Status of Pacific Billfish Stocks

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With the increasing worldwide importance of recreational fishing for billfishes, interest in the biological status of billfish populations has heightened. The first attempt at assessing their status on a Pacific-wide basis occurred at a workshop held in Honolulu, Hawaii, U.S.A., in 1977 (Shomura 1980). Indian Ocean billfish stocks were included in a 1979 stock assessment workshop held in Shimizu, Japan (FAO 1980).

This chapter updates the assessments of Pacific billfish by including both more recent data and logbook data from Korea and Taiwan. Additional objectives include determining whether Korean and Taiwanese data can be used to extend the assessment beyond 1980, when Japanese logbook data ceased being published, identifying gaps in the data, and pinpointing other shortcomings in the analyses of individual species. Species included in the study are Indo-Pacific blue marlin (*Makaira mazara*), black marlin (*M. indica*), striped marlin *Tetrapturus audax*), Indo-Pacific sailfish (*Istiophorus platypterus*), shortbill spearfish (*T. angustirostris*), and swordfish (*Xiphias gladius*).

The present assessments are based on a generalized production model (Pella and Tomlinson 1969), analysis of catch rates derived from logbooks, and total catch estimates from volumes of the *Yearbook of Fishery Statistics* published by the FAO (1947-). Steps in the analysis involve (1) selection of probable stock boundaries; (2) selection of index areas for computing estimates of abundance; (3) computation and comparison of these catch rates based on Japanese, Korean, and Taiwanese logbook data; (4) estimation of effective fishing effort; and (5) computation and evaluation of surplus production model estimates of maximum sustainable yield (MSY) and optimum fishing effort at MSY (f_{opt}). The following sections describe the data sources and the steps listed above.

Data Sources

Two basic types of data are used in this study, namely catch-and-effort statistics and estimates of total catch. The former is derived from logbooks and includes estimates of nominal fishing effort and the resulting number of billfishes caught by the Japanese, Korean, and Taiwanese tuna longline fisheries. Unpublished Japanese data for 1952-1961 were provided by the Far Seas Fisheries Research Laboratory (7-1, 5 Chō me Orido, Shimizu 424, Japan) in 1977, whereas data for 1962-1980 are based on logbook statistics published by the Fisheries Agency of Japan, Research Division. Korean data for 1966-1970 and 1975-1982 are based on statistics published by the National Fisheries Research & Development Agency. Lastly, Taiwanese data for 1967-1979 and 1983-1984 were taken from computer listings provided by the Institute of Oceanography, National Taiwan University (P.O. Box 23-13, Taipei, Taiwan, Republic of China).

The second type of data, namely total catch data in metric tons (t), is derived from volumes of the *Yearbook of Fishery Statistics* published by the FAO. These data are the official, total catch statistics submitted by the nations for their flag vessels. Statistics for the early years used in this study are actually modifications of the FAO statistics made during the 1977 workshop (Shomura 1980). Participants agreed upon species estimates of total Pacific catch for 1952-1963, when FAO statistics were not presented by ocean, and also of separate estimates for blue and black marlins for a few years when FAO published only combined statistics. The total catch data used in this study appear in Table 1 and include updates from recent FAO yearbooks.

Stock Structure

To determine stock structure and to select index areas for computing stock abundance, basic information on the distribution and stock structure of each of these billfishes was extracted from Nakamura (1974) and Shomura (1980). This information was supplemented with annual and quarterly plots of the geographical distribution (5° rectangles) of Japanese catch, fishing effort, and catch rates (simple ratios of annual catches and fishing effort) (unpubl. data).

Indo-Pacific Blue Marlin

In the Pacific Ocean, blue marlin appear to consist of a single stock centered about the Equator, with the poleward extent of its distribution varying seasonally (Shomura 1980). The highest catch rates typically occur along the Equator; high catch rates also occur with varying degrees of regularity in subtropical waters. Thus, I selected five potential index areas (Fig. 1): area 1 has the longest history of higher catch rates and substantial fishing effort, area 4 has a less consistent temporal distribution of fishing effort, and areas 2, 3, and 5 have substantial catches and catch rates in some years. Based on catch rates by index areas (Fig. 2), I selected area 1 for computing indices of stock abundance, although areas 3 or 4 could also have been used. Catch rates for the entire Pacific and area 2 (not shown in Figure 2 to remove clutter) are low throughout the time series and show little or no trend.

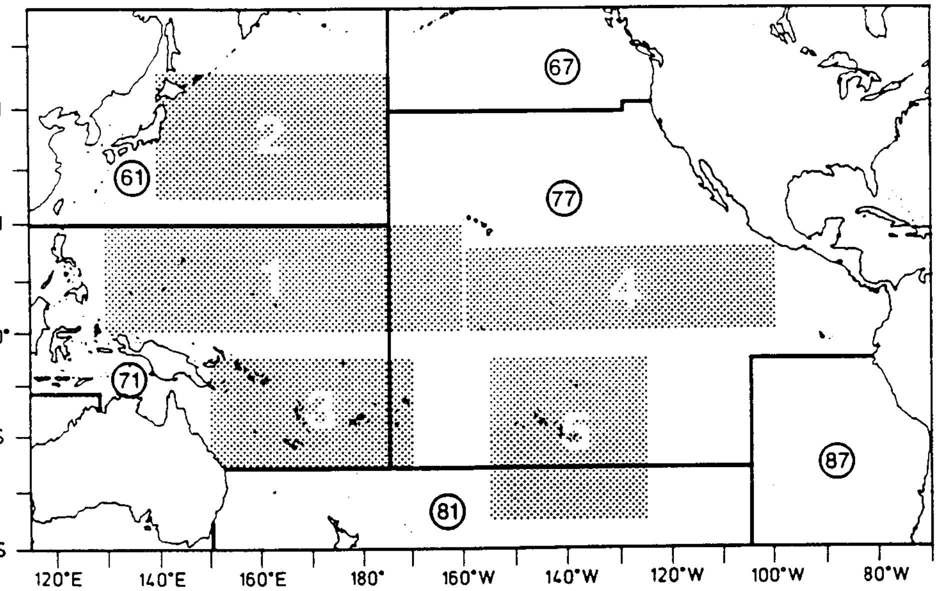
Black Marlin

The stock structure of black marlin is not known but may comprise several stocks on the eastern and western rims of the Pacific (Shomura 1980), and there may be exchange between Pacific and Indian Ocean stocks (FAO 1980). The distribution of catch rates suggest a single stock centered off Australia, with the species being widely distributed but not consistently abundant elsewhere. Hence, I set up four potential index areas (Fig. 1) and compared their catch rates (Fig. 2). Based on these results, and for lack of clear evidence to the contrary, I assume a single, Pacific-wide stock for the remainder of this analysis and use area 2 as the stock index area.

Table 1. Total Pacific billfish catch (in metric tons) by species and FAO statistical areas, 1952-85. Data were derived from Shomura (1980) and volumes of the Yearbook of Fishery Statistics *published by the Food and Agriculture Organization of the United Nations.*

Year	Blue marlin	Black marlin	Striped Marlin 61	71	77	81+87	All	Swordfish	Sailfish-Shortbill Spearfish 61+67	71	77	81	87	All
1952	15,525	1,806					4,992	11,339						2,300
1953	17,250	3,188					3,789	11,689						3,300
1954	10,519	5,370					7,256	13,392						2,400
1955	24,190	5,379					7,075	16,485						3,300
1956	18,770	6,466					7,724	12,584						3,200
1957	23,500	6,376					7,150	16,243						2,800
1958	22,106	4,548					8,999	21,341						3,400
1959	20,275	3,081					8,986	19,663						3,400
1960	18,155	2,721					7,362	23,409						5,000
1961	26,581	3,170					10,084	24,286						4,800
1962	20,743	4,066					13,685	14,604						6,800
1963	31,344	3,180					16,944	14,113						7,900
1964	23,233	2,805					23,480	10,112	3,700		2,100	300	0	6,100
1965	18,885	4,039	12,700		11,700	1,600	26,000	12,949	3,600		9,100	0	100	12,800
1966	18,588	3,729	9,600	1,900	9,500	3,500	24,500	14,601	3,800	1,200	5,900	0	100	11,000
1967	17,233	2,836	8,300	1,700	10,800	1,600	22,400	15,649	3,300	1,400	6,900	0	100	11,700
1968	15,283	2,362	10,200	1,200	11,400	2,700	25,500	15,230	4,800	400	6,100	0	1,200	12,500
1969	17,427	2,546	11,900	900	8,900	2,900	24,600	18,934	4,900	300	6,900	0	700	12,800
1970	20,115	2,207	11,000	1,300	11,100	2,400	25,800	15,727	3,700	300	[illegible]	0	200	9,100
1971	13,342	2,674	12,300	700	11,200	2,100	26,300	11,037	2,500	500	[illegible]	200	200	8,300
1972	15,300	3,424	3,800	800	7,600	2,000	14,200	11,029	2,000	800	[illegible]	0	100	8,600
1973	17,285	3,400	6,600	1,000	5,900	1,700	15,200	15,100	2,800	900	[illegible]	0	100	8,700
1974	15,594	2,665	6,287	591	5,846	2,176	14,900	14,622	1,959	539	[illegible]	57	29	7,737
1975	12,546	3,613	9,258	560	5,426	1,959	17,203	16,409	3,373	362	3,620	117	12	7,504
1976	12,611	3,086	5,676	328	5,961	2,034	13,999	19,322	2,708	514	10,187	92	59	13,670
1977	13,819	2,737	7,420	207	3,353	1,312	12,292	18,318	5,079	346	5,797	119	50	11,391
1978	15,398	3,796	8,472	691	2,507	1,263	12,933	18,032	3,778	851	5,425	40	31	10,125
1979	16,656	3,530	5,749	717	4,776	2,541	13,783	19,179	2,805	322	4,351	87	40	7,605
1980	19,029	2,120	7,454	904	5,134	2,292	15,784	16,616	5,209	449	1,525	78	56	7,377
1981	19,378	2,136	6,748	901	3,715	3,493	14,857	15,937	3,760	566	566	139	26	5,057
1982	15,398	1,712	4,822	1,194	5,193	2,964	14,173	18,649	2,603	537	2,259	241	58	5,668
1983	14,317	2,216	4,355	664	3,949	1,715	10,683	18,770	3,687	436	1,828	116	79	6,145
1984	14,149	1,577	5,980	589	3,141	990	10,690	15,161	2,988	482	1,270	108	47	4,790
1985	17,609	1,572	6,766	1,108	2,307	850	11,031	19,468	3,250	443	724	13	14	4,274

BLUE MARLIN



BLACK MARLIN

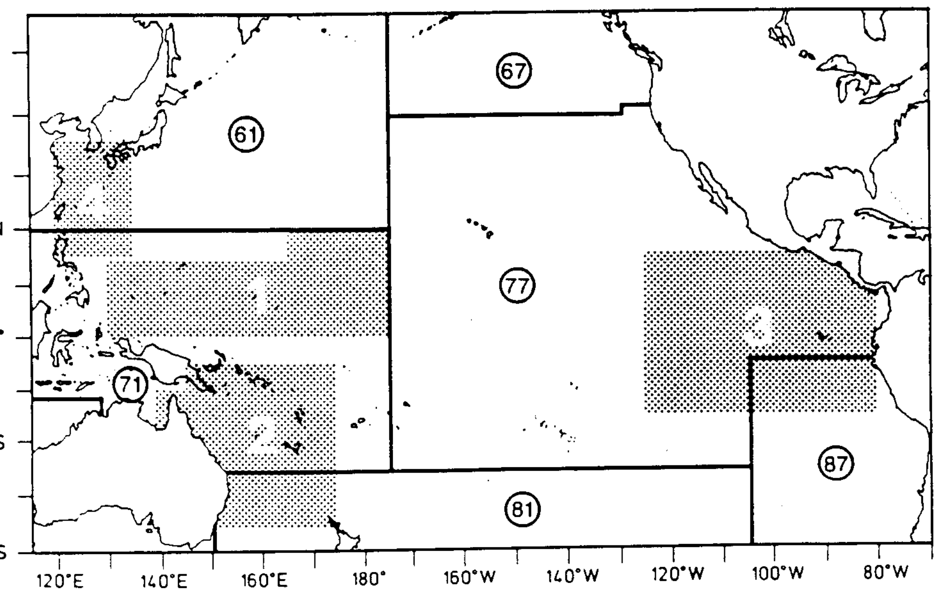
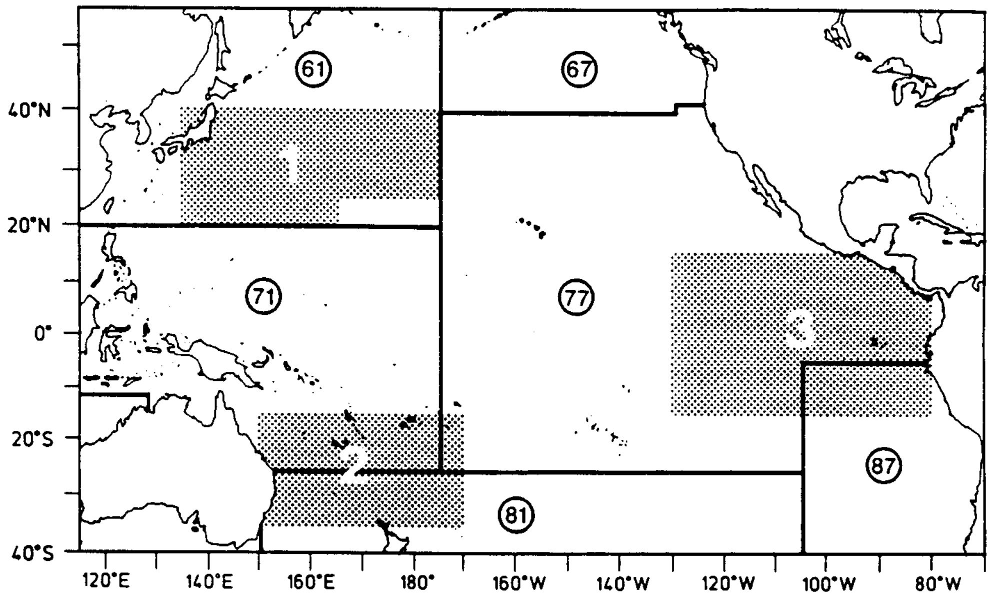
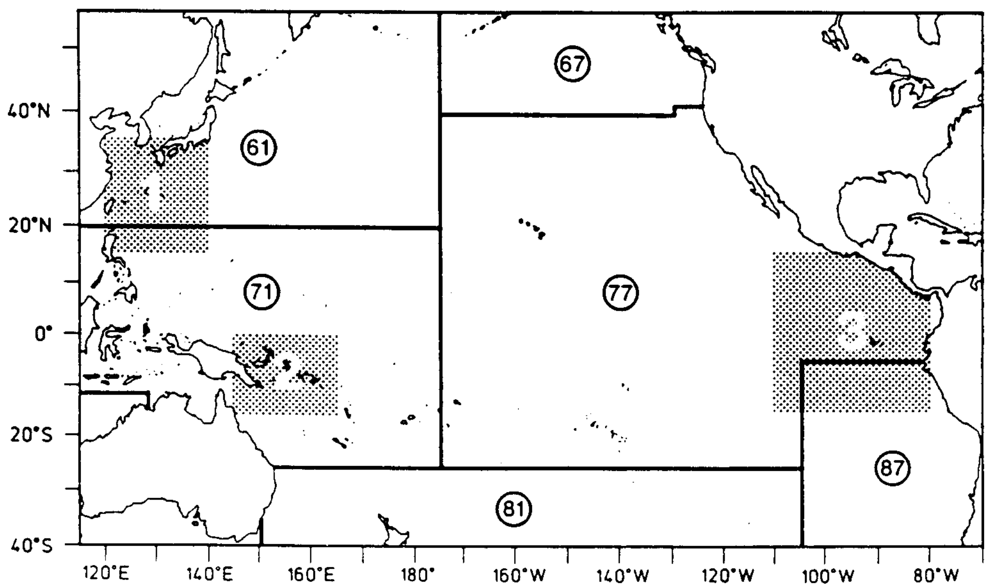


Figure 1. Index areas and Food and Agriculture Organization of the United Nations statistical areas.

STRIPED MARLIN



SAILFISH



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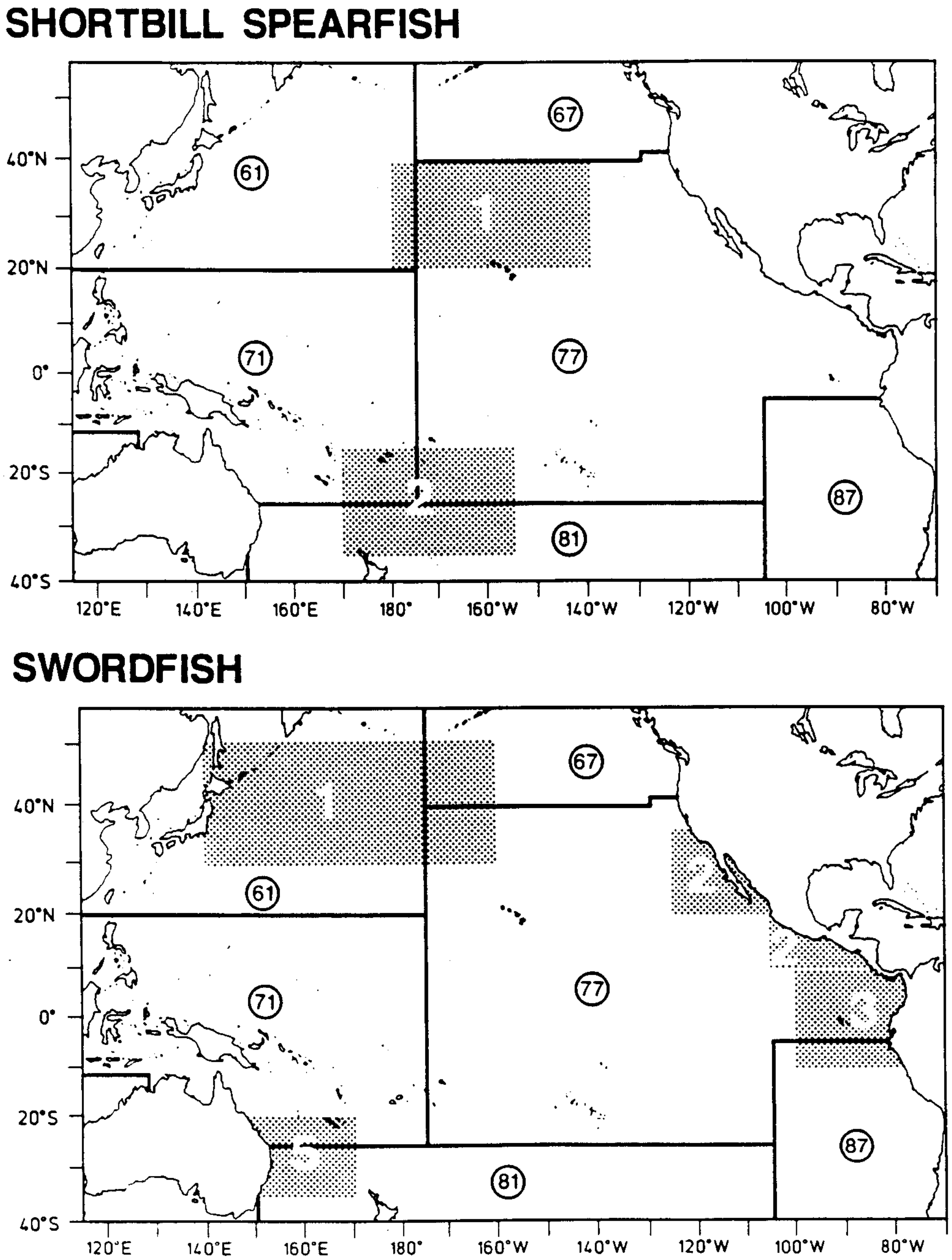

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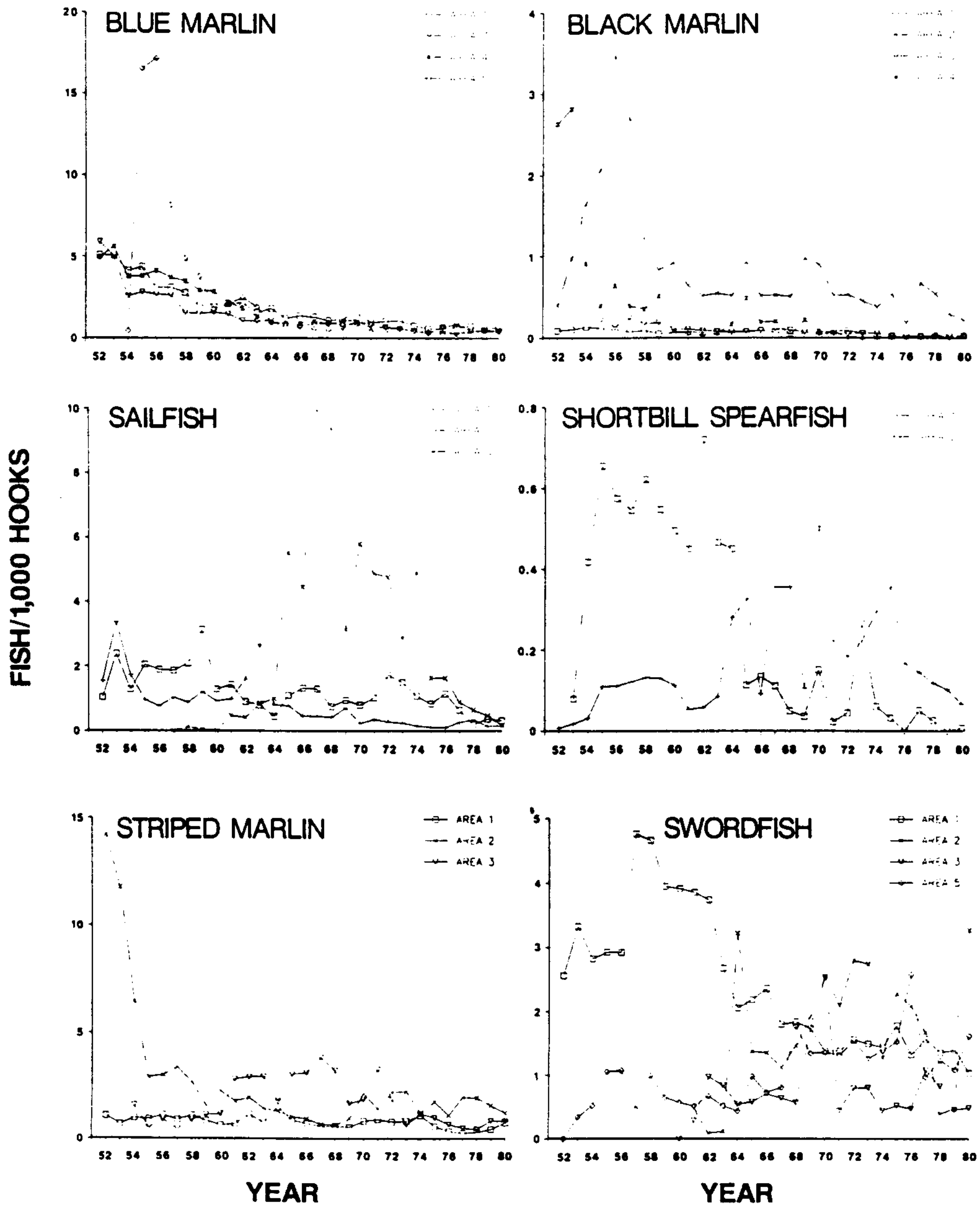

Figure 2. Historical trends in billfish catch rates by index areas.

Striped Marlin

Striped marlin may be composed either of separate north and south stocks or a single Pacific-wide stock (Shomura 1980). Consistent with either view is the distribution of catch rates, which are consistently high in the northern central Pacific, often in the southern central Pacific (frequently during the same quarters of the year), and also in eastern tropical Pacific waters on both sides of the Equator. Thus, I selected three potential index areas (Fig. 1) and compared the catch rates over time (Fig. 2). The catch rates in areas 1 and 2 are not correlated, but those in area 3 are negatively correlated with those in area 2 ($P < 0.05$). Thus, some evidence of separate north and south stocks exists, and assessment of this species was attempted accordingly.

Sailfish and Shortbill Spearfish

Very little is known about the stock structures of sailfish and shortbill spearfish. Assessment is difficult because statistics for the two species are reported together in both the distant-water logbook data and the FAO yearbooks. Sailfish are abundant along the American and Asian rims of the Pacific, indicating separate eastern and western stocks (Shomura 1980). Information presented by Nakamura (1974) suggests two western Pacific stocks. Based on these hypotheses, I set up three index areas (Fig. 1) and compared catch rates (Fig. 2), assuming the catch rates in these coastal areas represent mostly sailfish abundance. Because the three areas show dissimilar trends, I concluded there are three separate stocks.

Spearfish have a more oceanic distribution than sailfish and appear to have separate northern and southern central Pacific stocks. Based on this conjecture, I set up two potential index areas (Fig. 1) and compared the catch rates (Fig. 2), assuming catch rates in these pelagic areas represent mostly spearfish abundance. The two areas show dissimilar catch rate trends, thus lending support to the two-stock hypothesis.

Swordfish

Swordfish may consist of a single, Pacific-wide stock or northwestern, southwestern and eastern Pacific stocks (Shomura 1980). Plots of catch-rate data suggest a single stock centered in the northwest Pacific that extends over the entire Pacific at lower densities; higher catches occur in some coastal fisheries. After setting up four potential index areas (Fig. 1) and comparing their catch rates (Fig. 2), I concluded that swordfish consist of a single Pacific-wide stock and used area 1 as the index area.

Extending the Time Series

The Japanese catch-and-effort statistics, which have served as the mainstay of stock assessment efforts for tunas and billfishes, are no longer published. Therefore, I explored whether Korean and Taiwanese tuna longline statistics could be used to extend the Japanese time series beyond 1980. This evaluation was conducted for each species by plotting the annual ratio of average catch rate (fish/1,000 hooks) for the selected index area and by calculating the coefficient of correlation for the years of overlap among the different national data series. The interrupted nature of the Korean and Taiwanese data complicates the interpretation of the results; also, these countries entered the tuna longline fishery after much of the decline in abundance of billfishes had occurred.

Starting with blue marlin in index area 1 (Fig. 3), the time series for Japan and Korea are significantly correlated ($r = 0.767$, $P < 0.05$), while other possible comparisons are not significant ($r = -0.241$, Japan-Taiwan; $r = 0.024$, Taiwan-Korean; $P > 0.05$). Paired t-tests show, as expected, that the catch rates for Japan are significantly higher than those for Korea and Taiwan ($t = 7.517$ and 3.863, respectively; $P < 0.01$), while those for Korea and Taiwan are not significantly different ($t = 2.138$, $P > 0.05$). These statistics indicate that Korean data could be used to extend the time series by 2 years, but they must be scaled to the Japanese time series.

For black marlin in index area 2 (Fig. 3), none of the time series is significantly correlated ($r = -0.502$, Taiwan-Japan; $r = -0.756$, Korea-Taiwan; $r = -0.568$, Japan-Korea; $P > 0.05$). Korean and Taiwanese data cannot be used to extend the Japanese time series.

For striped marlin, I compared the statistics by using a composite of index areas 1, 2, and 3, rather than each area separately (Fig. 3). As with blue marlin, the Japanese catch rates were significantly greater than those for Korea and Taiwan (paired t-test $= 6.836$ and 8.289, respectively; $P < 0.01$), but were correlated with those for Taiwan ($r = 0.654$, $P < 0.05$) rather than Korea $r = 0.040$, $P > 0.05$). Thus, the Taiwanese data could, once scaled, be used to extend the time series; however, a 3-year gap

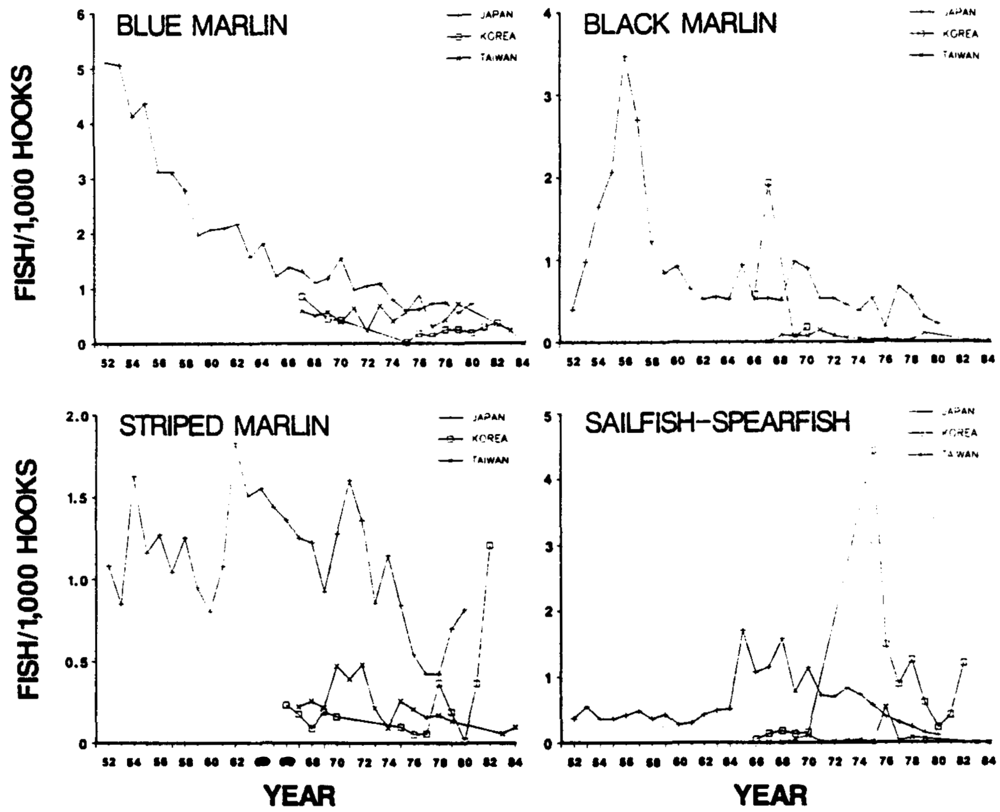

Figure 3. Comparison of Japanese, Korean, and Taiwanese catch rates of blue marlin (index area 1), black marlin (index area 2), striped marlin (index areas 1, 2, and 3 combined), and sailfish-shortbill spearfish (entire Pacific).

exists between the end of the Japanese time series and the last two Taiwanese data points.

For sailfish and spearfish combined, the catch rate trends are quite dissimilar (Fig. 3), indicating that neither Korean nor Taiwanese data can be used to extend the Japanese time series.

For swordfish in index area 1, Taiwan reported catches for only 1 year, and the Japanese and low Korean catch rates are quite dissimilar. For a composite of all the potential index areas, none of the time series is correlated ($r=0.377$, Japan-Korea; $r=0.211$, Japan-Taiwan; $r=0.654$, Korea-Taiwan; $P > 0.05$). Thus, Korean and Taiwanese data cannot be used to extend the time series.

Based on these results, the Korean and Taiwanese data for billfishes are not of sufficient quality to extend the published Japanese time series. A couple of significant correlations out of 16 comparisons is not sufficient to convince me that these data can be used to assess the status of any of the billfish stock.

Some Conversions Before Fitting the Production Model

The most straightforward situation in fitting the surplus production model is when one has a complete time series of estimates of fishing effort and the resultant weight of fish caught. This situation rarely, if ever, exists. While reasonably good estimates of the weight of the various billfishes caught are available, catch-and-effort statistics are available for only the generally predominant fishing method (tuna longline) and then effectively for only one of the nations (Japan). Thus, I followed the common procedure of computing catch rates from available catch-and-effort statistics, dividing

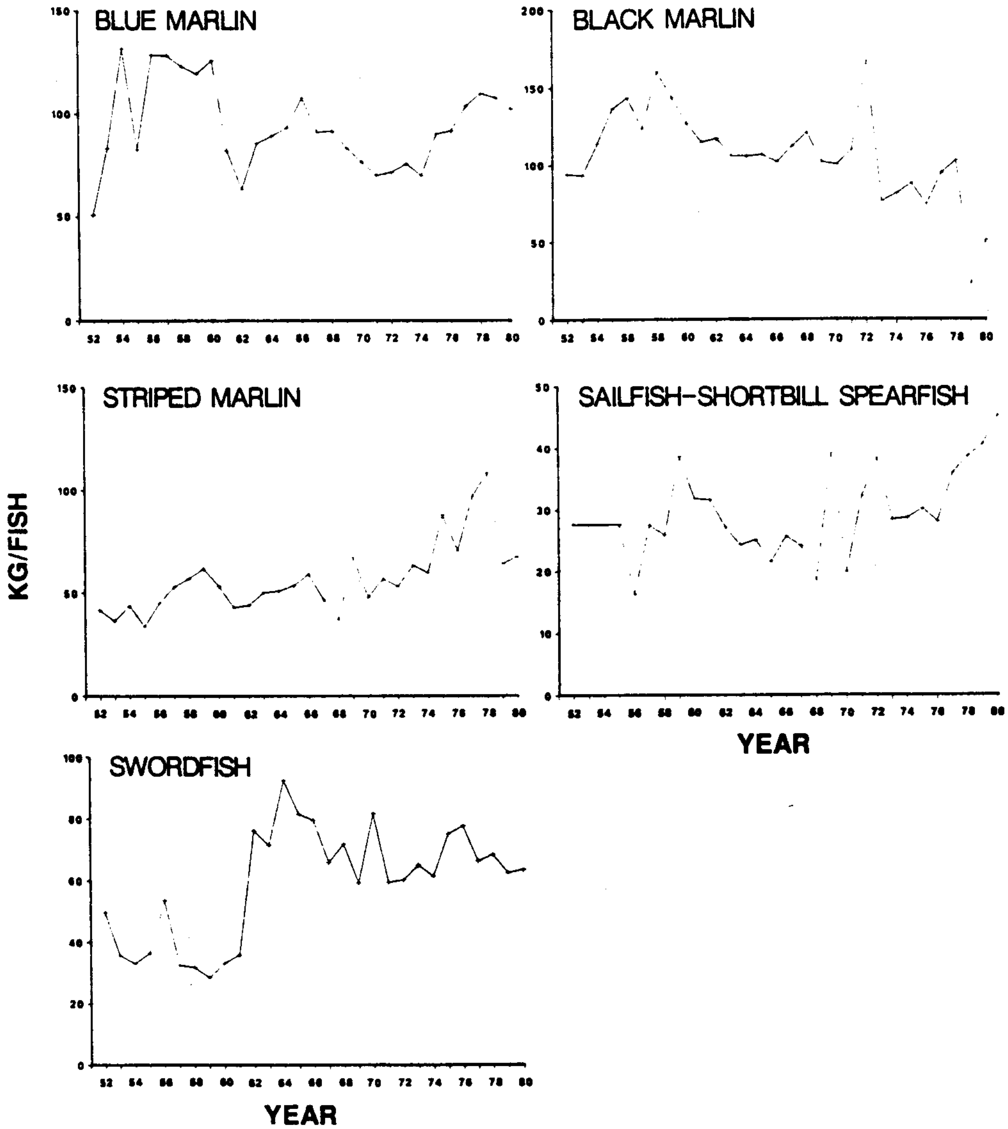

Figure 4. Billfish average weight statistics.

this rate into total catch to obtain an estimate of the total effective effort and then using the estimated total effective effort and total catch to assess the stock. To use this procedure for billfishes (and tunas, for that matter), catch rates must be converted from number of fish per 1,000 hooks to the weight units used for the total catch estimates.

Average Weights

Average weight statistics used to convert the catch rates from number of fish per 1,000 hooks to weight per 1,000 hooks were calculated as follows. Estimates of the number of fish caught, from the Japanese logbook data, were raised to the estimated total number of fish caught for all nations, based on the percent Japanese contribution to the total catch in weight reported for all nations in the FAO yearbooks. This estimate of total number of fish caught was then divided into the FAO estimate of total weight (in metric tons) to estimate average weight. Since this can be done only for the FAO statistical areas, or for the entire Pacific Ocean, it is not possible to assess the status of some of the hypothesized stocks and modifications had to be made for others.

Indo-Pacific Blue Marlin. The trend in Pacific-wide average weight statistics for blue marlin (Fig. 4) appears reasonable, except possibly at the start and end of the series. At the start of the series, the values appear lower than expected from the trend following. After 1975, average weight increases; this change in trend could be caused by reduced fishing pressure, changes in fleet make up or fishing strategy, or even diminished recruitment due to random events or excessive fishing pressure.

Black Marlin. Estimated average weight of black marlin for the entire Pacific follows a downward trend, particularly in the last few years (Fig. 4). Again, average weight in the first few years in the series appears to be too low given the remainder of the series.

Striped Marlin. For striped marlin, the average size statistics using Pacific-wide data (Fig. 4) show an increasing trend throughout the history of the fishery. Since this trend is the opposite of that expected for heavily exploited stocks, the reliability of the statistics and the validity of any production model fit to the data are suspect. Such a trend might be due to changes in fleet make up or fishing strategy, mismatching (in time) of the logbook and total catch data, or underreporting of tuna longline logbook data. Suzuki (pers. commun.) notes that changes in the average size statistics coincide with increases in the drift-net fishery targeting striped marlin off Japan.

Sailfish-Shortbill Spearfish. The combined reporting of sailfish and shortbill spearfish total catches by FAO and the distribution of the index areas for sailfish and spearfish with respect to the FAO statistical areas (Fig. 1) make average weight statistics impossible to compute for either species. Thus, average size statistics are computed on a Pacific-wide basis for the two species combined. The statistics are variable but show no obvious trend, except for the last several years when sizes increased (Fig. 4).

Swordfish. The average weight trend (Fig. 4) for swordfish on a Pacific-wide basis exhibits a discontinuity between 1961 and 1962. This is when Japan changed to a new statistical system, and about when day setting of longline gear in the Japanese swordfish fishery replaced night setting. After 1962, the trend is gradually toward smaller sizes, which is consistent with a stock exposed to increased fishing pressure.

Effects of Deep Longlining Gear

Use of deep longlining gear, which is designed to place more hooks in deeper water where bigeye tuna and albacore are most abundant, began in about 1974 and increased thereafter. This trend resulted in problems in assessing billfishes. The gear is less efficient at capturing surface-dwelling billfishes (Suzuki and Warashina unpub.), so lower billfish catch rates could be due to use of this gear. The efficiency of deep longling gear has been determined for most billfishes, but the relative proportions of deep and traditional longline gear used have not been documented for any of the distant-water fishing fleets. Thus, a direct means of correcting the catch rate statistics is not available, but it is possible to simulate different scenarios.

Assuming that deep longlining gear was first introduced into the fishery in 1974, and that its use increased slowly at first and then more rapidly by 1980, I examined two hypothetical situations. In the first, the efficiency of the total longline fishery for catching billfish was reduced by 25% by 1980 and, in the second, by 50% (Table 2). These relative efficiency factors were divided into the annual catch rate statistics, and then these adjusted abundance estimates were used, along with the corresponding adjusted estimates of effective effort, to fit the surplus production model.

Table 2. Two scenarios for the effect of deep longline gear on the catch rates of billfishes: i.e., 25% and 50% less than what the catch rates would have been if traditional longline gear had been used exclusively.

Year	25%	50%
1973	1.0	1.0
1974	0.97	0.95
1975	0.94	0.90
1976	0.91	0.85
1977	0.88	0.80
1978	0.84	0.70
1979	0.80	0.60
1980	0.75	0.50

Equilibrium Approximation

To approximate equilibrium conditions, estimated effective effort was adjusted according to the method of Gulland (1969). That is, for each species, the annual effective effort was replaced by the average of that year's effort and k - 1 preceding years, where k is the number of years a year-class was reckoned to contribute significantly to the fishery.

Surplus Production Modeling

The generalized surplus production model in the form of

$$Y/EF = (MSY/f_{opt})\,[m + (1-m)\,(EF/f_{opt})]^{1/(m-1)}$$

(Wetherall and Yong 1984) — where Y/EF = catch rate or index of abundance (kg/1,000 hooks), EF = adjusted effective effort (in millions of hooks), and m = the shape parameter of the production curve — was fit by nonlinear least squares to obtain estimates of MSY, the optimum level of fishing effort at (f_{opt}) MSY, and the shape parameter (m). In addition, MSY and f_{opt} were estimated with m fixed at 0 (which assumes that catch rate versus effort curve is concave and that the yield curve is asymptotic), at 1 (since m cannot exactly equal 1, I used 1.0000001; the catch rate curve is slightly concave and the yield curve is skewed) and at 2 (catch rate curve is a straight line and the production curve is symmetrical).

Indo-Pacific Blue Marlin

For blue marlin, I used running averages of 2, 3, and 4 years on the effective effort statistics to approximate equilibrium conditions. Duplicate effort values were added to the beginning of the time series to preserve the number of years used in the assessment. However, since the results differed little, only that for the 3-year effort averaging is presented (Table 3). Although the gear effectiveness adjustments shifted the post-1974 data points from the extreme right side of the production curve progressively more to the left, the effect of these adjustments on the parameter estimates was much less than the effect of m. When m was allowed to vary freely, the nonlinear fitting procedure rarely converged. When convergence did occur, the parameter estimates and the regression mean square were lower than when m was fixed at 1 or 2. When m was set at 0, convergence did not occur. The parameter estimates differed little (<1,900 t for 25% gear effectiveness) whether m was fixed at 1 or 2, undoubtedly because of the relatively flat shape of the production curve (Fig. 5). The MSY appears to be about 20,000 to 24,000 t with f_{opt} at about 100 to 140 million hooks.

Table 3. Surplus production model parameter estimates for blue marlin, $k = 3$.

m	MSY (in metric tons)	f_{opt} (in millions of hooks)	Regression mean square
	Unadjusted		
Free 0.3	19,246	70.9	240.9
Fixed 0.0	No solution		
Fixed 1.0	21,734	105.6	361.2
Fixed 2.0	23,757	141.4	360.6
	25% Gear Efficiency		
Free	No solution		
Fixed 0.0	No solution		
Fixed 1.0	21,589	103.0	365.6
Fixed 2.0	23,468	134.6	365.0
	50% Gear Efficiency		
Free	No solution		
Fixed 0.0	No solution		
Fixed 1.0	21,478	103.1	370.6
Fixed 2.0	23,265	133.5	370.1

Black and Striped Marlins

No attempt was made to fit a surplus production model for black marlin because total catch data did not vary with increasing effective effort (Fig. 6).

I attempted to fit the surplus production model ($k = 4$ for equilibrium averaging) to the striped marlin data, but no solution could be found for any of the shape parameter or gear efficiency adjustments. The production data are too linear for the model to be successfully fit (Fig. 6).

Sailfish-Shortbill Spearfish

Effort was smoothed over 2 years to approximate equilibrium conditions. The gear efficiency adjustments have a substantial effect on the parameter estimates, increasing both the estimates of MSY and f_{opt} (Table 4). The production curve (Fig. 5) suggests that the composite

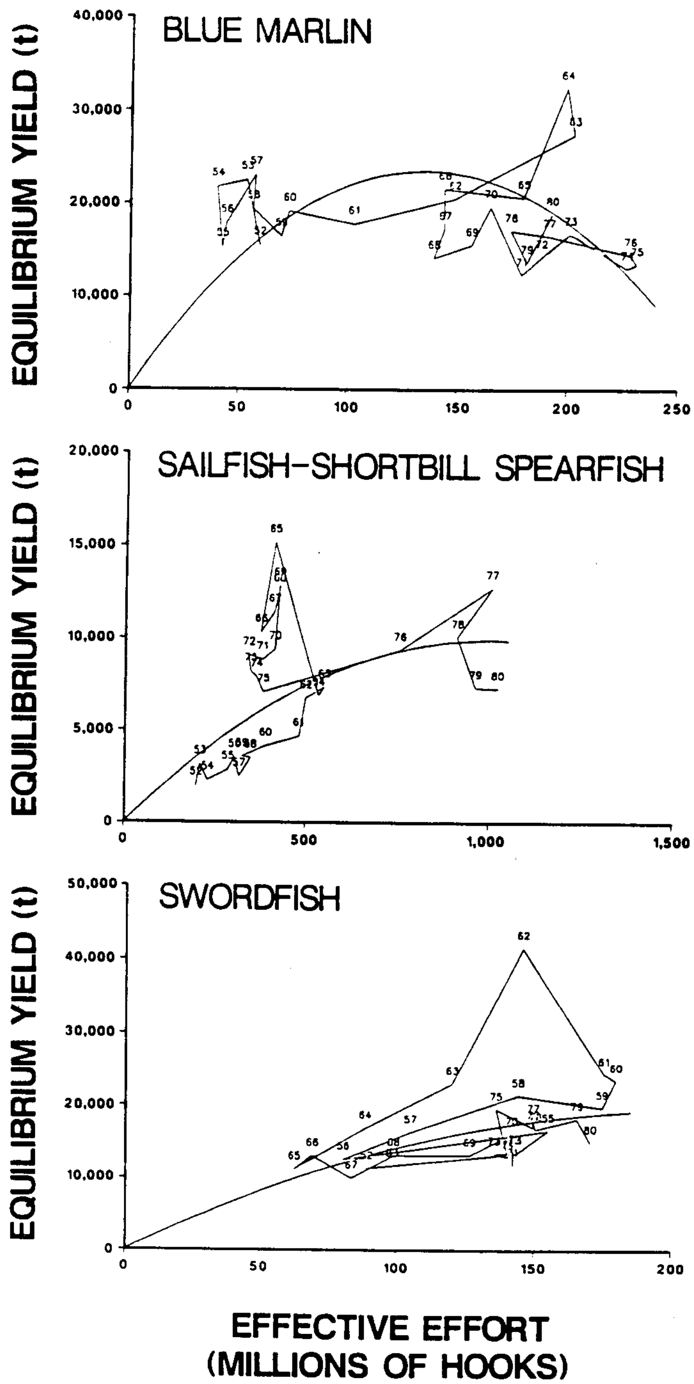

Figure 5. Surplus production using 25% gear efficiency model curves with observed (smoothed and adjusted data for blue marlin ($k = 3$, $m = 2$), sailfish-shortbill spearfish ($k = 2$, $m = 2$), and swordfish $k = 1$ and 4, $m = 2$).

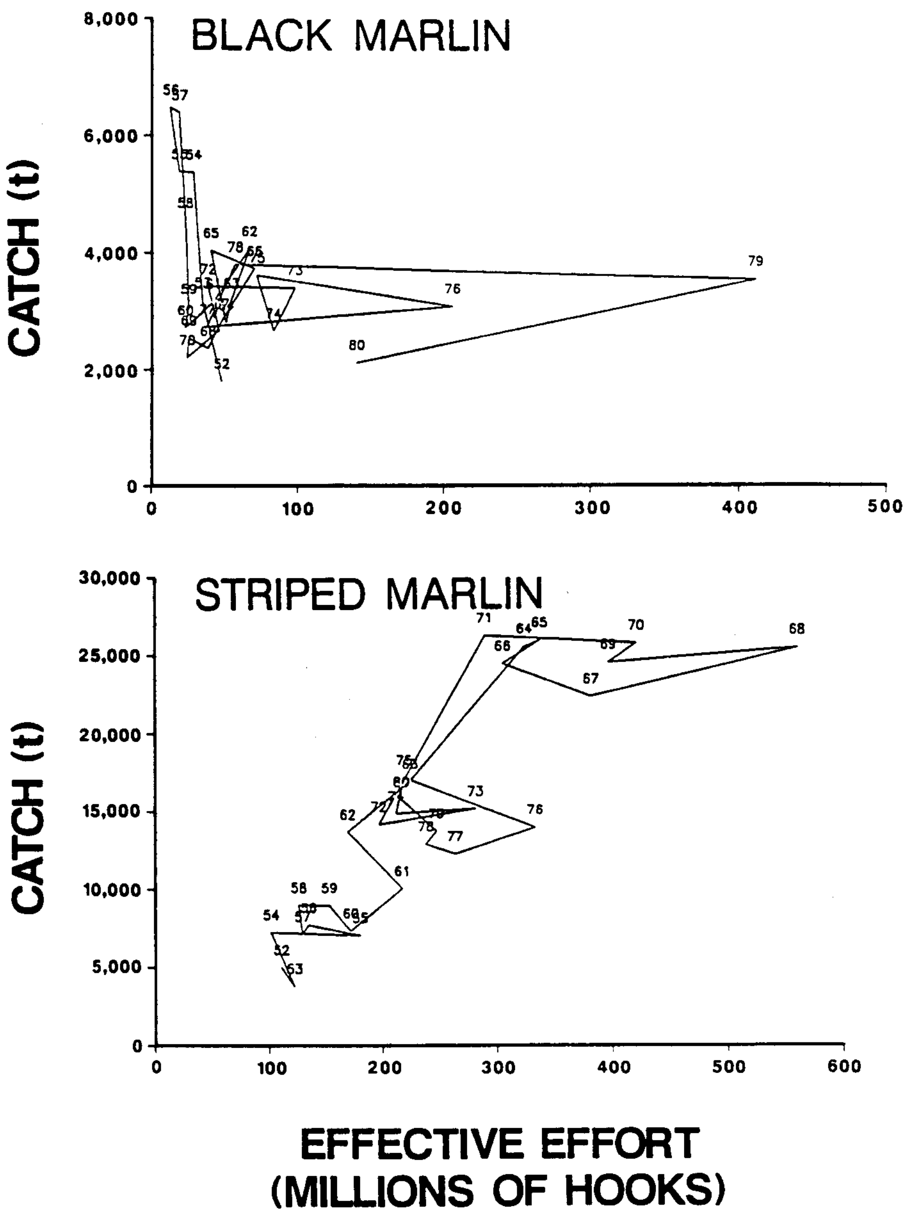

Figure 6. Production model data for black and striped marlins, assuming 25% gear efficiency.

fishery for these two species is still on the ascending limb.

Table 4. Surplus production model parameter estimates for sailfish and shortbill spearfish combined, $k = 2$.

m	MSY (in metric tons)	f_{opt} (in millions of hooks)	Regression mean square
	Unadjusted		
Free 3.0	10,361	954.7	69.5
Fixed 0.0	19,010	∞	104.0
Fixed 1.0	9,903	1,253.6	104.1
Fixed 2.0	9,608	954.8	104.2
	25% Gear Efficiency		
Free 3.0	9,686	876.3	70.9
Fixed 0.0	26,091	∞	106.3
Fixed 1.0	11,585	1,562.3	106.3
Fixed 2.0	9,884	1,000.0	106.4
	50% Gear Efficiency		
Free 3.0	13,492	1,322.9	72.7
Fixed 0.0	68,919	∞	109.0
Fixed 1.0	24,708	3,860.4	109.0
Fixed 2.0	16,762	1,907.5	109.0

Swordfish

Fishing effort was not averaged from 1952 through 1961, when the Japanese night fishery predominated and the average size was small (Fig. 4); thereafter, a k value of 4 years was used to approximate equilibrium conditions. The adjustments for gear efficiency had a large effect on the parameter estimates, generally increasing estimates of both MSY and f_{opt} while decreasing the shape parameter estimate (Table 5). When m was fixed at 0, valid solutions did not result. As the value of m decreased (whether fixed or estimated), the estimates of MSY and f_{opt} increased. The Pacific-wide stock of swordfish appears to be in good health, with the fishery operating at about the MSY level (Fig. 5).

Table 5. Surplus production model parameter estimates for swordfish, $k = 1$ through 1961 and $k = 4$ thereafter.

m	MSY (in metric tons)	f_{opt} (in millions of hooks)	Regression mean square
	Unadjusted		
Free 3.0	17,852	167.5	224.0
Fixed 0.0	27,952	∞	335.9
Fixed 1.0	18,219	219.5	335.9
Fixed 2.0	17,703	176.8	336.0
	25% Gear Efficiency		
Free 0.3	24,274	588.9	227.0
Fixed 0.0	34,677	∞	340.6
Fixed 1.0	20,583	274.4	340.6
Fixed 2.0	19,266	206.7	340.6
	50% Gear Efficiency		
Free 0.4	27,217	574.8	230.6
Fixed 0.0	43,126	∞	345.8
Fixed 1.0	23,765	335.6	345.8
Fixed 2.0	21,543	239.1	345.8

Discussion

Indo-Pacific Blue Marlin

Fitting the surplus production model was more successful with the blue marlin data than with data for any other species. In contrast to the other situations, the fishery for blue marlin has gone through a developmental phase, passed the MSY level, and tested the downward limb of the production curve. Use of the equatorial western Pacific index area for calculating catch rate is supported by the successful fit of the model. The large deviation of the 1963-1964 data points from the production curve (for the unsmoothed data, 1962-1963) is notable since the fishery apparently first exceeded the MSY level at about that time. If these data are in error, it is an inopportune time with respect to fitting the model. Since 1975, the adjusted, estimated effective effort statistics have declined, and yield has increased slightly, indicating some recovery of the stock. This view is also supported by the increase in average weights (Fig. 4).

The blue marlin stock still appears to be overfished, with more effort expended than is needed to take the MSY. The situation improved during the late 1970s, and further improvement should occur with the continued decline in the tuna longline fleets and increased use of deep longline gear. Given the corresponding increase in the tuna purse-seine fleets, which catch billfish incidentally, more current longline and purse-seine data are needed to monitor stock condition and to determine fishery interactions. The increase in average weight of blue marlin and the estimated decrease in effective longline effort should be welcome news to recreational fishermen and managers alike.

Black Marlin

From the shape of the catch-rate time series plot (Fig. 2) and the average size statistics (Fig. 4), the lack of a relationship in the production model data is surprising (Fig. 6). With these data, assessing the status of the stock is not possible. Independently derived catch-rate data should be sought since, even by billfish standards, black marlin are an incidental or rare species in the tuna longline fisheries, and catch rate computed from these statistics may not be a good index of abundance. In addition, total catch statistics may be underestimates because of continuing problems in the separation of black and blue marlins in the statistics submitted to FAO (Suzuki pers. commun.).

Striped Marlin

The fishery, assuming a single Pacific-wide stock, reached its highest level of development during the late 1960s and early 1970s, but it is still operating on the ascending limb of the production curve. Post-1974 data seem to fall in the middle of the ascending limb, particularly after adjusting for the use of deep longline gear. Thus, the Pacific fishery for striped marlin is apparently still in the development stage, and the MSY level has not yet been approached by the fishery. In fact, the pressure on the stock in the late 1970s to 1980 appears to have been less than in the late 1960s.

The increasing trend in the average size statistics (Fig. 4) casts doubt on the quality of the statistics and may have led to the failure to fit the surplus production model successfully. Independently obtained average-size statistics are needed both to assess the resource under the assumption of north and south stocks and to investigate the validity of the assessment assuming a single Pacific-wide stock. Data on the drift gill-net fishery conducted off Japan need to be made available and incorporated into the analysis.

Sailfish

As indicated above, surplus production model assessment of the three presumed stocks of sailfish is not possible because of the broad nature of the FAO statistical areas and the reporting of sailfish and spearfish catches together in both the logbook and total catch statistics. However, the trend in the catch-rate statistics (Fig. 2) provides some information on the probable condition of one of the stocks. For index area 3, which is in the eastern tropical Pacific, catch rates were low during the beginning of the time series, increased drastically in 1966, suggesting that the resource was "discovered" commercially, then declined possibly because of excessive fishing pressure in prior years or a loss of interest by the fishing fleets. If the decline was due to fishing, then the fishery had a substantial effect on the density of the stock during the last 10 to 15 years of the time series, resulting in the stock now being at a much reduced level. The catch-rate trends for the other stocks do not show much variation over time and probably would not result in valid surplus production model estimates even if the data were available. If these sailfish stocks are to be assessed, fishery statistics specific to this species and these stocks must be obtained.

Shortbill Spearfish

As with sailfish, assessing the status of shortbill spearfish was not possible with the surplus production model because of the combined nature of the statistics and the relationship between the chosen index areas and the FAO statistical area (Fig. 1). The historical trend of catch rates for the hypothesized northern stock (area 1 in Fig. 2) shows fluctuating but increased abundance during the middle years of the time series, with the catch rate returning to previous levels by 1980. The catch rates are quite low throughout the time series, even by billfish standards, suggesting that the stock has not been seriously impacted by the tuna longline fishery and probably is in reasonably good shape. The Asian squid drift gill-net fishery, although operating mostly north of the index area for the northern stock of spearfish, may be of some concern.

For the assumed southern stocks, the trend in catch rates is more difficult to interpret (area 2 in Fig. 2) but may be related to changes in species targeting. Catch rates increased rapidly as the Japanese entered the south Pacific longline fishery for albacore and remained high until they began leaving the fishery (Skillman 1975), after which catch rate dropped precipitously. The real trend in abundance of this assumed stock is not clear from the available statistics.

Sailfish-Shortbill Spearfish Combined

Surplus production model assessment, using data for the entire Pacific, suggests that the combined fishery for sailfish and shortbill spearfish (Fig. 5) is still on the ascending limb of the production curve but closely approaching the MSY level of 10,000 to 12,000 t. This result implies that sailfish stocks are to some degree overharvested, since overharvesting of the spearfish is doubtful. Although the surplus production model fits the combined data reasonably well, investigating the 1965-1975 data, which deviate in a consistent fashion from the production model curve, might be informative.

Swordfish

The surplus production model assessment of this fishery indicates that the assumed, single Pacific-wide stock is being harvested below

MSY (Fig. 5). As indicated by the average weight statistics (Fig. 4) and the production curve, this fishery apparently has had three phases. First, a night-set longline fishery for small fish predominated from 1952 to 1961, and the fishery expanded, nearly reaching the estimated MSY. With the introduction, in 1962, of the day-set longline fishery, which harvests larger fish, catches exceeded the former production levels even as total effective effort declined through 1965. After that, fishing effort expanded, and the catches moved up the ascending limb of the production curve, but at a level comparable with those in the first period (1956-1961) for smaller fish.

Since deep longline gear has less effect on swordfish catches than any other billfish catches (Suzuki and Warashina unpub.), the production model for unadjusted data may be more appropriate. Since this choice leaves the data for the last few years out on the right limb of the production curve, the estimates of MSY and f_{opt} are reduced to about 18,000 t and 200 million hooks, respectively, and the fishery seems to be at about the point of MSY and f_{opt}. To improve this assessment, detailed information on fleet composition, fishing strategy, and fishing gear, including deep longline gear, must become available.

General

The status of most billfishes in the Pacific seems to have improved from 1975 to 1980, although the blue marlin is still being overharvested and swordfish and sailfish may be approaching that condition.

Japan is ceasing to release its data for use by the international community and is reducing the size of its tuna longline fleet. Korean and Taiwanese data have thus become more important for the assessment of billfish and tuna stocks. Consequently, the quality of Korean and Taiwanese tuna longline statistics must be improved, for example, by increasing fleet coverage and by accurately recording billfish catches. Because assessing some of the billfish stocks seems possible by employing the index area method, I propose that judicious selection of index areas would allow the international fishery community to continue monitoring the status of billfish stocks without compromising Japan's position in international and bilateral management negotiations.

Nations should strive to obtain separate statistics for blue and black marlins as well as for sailfish and shortbill spearfish. Coverage of coastal fisheries for swordfish could also be improved. Statistics from gill-net fisheries, whether billfishes are targeted or incidentally caught, and from purse-seine fisheries need to be made available.

The FAO fishery statistical areas for reporting total catches may be appropriate for coastal pelagic and demersal resources, but must be revised to facilitate assessment of offshore pelagic resources like billfishes and tunas. In the Pacific, area 77 is particularly in need of subdivision into Northern and Southern Hemisphere areas. Also the boundary between areas 61 and 71 in the western Pacific may be too far north for a reasonable division of north and south pelagic stocks.

For all billfish species, size data must be collected directly from landings, compiled, and published. Doing so will place the assessments on much sounder ground and allow evaluation of some of the unexpected trends seen for average weights calculated from total catch and logbook data, for example, for striped marlin.

Modeling of the potential effects of deep longline gear indicates that incorporating data on this development would improve the fit and accuracy of the production models. Hence, the distant-water tuna longline nations should be encouraged to modify their data collection procedures accordingly and to publish the resulting data.

Summary

Surplus production model assessments were completed, using geographic index areas for computation of indices of stock abundance, for Pacific stocks of blue marlin, swordfish, and sailfish-shortbill spearfish combined. No attempt was made to fit the model to black marlin data, nor to sailfish and spearfish separately, because of data problems, and no satisfactory fit could be obtained for striped marlin. Average weight statistics, computed from reported logbook numbers and FAO weight statistics, did not always follow expected trends, particularly for striped marlin for which the computed average weight increased throughout the history of the fishery. The effect of deep longline gear was simulated using assumed 25% and 50% reductions in the effective catch rates for billfishes. In general, the status of billfish stocks seems to have improved in the latter part of the time

series, from the late 1970s to 1980s, as estimated total effective effort declined, particularly under the assumption of declining overall gear effectiveness with the more widespread use of deep tuna longline gear.

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