the average catch-per-set in positive sets. These indices for sets made in waters with sea surface temperature greater than 28°C are presented in Figure 4.2.3, along with the estimated DEL and NOA indices from the fitted model. In contrast to the JPN LL and MEX RG indices, the estimated trends do not follow the purse-seine abundance indices during 1993-2011.

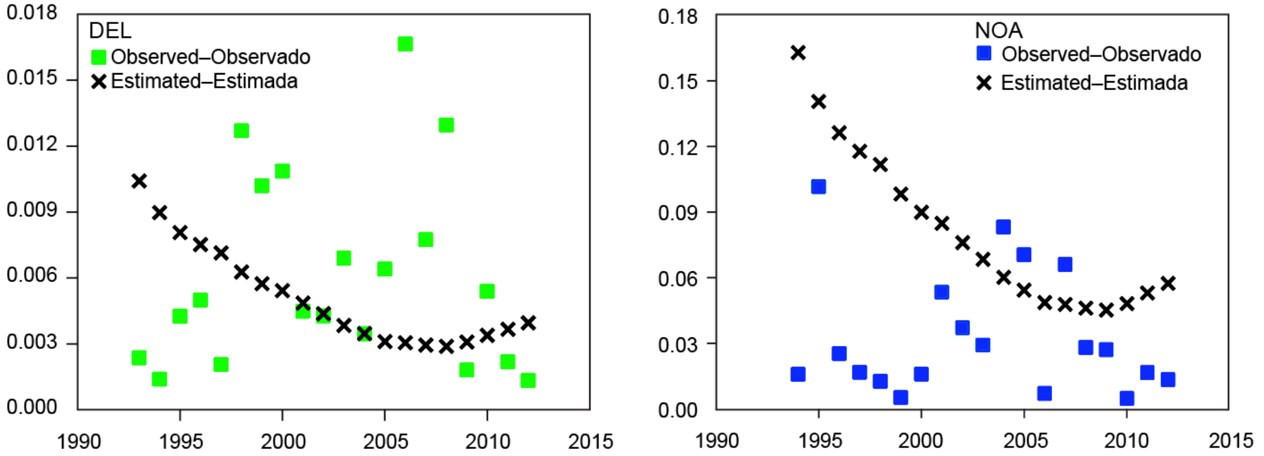

FIGURE 4.2.3. Nominal abundance indices for dolphin (DEL) associated and unassociated (NOA) sets made in waters with SST > 28°C, 1993-2012, and the estimated trends from the fitted model.

4.3. Comparisons to external data sources

No comparisons to external data were made in this assessment.

4.4. Comparison to previous assessment

There was no previous assessment of sailfish in the EPO.

5. STOCK STATUS AND RECOMMENDATIONS

The objective of the Antigua Convention is to "… ensure the long-term conservation and sustainable use of the fish stocks covered by [the] Convention, in accordance with the relevant rules of international law, …" and calls on the Members of the Commission to "… determine whether, according to the best scientific information available, a specific fish stock … is fully fished or overfished and, on this basis, whether an increase in fishing capacity and/or the level of fishing effort would threaten the conservation of that stock."

It is not possible to determine the status of the sailfish stock in the EPO based on the results of this assessment, because the values of commonly-used management parameters, such as MSY, that are used in making these determinations cannot in this case be derived from the model results because the results do not provide reliable information on stock productivity and the biomass level corresponding to MSY.

Based on the indices used in the model, the abundance of sailfish trended downward over 1994-2009, after which it remained relatively constant or increased slightly, based on the single abundance index available after 2009.

The reported level of recent catch is on the order of 500 t, which is significantly less than the average reported annual catch of about 2,100 t during 1993-2007. Considering the fisheries of the EPO, the actual catch prior to 1993 was likely at least on the order of the recent average annual catch.. Since the current level of harvest has continued for a long period of time, it is expected that the stock condition will not deteriorate if catch is not increased above current levels.

A precautionary approach that does not increase fishing effort directed at sailfish and which closely monitors catch is recommended. A reliable assessment of status and trends of the sailfish stock in the EPO is not possible without reliable estimates of catch.

It is recommended that historical data on catches of sailfish be obtained wherever possible, and that existing data from current fisheries, including recreational, smaller longline vessel operations, and artisanal fisheries, be identified for use in assessments.

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