SOME PRODUCTION MODEL ANALYSES OF TUNA AND BILLFISH STOCKS IN THE INDIAN OCEAN

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PURPOSE AND SCOPE

This report summarizes some production model analyses of tuna and billfish stocks in the Indian Ocean, using historical total catch statistics and abundance indices computed from longline catch per unit effort data. The purpose is to get a rough idea of the status of the stocks; time and resources did not permit a thorough analysis. Size-composition data were not evaluated, and the completeness and reliability of total catch statistics is open to question. In the case of albacore, yellowfin, and bigeye tuna stocks, the production model results will be compared to earlier assessments by Suda (1973, 1974).

DATA SOURCES

Annual total catch statistics in metric tons (MT) were provided for Japan (1952-77) and Taiwan (1962-77) by S. Ueyanagi of the Far Seas Fisheries Research Laboratory, Shimizu, Japan, and R. T. Yang of National Taiwan University (Tables 1-8). Billfish catches for Taiwan were provided with species combined for 1963-66, so the breakdown by species in these years was estimated by applying the average species composition for 1967 and 1968. No data were available for the catch by longliners from the Republic of Korea except for FAO statistics on tuna catches (1965-76) and the catches of blue marlin, swordfish, and sailfish (1975-76). To estimate the Korean catches of blue marlin for 1965-74 we computed the ratio of blue marlin catch to yellowfin catch during 1975 and 1976 and assumed this ratio prevailed in the earlier years also. To estimate the missing Korean catch figures for other billfish species we computed the ratio of estimated Korean blue marlin catch to the blue marlin catch by Taiwan in each year and multiplied this times the catch of the given species by Taiwan. These procedures clearly give only a very rough estimation of the Korean catches.

Concerning the catches by countries other than Japan, Taiwan, and Korea, we used statistics from various FAO compilations (FAO 1974, 1975, 1977). These included estimates of longline catches by the U.S.S.R. and Sri Lanka, and surface yellowfin catches by Australia, India, Madagascar, Maldives, Pakistan, Sri Lanka, Democratic Republic of Yemen, Seychelles, and Oman.

Statistics on nominal effort in hooks and associated catch in number of fish by month and 5° square were available for Taiwan (1967-77) and Japan (1952-76).

INDICES OF ABUNDANCE AND EFFECTIVE EFFORT

Annual abundance indices for each species were constructed in the manner described by Wetherall et al. (1979), using the detailed Japanese catch and nominal effort statistics and average weight estimates computed over the entire ocean (Table 9). Index areas were selected after consideration of stock structure information in Suda (1974) and examination of plots of spatial variation in average catch rates (Figures 1 through 8). Boundaries of the selected index areas are as follows:

Species		Latitude	Longitude
Albacore		0°-45°S	20°-120°E
Yellowfin tuna		15°N-15°S	40°-100°E
Bigeye tuna		15°N-35°S	40°-110°E
Blue marlin		10°N-25°S	40°-100°E
Striped marlin		20°N-30°S	20°-125°E
Black marlin		20°N-25°S	90°-125°E
Swordfish	(1)	20°N-15°S	45°-100°E
	(2)	20°S-45°S	20°-55°E
Sailfish	(1)	20°N-5°S	45°-100°E
	(2)	0°-30°S	35°-50°E

Tables 10,11
Figs. 9-14

Effective effort was computed by dividing the abundance indices into appropriate annual total catch statistics (Tables 10 and 11; Figures 9 through 14). Abundance indices and effective effort were standardized to Japanese data in the first year of each time series.

PRODUCTION MODELS

The PRODFIT program by Fox (1975) was used to fit production models to abundance indices and the associated measures of effective effort. Effort was averaged over 1-, 2-, 3-, and 4-year periods to approximate equilibrium conditions.

Tables 12,13
Figs. 17-22

Results are summarized in Tables 12 and 13, and Figures 17 through 22, and are evaluated here species by species:

Albacore

The total albacore catch rose steadily in the first decade of the fishery to about 17,700 MT and then fluctuated rather markedly after 1962 (Table 10). The highest catch of 28,250 MT was taken in 1974. The abundance index tripled in the first few years of the fishery, but has since declined steadily to less than one-tenth its peak value (Figure 9).

The production model analysis (Table 12) gives a best estimate of maximum sustainable yield (MSY) equal to about 17,800 MT at an infinitely high effective effort. However, the yield curve is very flat over a wide range of effort, and an average catch nearly equal to the MSY could apparently be achieved at an effort significantly less than the 1976 level (Figure 17).

Suda (1973) estimated the MSY for Indian Ocean albacore to be in the range of 20,000-25,000 MT. We believe much of the discrepancy between our estimate and his can be accounted for by the tendency of his total catch estimates to be greater than ours. At any rate, the conclusion of both analyses is that the stock is fully harvested. The failure of the total catch to increase significantly in spite of the expansion of fishing effort south of lat. 30°S during the 1960's and 1970's (Table 14) is consistent with Suda's yield per recruit assessments (and similar analyses on other albacore stocks) which suggest no gain in yield per recruit from harvesting the younger fish found in the more southerly waters.

Bigeye tuna

Total catch of bigeye tuna in the Indian Ocean increased fairly steadily until 1968, when almost 39,000 MT were taken, and then fell in the next 5 years to only about 15,000 MT in 1973. It then roughly doubled, ranging between 26,448 to 38,359 MT during the next 3 years. The decline in total catch between 1968 and 1973 was experienced by all three longline fleets, whereas the increase in total catch estimates during 1974-76 was due mostly to a reported rise in the Korean catch (Table 2). The abundance index for bigeye has fluctuated moderately but has shown a definite downward trend since the inception of longlining. However, the apparent abundance is still about 50% of its initial level (Figure 10).

The production model analysis (Table 12) gives two different results, depending on the number of years over which effective effort is averaged. With 1- or 2-year averaging, the estimated MSY is 59,000-60,000 MT at infinitely high effort. On the other hand, smoothing by 3 or 4 years gives an MSY of about 30,600 to 32,500 MT at effort levels only slightly greater than recent ones (Figure 18). The analysis is quite sensitive to the choice of smoothing period because there are no observations to clearly define either the right hand side of a dome-shaped production curve or the flat top of an asymptotic one. Suda had similar difficulties in establishing the behavior of the yield curve and high efforts. He concluded that MSY was about 30,000 MT for the whole Indian Ocean, and could be realized by roughly doubling effective effort over the 1970-71 level. This is consistent with our findings when the 3- or 4-year effort averaging is chosen.

Yellowfin tuna

During the early years of Japanese longlining in the Indian Ocean, yellowfin tuna were a primary target and the total catch of yellowfin tuna rose quickly as effort was concentrated in good yellowfin tuna grounds. The peak Japanese yellowfin tuna catch of about 52,000 MT was in 1962, and annual Japanese harvests varied widely from 25,000-50,000 MT throughout the 1960's. During the 1970's the Japanese catch has been much lower, well under 10,000 MT in most years (Table 3) as effort has shifted away from the equatorial yellowfin tuna grounds. The catch by Taiwan reached high levels in 1968-71, but has been less than 5,000 MT in most other years. According to FAO statistics, the longline catch of Indian Ocean yellowfin tuna since 1972 has been dominated by Korea.

Besides the longline fishery for yellowfin tuna there is a substantial surface fishery. While the surface catch is very poorly documented, various FAO records show that it has increased dramatically during the 1970's, with catches in 1975 and 1976 exceeding 20,000 MT (not including the harvest by Sri Lanka which was probably about 5,000 MT each year). The surface fishery takes yellowfin tuna mostly 2 years old or younger (FAO 1974) whereas the longliners harvest predominantly 2- and 3-year olds (Suda 1974). In recent years the decline in total longline harvest has been balanced by the increase in surface catch (Table 3).

While it has been hypothesized that at least two stocks of Indian Ocean yellowfin tuna exist, east and west of approximately long. 90°E, we were unable to break our total catch statistics down into the two hypothesized regions. Therefore we fit a production model to the aggregated statistics for the whole ocean. The abundance index for the region has shown a steady decline since 1954 to levels perhaps only one-fifth or one-sixth as high as at the inception of fishing (Figure 11). With smoothing periods of 2 or 3 years, the MSY is estimated to be about 43,000-45,400 MT. This can be compared to Suda's estimate of about 35,000 MT. Under all averaging periods considered the equilibrium yield curve (Figure 19) is essentially asymptotic to MSY, and the analysis suggests that no substantial increase in average annual yield can be achieved. From 1970 to 1976 the effective effort by longliners has been relatively steady while effective effort by surface fleets has quadrupled. Although the stock size has declined during this period, the total catch has been relatively constant. The fraction taken by surface fisheries has grown while the longline catch has diminished.

Blue Marlin

Information on the population biology of blue marlin in the Indian Ocean is virtually non-existent. Assuming a single stock, our abundance index for blue marlin suggests a fairly steady decline since the beginning of Japanese longlining in 1952, except for a momentary increase during 1972-74 (Figure 12). Total catch apparently peaked in 1956 at about 5,000 MT, fluctuated between 2,600 and 4,300 MT thereafter through 1970, and has usually been less than 2,500 MT in more recent years. Note that the Korean catch totals were roughly estimated in all years except 1975 and 1976 (Table 4).

The production models for blue marlin (Table 13) suggest an MSY of 3,400-3,600 MT achievable at an effort substantially less than any recent level (Figure 20), but the curves fit poorly. There may be significant errors in our total catch estimates.

Striped Marlin

As with blue marlin, no assessment work has yet been done with Indian Ocean striped marlin. However, the distribution and biology of striped marlin taken by the Japanese tuna longline fishery in the Indian Ocean has been studied, most recently by Pillai and Ueyanagi (1978).

Our statistics (Table 5) show that the total catch fluctuated between 800 and 2,400 MT annually from 1954 through 1964. Relatively high catches were taken in the following 6 years. During the 1970's the estimated catch dropped off considerably until 1976. The decline of Japanese longline catches during the 1970's is due in part to a shift of effort to more southerly waters where striped marlin are much less abundant. The Korean catches are estimated very roughly, as mentioned earlier.

The abundance index for striped marlin, assuming a single stock, shows a fair degree of annual variation, but the overall trend in stock size since the beginning of longlining is downward to a level perhaps one-fourth of the original abundance. The index has increased steadily over 1972-76 (Figure 13). The production model analysis for striped marlin gives an MSY of about 3,500 MT at an effort level above any yet experienced. The yield curve is very flat over a broad range of efforts (Figure 21).

Black Marlin

The total Indian Ocean catch of black marlin ranged from 1,100 to 1,600 MT during 1954-67, then reached the highest levels on record during 1968-69. The average catch during the 1970's has been substantially lower (Table 5, Figure 14). As in the Pacific Ocean, black marlin abundance is apparently greatest in coastal regions. The highest catch rates are seen in the eastern Indian Ocean. On the basis of catch rates, other concentrations also exist off southern Africa and Saudi Arabia.

The stock structure of black marlin is unknown. There may be more than one stock in the Indian Ocean, and interactions between the species in the eastern Indian Ocean and western Pacific (Shomura 1978). For the purposes of our analysis we considered the aggregate catch of black marlin in the Indian Ocean and assumed trends in the index for the eastern area were representative of trends in average abundance throughout the ocean. The index (Figure 14) shows a definite declining trend from the early 1950's until the present. The estimated MSY (Table 13) is 1,400-1,500 MT. Optimum effort is less than recent levels, but the yield-effort curve is quite flat (Figure 22). The equilibrium data points for 1972-76 are clustered below the expected yield curve, whereas the points for 1968-71 are above it, suggesting the possibility of some systematic bias in the above estimates.

Swordfish

While the distribution of catch rates in Figure 7 does not show it clearly, due to the scaling chosen for the plot, there seem to be two areas where densities of swordfish are relatively high. We constructed

Fig. 15

abundance indices in both areas (Table 11, Figure 15). Total catch of swordfish increased steadily from the early 1950's up through the 1960's, but has decreased during the 1970's. Both indices suggest rather marked variations in abundance, although an early decline in stock size through the mid-1960's is apparent. Since then the indices have been erratic with no evidence of sustained stock decrease in spite of a relatively large increase in average annual catch. The data suggest that longlinging has had no significant impact on the swordfish population, (for example, stock size has not been reduced below about 65% of its original level), so no production model analysis was attempted.

Sailfish

The "sailfish" catch contains an unknown percentage of shortbill spearfish, the proportion of spearfish being higher in offshore areas. However, the population dynamics of these species may be rather similar, so we may assume similar responses to exploitation. Two index areas were selected, based on average catch rates. As shown in Table 11 and
Fig. 16 Figure 16, total catch in the Indian Ocean climbed from about 200 MT in 1954 to nearly 2,000 MT in 1968. Since then it has declined, and the reported longline catch was less than 1,000 MT per year during 1974-76.

The stock abundance indices show considerable variability, with much higher variation in the more northerly index area. In general a long-term increase in apparent abundance of sailfish is evident, particularly in the southern index region. In neither case is there any indication that the stock has been affected by fishing, and we conclude that the potential yield for sailfish is much higher than the maximum annual catch taken thus far.

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Table 1.--Estimated annual catches (metric tons) of Indian Ocean albacore, by nation and year.

Year	Japan[1]	Taiwan[2]	Korea[3]	U.S.S.R.[4]	Total
1952	67				67
1953	1,099				1,099
1954	2,759				2,759
1955	3,302				3,302
1956	4,821				4,821
1957	4,664				4,664
1958	6,285				6,285
1959	10,412				10,412
1960	11,066				11,066
1961	15,438				15,438
1962	17,668				17,668
1963	12,546	74			12,620
1964	17,874	210	--		18,084
1965	11,375	22	500	500	12,397
1966	13,130	2,646	500	1,000	17,276
1967	14,098	5,205	2,900	1,500	23,703
1968	10,034	6,135	600	600	17,369
1969	8,546	9,427	3,000	900	21,873
1970	4,684	6,436	3,000	1,100	15,220
1971	3,140	4,346	2,100	600	10,186
1972	1,257	6,278	3,600	600	11,735
1973	1,835	10,570	9,000	900	22,305
1974	2,606	15,438	9,206	[5]1,000	28,250
1975	1,168	5,794	3,243	[5]1,000	11,205
1976	1,166	8,924	3,847	[5]1,000	14,937
1977	404	9,502	--	--	--
1978	--	7,824	--	--	--

[1]Courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory, Japan.

[2]Courtesy of R. T. Yang, National Taiwan University, Taiwan

[3]FAO (1977).

[4]FAO (1974, 1975)

[5]Guessed value.

Table 2.--Estimated annual catches (metric tons) of Indian Ocean bigeye tuna, by nation and year.

Year	Japan[1]	Taiwan[2]	Korea[3]	Sri Lanka[4]	U.S.S.R.[4]	Yemen[3]	Total
1952	1,500						1,500
1953	3,600						3,600
1954	7,900						7,900
1955	6,060						6,060
1956	8,040						8,040
1957	12,400						12,400
1958	11,300						11,300
1959	8,900						8,900
1960	15,700						15,700
1961	13,500						13,500
1962	18,700	1,226					19,926
1963	12,400	1,653			100		14,153
1964	16,700	1,771	--		400		18,871
1965	18,200	1,362	100		500		20,162
1966	22,600	2,175	100	100	1,400		26,375
1967	22,400	2,324	200	100	2,000		27,024
1968	24,600	7,209	5,400	200	1,300		38,709
1969	15,000	7,980	10,000	200	1,100		34,280
1970	13,600	7,604	11,000	100	1,800		34,104
1971	11,700	5,701	4,100	100	1,100		22,701
1972	8,800	4,143	4,300	100	800		18,143
1973	5,700	2,955	5,600	100	600		14,955
1974	7,700	4,448	13,300	--	[5]1,000		26,448
1975	8,500	4,005	24,691	--	[5]1,000	163	38,359
1976	2,900	3,165	21,018	--	[5]1,000	163	28,246
1977	5,200	5,170	--	--	--	--	--
1978	--	1,601	--	--	--	--	--

[1]Courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory, Japan.

[2]Courtesy of R. T. Yang, National Taiwan University, Taiwan.

[3]FAO (1977).

[4]FAO (1974, 1975).

[5]Guessed value.

Table 3.--Estimated annual catches (metric tons) of Indian Ocean yellowfin tuna, by nation and year.

	Longline catch						Surface catch											
Year	Japan[1]	Taiwan[2]	Korea[3]	U.S.S.R.[3]	Sri Lanka[3]	Total longline	Australia[4]	Bangladesh[4]	India[4]	Madagascar[4]	Maldives[3]	Pakistan[4]	Sri Lanka[4]	Seychelles[3]	Yemen[3]	Oman[3]	Total surface	Grand total
1952	8,858					8,858												8,858
1953	13,258					13,258												13,258
1954	24,883					24,883												24,883
1955	27,875					27,875												27,875
1956	38,641					38,641												38,641
1957	36,036					36,036												36,036
1958	25,727					25,727												25,727
1959	24,428					24,428												24,428
1960	40,292					40,292												40,292
1961	34,551					34,551												34,551
1962	51,665	3,468				55,133												55,133
1963	25,888	3,402		100		29,390												29,390
1964	24,752	2,859		300	200	28,111							2,000				2,000	30,111
1965	27,579	2,180	0	900	200	30,859		100	800		500	500	1,700				3,600	34,459
1966	44,106	4,368	100	2,600	200	51,374		200	1,000		1,500	700	2,000				5,400	56,774
1967	31,597	3,380	200	3,100	300	38,577		100	1,000		1,700	800	2,600				6,200	44,777
1968	50,475	22,646	4,000	2,700	400	80,221		100	1,300		1,700	700	4,100				7,900	88,121
1969	25,228	21,089	7,000	1,600	400	55,317		100	1,100		1,800	600	3,800				7,400	62,717
1970	14,459	11,865	8,000	2,000	300	36,624			500		1,200	300	4,000				6,000	42,624
1971	13,471	16,536	6,500	1,500	200	38,207	100		200		1,300	200	3,800				5,600	43,807
1972	8,880	8,833	9,600	1,600	100	29,013	100		200	200	5,000	300	5,100				10,900	39,913
1973	7,470	4,216	9,200	900	100	21,886	--		200	500	5,200	200	5,000	100	7,400		18,600	40,486
1974	7,935	3,147	11,563	--	--	[5]22,645	--		200	1,700	4,500	--	--	150	7,391		[5]13,941	[5]36,586
1975	8,577	3,371	11,694	--	--	[5]23,642	--		--	--	4,200	--	--	100	7,391	8,500	[5]20,191	[5]43,833
1976	3,507	2,545	12,848	--	--	[5]18,900	--		--	--	4,800	--	--	50	7,391	8,280	[5]20,521	[5]39,421
1977	3,521	6,690	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--
1978	--	2,114	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--

[1]Courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory, Japan.

[2]Courtesy of R. T. Yang, National Taiwan University, Taiwan.

[3]FAO (1977).

[4]FAO (1974, 1975).

[5]Incomplete.

Table 4.--Estimated annual catches (metric tons) of Indian Ocean blue marlin, by nation and year.

Year	Japan[1]	Taiwan[2]	Korea[3]	Total
1952	800			800
1953	2,000			2,000
1954	3,300			3,300
1955	3,600			3,600
1956	4.980			4,980
1957	3,800			3,800
1958	4,100			4,100
1959	4,300			4,300
1960	3,700			3,700
1961	3,200			3,200
1962	3,100			3,100
1963	1,800	834		2,634
1964	2,900	840		3,740
1965	3,300	578	0	3,878
1966	3,300	446	8	3,754
1967	3,400	658	16	4,074
1968	2,300	1,410	326	4,036
1969	1,800	1,504	571	3,875
1970	1,200	1,185	653	3,038
1971	1,000	1,002	530	2,532
1972	900	826	783	2,509
1973	600	540	751	1,891
1974	900	526	944	2,370
1975	700	447	1,130	2,277
1976	300	343	872	1,515
1977	300	452	--	--

[1]Courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory, Japan.

[2]Courtesy of R. T. Yang, National Taiwan University, Taiwan; 1963-66 estimated.

[3]1965-74 estimated; see text. 1975-76 from FAO (1977).

Table 5.--Estimated annual catches (metric tons) of Indian Ocean striped marlin, by nation and year.

Year	Japan[1]	Taiwan[2]	Korea[3]	Total
1952	100			100
1953	300			300
1954	800			800
1955	780			780
1956	1,740			1,740
1957	1,800			1,800
1958	1,700			1,700
1959	2,100			2,100
1960	2,000			2,000
1961	2,400			2,400
1962	1,800			1,800
1963	1,300	483		1,783
1964	1,400	486		1,886
1965	3,000	335	0	3,335
1966	3,900	258	5	4,163
1967	4,200	257	6	4,463
1968	2,300	923	213	3,436
1969	2,200	1,833	696	4,729
1970	1,700	909	501	3,110
1971	1,000	714	378	2,092
1972	800	365	346	1,511
1973	500	258	359	1,117
1974	1,400	501	899	2,800
1975	900	344	870	2,114
1976	500	819	2,082	3,401
1977	500	1,401	--	--

[1]Courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory, Japan.

[2]Courtesy of R. T. Yang, National Taiwan University; 1963-66 estimated.

[3]Estimated, see text.

Table 6.--Estimated annual catches (metric tons) of Indian Ocean black marlin, by nation and year.

Year	Japan[1]	Taiwan[2]	Korea[3]	Total
1952	300			300
1953	800			800
1954	1,100			1,100
1955	1,080			1,080
1956	1,500			1,500
1957	1,400			1,400
1958	1,200			1,200
1959	1,200			1,200
1960	1,700			1,700
1961	1,400			1,400
1962	1,800			1,800
1963	1,100	351		1,451
1964	1,300	354		1,654
1965	1,100	244	0	1,344
1966	1,200	188	3	1,391
1967	1,300	242	6	1,548
1968	1,700	617	143	2,460
1969	1,300	753	286	2,339
1970	900	609	336	1,845
1971	700	481	254	1,435
1972	200	356	337	893
1973	200	213	296	709
1974	400	337	605	1,342
1975	500	192	495	1,187
1976	200	78	198	476
1977	100	120	--	--

[1]Courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory, Japan.

[2]Courtesy of R. T. Yang, National Taiwan University, Taiwan; 1963-66 estimated.

[3]Estimated, see text.

Table 7.--Estimated annual catches (metric tons) of Indian Ocean swordfish, by nation and year.

Year	Japan[1]	Taiwan[2]	Korea[3]	Total
1952	<100			<100
1953	100			100
1954	200			200
1955	240			240
1956	480			480
1957	300			300
1958	500			500
1959	500			500
1960	600			600
1961	700			700
1962	900			900
1963	700	351		1,051
1964	900	354		1,254
1965	1,100	244	0	1,344
1966	1,200	188	3	1,391
1967	1,600	226	5	1,831
1968	1,200	626	145	1,971
1969	1,200	786	298	2,284
1970	1,000	809	446	2,255
1971	800	512	271	1,583
1972	800	387	367	1,554
1973	500	271	377	1,148
1974	600	419	752	1,771
1975	700	291	244	1,235
1976	300	371	398	1,069
1977	300	400	--	--

[1]Courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory, Japan.

[2]Courtesy of R. T. Yang, National Taiwan University; 1963-66 estimated.

[3]1965-74 estimated; see text. 1975-76 from FAO (1977).

Table 8.--Estimated annual catches (metric tons) of Indian Ocean sailfish, by nation and year.

Year	Japan[1]	Taiwan[2]	Korea[3]	Total
1952	<100			<100
1953	100			100
1954	200			200
1955	180			180
1956	300			300
1957	300			300
1958	400			400
1959	500			500
1960	500			500
1961	500			500
1962	800			800
1963	500	175		675
1964	600	177		777
1965	1,100	122	0	1,222
1966	1,200	94	2	1,296
1967	1,900	70	2	1,972
1968	1,200	349	81	1,630
1969	700	353	134	1,187
1970	600	268	148	1,016
1971	800	359	190	1,349
1972	600	280	265	1,145
1973	300	54	75	429
1974	300	126	226	652
1975	200	511	280	991
1976	200	261	140	601
1977	<100	29	--	--

[1]Courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory, Japan.

[2]Courtesy of R. T. Yang, National Taiwan University, Taiwan; 1963-66 estimated.

[3]1965-1974 estimated; see text. 1975-76 from FAO (1977).

Table 9.--Estimated mean weights (kg) of tunas and billfishes caught in the Indian Ocean by longliners of Japan and Taiwan.

Year	Albacore	Bigeye tuna	Yellowfin tuna	Blue marlin	Striped marlin	Black marlin	Swordfish	Sailfish
				Japan				
1952	18.8	53.4	52.0	67.8	32.8	36.4	--	--
1953	19.2	54.8	48.1	63.8	40.5	37.8	42.4	21.2
1954	19.4	54.8	48.6	63.3	37.7	36.3	49.4	33.3
1955	19.7	32.1	26.3	64.6	37.5	35.5	46.7	23.5
1956	19.9	27.3	29.0	64.7	37.0	35.5	43.8	25.2
1957	20.1	54.1	46.8	65.2	36.1	36.0	36.4	23.9
1958	20.8	55.9	43.7	64.6	36.5	37.6	39.7	28.5
1959	19.8	51.0	39.2	65.4	37.0	37.2	42.5	27.4
1960	19.3	48.5	39.9	64.6	38.0	35.5	38.5	27.3
1961	19.9	49.8	39.7	65.0	36.9	35.5	41.5	26.9
1962	17.5	43.3	36.6	64.7	37.5	37.0	38.8	26.0
1963	17.5	45.3	37.3	64.2	38.5	36.6	38.9	26.2
1964	17.7	48.9	39.9	66.1	36.8	36.5	41.2	26.3
1965	18.1	46.1	33.9	65.2	36.8	35.6	42.5	25.9
1966	17.5	46.1	36.9	65.3	37.0	36.3	40.8	24.2
1967	16.6	43.0	34.6	65.7	36.7	36.2	40.2	24.5
1968	16.2	44.5	28.8	66.0	36.2	35.9	38.2	24.3
1969	14.6	38.5	30.8	66.8	37.1	35.9	37.8	25.1
1970	15.6	39.4	36.3	66.3	37.7	34.6	35.9	27.4
1971	13.9	39.7	27.0	68.1	35.1	38.5	33.0	25.0
1972	13.2	41.3	29.7	64.4	37.7	33.1	38.9	26.6
1973	12.7	39.9	42.9	68.2	34.3	35.8	29.1	29.6
1974	14.4	39.3	37.1	67.1	37.3	36.4	33.1	27.7
1975	14.7	41.2	31.0	67.3	36.0	40.5	34.4	30.0
1976	11.9	39.0	33.5	65.7	35.0	41.7	29.5	31.2
1977[1]	12.2	41.3	33.5	75.0	38.5	33.3	37.5	--
				Taiwan				
1967	15.5	36.4	32.4	75.5	45.3	68.5	42.5	30.1
1968	15.3	34.3	22.2	72.4	40.1	58.0	45.0	26.7
1969	16.9	32.6	27.4	71.9	40.4	61.6	45.8	26.5
1970	17.2	33.3	28.8	69.4	42.5	47.8	40.7	23.3
1971	19.1	33.4	21.0	66.0	39.7	64.0	42.3	25.0
1972	17.5	32.0	26.1	67.1	37.8	61.2	41.9	21.8
1973	14.9	31.4	30.8	69.7	42.3	71.0	45.5	27.2
1974	16.1	34.6	30.5	65.5	42.1	52.3	44.2	24.6
1975	17.5	32.6	26.6	60.3	40.0	49.1	28.8	28.3
1976	15.9	28.3	28.9	31.8	40.8	61.9	45.5	14.6
1977	15.3	31.9	32.0	65.5	41.6	62.2	41.4	26.0

[1]1977 average weights for Japan estimated.

Table 10.--Estimated total catch (MT) relative abundance (kg/100 hooks) and effective effort (10^6 hooks) for Indian Ocean albacore, bigeye tuna, and yellowfin tuna.

Year	Albacore			Bigeye tuna			Yellowfin tuna		
	Catch (MT)	Abundance index (kg/100 hooks)	Effective effort (10^6 hooks)	Catch (MT)	Abundance index (kg/100 hooks)	Effective effort (10^6 hooks)	Catch (MT)	Abundance index (kg/100 hooks)	Effective effort (10^6 hooks)
1952	67	21.24	0.32						
1953	1,099	33.56	3.30	3,600	58.62	6.14	13,258	164.33	8.07
1954	2,759	42.52	6.51	7,900	67.06	11.77	24,883	172.62	14.41
1955	3,302	63.84	5.19	6,060	41.85	14.47	27,875	102.12	27.28
1956	4,821	37.46	12.92	8,040	34.92	22.97	38,641	97.93	39.44
1957	4,664	42.36	11.05	12,400	60.19	20.59	36,036	96.09	37.49
1958	6,285	26.29	24.00	11,300	67.37	16.76	25,727	75.44	34.09
1959	10,412	18.63	56.09	8,900	47.15	18.86	24,428	78.74	31.01
1960	11,066	14.78	75.16	15,700	54.71	28.68	40,292	76.44	52.69
1961	15,438	16.48	94.04	13,500	44.81	30.11	34,551	62.19	55.53
1962	17,668	11.60	152.90	19,926	41.92	47.51	55,133	52.20	105.58
1963	12,620	7.37	171.88	14,153	46.63	30.12	29,390	37.32	78.72
1964	18,084	9.56	189.88	18,871	44.75	41.25	30,111	32.30	93.18
1965	12,397	7.11	167.87	20,162	35.81	54.87	34,459	27.33	126.05
1966	17,276	6.26	261.05	26,375	40.34	61.63	56,774	39.74	142.82
1967	23,703	5.74	388.46	27,024	37.38	66.63	44,777	24.04	186.16
1968	17,369	4.55	369.70	38,709	42.38	87.76	88,121	36.21	243.26
1969	21,873	3.42	615.82	34,280	34.06	96.79	62,717	26.87	233.29
1970	15,220	2.90	488.50	34,104	39.23	82.04	42,624	22.23	191.67
1971	10,186	2.02	475.34	22,701	29.99	71.66	43,907	19.91	220.48
1972	11,735	2.46	453.96	18,143	31.56	54.61	40,013	18.04	221.66
1973	22,305	9.23	232.66	14,955	36.15	39.41	40,486	22.69	178.35
1974	28,250	4.44	615.72	26,448	33.69	75.51	36,545	14.14	258.26
1975	11,205	4.55	225.16	38,359	22.71	164.39	43,833	13.82	317.04
1976	14,937	3.87	361.52	28,246	25.12	108.42	39,421	14.54	271.01

Table 11.--Estimated total catch (MT) relative abundance (kg/100 hooks) and effective effort (10^6 hooks) for Indian Ocean billfishes.

Year	Blue marlin Catch (MT)	Blue marlin Abundance index (kg/100 hooks)	Blue marlin Effective effort (10^6 hooks)	Striped marlin Catch (MT)	Striped marlin Abundance index (kg/100 hooks)	Striped marlin Effective effort (10^6 hooks)	Black marlin Catch (MT)	Black marlin Abundance index (kg/100 hooks)	Black marlin Effective effort (10^6 hooks)	Swordfish Catch (MT)	Swordfish Abundance index (kg/100 hooks) North	Swordfish Abundance index (kg/100 hooks) South	Sailfish Catch (MT)	Sailfish Abundance index (kg/100 hooks) North	Sailfish Abundance index (kg/100 hooks) South
1952	800	49.35	1.62	100	5.60	1.78	300	8.99	3.34						
1953	2,000	23.86	8.40	300	4.24	7.10	800	9.17	8.72						
1954	3,300	16.78	19.70	800	5.23	15.32	1,100	10.11	10.87	200	1.38		200	1.90	
1955	3,600	14.21	25.38	780	4.42	17.66	1,080	11.10	9.72	240	2.06		180	1.41	3.90
1956	4,980	10.58	47.17	1,740	3.99	43.72	1,500	7.87	19.06	480	2.00		300	0.97	2.29
1957	3,800	9.09	41.87	1,800	3.36	53.64	1,400	6.29	22.24	300	1.30		300	1.61	1.84
1958	4,100	11.07	37.09	1,700	3.56	47.89	1,200	9.57	12.31	500	1.72	1.47	400	1.90	0.92
1959	4,300	8.94	48.17	2,100	4.26	49.38	1,200	6.83	17.56	500	1.15	2.10	500	3.07	1.84
1960	3,700	6.17	60.06	2,000	2.70	74.19	1,700	5.93	28.64	600	1.36	1.40	500	2.29	2.98
1961	3,200	5.07	63.28	2,400	2.39	100.82	1,400	4.50	31.14	700	1.26	1.33	500	2.63	1.84
1962	3,100	5.08	61.10	1,800	2.24	80.53	1,800	5.17	34.81	900	1.17	1.12	800	2.34	3.90
1963	2,634	3.84	68.63	1,783	2.01	88.93	1,451	4.50	32.27	1,051	1.22	1.40	675	1.70	2.52
1964	3,740	4.32	86.66	1,886	1.85	102.09	1,654	4.23	39.13	1,254	1.10	1.40	777	1.51	1.84
1965	3,878	2.95	131.53	3,335	2.45	136.61	1,344	3.42	39.33	1,344	1.22	1.05	1,222	2.73	3.21
1966	3,754	2.84	132.51	4,163	1.92	216.80	1,391	4.09	34.00	1,391	1.24	1.12	1,296	2.24	3.21
1967	4,074	2.59	157.54	4,463	1.34	334.90	1,548	3.64	42.50	1,831	1.46	1.05	1,972	3.12	3.90
1968	4,036	2.26	178.85	3,436	1.55	226.58	2,460	4.18	58.83	1,971	1.32	0.91	1,630	2.34	2.98
1969	3,875	1.86	208.19	4,729	1.31	361.45	2,339	4.27	54.76	2,284	1.35	1.33	1,187	1.80	3.67
1970	3,038	1.72	177.35	3,110	1.00	313.06	1,845	2.65	69.55	2,255	1.25	1.40	1,016	3.17	3.90
1971	2,532	2.03	124.97	2,092	0.94	222.82	1,435	3.24	44.33	1,583	1.10	1.61	1,349	2.63	3.44
1972	2,509	2.82	89.08	1,511	0.79	191.88	893	1.89	47.29	1,554	1.62	1.96	1,145	2.87	4.36
1973	1,891	3.28	57.69	1,117	1.03	108.48	709	1.93	36.67	1,148	1.05	1.12	429	2.09	5.05
1974	2,370	3.30	71.94	2,800	1.31	214.01	1,342	1.98	67.83	1,771	1.32	0.84	652	2.09	4.59
1975	2,277	1.86	22.33	2,114	1.37	154.43	1,187	1.93	61.39	1,235	1.21	1.19	991	1.51	3.21
1976	1,515	1.88	80.68	3,401	1.92	177.13	476	1.75	27.14	1,069	1.26	1.12	601	2.39	5.28

Table 12.--Results of production model analyses for Indian Ocean albacore, bigeye tuna, and yellowfin tuna.

Smoothing period (yr)	Albacore $\hat{MSY}$ (MT)	Albacore $\hat{E}_{opt}$ (10^6 hooks)	Albacore $\hat{M}$	Albacore Fit index	Yellowfin tuna $\hat{MSY}$ (MT)	Yellowfin tuna $\hat{E}_{opt}$ (10^6 hooks)	Yellowfin tuna $\hat{M}$	Yellowfin tuna Fit index	Bigeye tuna $\hat{MSY}$ (MT)	Bigeye tuna $\hat{E}_{opt}$ (10^6 hooks)	Bigeye tuna $\hat{M}$	Bigeye tuna Fit index
1	16,199	86	0.39	0.8065	49,936	∞	0.0	0.9370	59,953	∞	0.0	0.6302
2	17,760	∞	0.0	1.1044	43,058	∞	0.0	1.0138	59,070	∞	0.0	1.0098
3	12,784	∞	0.0	1.0089	45,444	1,455	0.05	1.0019	32,490	452	1.20	1.0024
4	8,864	∞	0.0	1.0025	43,534	∞	0.0	1.0006	30,644	443	0.99	1.0009

Table 13.--Results of production model analyses for Indian Ocean blue marlin, striped marlin, and black marlin.

Smoothing period	Striped marlin				Blue marlin				Black marlin			
	$\hat{MSY}$	$\hat{E}_{opt}$	$\hat{M}$	Fit index	$\hat{MSY}$	$\hat{E}_{opt}$	$\hat{M}$	Fit index	$\hat{MSY}$	$\hat{E}_{opt}$	$\hat{M}$	Fit index
(yr)	(MT)	(10^6 hooks)			(MT)	(10^6 hooks)			(MT)	(10^6 hooks)		
1	3,215	449	0.10	1.0000	3,572	229	0.05	0.9774	1,526	173	0.75	1.0001
2	2,930	219	0.24	1.0128	3,652	71	0.62	1.0282	1,484	158	0.63	1.0001
3	3,557	∞	0.00	1.0022	3,527	77	0.63	1.0023	1,430	170	0.35	1.0000
4	3,153	607	0.07	1.0008	3,377	78	0.52	1.0008	1,397	217	0.17	1.0000

Table 14.--Percentage distribution of nominal effort (hooks) by Japanese longliners in the Indian Ocean, by latitude, 1952-76.

Year	Latitude														Effort (10^3 hooks)
	20°-15°N	15°-10°N	10°-5°N	5°N-0°	0°-5°S	5°-10°S	10°-15°S	15°-20°S	20°-25°S	25°-30°S	30°-35°S	35°-40°S	40°-45°S	45°-50°S	
1952	0.0	0.0	0.0	0.0	28.14	39.34	30.13	2.39	0.0	0.0	0.0	0.0	0.0	0.0	2,974
1953	0.0	0.0	0.0	0.0	8.96	41.22	42.22	7.60	0.0	0.0	0.0	0.0	0.0	0.0	8,437
1954	0.0	5.11	11.87	3.56	22.02	26.68	25.35	4.07	1.34	0.0	0.0	0.0	0.0	0.0	13,783
1955	0.0	0.31	2.65	10.69	34.75	29.60	20.46	0.56	0.89	0.09	0.0	0.0	0.0	0.0	29,626
1956	0.0	1.06	2.35	9.99	26.01	30.69	26.52	2.92	0.45	0.01	0.0	0.0	0.0	0.0	51,959
1957	0.53	3.74	8.08	10.90	11.48	27.86	29.17	7.96	0.28	0.0	0.0	0.0	0.0	0.0	28,023
1958	3.95	7.03	11.48	11.69	9.63	17.19	24.24	7.75	5.72	1.32	0.0	0.0	0.0	0.0	24,573
1959	1.11	4.28	6.06	10.28	10.78	8.49	13.74	13.91	16.93	14.36	0.06	0.0	0.0	0.0	34,944
1960	0.02	1.55	3.57	8.73	13.67	12.69	17.95	8.69	7.02	25.47	0.63	0.01	0.0	0.0	54,237
1961	0.52	1.53	3.73	6.31	8.17	13.80	18.26	12.09	16.17	19.31	0.11	0.0	0.0	0.0	60,027
1962	0.19	0.46	1.69	7.78	17.24	22.03	13.37	7.60	6.49	17.99	4.98	0.18	0.0	0.0	68,093
1963	0.24	0.99	2.32	2.54	7.02	17.86	13.23	10.73	8.47	31.22	4.97	0.41	0.0	0.0	57,420
1964	0.05	0.65	2.30	3.95	6.37	20.59	16.66	7.21	4.40	29.53	7.90	0.39	0.0	0.0	68,872
1965	0.89	1.35	5.92	11.48	12.18	17.08	11.50	7.14	4.28	21.20	6.03	0.90	0.04	0.01	79,848
1966	0.18	3.77	6.74	9.40	15.27	17.09	11.84	3.64	4.51	15.76	4.17	0.96	1.80	4.87	89,566
1967	1.23	3.98	9.20	7.44	8.20	11.19	9.89	4.17	2.19	7.01	10.47	8.14	13.40	3.48	126,305
1968	0.13	0.65	1.10	5.78	10.08	17.92	9.78	4.77	1.16	3.41	8.53	9.04	15.57	12.08	118,557
1969	0.78	4.77	6.78	9.68	7.77	5.30	4.81	3.28	1.48	2.74	6.37	20.14	20.92	5.18	101,107
1970	1.56	2.82	3.55	2.57	4.27	13.51	5.75	4.56	1.22	5.82	7.36	12.98	22.27	11.76	78,170
1971	0.77	1.17	4.51	4.43	9.35	8.63	2.06	1.79	1.39	3.29	10.54	11.71	19.16	21.20	88,598
1972	0.48	1.29	10.28	7.95	3.77	5.75	1.93	0.74	0.38	1.06	1.78	12.74	25.95	25.90	72,105
1973	0.49	0.67	3.68	2.01	2.86	4.00	1.83	1.05	0.60	2.26	2.53	19.73	35.52	22.77	79,326
1974	0.11	1.32	2.06	3.69	3.91	7.52	4.24	2.21	1.61	2.97	4.19	14.39	33.90	17.88	85,617
1975	0.35	1.07	2.89	2.68	4.79	8.75	5.90	1.92	1.09	1.79	3.68	16.81	33.71	14.57	91,207
1976	0.74	0.97	1.72	0.85	1.64	1.77	2.61	0.55	0.48	0.67	1.61	19.23	45.90	21.26	79,914

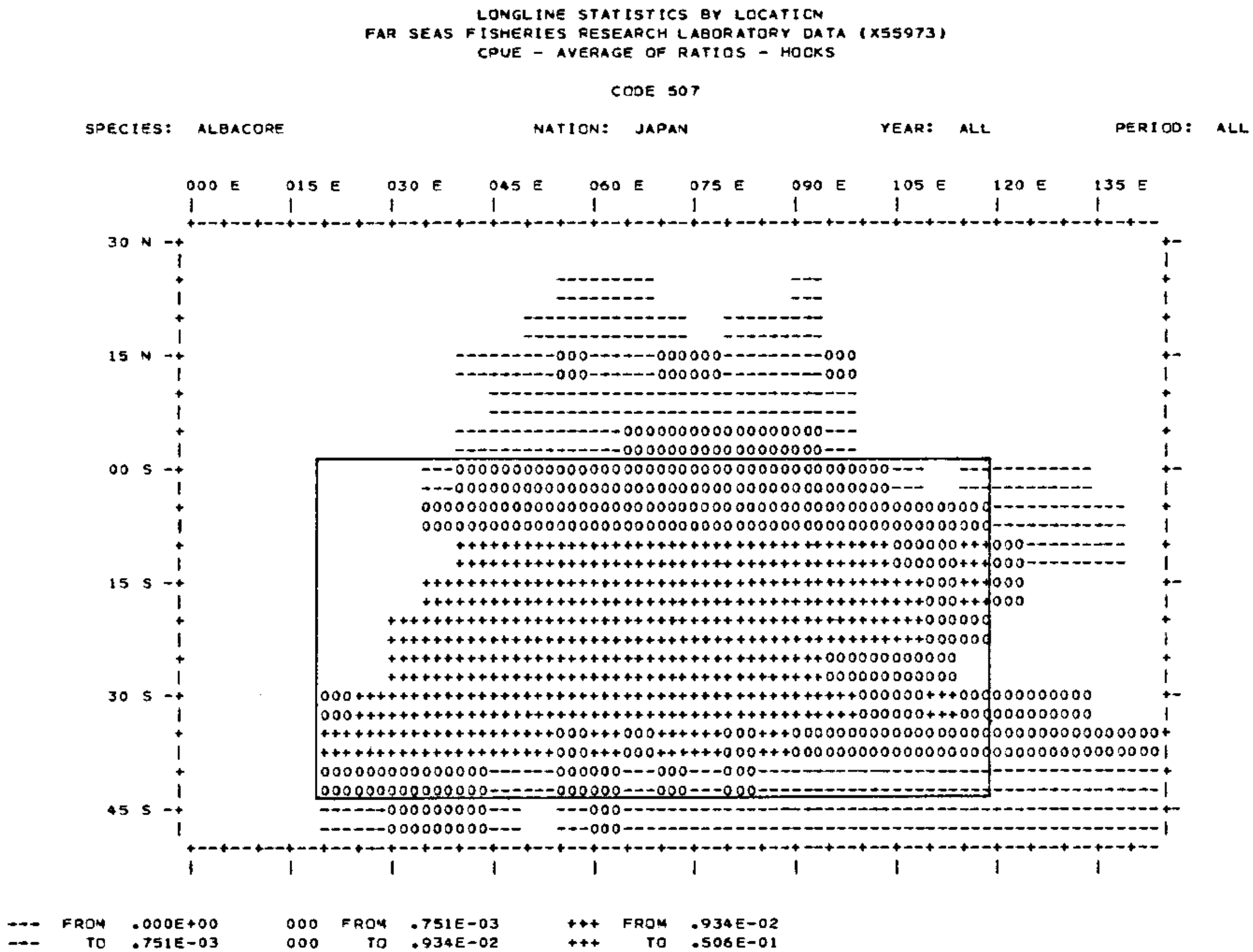
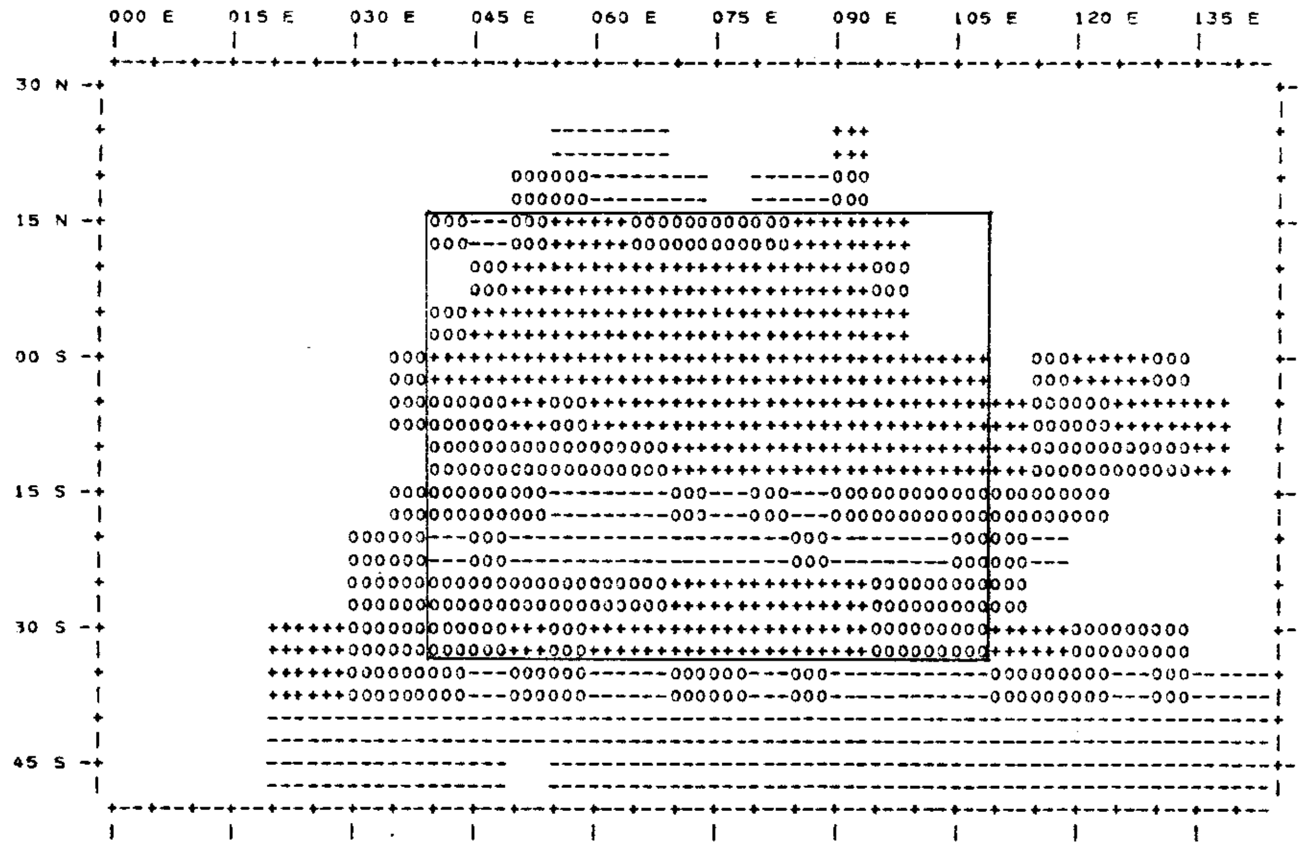


Figure 1.--Distribution of average catch per hook for albacore caught by Japanese longliners in the Indian Ocean, 1952-76. Index area outlined.

LONGLINE STATISTICS BY LOCATION
FAR SEAS FISHERIES RESEARCH LABORATORY DATA (X55973)
CPUE - AVERAGE OF RATIOS - HOOKS

CODE 507

SPECIES: BIGEYE   NATION: JAPAN   YEAR: ALL   PERIOD: ALL



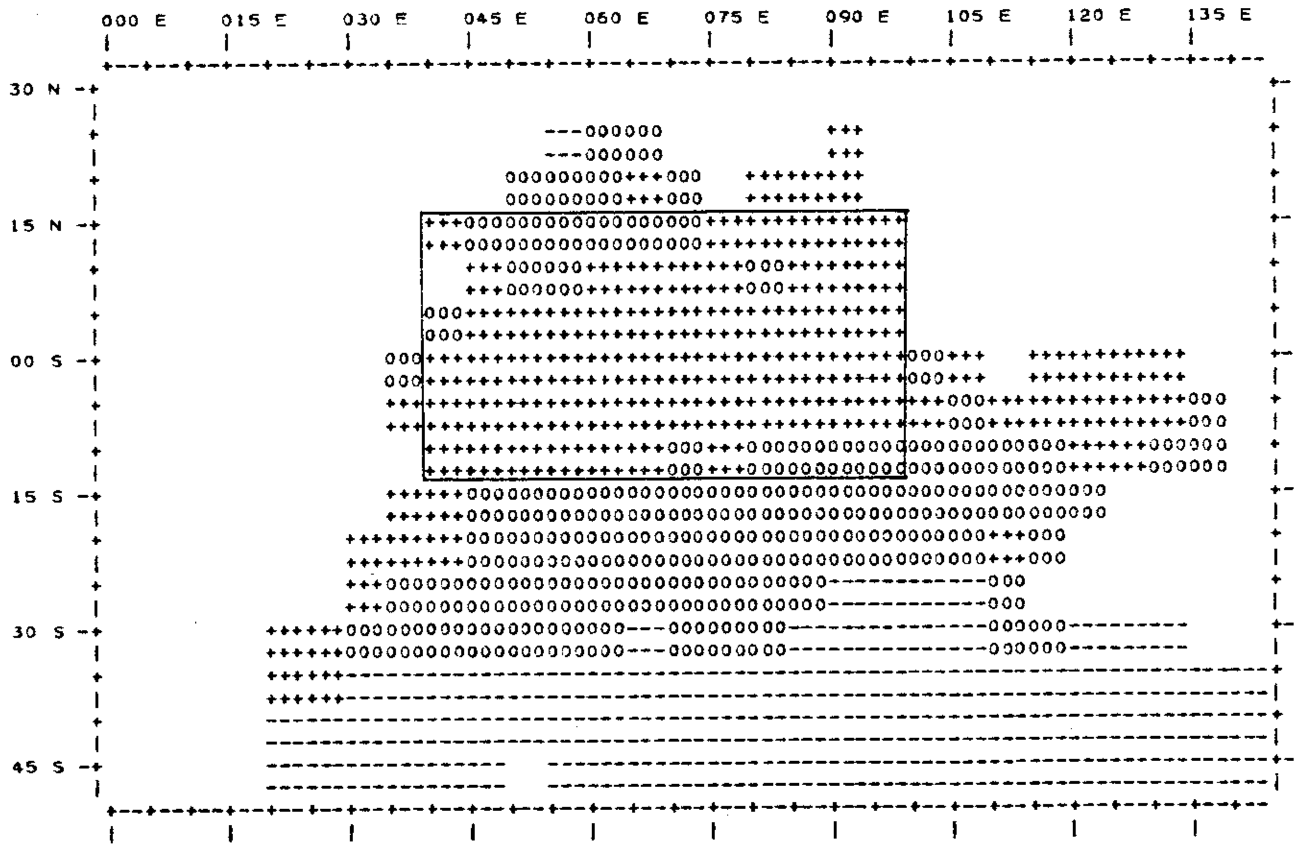
--- FROM .000E+00 TO .135E-02
000 FROM .135E-02 TO .581E-02
+++ FROM .581E-02 TO .506E-01

Figure 2.--Distribution of average catch per hook for bigeye tuna caught by Japanese longliners in the Indian Ocean, 1952-76. Index area outlined.

LONGLINE STATISTICS BY LOCATION
FAR SEAS FISHERIES RESEARCH LABORATORY DATA (X55973)
CPUE - AVERAGE OF RATIOS - HOOKS

CODE 507

SPECIES: YELLOWFIN NATION: JAPAN YEAR: ALL PERIOD: ALL



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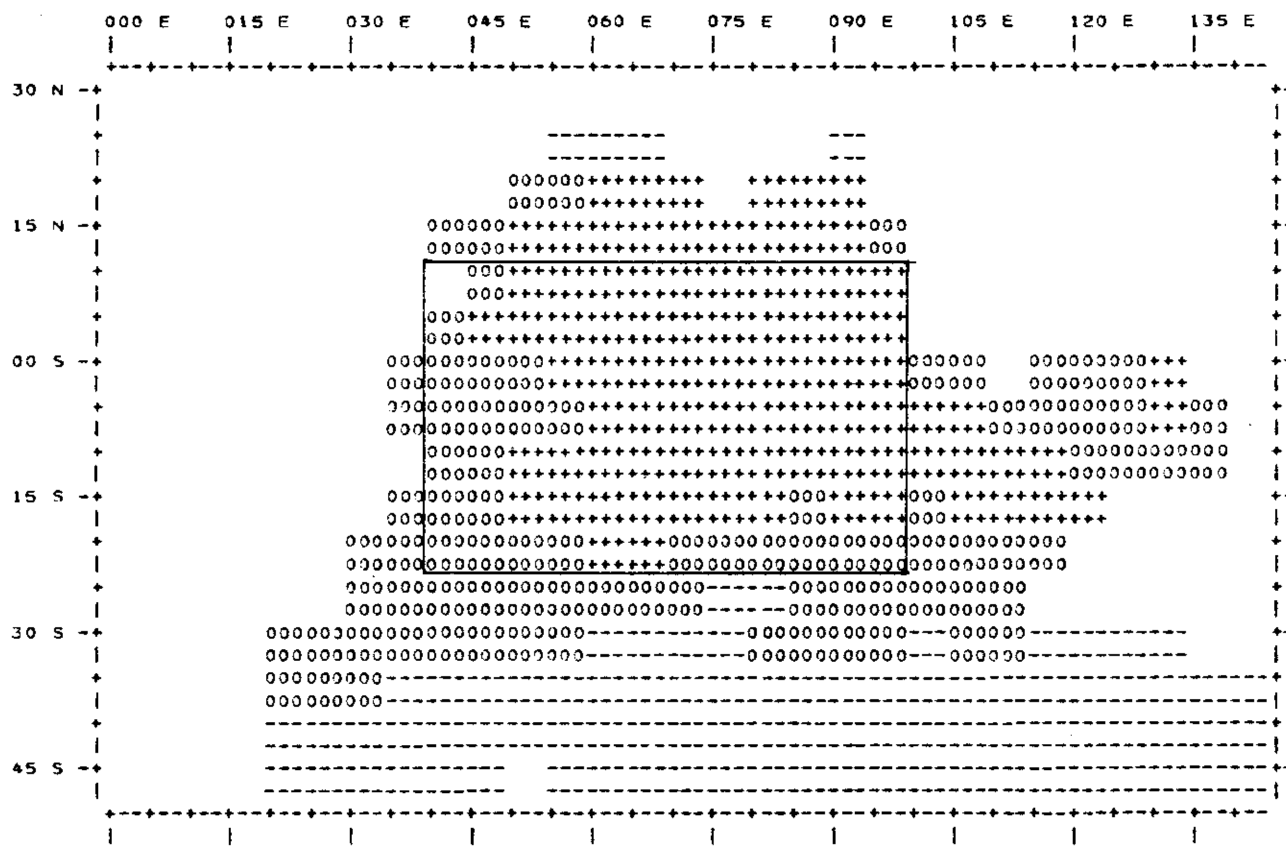
000 FROM .168E-02 TO .135E-01
+++ FROM .135E-01 TO .584E-01

Figure 3.--Distribution of average catch per hook for yellowfin tuna caught by Japanese longliners in the Indian Ocean, 1952-76. Index area outlined.

LONGLINE STATISTICS BY LOCATION
FAR SEAS FISHERIES RESEARCH LABORATORY DATA (X55973)
CPUE - AVERAGE OF RATIOS - HOCKS

CODE 507

SPECIES: BLUE MARLIN NATION: JAPAN YEAR: ALL PERIOD: ALL



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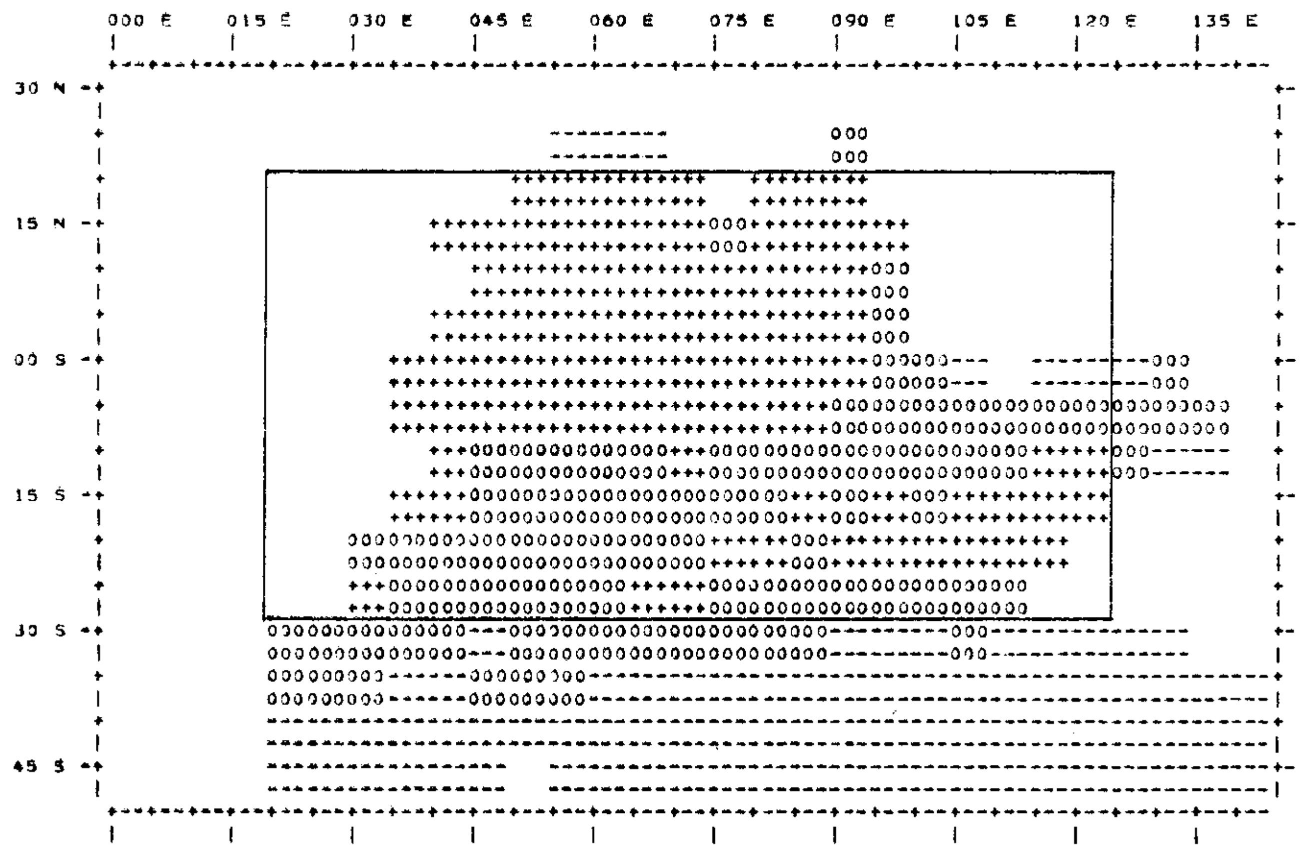
--- TO .818E-05 000 TO .839E-03 +++ TO .369E-02

Figure 4.--Distribution of average catch per hook for blue marlin caught by Japanese longliners in the Indian Ocean, 1952-76. Index area outlined.

LONGLINE STATISTICS BY LOCATION
FAR SEAS FISHERIES RESEARCH LABORATORY DATA (X55973)
CPUE - AVERAGE OF RATIOS - HOOKS

CODE 507

SPECIES: STRIPED MARLIN　　NATION: JAPAN　　YEAR: ALL　　PERIOD: ALL



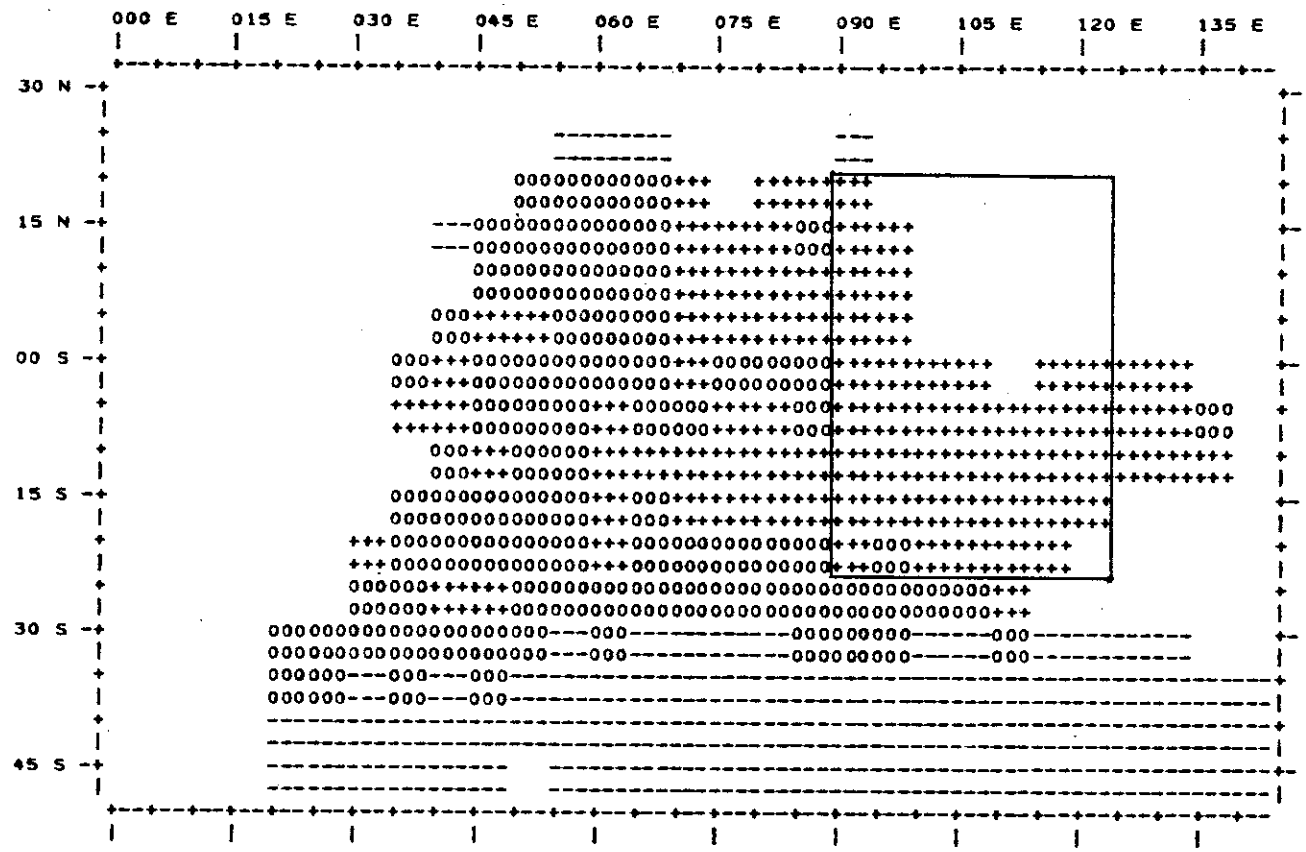
--- FROM .000E+00 TO .824E-04　　000 FROM .824E-04 TO .679E-03　　+++ FROM .679E-03 TO .957E-02

Figure 5.--Distribution of average catch per hook for striped marlin caught by Japanese longliners in the Indian Ocean, 1952-76. Index area outlined.

LONGLINE STATISTICS BY LOCATION
FAR SEAS FISHERIES RESEARCH LABORATORY DATA (X55973)
CPUE - AVERAGE OF RATIOS - HOOKS

CODE 507

SPECIES: BLACK MARLIN NATION: JAPAN YEAR: ALL PERIOD: ALL



--- FROM .000E+00	000 FROM .103E-04	+++ FROM .367E-03
--- TO .103E-04	000 TO .367E-03	+++ TO .676E-02

Figure 6.--Distribution of average catch per hook for black marlin caught by Japanese longliners in the Indian Ocean, 1952-76. Index area outlined.

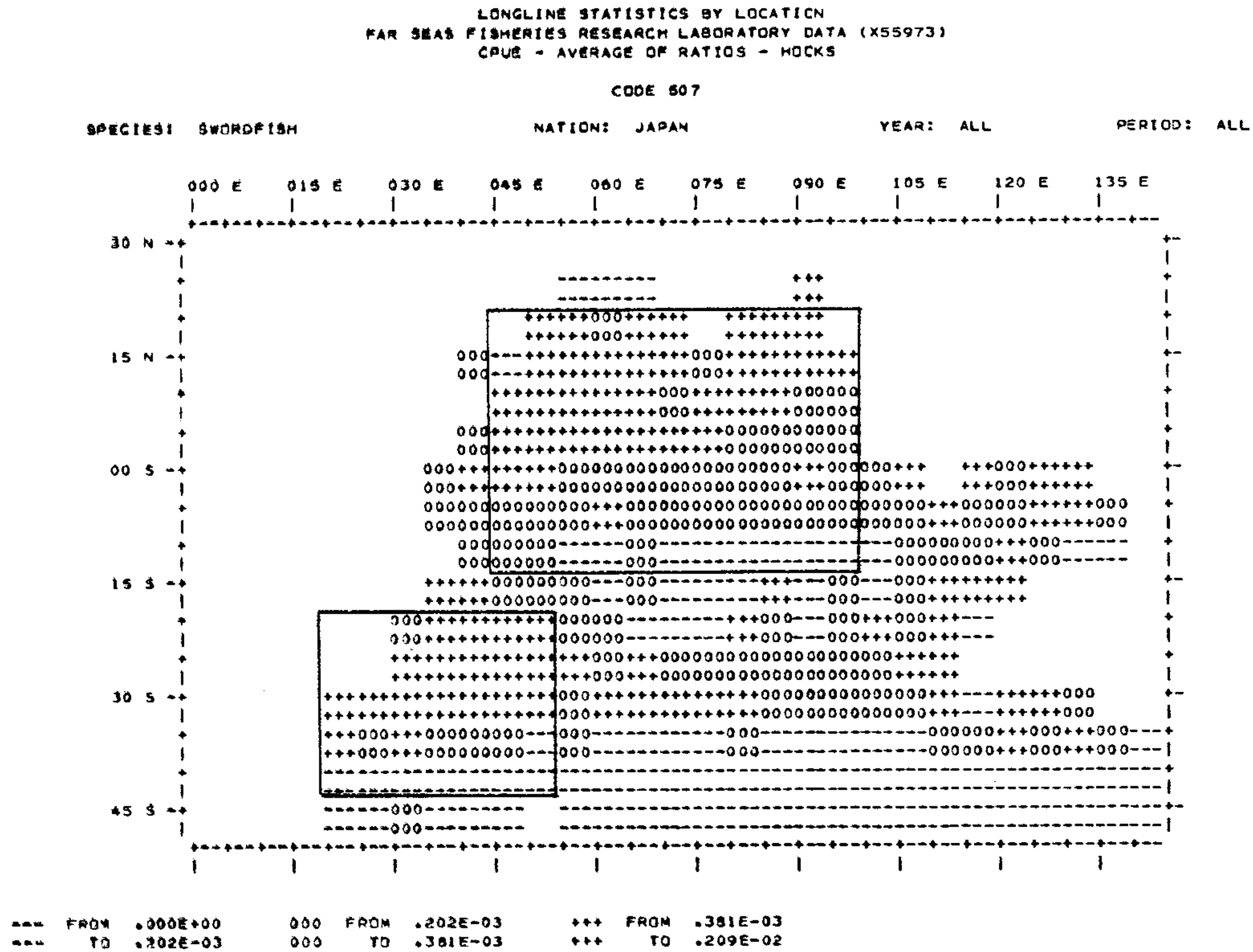
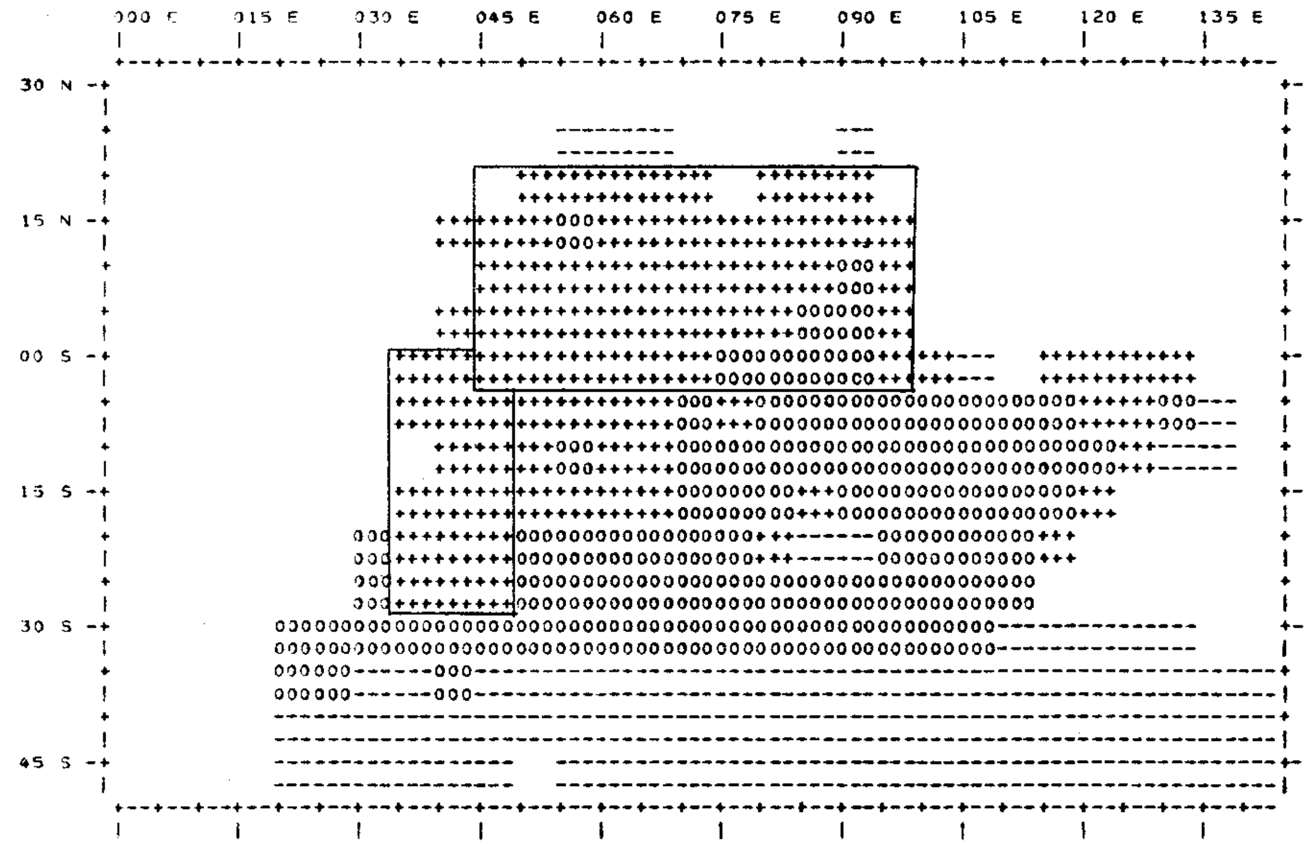


Figure 7.--Distribution of average catch per hook for swordfish caught by Japanese longliners in the Indian Ocean, 1952-76. Index areas outlined.

LONGLINE STATISTICS BY LOCATION
FAR SEAS FISHERIES RESEARCH LABORATORY DATA (X55973)
CPUE - AVERAGE OF RATIOS - HOOKS

CODE 507

SPECIES: OTHER BILLFISHES NATION: JAPAN YEAR: ALL PERIOD: ALL



--- FROM .000E+00 TO .109E-04
000 FROM .109E-04 TO .483E-03
+++ FROM .483E-03 TO .561E-02

Figure 8.--Distribution of average catch per hook for sailfish caught by Japanese longliners in the Indian Ocean, 1952-76. Index areas outlined.

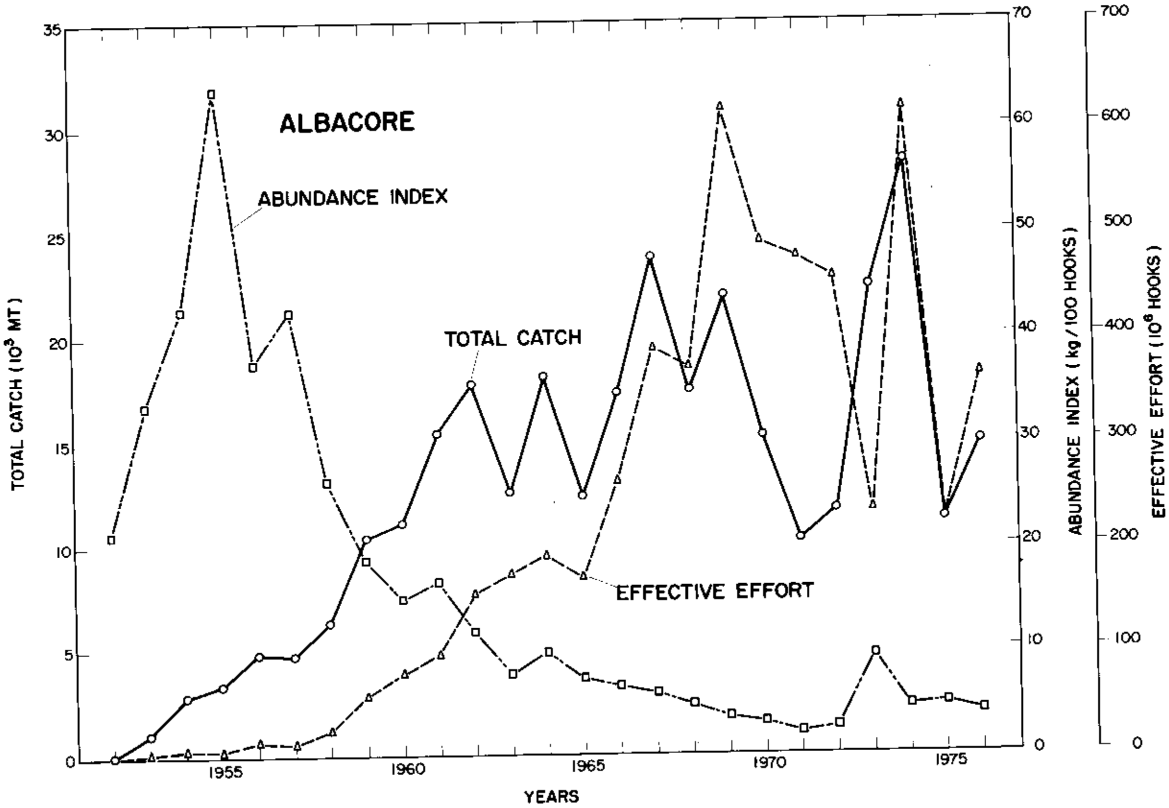


Figure 9.--Estimated total catch (10^3 MT), relative abundance (kg/100 hooks), and effective effort (10^6 hooks) for Indian Ocean albacore.

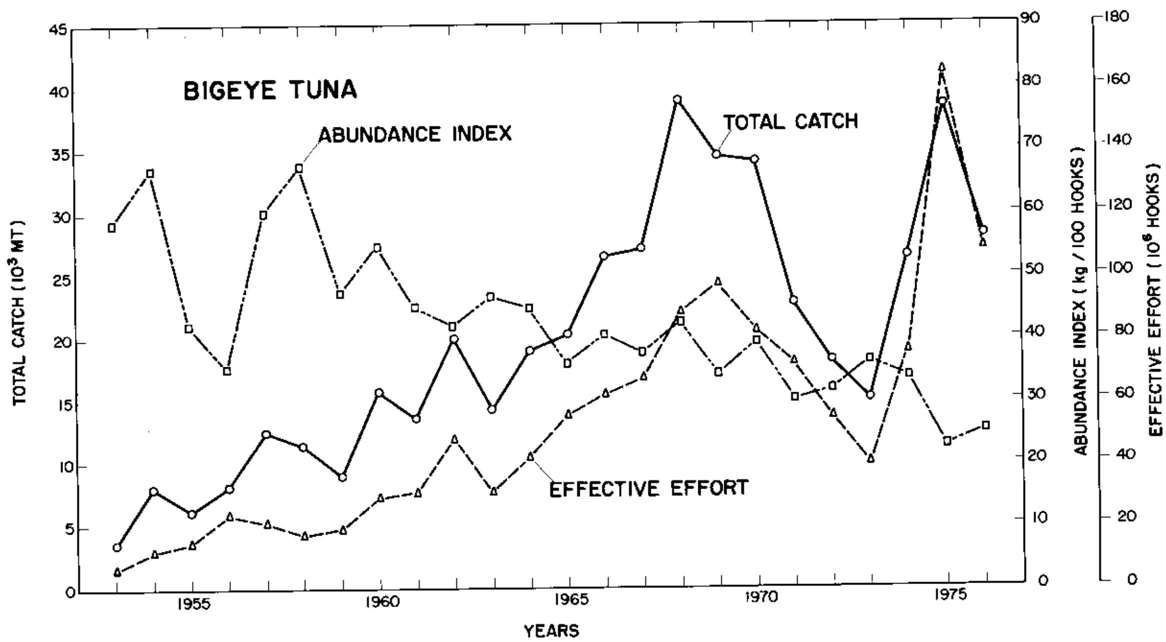


Figure 10.--Estimated total catch (10^3 MT), relative abundance (kg/100 hooks), and effective effort (10^6 hooks) for Indian Ocean bigeye tuna.

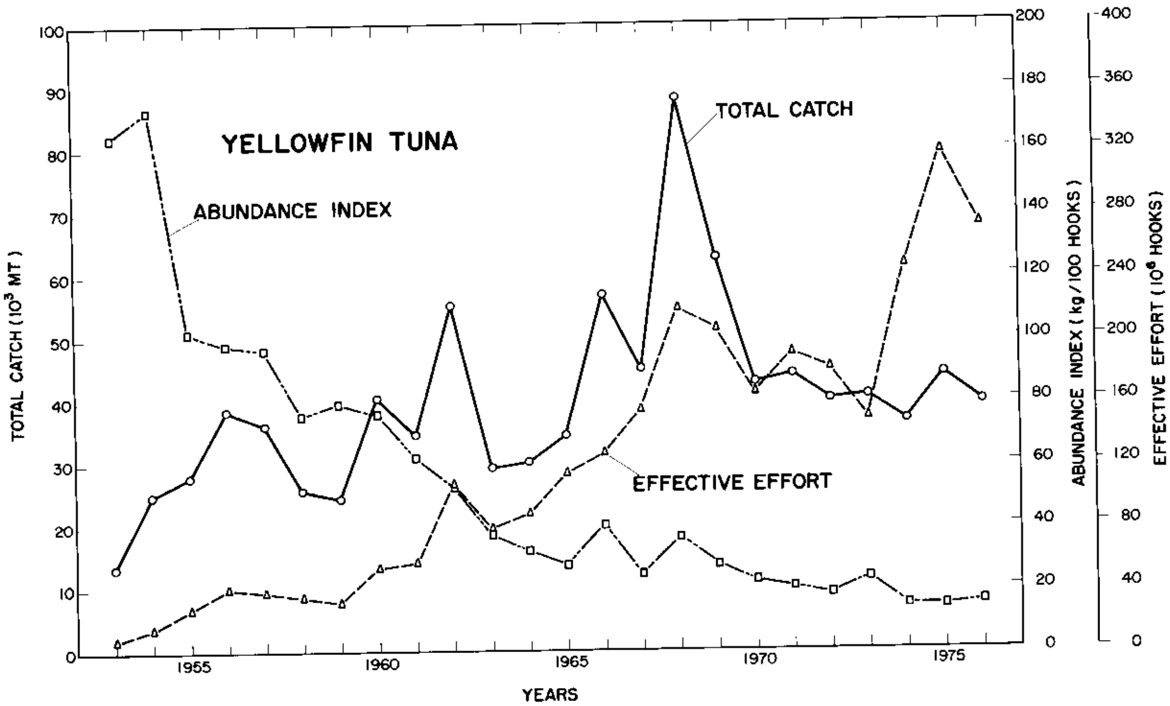


Figure 11.--Estimated total catch (10^3 MT), relative abundance (kg/100 hooks), and effective effort (10^6 hooks) for Indian Ocean yellowfin tuna.

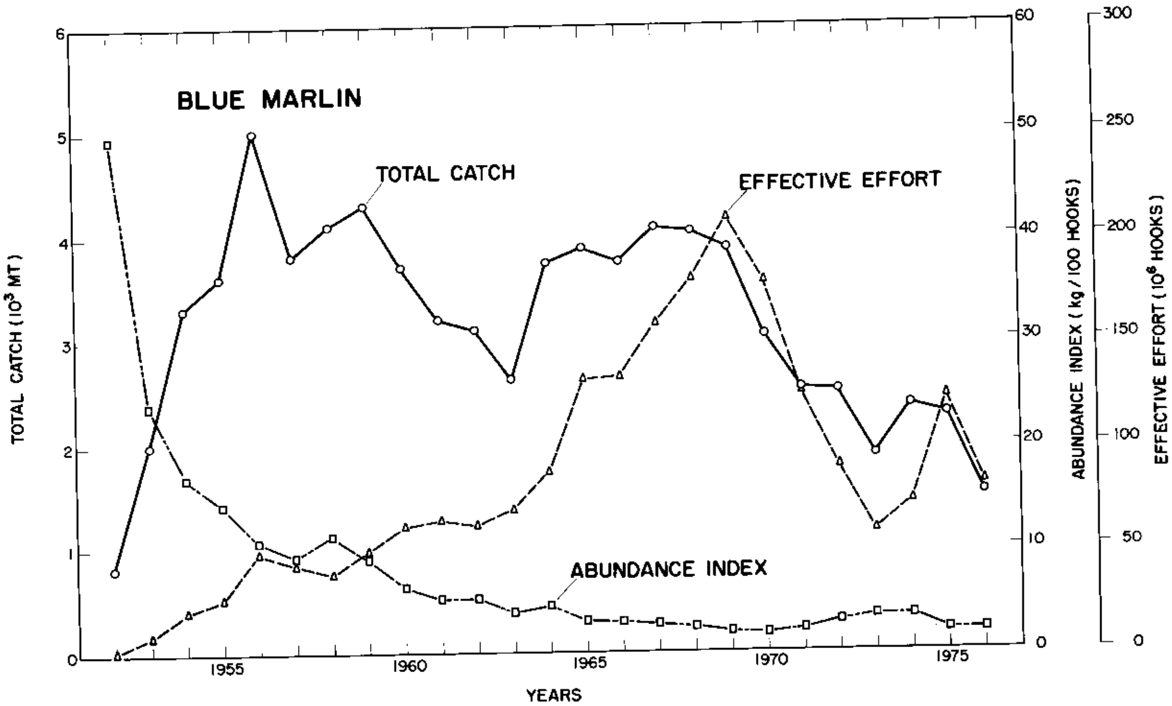


Figure 12.--Estimated total catch (10^3 MT), relative abundance (kg/100 hooks), and effective effort (10^6 hooks) for Indian Ocean blue marlin.

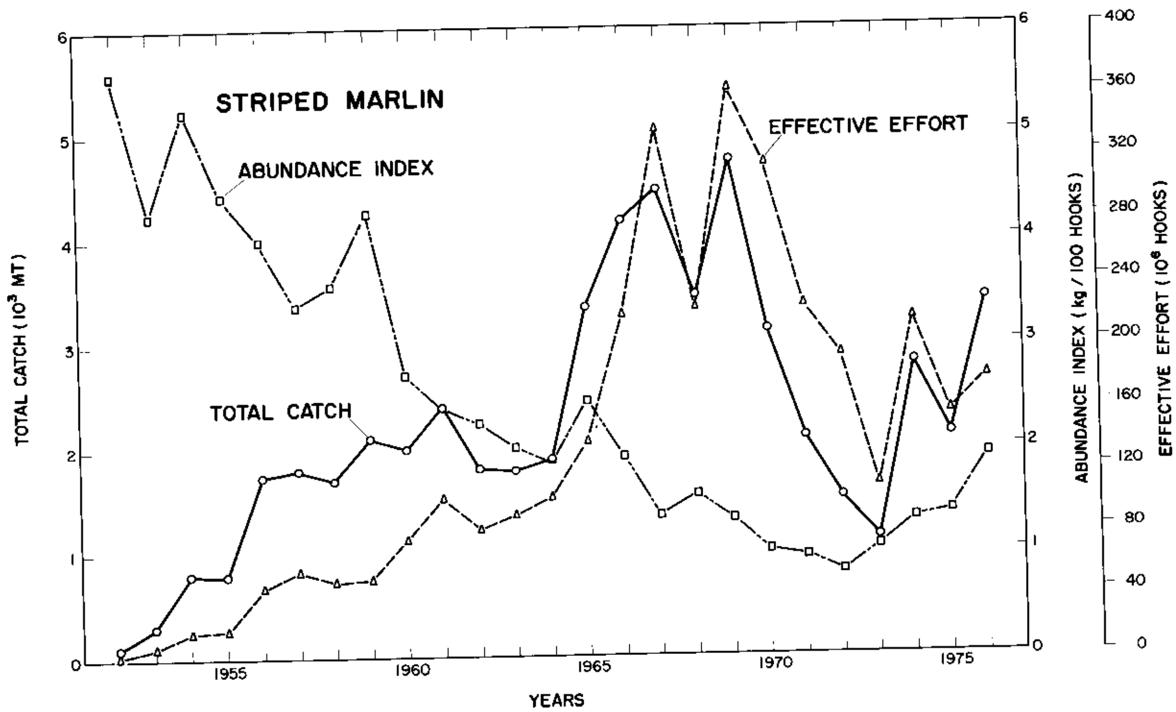


Figure 13.--Estimated total catch (10^3 MT), relative abundance (kg/100 hooks), and effective effort (10^6 hooks) for Indian Ocean striped marlin.

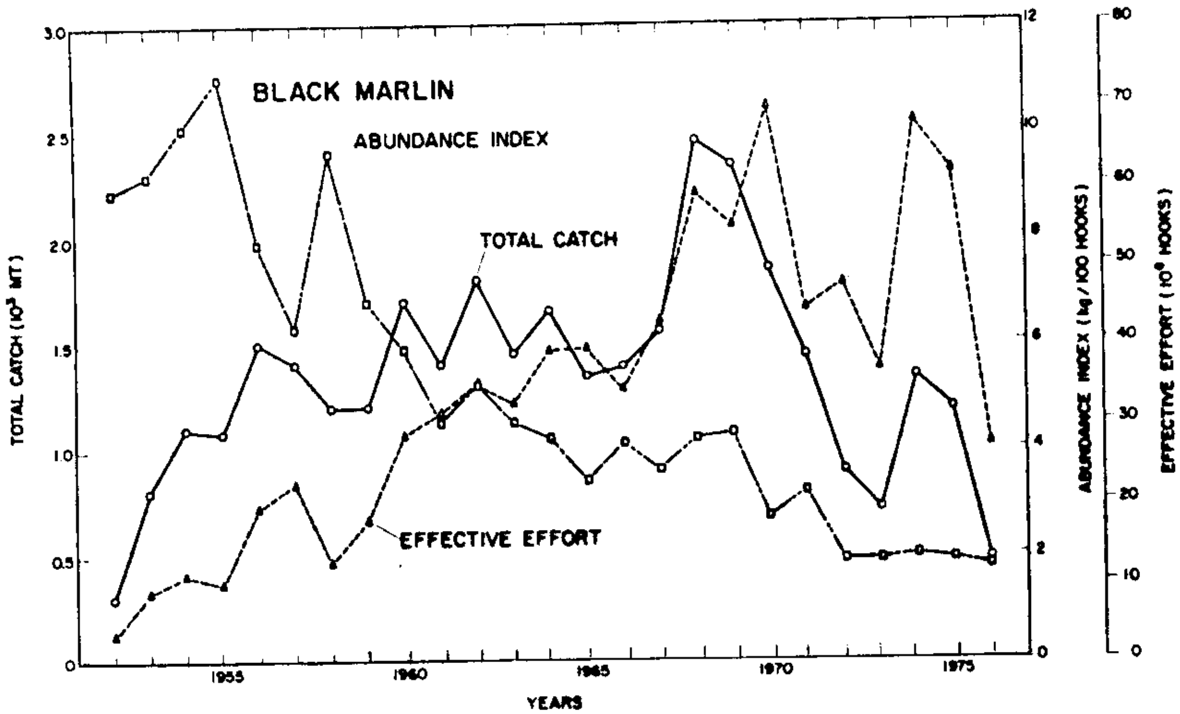


Figure 14.--Estimated total catch (10^3 MT), relative abundance (kg/100 hooks), and effective effort (10^6 hooks) for Indian Ocean black marlin.

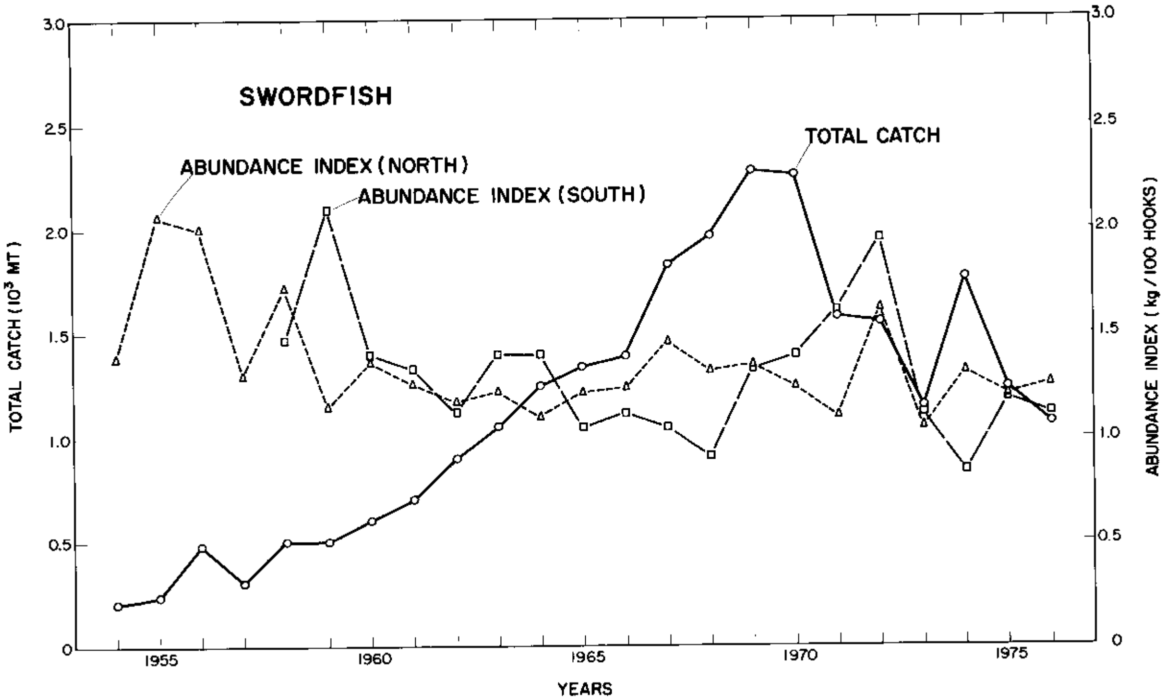


Figure 15.--Estimated total catch (10^3 MT) and relative abundance (kg/100 hooks) for Indian Ocean swordfish. Abundance indices are given for two index areas.

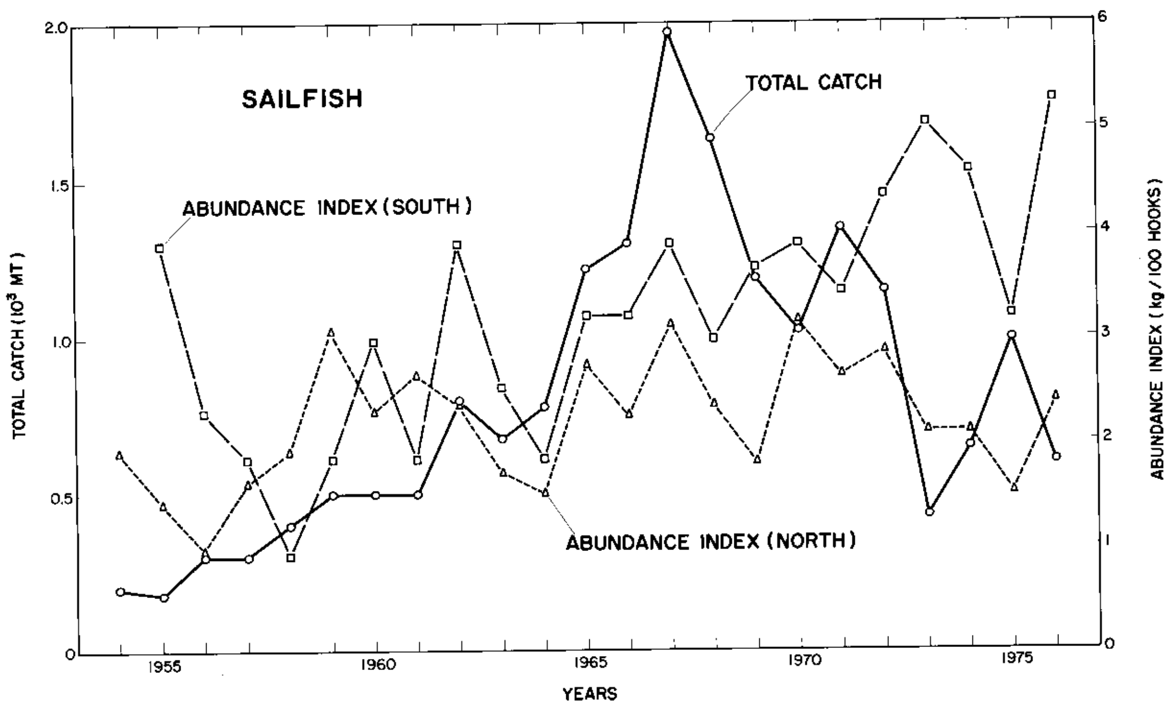


Figure 16.--Estimated total catch (10^3 MT) and relative abundance (kg/100 hooks) for Indian Ocean sailfish. Abundance indices are given for two index areas.

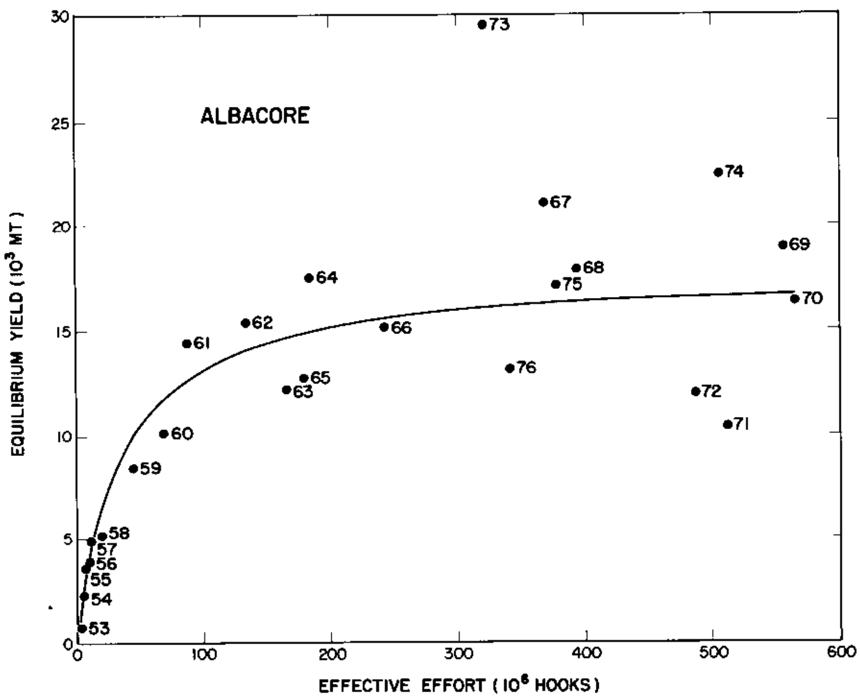


Figure 17.--Predicted relationship between equilibrium yield (10^3 MT) and effective effort (10^6 hooks) for Indian Ocean albacore, based on production model analysis.

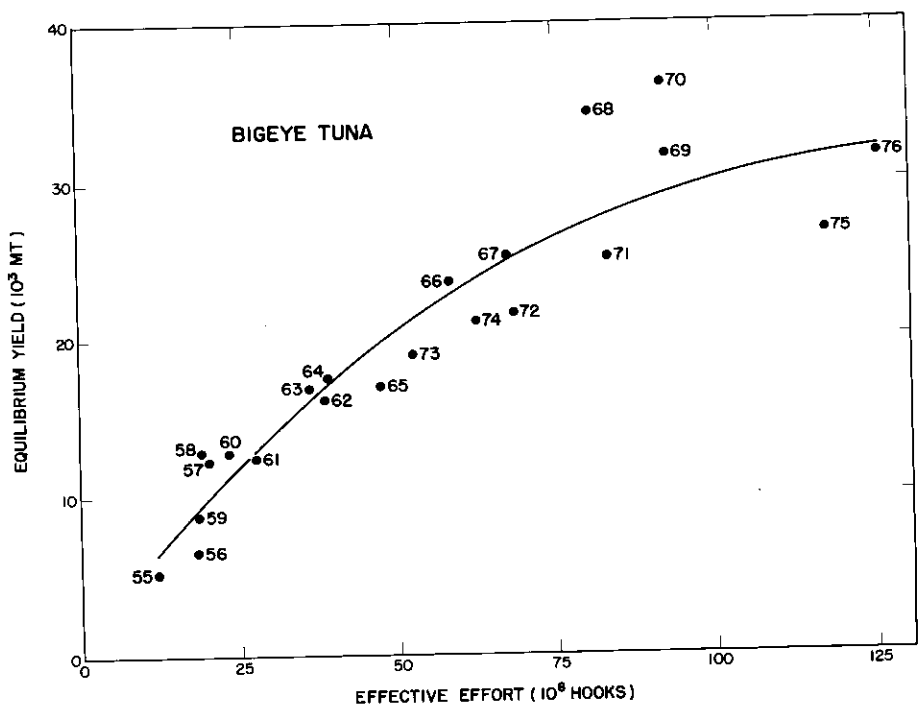


Figure 18.--Predicted relationship between equilibrium yield (10^3 MT) and effective effort (10^6 hooks) for Indian Ocean bigeye tuna, based on production model analysis.

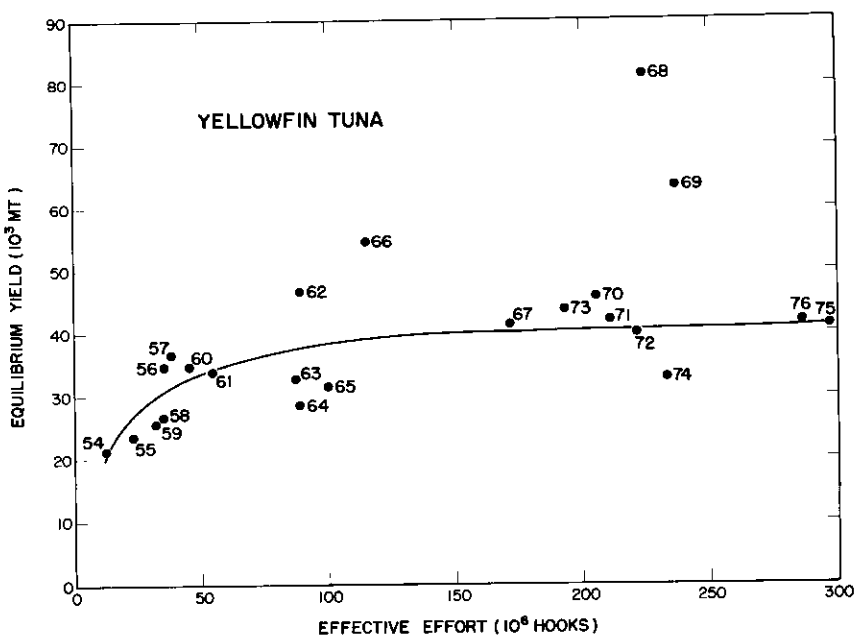


Figure 19.--Predicted relationship between equilibrium yield (10^3 MT) and effective effort (10^6 hooks) for Indian Ocean yellowfin tuna, based on production model analysis.

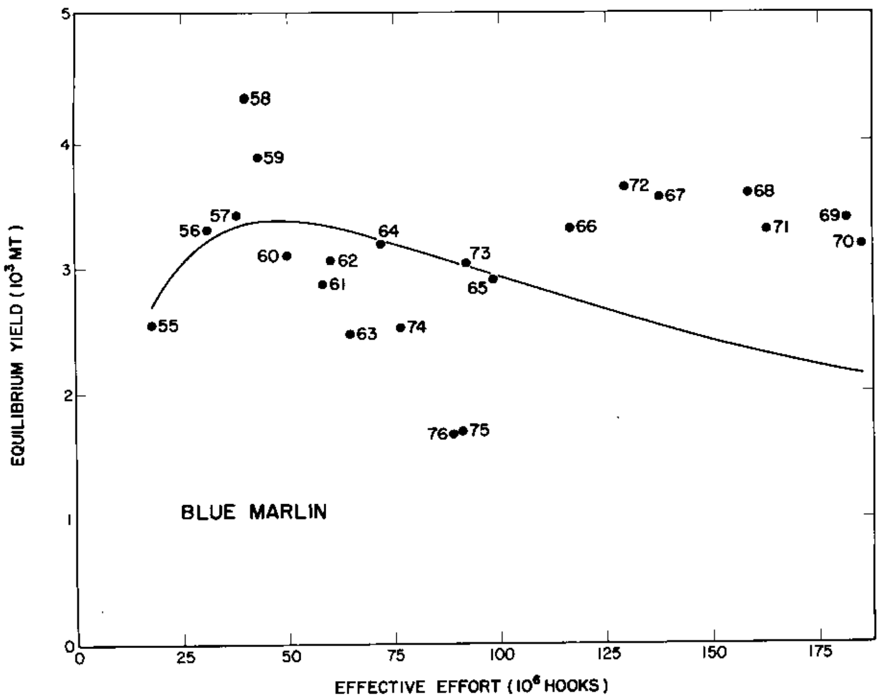


Figure 20.--Predicted relationship between equilibrium yield (10^3 MT) and effective effort (10^6 hooks) for Indian Ocean blue marlin, based on production model analysis.

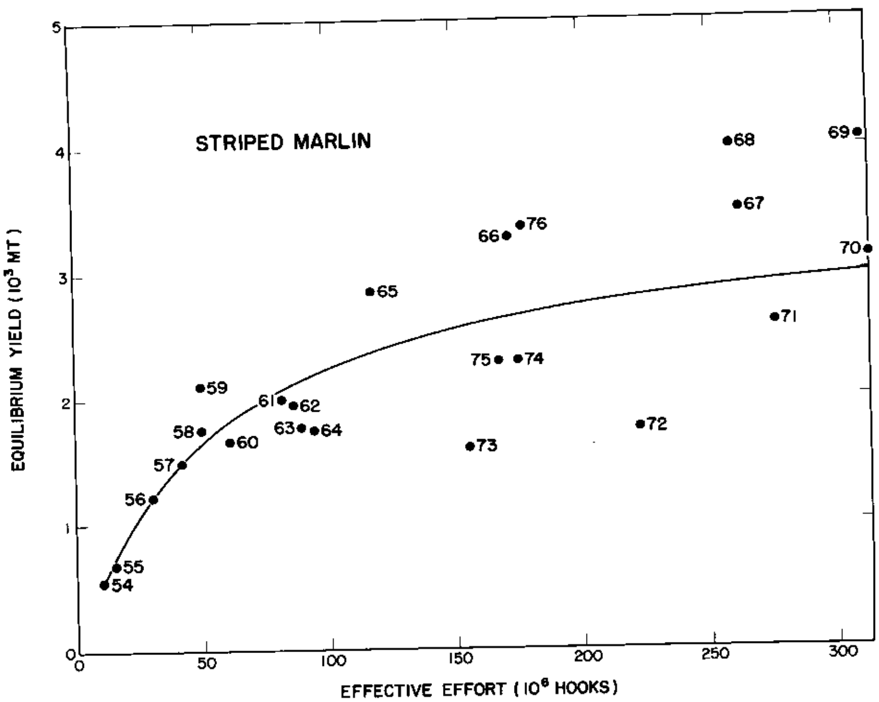


Figure 21.--Predicted relationship between equilibrium yield (10^3 MT) and effective effort (10^6 hooks) for Indian Ocean striped marlin, based on production model analysis.

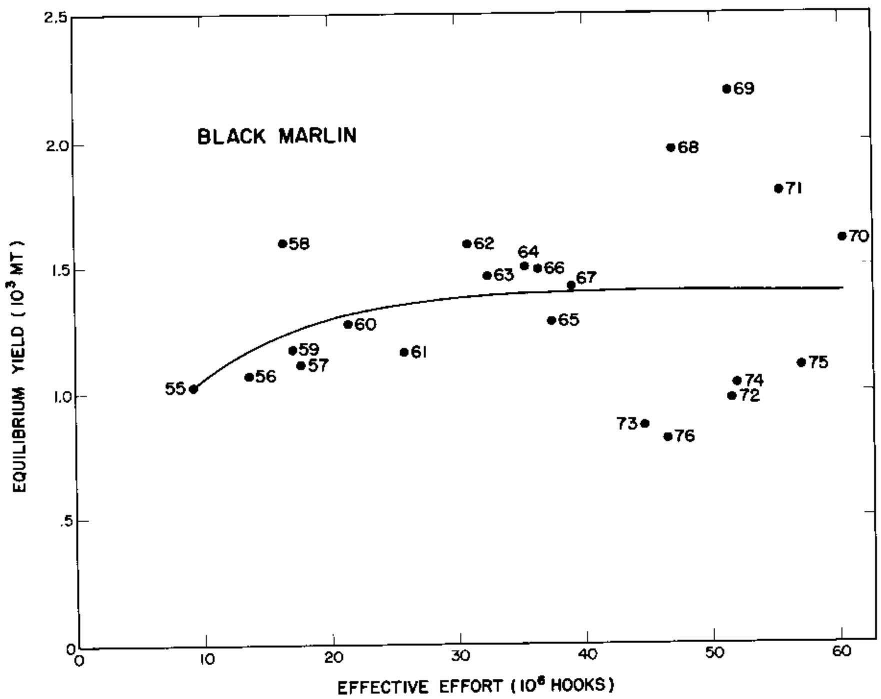


Figure 22.--Predicted relationship between equilibrium yield (10^3 MT) and effective effort (10^6 hooks) for Indian Ocean black marlin, based on production model analysis.