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ASSESSMENT OF THE SOUTH PACIFIC ALBACORE STOCK

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INTRODUCTION

The albacore, *Thunnus alalunga*, has been a principal target of tuna
fishing in the South Pacific since Japanese longliners began operating
near the Solomon Islands in 1952. The Japanese fleet extended eastward
and in 1954 some of these vessels began landing albacore, yellowfin
tuna, *T. albacares*, and bigeye tuna, *T. obesus*, at Pago Pago, American
Samoa, under contract to a U.S. cannery there. The fishery grew steadily
and was entered by longliners from Taiwan and the Republic of Korea,
Table 1 based at Pago Pago (Table 1). A second U.S. cannery was opened in
American Samoa, and other bases for foreign tuna longliners were
established in the New Hebrides, Fiji, and Tahiti. Whereas most of
the South Pacific albacore catch made by longliners of Korea and
Taiwan is taken by vessels based at American Samoa and other foreign
ports, the majority of the Japanese catch has always been by Japan-
based longliners, and the Japanese eventually withdrew from the
Pago Pago base in 1973.

The longline fishery for albacore is carried out over a wide area
from about long. 150°E to 120°W and from equatorial waters south to lat.
Fig. 1 40°S (Figure 1). Until the 1970's effort was exerted mostly north of
lat. 20°S, especially during the first and fourth quarters, but there
Table 8 has been an increase in effort southward in recent years (Table 8).
While albacore remain the principal target of longliners based at Pago
Pago, yellowfin and bigeye tunas make up a substantial fraction of the
Table 2 landings, especially by Korean vessels since 1971 (Table 2). All of
these historical developments are discussed in greater detail by Otsu
(1966), Otsu and Sumida (1968), Skillman (1975), and Yoshida (1975).

Since the buildup of fishing effort in the South Pacific during the 1960's, there has been a keen interest among government scientists and the fishing industry in assessing the albacore resource and measuring the effects of fishing on the stock. The first comprehensive assessment was made by Skillman (1975). He estimated total catches, constructed a first-cut abundance index based on the catch per unit effort (CPUE) of American Samoan-based vessels and fit a production model. He concluded the stock was fully harvested, given the prevailing fishing practices, but left open the possibility that yield could be increased by altering the age-specific patterns of fishing mortality.

In this paper we re-evaluate the status of the South Pacific albacore stock, using more complete and reliable catch statistics than were available to Skillman. We construct an improved abundance index and repeat the production model analysis. Finally we briefly examine the prospects of increasing harvests by altering age at first capture. This is done with an age-structured simulation model of the albacore stock.

Catch Statistics

Estimates of the catch of South Pacific albacore by Japanese longliners are available from the beginning of fishing in 1952. Sample logbook statistics are used to estimate the total catch in number of fish. Estimates of the average weight per fish are obtained by sampling the landings. These two factors are multiplied and summed over time-area strata to produce total yield figures for each year. Tonnage estimates used in this paper were provided by S. Ueyanagi of the Far Seas Fisheries Research Laboratory, Shimizu, Japan.

The catch statistics for longliners from Taiwan are compiled in a similar fashion and have been published annually since 1967. Catch data for earlier years, 1963 through 1966, were provided for this analysis by R. T. Yang of National Taiwan University. Until 1978 the Taiwan government did not determine the size composition of tuna catches, and average weight figures used in the official Taiwan statistics are based on "eye ball" assessments of weight made as the longlines are hauled. For this reason, we constructed our own estimates of total tonnage. We multiplied the published catch in numbers in each 5° square-month stratum by average weights of albacore caught by vessels from Taiwan in that stratum and measured by biological technicians at the landing sites in Pago Pago.

In the case of Korea the only government statistics available to us were the published longline data covering 1966-70, giving sample catch in number of fish and associated nominal effort. We did not use these statistics. Instead, we estimated the annual Korean albacore catches as the product of two factors: a) the sum of the South Pacific albacore catch by longliners of Japan and Taiwan (as estimated above), and b) the estimated ratio of Korean catches to the combined catches of Japan and Taiwan, as derived from the statistics of Skillman (1975).

Table 3

The estimated total catches of South Pacific albacore by Japan, Taiwan, and Korea are given in Table 3. The catch by other nations includes small quantitites landed by longliners in Fiji and by trollers in Chile and New Zealand.

The catch statistics presented above for Japan and Taiwan are based on the sampling of vessel logbooks (Korea has a similar system). Besides these data sources, there has been since 1962 a separate system of logbook statistics for those vessels based at American Samoa. Data on the numbers of hooks fished and resulting catch by species (number of fish) for each day of fishing, along with fishing positions, are obtained from 80%-90% of the vessels. These statistics are collected by the Office of Marine Resources in Pago Pago, and copies are processed by the NMFS Honolulu Laboratory. In addition, NMFS maintains files of landings statistics from the Starkist and Van Camp tuna canneries in Pago Pago. These give the tonnage of tunas and other species landed by the longliners, number of trips, trip length, and other data. Tables 2 and 4 present some of these statistics.

Table 4

Trends in Catch and Nominal Effort

Table 3 shows that the total albacore catch rose to high levels in the first decade of the fishery and has fluctuated around an average annual catch of about 36,000 metric tons (MT) since 1962. The catch peaked in 1973 when 49,000 MT were taken. Trends in nominal effort are best indicated by the data in Table 4, which show the growth in the total number of trips and days fished per trip for vessels based at Pago Pago. Total days fished reached a peak in 1973 and then dropped sharply after the fuel crisis forced the withdrawal or inactivity of many longliners beginning in mid-1974.

Size Composition

Information on the size composition of South Pacific albacore catches is available from two sources. The Japanese have sampled their catches and determined fork-length distributions since the 1950's. On a much larger scale, NMFS established a biological sampling program at Pago Pago in 1962, and gathered data on sex, fork length, and weight of albacore landed by vessels of Japan, Korea, and Taiwan. The time and position of capture were estimated for each sample. Since 1970 sex and weight determinations have been discontinued due to changes in unloading procedures at the canneries, but length-frequency data are still gathered.

In this report we discuss only the NMFS data. This has been treated extensively by Otsu and Sumida (1968) and Yoshida (1975). The size composition of South Pacific albacore varies markedly between latitudes and sex (Figures 2 and 3). Variation between longitudes and seasons is not so significant. Table 5 shows mean weights and fork lengths of males and females in 5° bands of latitude from the equator to lat. 45°S. North of lat. 30°S males are consistently larger than females and the difference is especially pronounced at the mid-latitudes of lat. 15°-25°S where the mean size of both sexes is greatest. In both sexes, average size increases going southward from the equator until about lat. 25°S, and then declines sharply further south.

Figs. 2,3

Table 5

The size composition of catches also varies with latitude. Figure 3, with sexes combined, shows that the catch north of lat. 25°S is composed almost entirely of fish larger than 80 cm, and that the fork length distributions are unimodal. Figure 4, taken from Yoshida (1975),

Fig. 4

gives latitudinal distributions of fork length separated by sex, and shows this even more clearly. The variability within these unimodal distributions is wholly consistent with the expected variation of size at age for a single cohort as predicted by stochastic versions of the von Bertalanffy growth model, particularly if we assume South Pacific albacore grow to the same maximum sizes as their North Pacific counterparts. The proportion of very large albacore (>110 cm fork length) in South Pacific catches seems to be somewhat less than in the North Pacific, but this may be due to differences in availability.

South of lat. 25°S the size composition of albacore catches changes dramatically, with progressively smaller fish appearing in samples along with the large ones found further north. Either these younger albacore (less than about 5 years) are virtually absent north of lat. 25°S or they are simply unavailable to the longline gear in this region.

In the jig fishery for South Pacific albacore off New Zealand fish range from 45 to 100 cm with 2-4 year old fish predominating (Habib and Cade 1978). Off of Chile, the small catch by trollers consists of fish over a similar size range, with 4-year olds appearing most frequently (Yoshida and Otsu 1963).

Fig. 5
Tables 6,7

Figure 5 and Tables 6 and 7 show the changes in size composition and mean size in the catches since 1962. [All the composite frequency distributions are weighted by total catches in the substrata.] There was no significant change in size composition until the late 1960's, when expansion of effort south of lat. 20°S (Table 8) brought more smaller fish into the catch. In 1973 and 1974 there was a dramatic

Table 8

shift towards smaller albacore in the catch, but the larger fish prevailed again in 1975 and 1976 (Figure 5).

Index of Abundance

We constructed an annual index of abundance for albacore within a specified stock index region based on an average of standardized indices for each group of longliners based at American Samoa. The index for each class (nationality) of vessels was computed from

$$U_i = \sum_{k=1}^{\ell_i} \sum_{j=1}^{m_{ik}} \frac{C_{ijk} A_{ijk}}{f_{ijk} p_{ijk}} \Bigg/ \sum_{k=1}^{\ell_i} m_{ik}$$

where U_i = index of abundance in year i in the defined index region

C_{ijk} = catch in the j^{th} fishing zone and k^{th} fishing season during year i

f_{ijk} = associated nominal effort (number of hooks)

A_{ijk} = area of the j^{th} fishing zone relative to a standard zone

p_{ijk} = ratio of the average abundance of albacore in the $(j, k)^{th}$ cell during year i to the average abundance in the entire index region during year i

ℓ_i = actual number of seasons in which fishing occurred in year i

m_{ik} = actual number of fishing zones in which effort was exerted during the k^{th} fishing season of year i

All elements of U_i are observed except for p_{ijk}. Let n_i denote the total number of fishing zones in the stock region and r_i be the total number of potential fishing seasons. Then for years when the time-space coverage of the index area by the fleet is complete, $\ell_i = r_i$ and $m_{ik} = n_i$ for all i and k and

$$\hat{p}_{ijk} = \frac{\left(\frac{C_{ijk} A_{ijk}}{f_{ijk}}\right)}{\sum_{k=1}^{\ell_i} \left(\sum_{j=1}^{m_{ik}} \frac{C_{ijk} A_{ijk}}{f_{ijk}} \right) n_i \Big/ m_{ik} \cdot \ell_i} .$$

In this event U_i reduces to the ordinary average-of-ratios catch per unit effort statistic, except that the differences in area of fishing zones are taken into account. Of course, when $\ell_i < r_i$ and/or $m_{ik} < n_i$ for some i, then $\hat{p}_{ijk}$ will be biased unless the population is distributed uniformly in time and space or fishing zones and seasons are chosen at random. These conditions are unlikely at best. To circumvent these difficulties Honma (1974) invokes the assumption that the temporal and spatial distribution of the stock in the index region is constant each year, i.e., $p_{ijk} = p_{jk}$ for all i, and suggests estimating the p_{jk}'s using data from "standard" years when coverage was relatively complete. Supposing there are a_{jk} standard years when the $(jk)^{th}$ stratum was fished, we estimated the average p_{jk} for that stratum by

$$\hat{p}_{jk} = \sum_{i=1}^{a_{jk}} \hat{p}_{ijk} / a_{jk}$$

where $\hat{p}_{ijk}$ is as given above.

In applying this procedure to South Pacific albacore we used the logbook data for American Samoa-based longliners from Japan, Korea, and Taiwan. The boundaries of the stock index area were set at lat. 0° to 35°S and long. 160°E to 115°W (Figure 1). Fishing seasons and zones were defined as quarters of the year and areas of 5° lat. x 5° long.

Before the p_{jk}'s and the abundance indices were computed, the catches in each stratum were converted from numbers of albacore to weight of albacore by applying detailed average weight statistics derived from the Pago Pago sampling. Separate average weight estimates were usually available by nation, year, quarter, latitude (5° bands) and longitude (10° bands). In cases where corresponding average weight data were not available for a catch in a given stratum, an average figure for the appropriate latitude was substituted.

Estimates of the p_{jk}'s were computed using the nominal effort and catch-in-weight statistics of both Taiwan and Korea over the standard years 1967 through 1977, when relatively full coverage of the index region was achieved. In each case, p_{jk} were estimated only for strata fished at least five times during the period of standard years (i.e., $a_{jk} \geq 5$). Further, only those cells with $a_{jk} \geq 5$ were included in the subsequent estimation of the stock abundance indices.

Abundance indices, based on p_{jk} estimates from Taiwan data, were computed for Japan, Taiwan, and Korea. (Indices using Korean p_{jk}'s were not substantially different.) The indices for Taiwan and Korea were then standardized to the Japanese index following a fishing power analysis (Table 9). The fishing power analysis employed indices over the 1966-72 period. Table 9

After the standardization, indices for each nationality were averaged into a single index. This index is given in Table 10 and Figure 6. The index has been scaled to the Japanese catch rates for 1962 in kg/100 hooks. Figure 6 also shows an index of abundance based on published and unpublished Japanese longline data from 1952 through 1976, using the same p_{jk} as with the American Samoa data. This index is based on Japan-based as well as the Pago Pago-based vessels (Japanese vessels were absent from American Samoa beginning with 1973), and was standardized to the composite American Samoa index. Both the composite index based on American Samoa logbook data and this Japanese index show an apparent decline in abundance since the early 1960's. But the index derived from the unpublished Japanese statistics does not conform to our expectations during the first decade of the fishery when catch rose from nothing to nearly 40,000 MT. Whether this reflects inadequacies in the indexing procedure, biases in the basic data or oversimplified expectations remains to be determined. For the purposes of our production model analysis we will assume the composite index from 1962 to 1977 truly reflects a decline in average abundance over this period.

Table 10

Fig. 6

Estimating Effective Effort

The total effective effort on South Pacific albacore was estimated each year from 1962 to 1977 by dividing the composite index of abundance into the estimated total catch. Results are given in Table 10 and plotted in Figure 6, with units standardized in terms of effort by Japanese vessels based at Pago Pago in 1972.

Production Model

A production model was fit to the total catch statistics and effective effort measure (Table 10) using Fox's PRODFIT program (Fox 1975). Equilibrium conditions were approximated by smoothing the effective effort over 1-, 2-, 3-, or 4-year periods. The model's shape parameter, m, was both fixed at 2.0 (Schaefer form) and allowed to vary as one of the estimated parameters. Results are given in Table 11. It is clear from Figure 7 that the Schaefer model would be inappropriate. The remaining results, for m variable, indicate an MSY between 33,000 and 36,000 MT. The predicted optimum effective effort levels range from 60×10^6 hooks to 389×10^6 hooks, or 2.2 to 14.4 times the 1962 effort and 0.31 to 2.0 times the 1977 effective effort. The low (E_{opt}/E_{77}) figure of 0.31 is based on a 1-year smoothing, so is perhaps less reasonable than the other cases. Still, with both 2- and 4-year effort averaging, the analysis predicts that optimum effort would require a cutback of nearly 40% from the 1977 level. Figure 8 shows the equilibrium yield-effort curve for the 3-year averaging, and Figure 9 gives the result for 2-year smoothing. Both yield curves are fairly flat over a broad range of effort and predict similar catches for effort levels in the neighborhood of recently experienced ones. According to these production models, virtually no increase in yield can be expected to accompany an expansion of effort above the 1977 level, and in fact an average yield nearly equal to the MSY could be achieved at half the 1977 effort.

Table 11

Fig. 7

Fig. 8

Fig. 9

In 1975 Skillman presented a production model for South Pacific albacore, based on unadjusted ratio-of-average catch per hook statistics of Japanese longliners based at Pago Pago and on total catch statistics from the Asian Tuna Conference proceedings and other sources. His best estimate of MSY was about 35,000 MT at an effort roughly 4.5 times the 1962 effort. The variability in Skillman's data also left some doubt as to the shape of the production curve at high effort levels.

Effects of Age at First Capture on MSY Under Different Stock-Recruitment Models

In our production model results there is some suggestion that recruitment to the South Pacific albacore stock may be fairly independent of the spawning stock size. We estimated this constant recruitment level by applying the approach of Suda (1970) to the estimated annual total catch in number of fish and the associated effective effort statistics, again smoothed over 3-year periods to approximate equilibrium conditions. Using a nonlinear regression procedure, we fitted the model

$$\ln(C_i/f_i) = \ln(qR) - \ln\ (M + q\,f_i\,)$$

where C_i = annual catch in number of albacore

f_i = associated effective effort (smoothed)

q = catchability coefficient

R = number of fish recruited to exploited stock

M = natural mortality rate

In this model, the same estimate of R results for all guesses of M; and estimates of q are directly proportional to the M value. We fixed M at 0.4, and the resulting estimates of R and q were 2.54×10^6 fish and
Fig. 10 1.875×10^{-8}/hook. The fitted model is shown in Figure 10. Assuming the recruitment estimate corresponds to fish at about 5 years of age (85 cm fork length), the estimated number of recruits at an age of 2 years is 8.43×10^6 fish.

An age-structured simulation model was constructed to study the response of maximum sustainable yield of the albacore stock to changes in age at first capture under a variety of stock-recruitment hypotheses. Knife-edge recruitment was assumed. The natural mortality rate was assumed constant at 0.4 year^{-1}. An age-length model for North Pacific albacore was used in the absence of such a model for the South Pacific stock ($L(t) = 135.6\,(1 - \exp(-0.17\,(t + 0.87)))$), where L is fork length and t is age in years. Parameters of the length-weight relationship were estimated from Pago Pago sample statistics; the resulting equation was $W = 1.681 \times 10^{-5} \times L^{3.059}$, where weight is in kilograms and fork length is in centimeters.

Fig. 11 The stock-recruitment hypotheses displayed in Figure 11 were studied. The equation of this model is

$$R = R_{\max} \left(\frac{S}{S_{\max}} \right)^{\beta}$$

where $R_{\max}$ and $S_{\max}$ are upper limits on recruitment (R) and spawning biomass (S). We set $R_{\max} = 8.43 \times 10^6$ fish so that with $\beta = 0$,

$R = 8.43 \times 10^6$ fish (constant). S_{max} was determined as the biomass of spawning stock in the absence of fishing when $R = R_{max}$. Assuming fish above 5 years old are members of the spawning stock, $S_{max} = 1.33 \times 10^5$ MT.

With this set of parameters the maximum sustainable yield was determined for combinations of β(0, 0.15, 0.32, 0.51) and age at first capture (2 years, 3 years, 4 years, 5 years, 6 years, 7 years). Results are given in Figure 12. Under the constant recruitment hypothesis, the simulation model computes a maximum sustainable yield of 37,800 MT, corresponding to an age at first capture of 4 years. However, only slight increase in potential yield would result from lowering age at first capture from 5 years to 4 years. Under the more conservative stock-recruitment hypotheses, the yield potentials are reduced substantially and maximum sustainable yield is achieved at progressively higher ages at first capture. We also ran the model with $M = 0.2$ and with appropriately adjusted S_{max} and R_{max}. In this case the dome in the constant-recruitment yield curve disappeared and MSY was an increasing function of age at first capture (over the range of 2-6 years) for all stock recruitment hypotheses.

Future Studies

The production model analysis is intended to give no more than a rough idea of the status of the South Pacific albacore stock. As a guide for fishery management policy the analysis suggests that expansion of nominal longline effort should not be encouraged (as far as albacore catches are concerned), and in fact that substantial economic benefits might result from a cutback of effort. It would be interesting and useful to study the economics of the fleets based at Pago Pago, and to try to forecast the expected effort levels under a variety of economic conditions.

On the biological side, there are several tasks needing attention. First, there is an abundance of size composition data, so the possibility of doing a cohort analysis should be explored. A cohort analysis is likely to be difficult because relatively few age groups are found in the catch and there is no clear separation of length frequency modes for most of the catch. If a cohort analysis is attempted, it should be done by sex, and sex composition will have to be estimated for catches since 1970.

- The simulation model studies could be expanded, exploring more complicated hypotheses with respect to age-specific rates of natural mortality and catchability. An investigation of the robustness of the production model could be part of this.

- A detailed study of relative population density by time and area should be completed. Indices of abundance by size-class should be constructed, and forecasting models using such indices should be attempted.

- The possibility of tagging 2- and 3-year old albacore in New Zealand waters should be evaluated, so that hypotheses on the interdependence of the surface and longline fishery can be tested and so that growth rates and migration patterns can be estimated.

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Table 1.--Number of longline vessels based at Pago Pago, American Samoa, by nationality, 1954-76.

	Number of vessels				
Year	Japan	Taiwan	Korea	Undetermined	Total
1954	17	--	--	1	18
1955	50	--	--	--	50
1956	56	--	--	--	56
1957	61	--	--	1	62
1958	76	--	2	1	79
1959	64	--	4	1	69
1960	60	--	3	1	64
1961	55	--	2	1	58
1962	79	--	5	1	85
1963	117	--	10	1	128
1964	94	11	16	--	121
1965	101	23	33	--	157
1966	79	76	55	--	210
1967	62	128	69	--	259
1968	39	110	85	--	234
1969	18	71	76	--	165
1970	9	115	81	--	205
1971	4	124	90	--	218
1972	2	135	95	--	232
1973	--	172	172	--	344
1974	--	149	171	--	320
1975	--	77	135	--	212
1976	--	93	119	--	212

Table 2.--Landings of albacore (round weight, kg) and yellowfin and bigeye tunas (gilled and gutted, kg) at American Samoa by longliners from Japan, Korea, and Taiwan.

Year	Nation	Albacore	Yellowfin tuna	Bigeye tuna
1954	Japan	349,147	602,546	26,556
	Korea	--	--	--
	Taiwan	--	--	--
1955	Japan	2,109,792	2,260,364	24,181
	Korea	--	--	--
	Taiwan	--	--	--
1956	Japan	3,706,218	2,107,367	215,694
	Korea	--	--	--
	Taiwan	--	--	--
1957	Japan	6,003,530	1,577,288	310,425
	Korea	--	--	--
	Taiwan	--	--	--
1958	Japan	9.784,216	2.412,330	455,112
	Korea	145,974	70,338	17,818
	Taiwan	--	--	--
1959	Japan	9,834,443	1.705,524	422,299
	Korea	456,427	67,350	24,396
	Taiwan	--	--	--
1960	Japan	10,381,094	1,046,692	196,497
	Korea	609,897	83,976	49,567
	Taiwan	--	--	--
1961	Japan	9,225,419	1,230,710	131,197
	Korea	330,047	46,311	9,100
	Taiwan	--	--	--
1962	Japan	12.605,012	1,348,594	518,110
	Korea	634,535	46,658	26,104
	Taiwan	--	--	--
1963	Japan	12,669,394	1,819,131	1,310,142
	Korea	1,460,533	251,672	241,966
	Taiwan	--	--	--
1964	Japan	8,064,088	1,869,650	1,137,607
	Korea	1,767,730	400,476	358,912
	Taiwan	556,279	110,510	48,093
1965	Japan	9,506,437	2,398,729	1,269,411
	Korea	4,344,663	1,429,556	1,302,985
	Taiwan	1,607,648	647,633	360,810
1966	Japan	8,898,816	2,407,009	1,339,728
	Korea	9.116,649	2,019,914	2,268,187
	Taiwan	7,472,107	2,114,768	918,053
1967	Japan	7,477,506	1,124,017	994,319
	Korea	9,699,115	2,070,612	2,699,328
	Taiwan	11,133,742	2,131,791	1,846,787
1968	Japan	3,155,537	1,052,467	274,966
	Korea	6,476,349	3,045,761	1,273,197
	Taiwan	8,090,622	3,238,997	1,221,084
1969	Japan	1,570,750	649,830	80,584
	Korea	10,181,956	4,912,826	1,812,130
	Taiwan	6,977,831	2,576,833	1,327,978
1970	Japan	956,631	225,756	6,242
	Korea	11,942,262	3,663,516	1,321,666
	Taiwan	10,981,609	3,808,017	1,646,830
1971	Japan	379,523	75.240	84
	Korea	9,952,463	4,647,388	945,882
	Taiwan	11,861,105	3,844,595	1,112,017
1972	Japan	59,710	54,832	--
	Korea	9,854,751	6,685,235	1,138,297
	Taiwan	10,253,178	6,036,794	2,001,947
1973	Japan	--	--	--
	Korea	16,764,572	6,660,751	2,527,801
	Taiwan	13,383,806	3,819,636	1,968,300
1974	Japan	--	--	--
	Korea	6,837,893	5,193,551	2,138,182
	Taiwan	7,803,417	2,084,428	1,266,750
1975	Japan	--	--	--
	Korea	4,360,973	4,604,442	3,545,420
	Taiwan	3,478,611	1,537,972	803,607
1976	Japan	--	--	--
	Korea	8,509,220	4,885,548	2,953,224
	Taiwan	6,044,421	1,248,680	562,569

Table 3.--Estimated total catches of South Pacific albacore, 1952-77.

Column	1	2	3	4	5	6	7
Year	Japan	Taiwan	Japan and Taiwan	R	Korea	Other	Total
1952	210	--	210	--	--	--	210
1953	1,091	--	1,091	--	--	--	1,091
1954	10,200	--	10,200	--	--	--	10,200
1955	8,420	--	8,420	--	--	--	8,420
1956	6,220	--	6,220	--	--	--	6,220
1957	9,764	--	9,764	--	--	--	9,764
1958	21,558	--	21,558	--	146	--	21,704
1959	19,344	--	19,344	--	456	--	19,800
1960	23,756	--	23,756	--	610	--	24,366
1961	25,628	--	25,628	--	330	--	25,958
1962	38,880	0	38,880	0.0154	599	--	39,479
1963	33,500	608	34,108	0.0400	1,367	--	35,475
1964	21,435	629	22,064	0.1319	2,911	--	24,975
1965	19,305	1,640	20,945	0.3058	6,405	100	27,450
1966	23,401	6,669	30,070	0.3597	10,817	500	41,387
1967	16,640	14,910	31,550	0.4347	13,717	105	45,372
1968	7,707	14,496	22,203	0.4566	10,138	14	32,355
1969	5,559	9,883	15,442	0.6451	9,963	--	25,405
1970	6,560	12,463	19,023	0.6097	11,599	50	30,672
1971	4,339	21,584	25,923	0.5586	14,482	200	40,605
1972	2,796	23,050	25,846	0.5586	14,439	468	40,753
1973	2,381	28,858	31,239	0.5586	17,452	584	49,275
1974	1,847	19,980	21,827	0.5586	12,194	890	34,911
1975	1,045	15,092	16,137	0.5586	9,015	1,827	26,979
1976	1,906	19,954	21,860	0.5586	12,212	2,462	36,534
1977	2,240	21,345	23,585	0.5586	13,176	4,610	41,371

Comments:

Column 1 - Japanese longline catch in metric tons, courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory.

Column 2 - Catch by Taiwan's high-seas longliners (>50 GT) based at foreign ports, estimated from published Taiwan catch statistics and average weights of albacore landed at Pago Pago.

Column 3 - Column 1 plus column 2

Column 4 - R is ratio of Korean catch of South Pacific albacore to total catch of this species by Japan and Taiwan, estimated from data in Skillman (1975).

Column 5 - Column 3 x column 4, except for 1958-61, which are from American Samoa cannery records.

Column 6 - Includes catch by Chile (from FAO statistics), Fiji (courtesy of Ian Brown), and New Zealand (from Habib and Cade 1978).

Table 4.--Estimated number of vessel trips, fishing days per trip, and total fishing days for longliners based at American Samoa, 1954-76.

	Japan			Taiwan			Korea		
	Days/trip	Trips	Days	Days/trip	Trips	Days	Days/trip	Trips	Days
1954	--	58	--	--	--	--	--	--	--
1955	--	142	--	--	--	--	--	--	--
1956	--	262	--	--	--	--	--	--	--
1957	17.4	263	4,576	--	--	--	--	--	--
1958	21.1	330	6,963	--	--	--	22.6	7	158
1959	24.4	287	7,003	--	--	--	26.7	14	374
1960	23.3	283	6,594	--	--	--	23.0	44	1,012
1961	21.5	260	5,590	--	--	--	25.0	8	200
1962	22.0	349	7,678	--	--	--	24.9	40	996
1963	24.6	423	10,406	--	--	--	30.9	69	2,132
1964	27.5	277	7,618	23.2	27	626	27.4	69	1,891
1965	30.7	275	8,442	27.6	97	2,677	34.2	165	5,643
1966	32.1	229	7,351	27.5	295	8,112	41.6	246	10,234
1967	35.7	202	7,211	33.0	355	11,715	44.3	241	10,676
1968	39.6	100	3,960	40.3	267	10,760	47.5	214	10,165
1969	38.7	47	1,819	38.9	213	8,286	47.3	289	13,670
1970	37.9	26	985	40.4	326	13,170	46.7	289	13,496
1971	40.2	13	523	45.3	328	14,858	54.5	282	15,369
1972	29.8	4	119	46.8	350	16,128	54.4	349	18,986
1973	--	--	--	52.2	422	22,028	56.6	479	27,111
1974	--	--	--	55.4	327	18,116	47.6	422	20,087
1975	--	--	--	62.5	134	8,375	55.8	262	14,620
1976	--	--	--	59.2	152	8,998	57.6	276	15,898

Table 5.--Mean fork length (top row, cm) and weight (bottom row, kg) of harvested South Pacific albacore by latitude, sex, and vessel nationality.

	Latitude									
	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	0°-45°S
Sex:										
Male	88.8	90.9	93.9	97.3	97.2	87.6	83.3	77.6	--	91.2
	15.5	16.6	18.4	20.5	20.6	15.3	13.1	10.4	--	17.0
Female	86.8	87.6	89.8	92.4	91.7	86.6	84.1	78.8	--	88.0
	14.4	14.8	16.0	17.5	17.2	14.5	13.3	10.9	--	15.1
Undetermined	90.6	90.6	93.3	95.4	95.3	88.7	81.9	81.0	77.9	88.2
	16.5	16.6	18.1	19.4	19.4	15.8	12.6	12.1	10.6	15.6
Nation:										
Japan	88.0	90.6	93.4	96.7	95.6	87.7	83.7	75.0	--	--
	15.1	16.5	18.1	20.1	19.6	15.3	13.3	9.6	--	--
Taiwan	87.9	89.6	92.6	95.1	95.4	88.6	82.3	81.7	85.6	--
	15.0	15.9	17.7	19.2	19.4	15.7	12.7	12.5	14.8	--
Korea	89.2	90.0	92.5	95.3	95.1	87.3	82.7	80.7	77.9	--
	15.7	16.1	17.6	19.3	19.3	15.1	12.9	12.0	10.6	--
Overall	88.8	89.9	92.7	95.5	95.3	87.8	82.8	80.8	77.9	--
	15.5	16.1	17.7	19.4	19.4	15.3	12.9	12.1	10.6	--

Table 6.--Mean fork length (top row, cm) and weight (bottom row, kg) of harvested South Pacific albacore by latitude and year.

	Latitude									
Year	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	0°-45°S
1962	--	96.0	94.4	--	--	--	--	--	--	94.4
	--	19.6	18.7	--	--	--	--	--	--	18.7
1963	--	93.5	94.4	96.2	98.5	96.3	--	--	--	94.6
	--	18.1	18.7	19.9	21.2	19.8	--	--	--	18.8
1964	--	89.5	92.8	95.6	96.0	91.2	--	--	--	91.6
	--	15.9	17.7	19.4	19.8	17.1	--	--	--	17.1
1965	91.2	89.7	92.5	96.8	93.7	88.9	--	--	--	91.5
	16.8	16.0	17.5	20.2	18.5	15.8	--	--	--	17.1
1966	91.5	90.1	93.2	96.8	97.4	90.6	85.4	--	--	91.6
	17.0	16.2	17.9	20.2	20.7	16.7	14.0	--	--	17.1
1967	88.3	89.6	92.1	96.0	97.0	84.9	86.4	--	--	89.5
	15.1	15.9	17.3	19.7	20.3	13.8	14.6	--	--	16.1
1968	88.4	89.3	91.2	94.6	96.7	87.1	79.8	--	--	88.5
	15.2	15.7	16.8	18.8	20.1	14.9	11.4	--	--	15.6
1969	88.5	89.3	92.8	95.5	92.1	87.0	83.6	--	--	89.9
	15.3	15.7	17.7	19.4	17.6	14.8	13.1	--	--	16.2
1970	86.9	88.7	91.2	94.5	88.1	84.9	82.4	78.0	--	87.9
	14.5	15.4	16.9	18.8	15.2	13.7	12.6	10.6	--	15.2
1971	90.7	90.4	92.4	95.3	95.8	89.8	81.6	80.8	--	89.5
	16.5	16.4	17.6	19.3	19.6	16.5	12.6	12.2	--	16.3
1972	91.4	90.1	92.7	94.4	94.3	88.8	86.1	80.3	--	88.6
	17.0	16.3	17.8	18.8	18.8	15.8	14.4	11.9	--	15.8
1973	91.3	90.4	91.9	94.0	94.6	87.1	82.0	82.0	--	86.3
	17.0	16.5	17.4	18.6	18.9	15.0	12.5	12.6	--	14.6
1974	89.1	90.6	92.7	96.2	95.4	91.6	79.9	79.6	77.5	84.5
	15.8	16.6	17.8	20.0	19.5	17.4	11.8	11.5	10.4	13.9
1975	91.6	91.9	95.4	95.0	97.4	93.1	91.0	91.5	80.4	93.0
	17.1	17.2	19.3	19.0	20.6	18.1	17.0	17.1	11.8	18.0
1976	87.4	91.1	95.3	96.7	95.9	89.0	89.1	88.9	--	92.2
	15.0	16.9	19.3	20.3	19.8	16.0	16.0	15.9	--	17.7
All	88.8	89.9	92.7	95.5	95.3	87.8	82.8	80.8	77.9	--
years	15.5	16.1	17.7	19.4	19.4	15.3	12.9	12.1	10.6	--

Table 7.--Mean fork length (top row, cm) and weight (bottom row, kg) of harvested South Pacific albacore by year and vessel nationality.

Year	Japan	Taiwan	Korea	All nations
1962	94.4	--	--	94.4
	18.7	--	--	18.7
1963	94.8	--	93.7	94.6
	18.9	--	18.2	18.8
1964	91.7	93.1	90.4	91.6
	17.2	17.9	16.4	17.1
1965	91.9	90.5	91.3	91.5
	17.3	16.4	16.9	17.1
1966	91.4	91.6	91.7	91.6
	17.1	17.1	17.2	17.1
1967	87.5	89.9	90.7	89.5
	15.2	16.2	16.7	16.1
1968	84.5	89.4	89.3	88.5
	13.7	15.9	16.0	15.6
1969	86.6	90.3	90.2	89.9
	14.7	16.3	16.4	16.2
1970	84.8	89.7	86.6	87.9
	13.8	16.0	14.7	15.2
1971	79.2	89.4	89.8	89.5
	12.1	16.2	16.5	16.3
1972	99.9	91.6	86.6	88.6
	22.3	17.2	14.9	15.8
1973	--	88.9	84.9	86.3
	--	15.8	14.0	14.6
1974	--	86.6	83.1	84.5
	--	15.0	13.2	13.9
1975	--	93.3	92.6	93.0
	--	18.1	17.8	18.0
1976	--	92.6	92.0	92.2
	--	17.9	17.6	17.7

Table 8.--Estimated percentage of total nominal effort (10^3 hooks) by latitude for longliners of Taiwan and Korea based at American Samoa, 1964-77.

		Latitude								Effort
Year	Nation	0°-5°S	5°-10°S	10°-15°S	15°-20°S	20°-25°S	25°-30°S	30°-35°S	35°-40°S	(10^3 hooks)
1964	Taiwan	0	16.9	76.1	5.1	1.3	0.6	0	0	611
	Korea	0	45.9	53.9	0.2	0	0	0	0	1,280
1965	Taiwan	2.7	62.8	21.7	8.7	0.3	3.8	0	0	1,881
	Korea	0.2	54.4	34.5	6.3	1.5	3.1	0	0	4,708
1966	Taiwan	0.4	36.7	36.8	9.5	4.4	12.2	0	0	7,405
	Korea	0.4	44.2	28.4	13.3	0.5	10.1	3.1	0	10,061
1967	Taiwan	1.0	33.2	27.4	14.0	3.1	17.2	4.0	0.1	13,373
	Korea	2.2	31.8	27.5	19.5	2.1	7.1	9.5	0.3	15,378
1968	Taiwan	2.8	52.3	20.3	9.9	3.6	8.7	2.4	0	12,219
	Korea	10.3	41.8	15.6	15.3	1.3	10.0	5.7	0	14,276
1969	Taiwan	4.8	53.1	29.8	6.6	1.4	3.1	1.2	0	9,554
	Korea	12.7	40.5	19.0	10.7	1.5	13.8	1.8	0	20,681
1970	Taiwan	3.6	45.0	29.5	11.0	2.4	6.3	2.2	0	13,746
	Korea	9.5	27.1	16.9	15.6	1.6	16.6	10.8	1.9	20,405
1971	Taiwan	7.4	31.5	21.9	16.0	4.8	10.2	7.5	0.7	12,891
	Korea	6.3	17.4	16.8	21.8	6.3	14.5	13.0	3.9	21,994
1972	Taiwan	5.8	37.7	25.7	12.0	4.9	10.9	2.6	0.5	12,885
	Korea	10.2	21.8	19.2	14.4	2.9	13.7	5.4	12.4	21,603
1973	Taiwan	1.2	32.2	20.9	12.0	4.4	19.5	6.9	2.9	15,541
	Korea	5.6	19.9	13.6	6.8	6.5	19.3	14.4	13.9	32,682
1974	Taiwan	2.3	18.5	20.6	18.0	4.3	10.8	9.0	16.5	14,088
	Korea	16.9	14.2	11.7	12.0	9.7	7.5	9.8	18.2	27,872
1975	Taiwan	3.5	33.0	33.0	8.9	3.4	11.6	2.0	4.6	7,933
	Korea	13.1	44.5	24.1	8.3	4.2	2.8	1.2	1.8	19,876
1976	Taiwan	1.0	17.0	43.0	12.2	2.9	15.7	3.8	4.4	6,267
	Korea	5.4	25.4	18.0	22.8	7.3	17.0	1.9	2.2	22,514
1977	Taiwan	0.8	32.6	24.1	15.2	4.2	13.6	5.9	3.6	9,980
	Korea	7.1	28.8	20.9	11.0	7.8	14.5	6.3	3.6	25,041

Table 9.--Estimated relative fishing power, by nationality of vessel, with respect to the harvest of South Pacific albacore.

Nation	Data sets	Relative fishing power
Japan*	American Samoa	1.00
Taiwan	American Samoa	1.85
Korea	American Samoa	1.25
Japan	Far Seas Fisheries Research Laboratory	0.82

*Standard

Table 10.--Total catch of South Pacific albacore (MT), index of abundance (kg/100 hooks), and estimated total effective effort (10^6 hooks).

Year	Total catch (MT)	Abundance index (kg/100 hooks)	Effective effort (10^6 hooks)
1962	39,479	146.00	27
1963	35,475	85.76	41
1964	24,975	75.39	33
1965	27,450	72.02	38
1966	41,387	63.66	65
1967	45,372	42.56	107
1968	32,355	33.76	96
1969	25,405	41.03	62
1970	30,672	35.42	87
1971	40,605	29.90	136
1972	40,753	21.45	190
1973	49,275	20.19	244
1974	34,911	13.86	252
1975	26,979	13.64	198
1976	36,534	18.00	203
1977	41,371	21.71	191

Table 11.--Results of production model analysis for South Pacific albacore.

	m fixed				m variable				
Smoothing period	M$\hat{S}$Y (MT)	E_{opt} (10^6 hooks)	m	Fit index	M$\hat{S}$Y (MT)	E_{opt} (10^6 hooks)	m	Fit index	$\left(\frac{E_{opt}}{E_{77}}\right)$
1	56,509	126.17	2.0	0.6275	35,959	59.87	0.50	0.8507	0.31
2	49,498	133.14	2.0	1.0246	35,656	119.85	0.30	1.0049	0.63
3	46,169	134.72	2.0	1.0039	36,046	338.86	0.50	1.0004	2.00
4	43,229	137.07	2.0	1.0013	33,058	118.56	0.30	1.0001	0.62

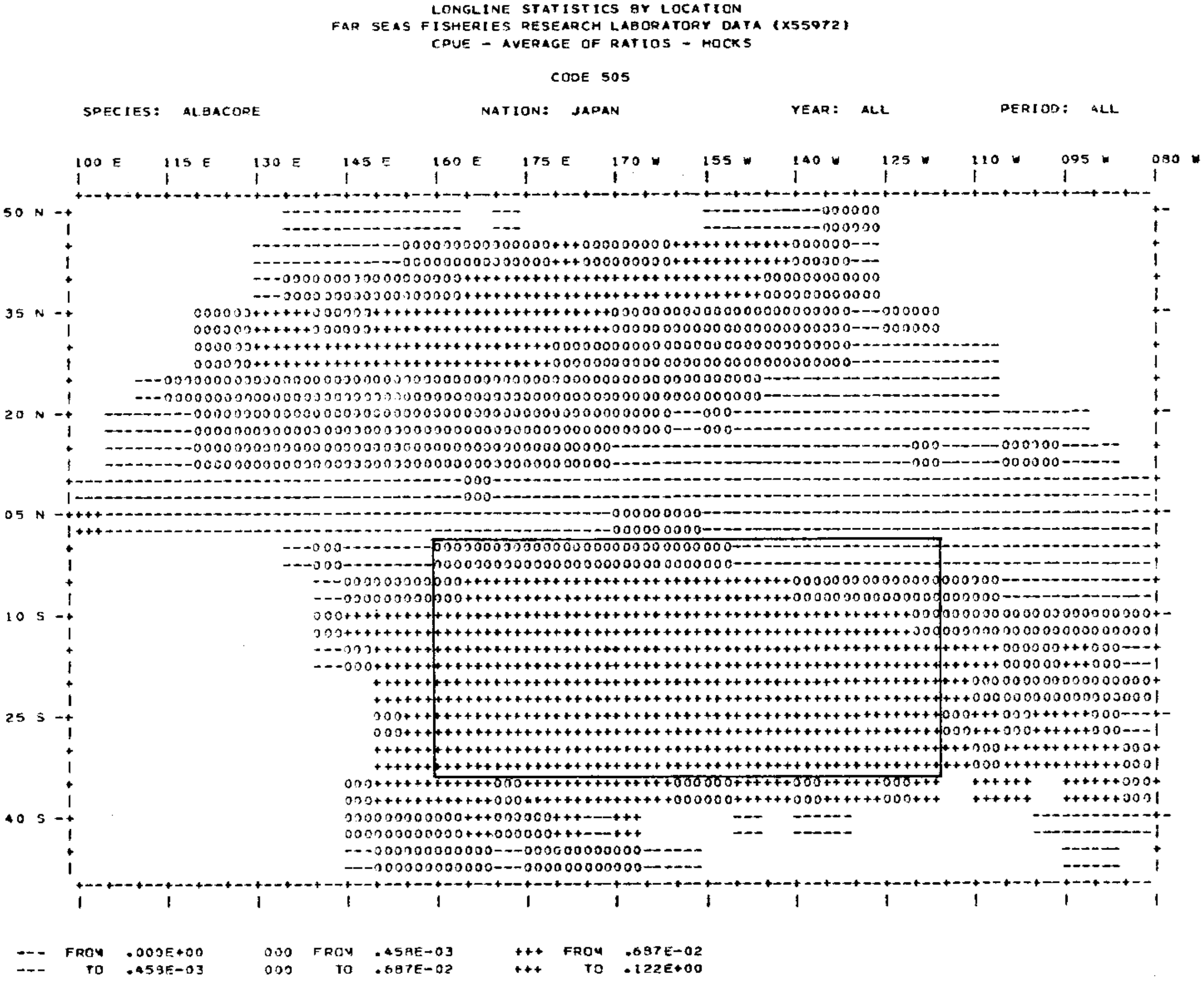

Figure 1.--Distribution of average catch per hook for Pacific Ocean albacore taken by Japanese longliners, averaged over 1952-76. Boundaries of the index area for the South Pacific albacore stock are also shown.

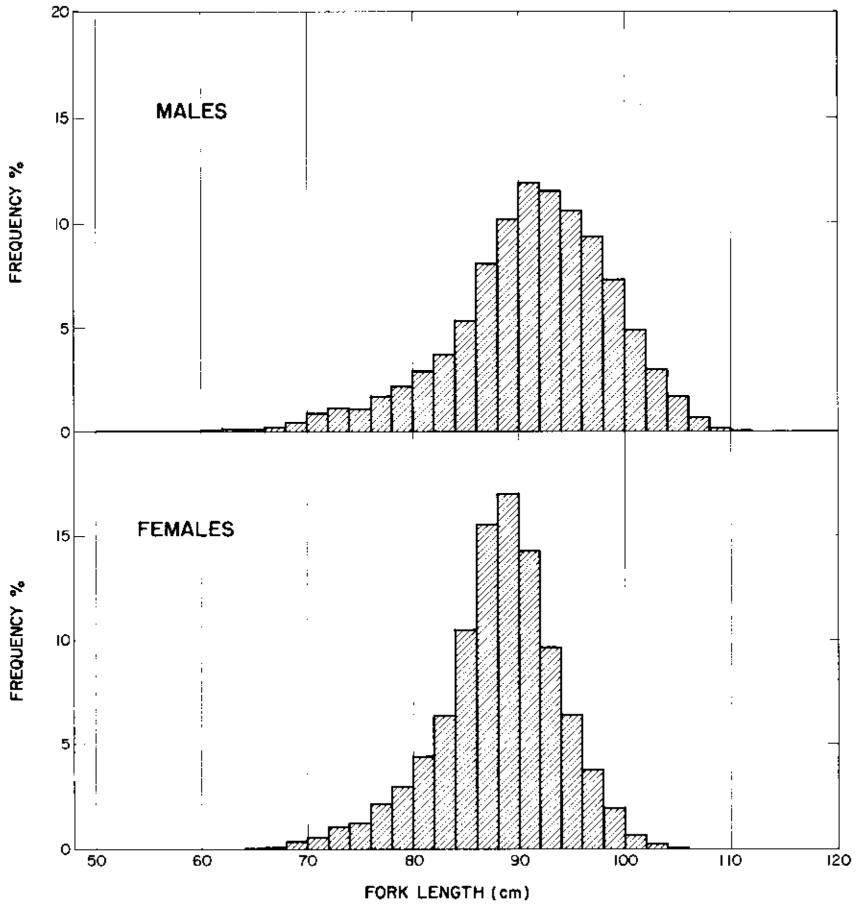

Figure 2.--Fork length composition of South Pacific albacore catches by longline vessels based at Pago Pago, by sex, 1962-70.

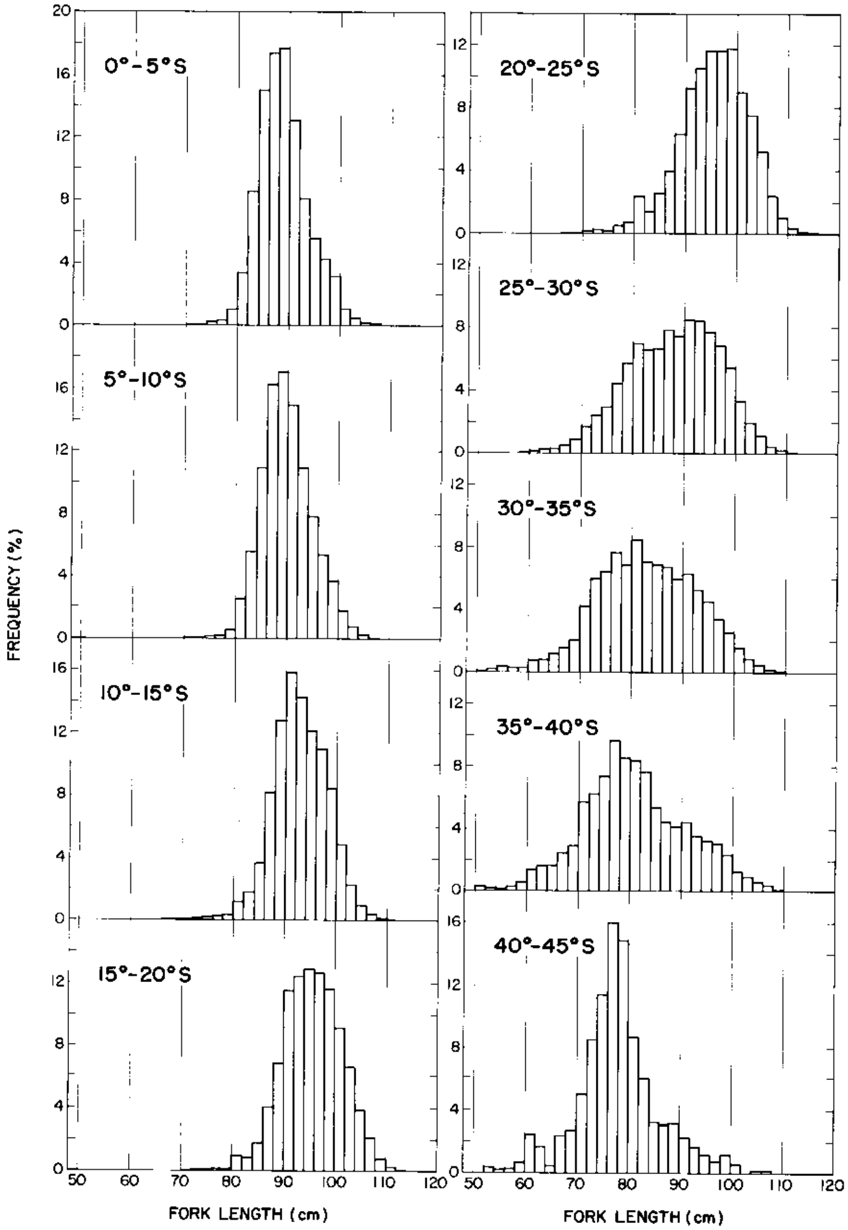

Figure 3.--Fork length composition of South Pacific albacore catches by longline vessels based at Pago Pago, by latitude, 1962-76.

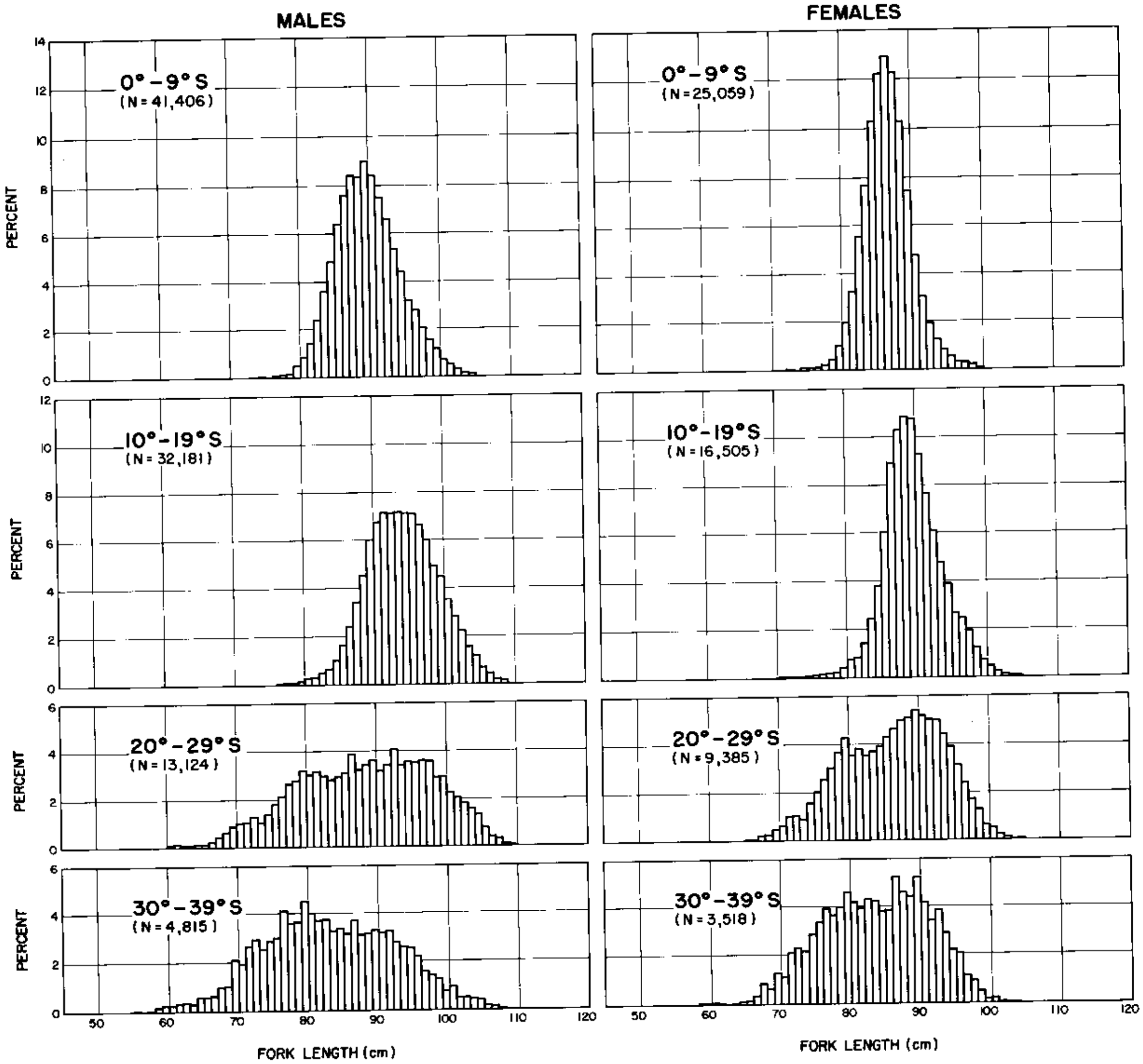

Figure 4.--Fork length composition of South Pacific albacore catches by longline vessels based at Pago Pago, by latitude and sex, 1962-70 (from Yoshida 1975).

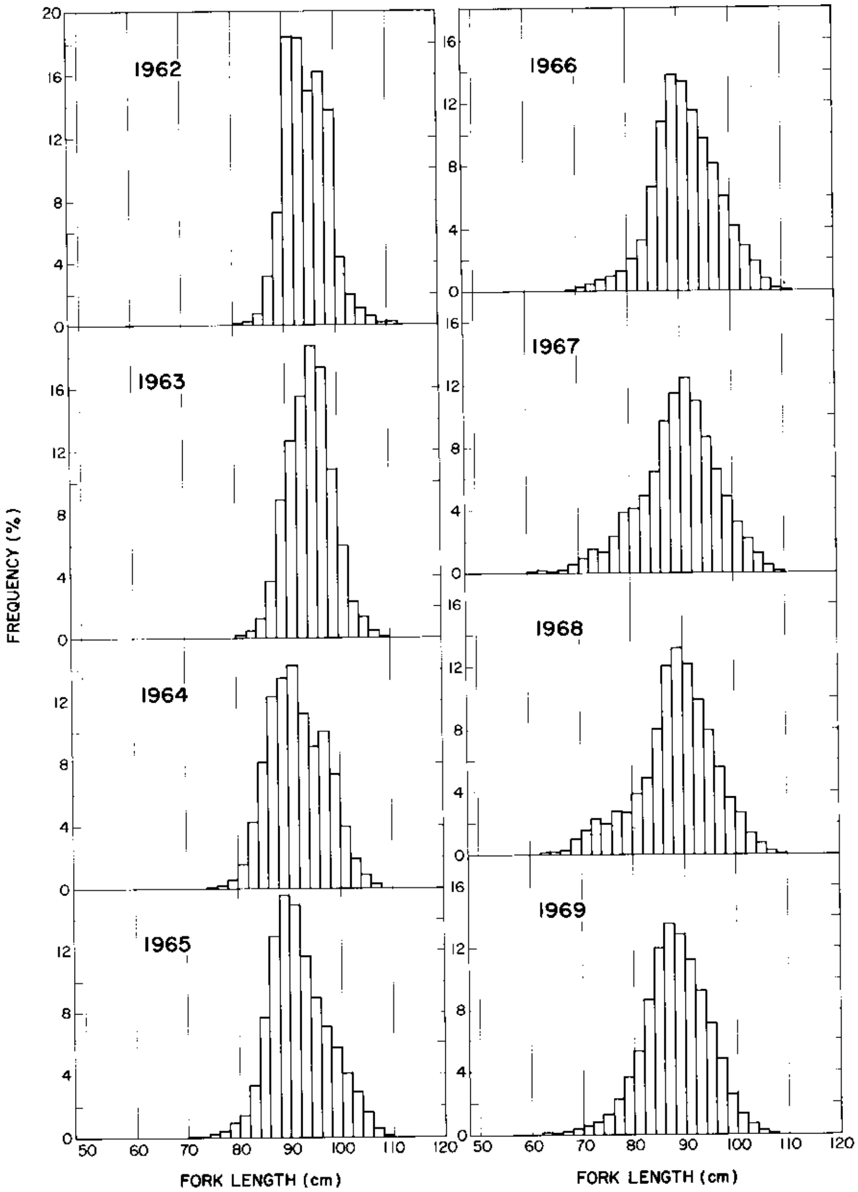

Figure 5.--Fork length composition of South Pacific albacore catches by longline vessels based at Pago Pago, by year, 1962-76.

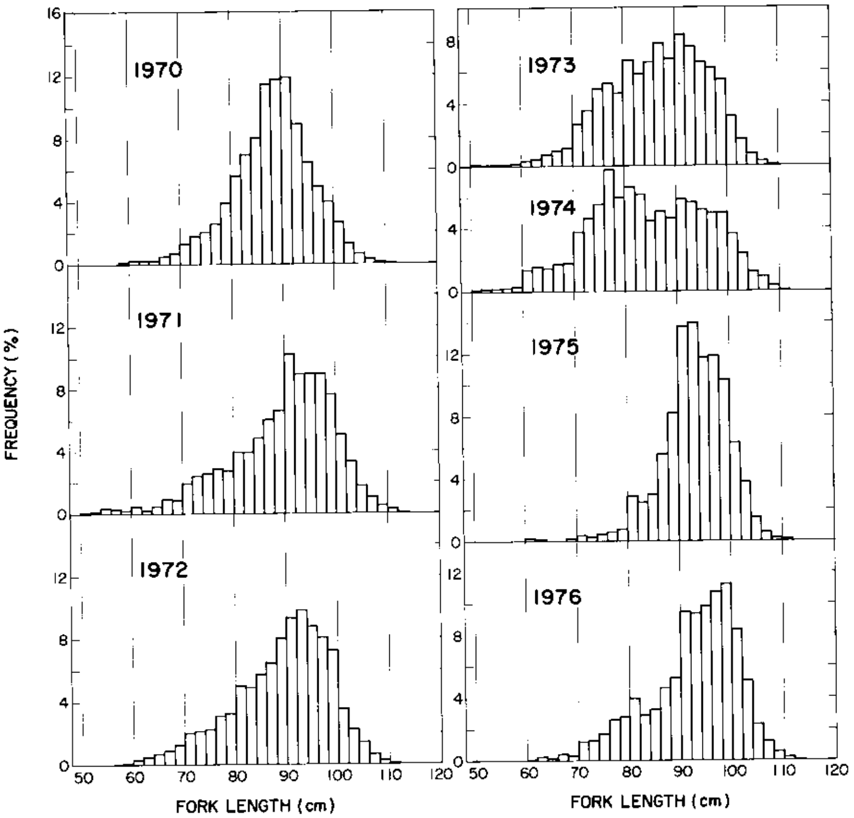

Figure 5.--Fork length composition of South Pacific albacore catches by longline vessels based at Pago Pago, by year, 1962-76.--Continued.

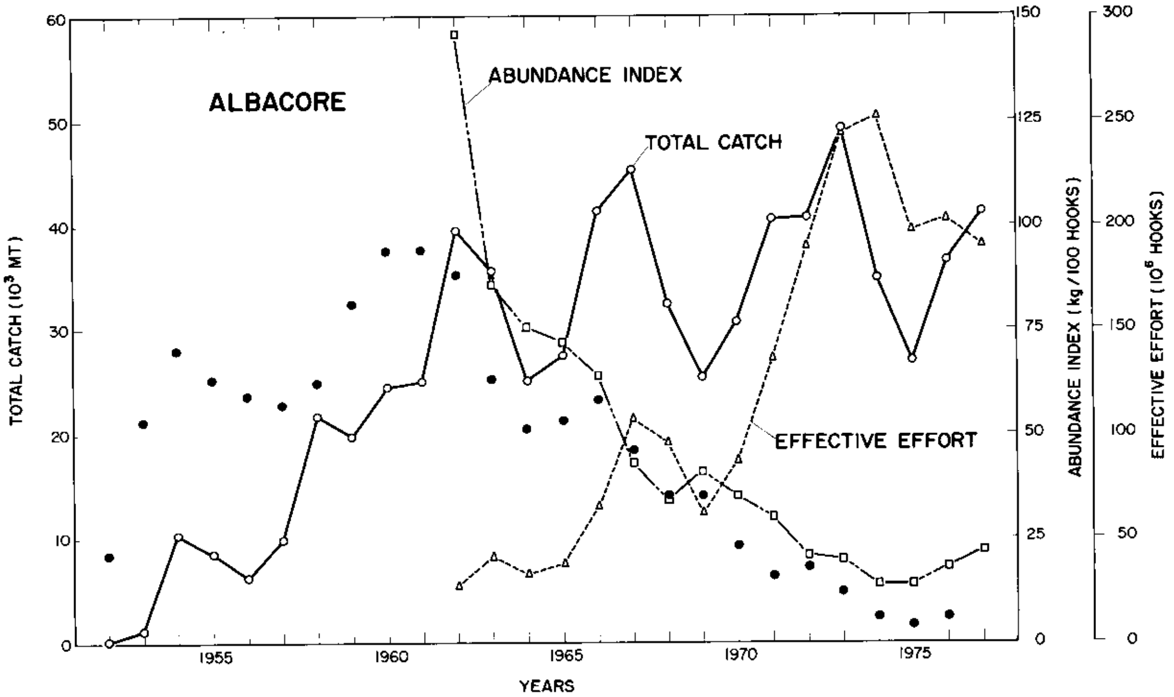

Figure 6.--Estimated total catch (10^3 MT), abundance index (kg/100 hooks), and effective effort (10^6 hooks) for South Pacific albacore. Solid circles denote a second abundance index based on historical Japanese longline statistics.

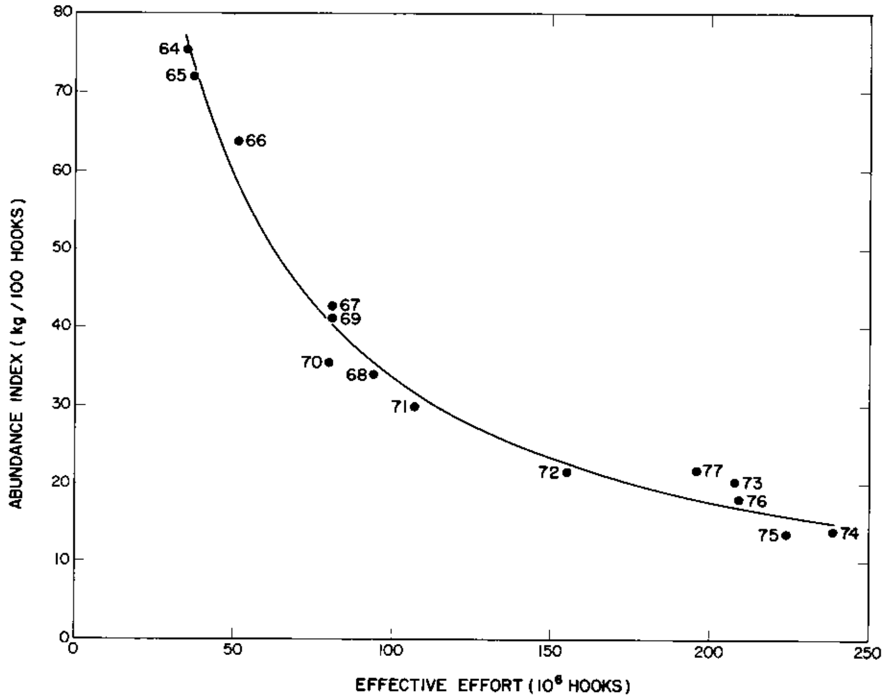

Figure 7.--Fitted production model for South Pacific albacore, based on 3-year effort averaging.

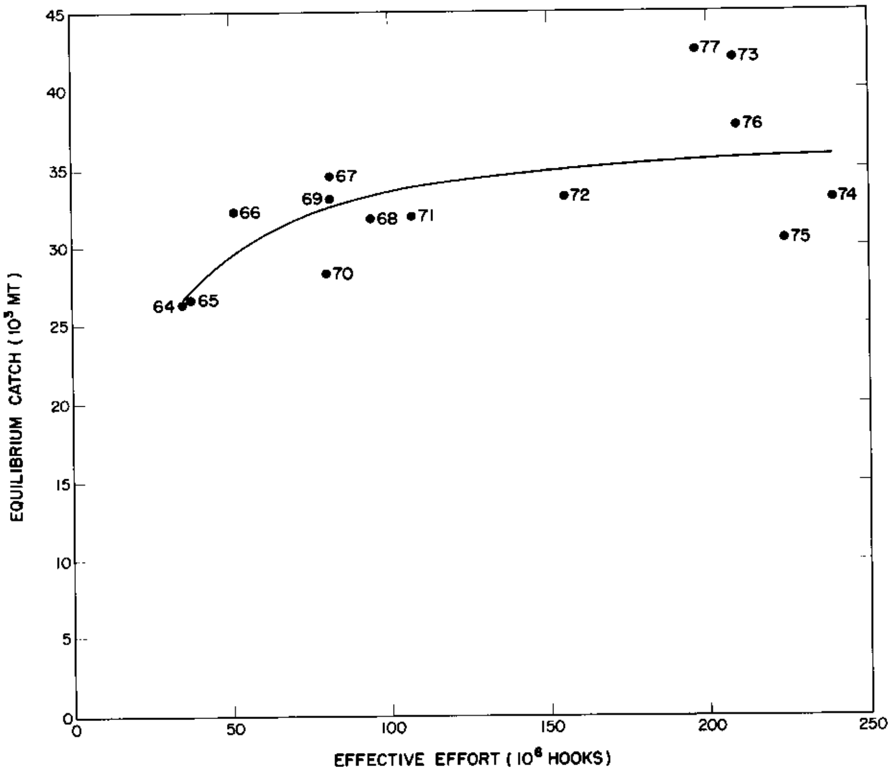

Figure 8.--Projected relationship between equilibrium yield and effective effort for South Pacific albacore, based on production model with 3-year effort averaging.

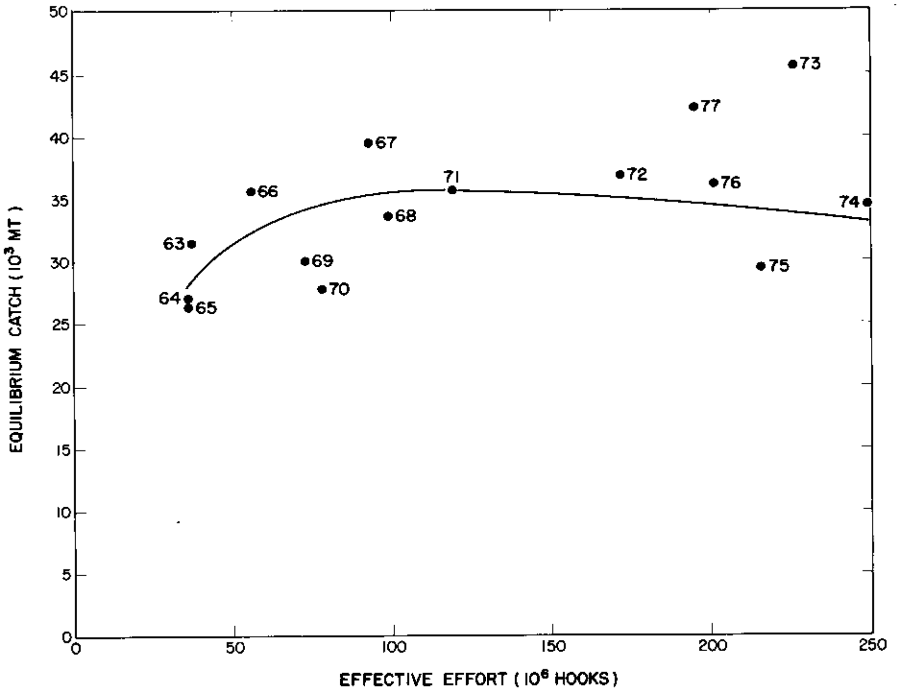

Figure 9.--Projected relationship between equilibrium yield and effective effort for South Pacific albacore, based on production model with 2-year effort averaging.

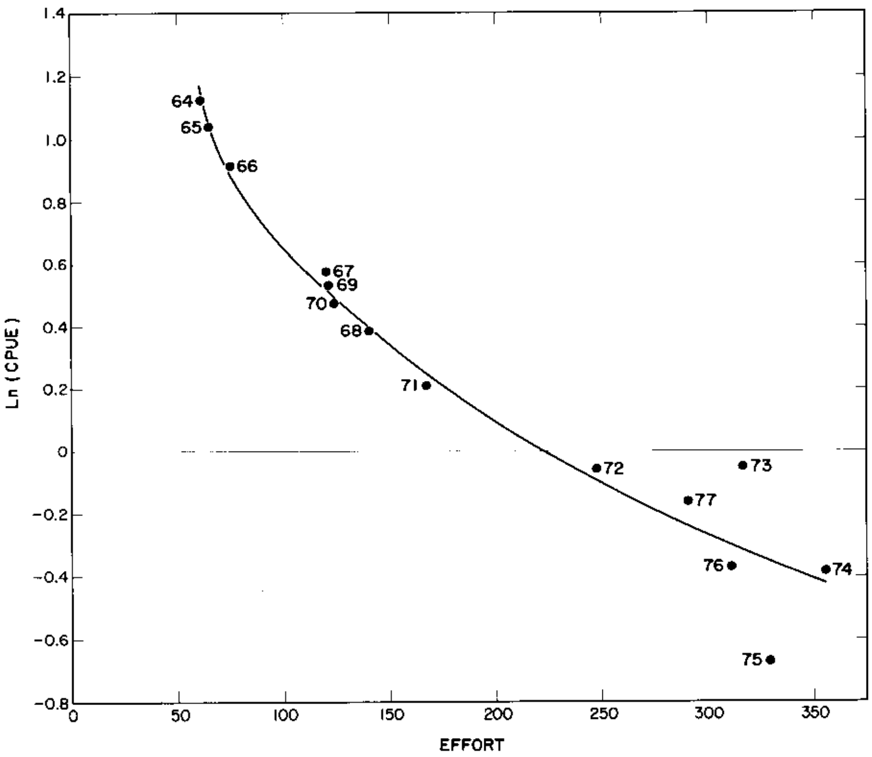

Figure 10.--Relationship between natural logarithm of abundance and effective effort for South Pacific albacore.

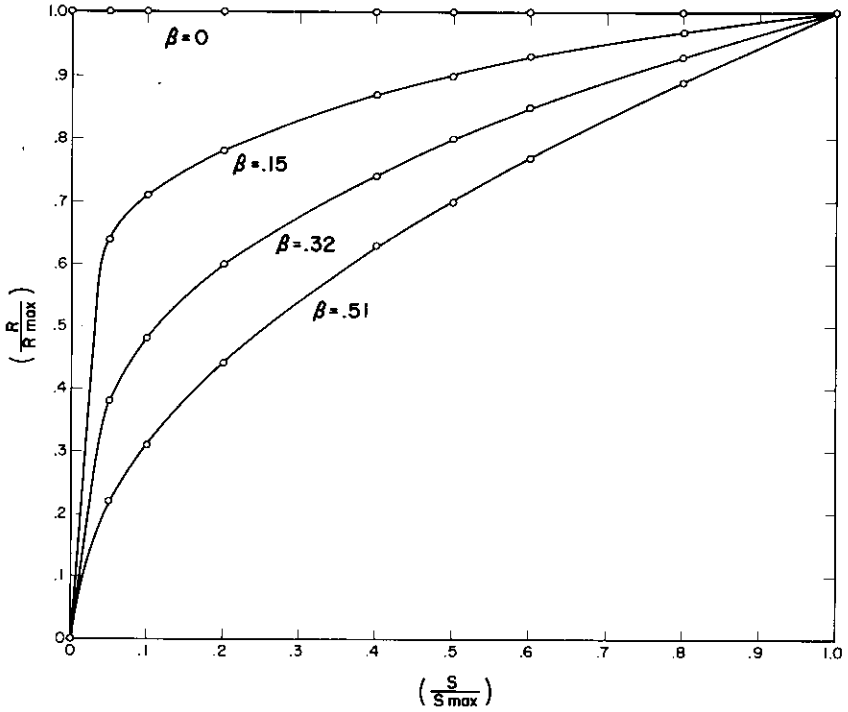

Figure 11.--Hypothetical relationships between recruitment of 2-year olds (R) and the spawning biomass (S) used in the South Pacific albacore simulation model.

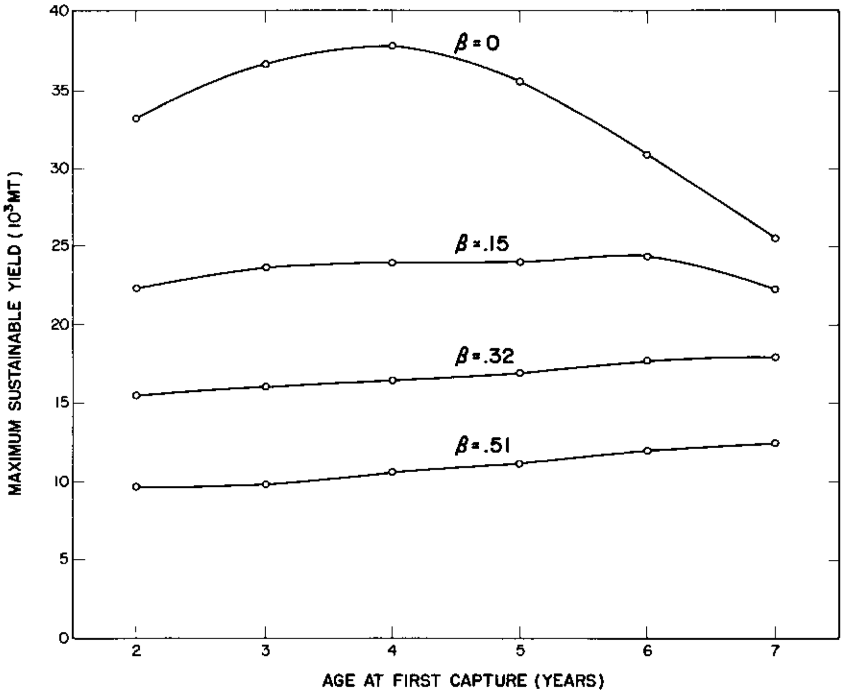

Figure 12.--Predicted relationships between maximum sustainable yield and age at first capture under different assumed stock-recruit relationships for South Pacific albacore.