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AN ASSESSMENT OF PACIFIC BILLFISH STOCKS BASED ON THE GENERALIZED PRODUCTION MODEL

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INTRODUCTION

The purpose of this paper is to present results of a preliminary assessment of Pacific billfish stocks. Attention is focused primarily on blue marlin, *Makaira nigricans*, and striped marlin, *Tetrapturus audax*, but black marlin, *M. indica*, swordfish, *Xiphias gladius*, and sailfish-spearfish, *Istiophorus platypterus* and *T. angustirostris* combined, are also treated.

The assessments are based on a standard production model analysis of Japanese tuna longline data, and the status of each assumed stock is measured in terms of the usual criteria of maximum sustainable yield (MSY) and the associated "optimum" fishing effort (E_{opt}). The analysis rests on some assumptions which may be untenable. We do not study these in detail here; they will be examined in depth in another paper.

The basic procedure followed was to (1) adopt stock boundaries, (2) compute an index of abundance for each stock, and a measure of effective fishing effort, and (3) estimate the MSY and E_{opt} parameters of the production model using computer programs. The following sections outline the data sources, describe the assumed stock boundaries, and discuss the abundance indices. Finally, the production model results are presented and evaluated.

DATA SOURCES

Data on number of billfish caught and nominal effort (hooks fished) by month and 5° square were taken from published statistics of the Japanese tuna longline fishery for the years 1962-75. These were augmented by unpublished Japanese data for the period 1952-61 provided by the Far Seas Fisheries Research Laboratory. Tuna longline catch and effort statistics by month and 5° square were also available for the Chinese fishery for 1967-74 and for the Korean fishery over the period 1966-70. Information on total weight of Pacific billfish catch and/or landings was extracted from FAO yearbooks of fishery statistics for the 1952-75 period.

To ensure consistency and completeness indices of abundance were based solely on Japanese longline statistics. However, total catch figures were estimated on the basis of raising factors computed either from Chinese and Korean longline data or the FAO statistics.

In the FAO data tables, estimates of billfish catches in metric tons are given for each ocean from 1964 through 1975, but figures for earlier years are not separated by ocean. Estimates of Pacific billfish catches prior to 1964 were derived using appropriate adjustment factors computed from more recent data. Even though Japanese catches dominate the FAO statistics, separate adjustment factors were applied to the Japanese data and the catch histories for all countries combined. Additional corrections were necessary in the case of blue and black marlin, for which catch data were combined in the earlier years. Again, adjustments were made to these data based on the known species composition of recent catches.

STOCK BOUNDARIES

For purposes of computing indices of abundance, several index

Fig. 1 areas were selected (Figure 1):

1. Total Pacific

   Lat. 40°S-40°N

   Long. 120°E-80°W

2. North Pacific

   Lat. 20°-45°N

   Long. 120°E-130°W

3. Central Pacific

   Lat. 10°S-20°N

   Long. 120°E-130°W

4. South Pacific

   Lat. 10°-35°S

   Long. 140°E-130°W

5. Eastern Pacific

   Lat. 30°S-35°N

   Long. 70°-130°W

6. Southwest Pacific

   Lat. 0°-50°S

   Long. 120°E-180°

The North, South, and eastern Pacific areas are assumed to encompass the distributions of three hypothesized striped marlin stocks, although a Pacific-wide stock is also considered. The central Pacific area is used in indexing the abundance of blue marlin, and the southwest area is used for black marlin. Swordfish and sailfish-spearfish are examined on a Pacific-wide basis.

INDICES OF ABUNDANCE

Two kinds of annual abundance indices were developed, each computed from Japanese statistics of catch and nominal effort by quarter and 5° square. The first was a simple average of ratios catch per unit of effort statistic:

$$U_{1i} = \sum_{j=1}^{n_i} (C_{ij} / f_{ij}) \Big/ n_i$$

where U_{1i} = average of ratios index of abundance for a particular species in year i (fish per 10^3 hooks)

C_{ij} = catch of the given species in time-area stratum j during year i, within a specified index area (10^3 fish)

f_{ij} = corresponding nominal effort in stratum j during year i (10^6 hooks)

n_i = number of quarter x 5° square strata in year i with non-zero effort.

This index may be satisfactory in situations where the time-area distribution of fishing effort is reasonably complete, e.g., in subareas of the Pacific. However, when the area considered is large, the index is apt to be biased as a result of incomplete coverage during years of fleet expansion or contraction. An alternate index of abundance which is corrected to some degree for incomplete coverage is based on the effective fishing intensity of Honma (1974):

$$U_{2i} = \sum_{j=1}^{\ell_i} C_{ij} \Big/ \sum_{j=1}^{\ell_i} f_{ij}\varepsilon_{ij}$$

where the new symbols are

U_{2i} = corrected index of abundance for a particular species in year i

ε_{ij} = relative efficiency of a unit of nominal effort in stratum j during year i for the particular species, equal to the average abundance in the j-th stratum divided by the average abundance over all strata

ℓ_i = number of time-area strata in year i with both non-zero effort and $m_j \geq 3$ (see following explanation).

When ℓ_i is equal to the total number of time-area strata covering the stock distribution, U_{2i} reduces to an unbiased average of ratios index of abundance. [Note that the effective fishing intensity is $f'_{i.} = \Sigma f_{ij}\varepsilon_{ij} = I_i \Sigma f_{ij}$, where I_i is the concentration coefficient and the summation is over all time-area strata. In other words, the concentration coefficient is a weighted average of Honma's relative efficiencies, with the weights equal to the nominal efforts.]

Honma's idea is to replace ε_{ij} by an estimate, $\hat{\varepsilon}_{ij} = \varepsilon_j$, based on data from years with nearly complete geographical-temporal coverage. He uses the estimator

$$\varepsilon'_j = d_j \Big/ (\Sigma d_j A_j / \Sigma A_j)$$

where $d_j = \sum_{k=1}^{m_j} (C_{kj} / f_{kj}) \Big/ m_j$

m_j = number of years when the j-th time-area stratum was fished

A_j = relative area of the geographical stratum associated with time-area stratum j

k = year index for j-th stratum (k = 1, 2,..., m_j).

Instead of Honma's statistic, we used

$$\varepsilon_j = \sum_{k=1}^{m_j} \left\{ g_{kj} \Big/ \left[\sum_{j=1}^{\ell_k} g_{kj} \, A_j \Big/ \sum_{j=1}^{\ell_k} A_j \right] \right\} \Big/ m_j$$

where $g_{kj} = C_{kj} / f_{kj}$.

Essentially, Honma's estimator is a ratio of averages, whereas ours is an average of ratios.

In practice, when computing U_{2i} we sum the catches and adjusted efforts only over those time-area strata having both non-zero effort in the index year and at least 3 years of non-zero effort during the period over which the ε_j are estimated.

Fig. 2 Figure 2 shows the relative time-space coverage of the Japanese tuna longline fleet in the different index areas over the 1952-75 period. The statistic plotted is the ratio of the number of quarter-5° square strata in which fishing occurred to the maximum number of strata covered during one of the 24 years. In estimating the ε_j we used Japanese longline statistics from the 1964-70 period, when coverage was the most complete.

EFFECTIVE EFFORT

Effective effort was computed by dividing the total annual catch of the species under consideration (raised to include the take of all harvesters) by the appropriate index of abundance, i.e.,

$$E_{1i} = C_{i.} \Big/ U_{1i}$$

$$E_{2i} = C_{i.} \Big/ U_{2i}$$

TRENDS IN ABUNDANCE AND EFFECTIVE EFFORT

Figs. 3-14

Tables 1-11

The indices of abundance and effective effort are plotted in Figures 3 through 14 and are listed in Tables 1 through 11. Two sets of indices are shown for blue marlin; the U_1 index for the central Pacific area (Figure 3) and the U_2 index for the total Pacific (Figure 4). Both indices depict a steady decline in blue marlin abundance since the inception of the Japanese pelagic longline fishery, with the 1975 stock size perhaps only 10%-20% of the 1952 stock level. Effective effort has increased fourfold or fivefold over the period.

The striped marlin index for the North Pacific area, of type U_1, shows marked fluctuations, but a generally increasing trend from 1952-71, followed by a sharp drop in the 1972-75 period (Figure 5). The corresponding effort index shows a declining tendency through the mid-1960's, followed by an increasing pattern through 1974. The U_1 index for striped marlin in the South Pacific (Figure 6) shows a sixfold decline from the early 1950's through 1967, followed by an increase in abundance in more recent years. The effective effort index, E_1, increased erratically through the mid-1960's, and has shown a fourfold or fivefold decrease since then. The eastern Pacific striped marlin index, U_1, was low until the Japanese longline fleet began to concentrate on this species in the early 1960's off Mexico and Central America (Figure 7). The abundance index then quadrupled, along with effective effort. Since then both indices have shown marked fluctuation around a fairly steady level, except that U_1 dropped to a low level in 1973-75.

The striped marlin indices in the North Pacific and eastern Pacific areas are not particularly clear in revealing expected relationships between average abundance and effective fishing effort. If separate striped marlin stocks exist in the three subareas, then only in the South Pacific would it seem possible to judge the effect of fishing on abundance using simple production model analysis. However, if we assume a single Pacific-wide stock, a more distinct pattern is seen. Figure 8 shows the U_2 and E_2 indices for striped marlin over the whole Pacific. A 2.5-fold reduction in striped marlin abundance is evident since the early 1950's, associated with a fivefold or sixfold expansion of effective fishing effort.

The U_2 and E_2 indices for the combined sailfish-spearfish group are shown in Figure 9. These were computed from Pacific-wide data, and show a reduction in average abundance over 1952-75 to half the original level, associated with an effective effort which increased steadily through 1968 and has decreased somewhat since. In Figure 10 we plotted the U_1 and E_1 indices for sailfish-spearfish in the eastern Pacific index area. The patterns are similar to the ones for striped marlin in that area.

Two sets of indices were computed for black marlin; U_1 and E_1 for the southwest Pacific index area, and U_2 and E_2 for the whole Pacific. The average of ratios catch per unit effort index, U_1, declined steadily from 1954 through 1975 (Figure 11). The associated effective effort increased erratically through 1966, but has fallen off in more recent years. The U_2 and E_2 indices show similar patterns; a fourfold to fivefold reduction in average abundance of black marlin

Pacific-wide, accompanied by an effective effort which increased through the mid-1960's and has been relatively constant since (Figure 12).

Figure 13 shows the U_2 and E_2 indices for broadbill swordfish, Pacific-wide. The abundance index increased from 1952 to 1958, then declined until 1964, and has been relatively steady since. Effective effort has been very erratic, but has had a basically increasing trend, at least up through 1970.

PRODUCTION MODEL ANALYSIS

The general production model was fitted to indices of abundance and to smoothed indices of effective effort using Fox's PRODFIT program (Fox 1975). For blue marlin, black marlin, striped marlin, and broadbill swordfish a 4-yr averaging period was employed in computing the equilibrium effort statistic while a 2-yr smoothing was applied to the sailfish-spearfish data. Dummy effort values were added at the beginning of each series so that all data points could be retained in the analysis.

The model fitted was

$$U_i = (\alpha + \beta \bar{E}_i)^{\left(\frac{1}{m-1}\right)} + \gamma_i$$

where U_i = equilibrium abundance index for year i

$\bar{E}_i$ = smoothed effective fishing effort (equilibrium approximation) in year i

γ_i = random error term.

PRODFIT finds α, β, and m such that

$$S = \sum_i (U_i - \hat{U}_i)^2 = \sum_i \gamma_i^2$$

is minimum. The estimates of α, β, and m yield three quantities of particular interest:

(1) the estimated MSY

$$C_{max} = (\alpha - \alpha m)(\alpha/m)^{(\frac{1}{m-1})} \Big/ m\beta$$

(2) the associated "optimum" effort

$$E_{opt} = (\alpha - \alpha m) \Big/ m\beta$$

(3) the "optimum" value of the abundance index

$$U_{opt} = C_{max} \Big/ E_{opt} = (\alpha/m)^{(\frac{1}{m-1})} .$$

The general approach was to estimate all three parameters simultaneously, i.e., to let m vary. However, we also fixed m equal to 2 (Schaefer model) in several instances.

Below we present the results species by species.

Blue Marlin

Fig. 15 Fig. 16 Table 12 The observed U_{1i} are plotted against E_{1i} in Figure 15 along with the fitted production model. In Figure 16, U_{2i} is plotted against E_{2i}. In both cases the catch unit is number of fish. Table 12 lists the parameter estimates for these cases along with those for the corresponding catch-in-weight data.

Estimates of Pacific-wide MSY are practically identical for the central Pacific index (U_1 index) and total Pacific index (U_2 index), being 220,000 fish and 221,000 fish, respectively. For the corresponding catch-in-weight indices, the MSY estimates are both 22,000 metric tons (MT). MSY in terms of weight is achieved at somewhat lower effort than MSY in number of fish.

Fig. 17 The plot of equilibrium yield versus effective effort is shown in Figure 17 for the total Pacific index ($U_2 \times \bar{E}_2$ vs. $\bar{E}_2$). As the figure shows, the "optimum" effort level for blue marlin harvest has been exceeded every year since 1961, and 1975 effort was at about twice the "optimum" level.

Striped Marlin

Table 13 Production model results for the total Pacific index of striped marlin abundance are listed in Table 13. When m was allowed to vary freely in the estimation, the resulting estimates of m were 0, suggesting that the equilibrium yield and effort curve for striped marlin is not dome-shaped as with blue marlin, but is asymptotic to MSY. However, the estimated MSY (817,000 fish or 54,500 MT) far exceeds any observed values in spite of a long history of exploitation, and is considered unreasonable. We therefore reapplied the model with m fixed at 2.0. The results in this case were $\widehat{MSY}$ = 390,000 fish or 21,000 MT. The estimated MSY would be achieved at an effective effort level somewhat greater than that applied in 1975 (Figure 18). Fig. 18

Black Marlin

When m was allowed to vary, the southwest area abundance index, U_1, yielded, at $\hat{m} = 0.29$, an estimated MSY of 42,700 fish taken at $\hat{E}_{opt}$ = 11.4 million effective hooks (Table 14). These results seemed Table 14 unreasonable, and so again the production model was fitted with m fixed at 2.0. Results in this instance were $\widehat{MSY}$ = 34,900 fish and $\hat{E}_{opt}$ = 69.3 million effective hooks. The effective effort in 1975 was about 82 million hooks.

When the U_2 index for the total Pacific was considered, MSY was estimated to be 34,200 fish and $\hat{E}_{opt}$ = 228 million effective
Fig. 19 hooks, with m fixed at 2.0 (Figure 19). When m was allowed to vary, the results were $\widehat{MSY}$ = 29,600 fish and $\hat{E}_{opt}$ = 169 million effective hooks, at $\hat{m}$ = 0.58. In both sets of results using the total Pacific index, the estimated E_{opt} is less than the 1975 effective effort of
Fig. 20 about 280 million hooks (Figure 20).

Sailfish-Spearfish

Production model results for the sailfish-spearfish group,
Table 15 using the Pacific-wide data (U_2 and E_2) are listed in Table 15. When m is permitted to vary, it is estimated as 0, and MSY is estimated to be 874,000 fish or 21,000 MT. With m fixed at 2.0, $\widehat{MSY}$ = 446,000 fish (11,800 MT) achieved at an effective effort of 491 million hooks (482 million hooks). In the 1972-75 period effort
Fig. 21 did not exceed 325 million hooks (Figure 21).

Swordfish

A production model for swordfish, Pacific-wide, is shown in

Fig. 22 Figure 22. The estimated MSY, with m fixed at 2.0, is 278,000 fish, and $\hat{E}_{opt}$ = 601,000 effective hooks. This effort is above the effort level of recent years.

CONCLUSIONS AND EVALUATIONS

The results presented above are provisional and should be viewed circumspectly. Some data sets and model fits inspire more confidence than others, and there is some danger that a data set's "good looks" will color our judgment of the parameter estimates unduly. This is a hazard in all modeling, and the only safeguard is a thorough validation of the model's assumptions. On the other hand, if enough detailed data were available on billfish population dynamics to permit a complete test of the production model assumptions, it would probably be possible to avoid the simple production model altogether and use a more elaborate approach to stock assessment.

In lieu of detailed data, simulation studies would shed some light on the robustness of the production model and should be undertaken. But where possible, some of the basic assumptions should be examined directly. For example, all the analyses here assumed a constant catchability coefficient, but changes in fish targets or harvest strategies may alter this parameter. Suzuki and Warashina (1977) have shown that recent increases in the fishing depth of tuna longline gear deployed in the central and western equatorial Pacific, while nearly doubling the catch rates of the target bigeye tuna, _Thunnus obesus_, have also affected catch rates of billfishes. They reported the following ratios of catch rates using the new gear versus the standard gear:

Species	Catch rate ratio deep/regular
Sailfish	0.07
Striped marlin	0.28
Black marlin	0.34
Blue marlin	0.56
Swordfish	0.79
Albacore, _Thunnus alalunga_	0.82
Yellowfin tuna, _T. albacares_	0.73
Bigeye tuna	1.79

The use of such deep longline gear may have altered the catchability coefficients in 1975. And considering the apparent impact on catch rates of billfishes, exhaustive comparative studies will be required to evaluate possible changes in abundance indices.

Other critical assumptions concern stock boundaries, and the index areas assumed in our analyses may be incorrect. In the case of striped marlin and sailfish, where more than one stock may exist, the subarea indices of abundance and effective effort were either inconsistent with the production model or too ill-behaved to permit a reliable production model assessment. On the other hand, the total Pacific indices for these two species gave reasonable results.

In spite of these uncertainties and other possible shortcomings, the production model analyses permit a rough characterization of the status of Pacific billfish stocks. Referring to the MSY criterion of the simple, deterministic equilibrium yield model, the analyses suggest that the catches of striped marlin and sailfish are still somewhat below MSY. Similarly, the data for swordfish do not indicate overexploitation. However, blue marlin and black marlin seem clearly to be overexploited on the basis of the MSY criterion.

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Table 1.--Blue marlin, central Pacific index area, U_1 and E_1.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1949							5.0*
1950							10.0*
1951							20.0*
1952	5.15	172.7	1.00	172.7	51.0	8.8	33.5
1953	4.74	192.0	1.00	192.0	83.3	16.0	40.5
1954	3.55	139.5	1.00	139.5	131.9	18.4	39.3
1955	3.51	257.6	1.00	257.6	82.7	21.3	73.4
1956	3.49	189.5	1.00	189.5	128.8	24.4	54.3
1957	3.15	242.0	1.00	242.0	128.5	31.1	76.8
1958	2.94	237.3	1.00	237.3	123.0	29.2	80.7
1959	2.49	209.9	1.00	209.9	119.6	25.1	84.3
1960	2.14	187.2	1.00	187.2	126.1	23.6	87.5
1961	2.19	285.8	1.00	285.8	82.2	23.5	130.5
1962	2.01	352.7	1.00	352.7	63.5	22.4	175.5
1963	1.59	300.0	1.00	300.0	85.7	25.7	188.7
1964	1.46	223.9	1.00	223.9	89.3	20.0	153.4
1965	1.06	172.5	1.00	172.5	93.3	16.1	162.7
1966	1.16	150.1	1.05	157.6	107.9	17.0	135.9
1967	1.12	143.6	1.13	162.3	91.2	14.8	144.9
1968	0.93	126.3	1.07	135.1	91.8	12.4	145.3
1969	1.08	144.9	1.07	155.0	83.5	12.9	143.5
1970	1.30	180.2	1.13	203.6	76.6	15.6	156.6
1971	0.88	102.5	1.30	133.2	70.2	9.4	151.4
1972	0.86	128.2	1.30	166.7	71.8	12.0	193.8
1973	0.89	128.6	1.30	167.2	75.4	12.6	187.9
1974	0.68	121.1	1.20	145.3	69.4	10.1	213.7
1975	0.48	85.7	1.25	107.1	85.2	9.1	223.1

*Dummy values.

Table 2.--Blue marlin, total Pacific index area, U_2 and E_2.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1949							10.0*
1950							20.0*
1951							40.0*
1952	2.83	172.7	1.00	172.7	51.0	8.8	61.0
1953	2.71	192.0	1.00	192.0	83.3	16.0	70.8
1954	2.14	124.5	1.00	124.5	147.8	18.4	58.2
1955	2.40	257.6	1.00	257.6	82.7	21.3	107.3
1956	2.29	189.5	1.00	189.5	128.8	24.4	82.8
1957	1.90	242.0	1.00	242.0	128.5	31.1	127.4
1958	1.65	237.3	1.00	237.3	123.0	29.2	143.8
1959	1.39	209.9	1.00	209.9	119.6	25.1	151.0
1960	1.26	187.2	1.00	187.2	126.1	23.6	148.6
1961	1.46	285.8	1.00	285.8	82.2	23.5	195.8
1962	1.26	352.7	1.00	352.7	63.5	22.4	279.9
1963	1.09	300.0	1.00	300.0	85.7	25.7	275.2
1964	0.96	223.9	1.00	223.9	89.3	20.0	233.2
1965	0.73	172.5	1.00	172.5	93.3	16.1	236.3
1966	0.72	150.1	1.05	157.6	107.9	17.0	218.9
1967	0.68	143.6	1.13	162.3	91.2	14.8	238.7
1968	0.63	126.3	1.07	135.1	91.8	12.4	214.4
1969	0.68	144.9	1.07	155.0	83.5	12.9	227.9
1970	0.79	180.2	1.13	203.6	76.6	15.6	257.7
1971	0.50	102.5	1.30	133.2	70.2	9.4	266.4
1972	0.56	128.2	1.30	166.7	71.8	12.0	297.7
1973	0.57	128.6	1.30	167.2	75.4	12.6	293.3
1974	0.46	121.1	1.20	145.3	69.4	10.1	315.9
1975	0.35	85.7	1.25	107.1	85.2	9.1	306.0

*Dummy values.

Table 3.--Striped marlin, North Pacific index area, U_1 and E_1.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1949							5.0*
1950							20.0*
1951							40.0*
1952	1.69	92.7	1.00	92.7			54.8
1953	1.09	68.4	1.00	68.4			62.8
1954	1.13	104.9	1.00	104.9			92.8
1955	1.24	117.9	1.00	117.9			95.1
1956	1.44	127.2	1.00	127.2			88.3
1957	1.30	98.6	1.00	98.6			75.8
1958	1.42	122.6	1.00	122.6			86.3
1959	1.60	120.5	1.00	120.5			75.3
1960	1.29	119.0	1.00	119.0			92.2
1961	1.29	101.4	1.00	101.4			78.6
1962	1.66	110.6	1.00	110.6			66.6
1963	1.28	91.0	1.00	91.0			71.1
1964	2.70	139.0	1.00	139.0			51.5
1965	1.88	120.5	1.00	120.5			64.1
1966	1.51	77.3	1.00	77.3			51.2
1967	1.85	137.1	1.00	137.1			74.1
1968	1.93	118.1	1.00	118.1			61.2
1969	1.25	80.3	1.00	80.3			64.2
1970	2.36	195.0	1.00	195.0			82.6
1971	1.52	104.6	1.00	104.6			68.8
1972	0.81	51.94	1.00	51.94			64.1
1973	1.00	70.10	1.00	70.10			70.1
1974	0.97	64.2	1.00	64.2			66.2
1975	0.80	40.18	1.00	40.18			50.2

*Dummy values.

Table 4.--Striped marlin, South Pacific index area, U_1 and E_1.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1949							0.0*
1950							0.0*
1951							0.0*
1952	3.57	0.03	1.00	0.03			.008
1953	1.86	12.9	1.00	12.9			6.9
1954	2.89	78.9	1.00	78.9			27.3
1955	1.73	47.4	1.00	47.4			27.4
1956	1.59	30.8	1.00	30.8			19.4
1957	1.19	21.5	1.00	21.5			18.1
1958	1.29	36.9	1.00	36.9			28.6
1959	1.00	27.6	1.00	27.6			27.6
1960	1.18	28.5	1.00	28.5			24.2
1961	1.29	38.0	1.00	38.0			29.4
1962	1.09	67.3	1.00	67.3			61.7
1963	0.83	40.6	1.00	40.6			48.9
1964	0.79	25.0	1.00	25.0			31.6
1965	0.71	22.4	1.00	22.4			31.5
1966	0.58	26.0	1.01	26.3			45.3
1967	0.57	13.9	1.02	14.2			24.9
1968	0.69	9.9	1.01	10.0			14.5
1969	0.77	9.8	1.02	10.0			13.0
1970	1.24	23.6	1.03	24.3			19.6
1971	1.04	19.4	1.07	20.8			20.0
1972	1.46	17.9	1.07	19.2			13.2
1973	1.14	17.7	1.07	18.8			16.5
1974	0.87	14.4	1.06	15.3			17.6
1975	1.04	9.6	1.06	10.2			9.8

*Dummy values.

Table 5.--Striped marlin, eastern Pacific index area, U_1 and E_1.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E. (10^6 hooks)
1952	0.00	0.00	1.00	0.00			0.00
1953	0.00	0.00	1.00	0.00			0.00
1954	1.57	0.04	1.00	0.04			0.025
1955	0.35	0.08	1.00	0.08			0.23
1956	1.06	0.23	1.00	0.23			0.22
1957	0.58	1.43	1.00	1.43			2.46
1958	0.77	3.50	1.00	3.50			4.54
1959	1.03	3.32	1.00	3.32			3.22
1960	1.14	4.70	1.00	4.70			4.12
1961	3.05	45.6	1.00	45.6			14.95
1962	4.55	141.4	1.00	141.4			31.1
1963	3.94	148.2	1.00	148.2			37.6
1964	3.35	270.7	1.00	270.7			80.8
1965	4.02	236.9	1.00	236.9			58.9
1966	3.71	223.4	1.01	225.6			60.8
1967	4.27	229.4	1.02	234.0			54.8
1968	3.78	339.1	1.01	342.5			90.6
1969	2.91	207.7	1.01	209.8			72.1
1970	3.10	183.4	1.02	187.1			60.4
1971	4.74	228.7	1.03	235.6			49.7
1972	2.65	172.3	1.07	184.4			69.6
1973	1.23	105.1	1.07	112.5			91.5
1974	1.98	133.1	1.06	141.1			71.3
1975	2.03	125.3	1.06	132.8			65.4

Table 6.--Striped marlin, total Pacific index area, U_2 and E_2.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1949							5.0*
1950							15.0*
1951							30.0*
1952	2.40	95.9	1.00	95.9	41.7	4.0	40.0
1953	2.10	85.0	1.00	85.0	36.5	3.1	40.5
1954	3.11	186.9	1.00	186.9	43.9	8.2	60.1
1955	2.12	171.4	1.00	171.4	33.8	5.8	80.8
1956	2.38	164.2	1.00	164.2	45.1	7.4	69.0
1957	2.04	132.2	1.00	132.2	53.0	7.0	64.8
1958	1.92	175.5	1.00	175.5	57.0	10.0	91.4
1959	1.50	167.9	1.00	167.9	61.9	10.4	111.9
1960	1.24	161.1	1.00	161.1	53.4	8.6	129.9
1961	1.59	218.3	1.00	218.3	43.1	9.4	137.3
1962	1.93	348.5	1.00	348.5	44.2	15.4	180.6
1963	1.61	317.8	1.00	317.8	50.3	16.0	197.4
1964	1.81	508.9	1.00	508.9	46.2	23.5	281.2
1965	1.60	422.1	1.00	422.1	51.9	21.9	263.8
1966	1.50	350.8	1.01	354.3	55.3	19.6	236.2
1967	1.56	405.9	1.02	414.0	46.6	19.3	265.4
1968	1.70	507.2	1.01	512.3	41.2	21.1	301.4
1969	1.12	323.4	1.01	326.6	60.6	19.8	291.6
1970	1.68	457.1	1.02	466.2	46.2	21.5	277.5
1971	1.78	394.0	1.03	405.8	54.6	22.2	228.0
1972	1.12	270.2	1.07	289.1	49.2	14.2	258.1
1973	0.80	230.7	1.07	246.8	61.6	15.2	308.5
1974	0.94	238.2	1.06	252.5	56.7	14.3	268.6
1975	0.84	194.1	1.06	205.7	75.7	15.6	244.9

*Dummy values.

Table 7.--Sailfish-spearfish, total Pacific index area, U_2 and E_2.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1951							20.0*
1952	1.98	41.5	1.75	72.6	27.6	2.0	36.7
1953	2.51	68.1	1.75	119.2	27.6	3.3	47.5
1954	1.36	50.4	1.75	88.2	27.6	2.4	64.9
1955	1.76	68.9	1.75	120.6	27.6	3.3	68.5
1956	1.82	66.0	1.75	115.5	27.6	3.2	63.5
1957	1.67	85.8	2.00	171.6	16.3	2.8	102.8
1958	1.49	72.6	1.68	122.0	27.5	3.4	81.9
1959	1.96	92.8	1.53	142.0	25.9	3.7	72.4
1960	1.29	67.3	1.92	129.2	38.6	5.0	100.2
1961	1.13	88.0	1.73	152.2	31.8	4.8	134.7
1962	1.04	132.7	1.63	216.3	31.6	6.8	208.0
1963	1.39	161.6	1.79	289.3	27.2	7.9	208.1
1964	0.97	148.2	1.69	250.4	24.3	6.1	258.1
1965	1.66	494.3	1.21	598.1	21.4	12.8	360.3
1966	1.19	313.2	1.39	435.3	25.5	11.1	365.8
1967	1.43	350.6	1.39	487.3	24.2	11.8	340.8
1968	1.12	454.0	1.49	676.5	18.5	12.5	604.0
1969	0.93	229.8	1.45	333.2	38.3	12.8	358.3
1970	1.13	323.9	1.44	466.4	19.4	9.0	412.7
1971	0.84	195.7	1.33	260.3	31.2	8.1	309.9
1972	0.74	193.3	1.19	230.0	37.2	8.6	310.8
1973	0.92	230.8	1.34	309.3	28.2	8.7	336.2
1974	0.93	213.0	1.19	253.5	28.2	7.1	272.6
1975	0.70	151.8	1.26	191.3	29.0	5.5	273.3

*Dummy values.

Table 8.--Sailfish-spearfish, eastern Pacific index area, U_1 and E_1.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1952	0.00	0.00	1.00	0.00			0.00
1953	0.00	0.00	1.00	0.00			0.00
1954	0.35	0.01	1.00	0.01			0.03
1955	0.39	0.03	1.00	0.03			0.08
1956	0.26	0.11	1.00	0.11			0.42
1957	0.09	0.61	1.00	0.61			6.78
1958	0.17	0.42	1.00	0.42			2.47
1959	0.06	0.15	1.00	0.15			2.50
1960	0.07	0.44	1.00	0.44			6.29
1961	0.50	6.72	1.00	6.72			13.44
1962	0.40	12.75	1.00	12.75			31.88
1963	0.98	35.28	1.00	35.28			36.00
1964	2.86	87.28	1.00	87.28			30.52
1965	6.01	418.60	1.00	418.60			69.65
1966	4.63	232.85	1.00	232.85			50.29
1967	6.27	283.97	1.00	283.97			45.29
1968	4.82	398.00	1.00	398.00			82.57
1969	4.42	193.62	1.00	193.62			43.81
1970	4.84	268.15	1.00	268.15			55.40
1971	3.87	155.17	1.00	155.17			40.10
1972	2.89	154.17	1.00	154.17			53.35
1973	4.47	171.04	1.00	171.04			38.26
1974	4.03	166.49	1.00	166.49			41.31
1975	4.33	117.43	1.00	117.43			27.12

Table 9.--Black marlin, southwest Pacific index area, U_1 and E_1.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1949							10.0*
1950							20.0*
1951							40.0*
1952	0.35	19.2	1.00	19.2			54.9
1953	0.81	34.2	1.00	34.2			42.2
1954	0.99	47.2	1.00	47.2			47.7
1955	0.90	39.5	1.00	39.5			43.9
1956	0.92	45.1	1.00	45.1			49.0
1957	0.62	51.7	1.00	51.7			83.4
1958	0.51	28.4	1.00	28.4			55.7
1959	0.40	21.5	1.00	21.5			53.8
1960	0.40	21.5	1.00	21.5			53.8
1961	0.40	27.7	1.00	27.7			69.2
1962	0.34	34.8	1.00	34.8			102.4
1963	0.31	30.1	1.00	30.1			97.1
1964	0.28	26.6	1.00	26.6			95.0
1965	0.36	38.0	1.00	38.0			105.6
1966	0.27	34.0	1.08	36.7			135.9
1967	0.29	22.3	1.14	25.4			87.6
1968	0.23	17.0	1.15	19.6			85.2
1969	0.21	22.0	1.14	25.1			119.5
1970	0.22	18.1	1.22	22.1			100.5
1971	0.34	19.2	1.27	24.4			71.8
1972	0.24	17.2	1.19	20.5			85.4
1973	0.23	17.7	1.19	21.1			91.7
1974	0.18	13.3	1.17	15.6			86.7
1975	0.19	10.2	1.17	11.9			62.6

*Dummy values.

Table 10.--Black marlin, total Pacific index area, U_2 and E_2.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1949							10.0*
1950							30.0*
1951							60.0*
1952	0.24	19.2	1.00	19.2			80.0
1953	0.35	34.2	1.00	34.2			97.7
1954	0.28	47.2	1.00	47.2			168.6
1955	0.29	39.5	1.00	39.5			136.2
1956	0.29	45.1	1.00	45.1			155.5
1957	0.17	51.7	1.00	51.7			304.1
1958	0.13	28.4	1.00	28.4			218.5
1959	0.13	21.5	1.00	21.5			165.4
1960	0.12	21.5	1.00	21.5			179.2
1961	0.13	27.7	1.00	27.7			213.1
1962	0.11	34.8	1.00	34.8			316.4
1963	0.09	30.1	1.00	30.1			334.4
1964	0.10	26.6	1.00	26.6			266.0
1965	0.10	38.0	1.00	38.0			380.0
1966	0.08	34.0	1.08	36.7			458.8
1967	0.09	22.3	1.14	25.4			282.2
1968	0.07	17.0	1.15	19.6			280.0
1969	0.08	22.0	1.14	25.1			313.8
1970	0.07	18.1	1.22	22.1			315.7
1971	0.08	19.2	1.27	24.4			305.0
1972	0.10	17.2	1.19	20.5			205.0
1973	0.07	17.7	1.19	21.1			301.4
1974	0.05	13.3	1.17	15.6			312.0
1975	0.04	10.2	1.17	11.9			297.5

*Dummy values.

Table 11.--Swordfish, total Pacific index area, U_2 and E_2.

Year	U (fish/10^3 hooks)	C. Japan (10^3 fish)	Raising factor	C. Total (10^3 fish)	Average weight (kg/fish)	C. Total (MT)	E (10^6 hooks)
1949							100.0*
1950							200.0*
1951							300.0*
1952	0.52	177.1	1.08	191.2	49.7	9.5	367.7
1953	0.63	215.6	1.05	226.9	35.7	8.1	360.2
1954	0.62	259.9	1.00	259.8	33.1	8.6	419.0
1955	0.59	291.3	0.91	266.5	36.4	9.7	451.7
1956	0.53	210.6	0.91	192.2	53.6	10.3	362.6
1957	0.78	291.9	1.01	295.4	32.5	9.6	378.7
1958	0.87	380.0	0.95	361.6	31.8	11.5	415.6
1959	0.73	353.0	1.20	424.6	28.5	12.1	581.6
1960	0.68	405.4	0.88	357.4	33.3	11.9	525.6
1961	0.66	403.5	0.94	378.8	35.9	13.6	573.9
1962	0.48	224.5	0.91	203.4	76.2	15.5	423.8
1963	0.51	229.5	1.04	239.2	71.5	17.1	469.1
1964	0.42	174.9	1.10	192.2	92.6	17.8	457.6
1965	0.47	197.4	1.06	209.6	81.6	17.1	446.0
1966	0.46	231.1	1.08	248.7	79.6	19.8	540.7
1967	0.40	239.3	1.15	275.8	66.0	18.2	689.5
1968	0.40	225.2	1.12	253.1	71.9	18.2	632.8
1969	0.48	282.9	1.18	335.0	59.4	19.9	697.9
1970	0.46	196.8	1.27	249.4	81.8	20.4	542.2
1971	0.41	174.6	1.16	203.0	59.6	12.1	495.1
1972	0.48	172.4	1.20	207.3	60.3	12.5	431.9
1973	0.46	180.1	1.36	245.1	61.6	15.1	532.8
1974	0.46	161.4	1.20	193.8	65.0	12.6	421.3
1975	0.47	169.6	1.16	195.9	68.4	13.4	416.8

*Dummy values.

Table 12.--PRODFIT parameter estimates for blue marlin.

Case	$\hat{m}$	$\hat{C}_{max}$	$\hat{E}_{opt}$	$\hat{U}_{opt}$	$\hat{Q}$	$\hat{P}_o$	$\hat{P}_{opt}$
(1) Central Pacific Index area (U_1, E_1) T = 4	1.40	222×10^3 fish	98×10^6 hooks	2.2 fish/10^3 hooks	0.007	750×10^3 fish	324×10^3 fish
(2) Total Pacific (U_2, E_2) T = 4	1.54	221×10^3 fish	159×10^6 hooks	1.4 fish/10^3 hooks	0.006	503×10^3 fish	227×10^3 fish
(3) Central Pacific Index area (U_1, E_1) T = 4	1.41	22×10^3 MT	90.4×10^6 hooks	0.24 MT/10^3 hooks	0.012	45.3×10^3 MT	19.7×10^3 MT
(4) Total Pacific (U_2, E_2) T = 4	1.48	22×10^3 MT	141.8×10^6 hooks	0.16 MT/10^3 hooks	0.009	38.9×10^3 MT	17.2×10^3 MT

Table 13.--PRODFIT parameter estimates for striped marlin.

Case	$\hat{m}$	$\hat{C}_{max}$	$\hat{E}_{opt}$	$\hat{U}_{opt}$	$\hat{Q}$	$\hat{P}_o$	$\hat{P}_{opt}$
(1) Total Pacific (U_2, E_2) T = 4	2.0 fixed	390×10^3 fish	327×10^6 hooks	1.19 fish/10^3 hooks	0.002	118.5×10^4 fish	593×10^3 fish
(2) Total Pacific (U_2, E_2) T = 4	2.0 fixed	21.9×10^3 MT	411×10^6 hooks	0.05 MT/10^3 hooks	0.002	62.8×10^3 MT	31.4×10^3 MT
(3) Total Pacific (U_2, E_2) T = 4	0	$\rightarrow 54.5 \times 10^3$ MT	$\rightarrow \infty$	$\rightarrow 0$			
(4) Total Pacific (U_2, E_2) T = 4	0	$\rightarrow 817 \times 10^3$ fish	$\rightarrow \infty$	$\rightarrow 0$			

Table 14.--PRODFIT parameter estimates for black marlin.

	Case	$\hat{m}$	$\hat{C}_{max}$	$\hat{E}_{opt}$	$\hat{U}_{opt}$	$\hat{Q}$	$\hat{P}_o$	$\hat{P}_{opt}$
(1)	Southwest Index area (U_1, E_1) T = 4	2.0 fixed	34.9×10^3 fish	69.3×10^6 hooks	0.50 fish/10^3 hooks	0.018	56×10^3 fish	28×10^3 fish
(2)	Total Pacific (U_2, E_2) T = 4	2.0 fixed	34.2×10^3 fish	228×10^6 hooks	0.15 fish/10^3 hooks	0.004	68.8×10^3 fish	34.4×10^3 fish
(3)	Southwest Index area (U_1, E_1) T = 4	0.29	42.7×10^3 fish	11.4×10^6 hooks	3.8 fish/10^3 hooks	0.013	156×10^4 fish	279×10^3 fish
(4)	Total Pacific (U_2, E_2) T = 4	0.58	29.6×10^3 fish	169×10^6 hooks	0.18 fish/10^3 hooks	0.003	182×10^3 fish	50.2×10^3 fish

Table 15.--PRODFIT parameter estimates for sailfish-spearfish.

Case	$\hat{m}$	$\hat{C}_{max}$	$\hat{E}_{opt}$	$\hat{U}_{opt}$	$\hat{Q}$	$\hat{P}_o$	$\hat{P}_{opt}$
(1) Total Pacific (U_2, E_2) T = 2	2.0 fixed	446×10^3 fish	491×10^6 hooks	0.91 fish/10^3 hooks	0.002	909×10^3 fish	454×10^3 fish
(2) Total Pacific (U_2, E_2) T = 2	2.0 fixed	11.8×10^3 MT	482×10^6 hooks	0.024 MT/10^3 hooks	0.0015	33.3×10^3 MT	16.6×10^3 MT
(3) Total Pacific (U_2, E_2) T = 2	0	$\rightarrow 874 \times 10^3$ fish	$\rightarrow \infty$	$\rightarrow 0$			
(4) Total Pacific (U_2, E_2) T = 2	0	$\rightarrow 21 \times 10^3$ MT	$\rightarrow \infty$	$\rightarrow 0$			