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A COHORT ANALYSIS OF THE NORTH PACIFIC ALBACORE STOCK AND AN ASSESSMENT OF YIELD PER RECRUIT IN THE AMERICAN AND JAPANESE FISHERIES

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INTRODUCTION

The North Pacific albacore stock supports three major fisheries: an American surface fishery in the eastern North Pacific during the summer and fall, and two Japanese fisheries, the spring pole-and-line fishery and the winter longline fishery, both operating in the North Pacific Current area east of Japan.

From the early years of this century until the mid-1940's, total landings of North Pacific albacore ranged between 10,000 and 20,000 metric tons (MT) annually. In the postwar period catches increased fourfold, and, though fluctuating widely remained at a level of 60,000-70,000 MT until 1971.

In 1971 the Japanese pole-and-line harvest doubled to 52,000 MT, and continued to increase, reaching the 70,000 MT level in 1974. From 1972 to 1974 the aggregate landings from the three fisheries was in the neighborhood of 100,000 MT.

This sharp rise in landings is a source of concern to albacore fishermen and scientists on both sides of the Pacific, and has stimulated a bilateral inquiry, on the part of Japanese and American scientists, into the status of the North Pacific albacore stock and its capacity to sustain the increased harvest.

In this paper we present an assessment of the albacore stock and its fisheries in terms of the familiar yield per recruit criterion. The yield per recruit analysis is based on assumed growth and natural mortality characteristics and a set of age-specific fishing mortality rates which we estimated from a cohort analysis of year class catch histories.

Tagging studies (Ganssle and Clemens 1953; Clemens 1961; Otsu and Uchida 1963; Laurs and Associates 1974) have established the existence of complex intermigrations of North Pacific albacore between the eastern and western fishing areas and the dependence of the fisheries on a common stock. Thus it is widely recognized that a realistic appraisal of the stock must consider the harvests of all fisheries jointly. Still, to date no integrated analysis has been done. In our assessment we merge catch data from the three major fisheries, over the period 1952-72, and consider the interactions explicitly.

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DATA PREPARATION AND ESTIMATION OF CATCH BY LENGTH CLASS INTERVAL

The yield per recruit analysis and ancillary results followed an orderly sequence of steps involving data pooling, estimation of size and age composition of the catch, and the cohort analysis for each year class. A schematic diagram of the procedures is shown in

Fig. 1 Figure 1.

As the diagram indicates each fishery required a somewhat different treatment owing to differences in availability of data and special problems associated with each data set. Below we outline in some detail the preliminary steps of data processing and pooling and the estimation of size composition of the catch on a fishery-by-fishery basis.

JAPANESE POLE-AND-LINE FISHERY

The historical data for the Japanese pole-and-line fishery consist of three kinds of information on the catch:

1) Sample length composition (fork length, cm),
2) sample catch (number of fish) and effort (vessel days) for boats landing at the port of Yaizu, and
3) total landings (MT) of albacore by the pole-and-line vessels.

Table 1 Table 1 indicates the temporal and spatial detail in the data and gives the data sources.

The length-frequency data for 1951-59 are given as a composite annual sample covering all areas. For 1960-64 the data are given on a monthly basis (main months for the pole-and-line fishery) and by longitude (10° bands) but not by latitude. Data for the most recent years, 1965-73 are available in the greatest detail, by month, longitude and latitude (5° bands).

With respect to spatial and temporal variation in length composition of the pole-and-line catch, we made the following assumptions:

1) The annual length-frequency distributions for 1951-59 apply to all months and all latitudes.
2) The length-frequency distributions for all months in 1960-64 apply to all latitudes.
3) For all years, months and latitudes there is no significant longitudinal variation in length composition of the catch, so we can pool sample length-frequency data over longitudes.
4) For cases where Yaizu sample catch data are available for a particular month and latitude, but corresponding length-composition data are not at hand, we assume the length-frequency distribution can be represented by the appropriate data from adjacent latitudes in the same month and year, or from adjacent months in the same latitude and year. There were only a few such cases where sample catch information was not accompanied by size composition data. There were,

in addition, a handful of cases where length-frequency data were available but no corresponding catch data. These situations were ignored, and it was assumed there was no catch in that particular time-area stratum.

As indicated above, we assumed there was no significant

Table 2 longitudinal variation in sample mean lengths. Tables 2A and 2B show that there is a clear pattern in sample mean length latitudinally--smaller fish are taken in the higher latitudes--and that the picture longitudinally is more homogeneous. This latitudinal variation in average size is well-documented (see, e.g., Suda 1962; Koto 1963). The statistics in Tables 2A and 2B were computed from data covering the entire fishing season. Within each fishing month the variation, both longitudinally and latitudinally is less.

The landings of albacore by the pole-and-line fleet are available only as an aggregate annual tonnage (Table 1). We needed to estimate the total number of albacore landed and to allocate these by month and latitude. To accomplish this we assumed that the temporal and spatial distribution of the pole-and-line catch was identical to the distribution of the Yaizu sample catches. Then the estimated number of albacore taken by the pole-and-line fishery in latitude i, month j, year k was derived as

$$C_{ijk} = D_{ijk} \left(\frac{W_k}{a \sum_{ij} D_{ijk} \sum_{m} P_{ijkm} L_m^{\,b}} \right)$$

where

D_{ijk} = Yaizu sample catch in latitude i, month j, year k (Number of fish)

W_k = reported total tonnage of albacore taken by the pole-and-line fishery in year k

P_{ijkm} = proportion of sampled albacore in length class m for latitude i, month j, year k

L_m = fork length corresponding to length class m

$a = 2.24 \times 10^{-8}$

$b = 2.99$

The length-weight conversion parameters, a and b, were taken from Clemens (1961).

JAPANESE LONGLINE FISHERY

There are two kinds of historical statistics available for the longline albacore catch:

1) Sample length-frequency data (fork length, cm) and
2) estimates of the number of albacore landed, and the corresponding number of hooks fished.

As Table 1 indicates, the catch and nominal effort statistics are available by year, month and 5° square since 1952. Length-composition data go back to 1948, with information given by month and by 10° longitudinal band. Corresponding latitudinal data (by 5° band) are available only since 1965.

As with the pole-and-line fishery, in the longline fishery we assumed there was no significant longitudinal variation and pooled

Table 3

data over longitudes (Table 3B). In addition, for the early years, 1952-64, we assumed there was no latitudinal variation.

One problem with the longline data is that length-frequency data are available by three latitudinal bands--25°-30°N, 30°-35°N, and 35°-40°N. But the available catch data span a broader range of latitudes. Further, length-composition data are available only for main fishing months, whereas some albacore are caught each month. We estimated length composition of the catch in the "empty" months by using a composite frequency distribution formed by summing over months. For latitudinal banda not covered in the size composition samples, we used length-frequency information from an adjacent band--for size composition in 0°-25°N the data for 25°-30°N were used. For catches in 40°-45°N, the sample size composition in 35°-40°N was applied.

AMERICAN FISHERY

In our analyses we used two kinds of data from the American troll and bait fisheries:

1) Length composition of samples of catches, by year and state
2) estimated total landings (number of fish) by month, year and state.

Table 1 points out that the Oregon length-frequency statistics are used to represent Washington in several instances. In addition, California data is used for Oregon length frequencies in 1964.

The size-frequency data represent the entire season in all cases, and in what follows we assume that these annual statistics apply equally to all fishing months within each state.

CATCH BY LENGTH CLASS AND ESTIMATES OF MEAN LENGTH

Estimates of total catch (number of fish) by 1-cm length-class intervals were computed using the monthly statistics on total catch in each fishery and the sample length-frequency distributions. In the pole-and-line and longline fisheries, the length distributions were weighted by the estimated catch in each latitudinal band.

Quarterly and annual estimates of catch by length class were also computed, by simple summation. These provided estimates of the mean fork length of albacore caught in each fishery over a 21-year

Table 4 period, 1952-72 (Table 4). The mean length statistics have ranged from 73.2 to 89.3 cm in the pole-and-line fishery, from 81.6 to 96.3 cm for the longline fishery and from 63.5 to 73.7 cm for the American fishery. Annual variation in mean length is determined by fluctuations in year-class strength and by year-to-year changes in the geographical distribution of the fishing fleets, as discussed by Shiohama (1973).

There has clearly been no downward trend in the mean length of albacore landed in any of the fisheries. If anything there appears to be a slight upward trend, especially in the longlined albacore since 1964. Under conditions of steady recruitment, if the total mortality of principal exploited age groups had been increasing over the 21-year period, we would expect a reduction in average size of fish in the stock. And we would expect to find a corresponding decrease in the average size of albacore taken in the various fisheries, particularly so in the longline fishery which harvests the broadest size range. If recruitment has been decreasing, the effect of increased fishing mortality on mean size in the catches could be masked. At the same time, a steady drop in recruitment would produce a reduction in average abundance and perhaps mean catch rates. We will return to a consideration of all these issues later. Here we simply wish to point out that no reduction in mean length is apparent.

ESTIMATION OF AGE COMPOSITION AND CATCH HISTORIES FOR THE 1942-69 YEAR CLASSES

The quarterly estimates of catch by length class interval were used in conjunction with the growth model of Clemens (1961) to compute the age composition of the catches for each fishery. Clemens' estimate of the von Bertalanffy parameter t_o was increased by 1 year to give, on an annual time scale,

$$L_t = 135.6\ (1 - \mathrm{EXP}\ (-0.17\ (t + 0.87)))$$

where L_t is fork length in centimeters at age t years. Thus, on a monthly basis age was estimated from

$$t = -10.44 - \left(\frac{\mathrm{LN}\ (1 - (L/135.6))}{0.014}\right)$$

For each quarter, two sets of age compositions were produced

1) catch by 12-month intervals (annual grouping), giving 11 age-groups (LT2, 2, 3, 4,...,9, 10, GT10), and
2) catch by 6-month intervals (semiannual grouping), giving 20 age classes. This more detailed partitioning was not treated further.

The percentage age structure of the annual catches for each fishery were estimated. The results for 5 years, 1952, 1957, 1962, 1967, and 1972 are shown in Table 5. When the complete 21-year series is examined a remarkable year-to-year variation in the age composition of the Japanese catches is seen, due, as mentioned above, to shifts in the pattern of fishing in the longline and pole-and-line fisheries and to variation in recruitment. Similar annual variation is seen in the composition of American catches.

An inspection of the complete sequence of age compositions reveals that the age-4 albacore dominated the pole-and-line catches during the 1950's, with 5-year olds of secondary importance. During the 1960's the ranking changed, with 5-year olds most prevalent and 4-year old albacore in second position. In 1971 and 1972, there has been a shift back to the pattern of the 1950's. These changes in the composition of the pole-and-line catch were pointed out by Shiohama (1973) who ascribed them to latitudinal shifts in the center of fishing activity.

Shiohama (1973) could find no such patterns in the age composition of the longline catches. However, our computations showed that 5-year old albacore were generally predominant until 1962, with 4-year olds usually second, and since 1962 the ranking for these age groups has clearly reversed.

In the American fishery, the 3-year old albacore have dominated the catches in all but 1 of the 21 years. Four-year old fish have usually been in second place, although prior to 1960 this position was taken in a few years by 2-year old albacore.

The estimates of age composition provide the basis for constructing a complete catch history for 14-year classes, 1949-62, and a partial accounting of catches from year classes as far back as 1942 and as recent as 1969. We assumed here that the albacore have been fully exploitable beginning with their third year of life, i.e., that the significant impact of the fisheries on the stock, and our accounting of losses to fishing, begins at that time. Estimates of

Table 6 the catch by each fishery are presented in Table 6 on a quarterly basis for the 14 year classes with complete histories.

Catch histories were also generated on a weight basis, using an assumed weight-age relationship derived from the adjusted growth model of Clemens and Clemens' length-weight relation.

A complete summary of the estimated annual catch by each

Table 7 fishery, in numerical and weight units, is given in Table 7, which also lists the average weight of albacore caught each year by each

Fig. 2 fishery. Figure 2 shows the annual catches by fishery in metric tons,

Fig. 4 and Figure 4 gives the histories of average weight.

The total landings have fluctuated rather violently over the years, with a general downward trend in 1952-62, and an upward

Fig. 3 trend since then (Fig. 3). The pole-and-line landings for 1973 and 1974 (not shown) were about 69,000 and 73,000 MT, respectively, so the total landings have increased dramatically, by roughly 50%, since the late 1960's. (Apparently the 1975 total landings will be lower, in the neighborhood of 80,000 MT.)

While the pole-and-line fishery has shown increased catches since 1962, following a reduced catch in the previous decade, the longline fishery has diminished steadily after the peak harvest in 1967. The American fishery has shown a slight increase over the years, in the vicinity of 20%.

Mean weight of albacore taken in the longline fishery has increased by perhaps 30%-35% over the 21-year period, though with considerable year-to-year variation. The pole-and-line catch, as discussed above, was dominated by 5-year olds in the last half of the 1960's, and mainly 4-year olds prior to that, so the trend in mean weight was upward from 1952 to 1969. In the 1970's, however, the pole-and-line fleet has extended its operations into more northerly grounds inhabited by smaller albacore (Shiohama 1974) and the average weight of pole-and-line albacore has sharply declined.

Average weight in the American west coast albacore fishery has not changed significantly over the 1952-72 period.

COHORT ANALYSIS

The well-known methods of Gulland (1965) and Murphy (1965) were used in an analysis of the year class catch histories to estimate age-specific fishing mortality rates and initial cohort strengths.

A requirement of cohort analysis, as it is normally applied, is that we assume values for the instantaneous natural mortality rate at each age and for the fishing mortality coefficient in one of the fishing periods. Because estimates of age-specific natural mortality in tunas are not available, the usual procedure has been to assume a constant natural mortality rate, M. Below we discuss estimates of M for albacore and the partitioning of estimates of total instantaneous mortality rate, Z, into the components representing natural mortality and fishing mortality, F.

CONSTANT M AND TOTAL MORTALITY, Z

Assuming the natural mortality rate, M, to be constant with age, Lenarz and Coan (1974), in their cohort ananlysis of North Atlantic albacore put M = 0.2 on an annual basis. This estimate was taken from studies by Beardsley (1971) and Bard (1973) on the North Atlantic stock. Lenarz and Coan also took M to be 0.4, reasoning that the von Bertalanffy growth parameter, K, is 0.14-0.19 for the North Atlantic albacore and that the ratio M/K is estimated in the neighborhood of 2.0 for yellowfin tuna.

For North Pacific albacore, Suda (1963) estimated that the average total instantaneous mortality rate (Z = F + M) was about 0.4 in the early 1950's. In later studies (Suda 1966a, 1966b) he estimated M to be 0.2. Suda has continued to use this value of 0.2 to represent natural mortality of albacore through the first 6 years of life in more recent studies on the North Pacific albacore stock (Suda 1970) and on Indian Ocean albacore (Suda 1974).

In a manner similar to the one employed by Suda (1963), we estimated the average total mortality rate on 5-year old albacore over 20 fishing years, 1952-71. We constructed indices of abundance of 5-year and 6-year old fish as the catch per 100 hooks of fish from these age groups during the first quarter (peak of the longline season). Denoting these indices for the i-th year by I_{5i} and I_{6i}, we estimated the total mortality rate for 5-year olds during the year as

$$Z_{5i} = -LN\ (I_{6(i+1)} / I_{5i})$$

Table 8

The data and resulting estimates are given in Table 8. When all 20 years are considered, the average estimate is $Z_5 = 0.59$, with no trend apparent over the years. When the inadmissible (negative) values are omitted, the average estimate is $Z_5 = 0.68$. These are obviously exceedingly crude estimates when taken individually, but assuming a cancellation of annual errors in the method, an average total mortality rate of about 0.6 may be assumed for 5-year old albacore during the 20 years. Inasmuch as the rate of emigration from the principal longline grounds to the subequatorial spawning grounds is assumed to be greater for 6-year olds than for 5-year olds, we perhaps may take $Z_5 = 0.6$ as an upper limit.

Suda's estimation of total mortality rate (Suda 1963) involved 4-year and 5-year old albacore. In carrying out our procedure with these age groups for the 20 years, we find only 12 admissible annual estimates, and these average out to $Z_4 = 0.58$. We note that 8 of the 12 positive estimates were from the second half of the data series. During this period 4-year olds dominated the 5-year olds in the longline catch, whereas the opposite was true during the 1950's. It is thus clear that in estimates of both Z_4 and Z_5 there is a question of unequal availability and catchability for the age groups involved. This problem is probably most severe for Z_4, while Z_5 is more affected by differential emigration to the spawning grounds.

We attempted to partition our estimate of Z_5 into components of natural mortality, M_5, and fishing mortality, F_5, by regressing the Z_{5i} on crude estimates of standardized fishing effort during each year. The estimates of effort were constructed by dividing the total catch of 5-year olds in year i (all fisheries) by I_{5i}, doing the same for 6-year olds in year (i + 1), and then summing the two ratios and dividing by two. We thus computed the regression based on the model

$$- \text{LN} \left(I_{6(i+1)} / I_{5i} \right) = M_5 + q_5 f_i$$

where f_i is the estimated annual effort and q_5 is the average catchability coefficient for 5-year olds ($F_{5i} = q_5 f_i$).

The estimates obtained using just the 16 admissible data points were $M_5 = 0.55$ and $q_5 = 0.0004$. From this we obtain $F_5 = 0.13$. When the regression is fitted to all 20 points, we find $M_5 = 0.47$ and $F_5 = 0.12$. When a 15-point data set is considered (discarding the 4 inadmissible survival values and another outlier with unreasonably high effort) we get estimates of $M_5 = 0.27$ and $F_5 = 0.49$. Of the three sets of estimates this last one seem to us the most reasonable, as far as relative magnitudes of M and F are concerned. However, we feel each component is probably too high by perhaps 0.10.

AGE-SPECIFIC NATURAL MORTALITY RATE

A second approach with natural mortality is to assume that M varies with age (let the natural mortality rate for fish aged i years be denoted M_i). In particular, we may assume that M_i increases progressively after the onset of sexual maturity. This assumption was made by Suda (1966b, 1970), who assumed $M_6 = 0.4$, $M_7 = 0.6$, and $M_8 = 0.8$ for North Pacific albacore. Suda (1974) applied the same thinking in his study of Indian Ocean albacore, i.e., that natural mortality rate is greater among the spawning component of the stock.

Suda has modeled the North Pacific albacore stock as a

Fig. 6 two-phase system, which we show diagrammatically in Figure 6. In his recent work, Suda (1966b, 1970) assumed an abrupt transfer from the exploited phase to the more southerly spawning phase at the end of the 6th year, and at this time he assumes the rise in M from 0.2 to 0.4, then to 0.6 at the end of the 7th year and finally the jump to 0.8 at the end of year 8. An objection to Suda's model is that the albacore are not considered exploitable after their 6th year, whereas in fact the tonnage of albacore aged 6 years and older may make up a significant fraction of the Japanese catch.

In our treatment of the North Pacific albacore data below we considered two sets of assumptions on natural mortality rate:

1) M = 0.2 from the time of recruitment at age 2.5 years to the end of the exploited life at age 10.5 years

2) M = 0.2 from age 2.5 years to 5.5 years

M = 0.4 from age 5.5 years to 6.5 years

M = 0.5 from age 6.5 years to 7.5 years

M = 0.6 from age 7.5 years to 8.5 years

M = 0.7 from age 8.5 years to 9.5 years

M = 0.8 from age 9.5 years to 10.5 years

We thus differ from Suda in assuming a fraction of the fish older than 6 years remain exploitable. The increase in M values after age 5.5 years reflects not only a rise in natural mortality but the emigration of mature albacore from the major fishing grounds to the southerly spawning area.

ESTIMATION OF AGE-SPECIFIC FISHING MORTALITY RATES (FISHERIES COMBINED)

The estimation of age-specific fishing mortality rates was accomplished with the computer program COHORT, written by W. W. Fox, Jr. (National Marine Fisheries Service (NMFS), La Jolla). The quarterly catch histories for each year class, all fisheries combined, were used (Table 6). For year classes with complete catch histories (1949-62), the catch over an 8-year exposure to fishing was considered, with first exposure assumed to occur in the first quarter 3 years following the birth year. Thus for these 14 year classes there were 32 equal age intervals for which fishing mortality rate estimates were obtained. For the earlier year classes (1942-48) and the more recent ones (1963-69) an incomplete series of estimates was obtained. For example, the oldest year class, 1942, was represented in the catch data only by 10-year olds. And the 1969 cohort was available only in 1972, so just the 3-year olds from this year class could be treated.

Both the constant and age-specific natural mortality vectors described above were employed in the analysis.

Besides the assumptions on natural mortality rate, we began the reverse iterative solution of the COHORT catch equations by choosing a value for the fishing mortality rate in the terminal age interval. (F_{32} in the case of cohorts with complete catch histories.) We denote this initial value by F_o. We considered a wide range of F_o: 0.001, 0.01, 0.10, 0.20, and 0.40. These were used in combination with the assumption that M = 0.20. When the age-specific M, or variable M was employed we let F_o be 0.10, 0.20, and 0.40. All these rates are expressed here on an annual basis.

The cohort analysis provided age-specific estimates of the aggregate fishing mortality rate for each quarter of the fishing years 1952-72. In making inter-year comparisons, however, we must bear in mind that

1) only the estimated F vectors for the complete year classes, 1949-62 are wholly comparable, since $F_o = F_{32}$ in each case. And, in any event,
2) the average fishing mortality rate over each cohort was determined by the F_o chosen, and this was the same for all cohorts, so it is difficult to unravel year-to-year changes in age-specific fishing mortality with complete confidence.

Nevertheless, it is possible to study the age-specific pattern of aggregate fishing mortality rates on a quarterly basis by averaging over years. We have done this by dividing the 1952-72 fishing interval into three 7-year periods. For the first two periods, 1952-58 and 1959-65, estimates of fishing mortality rates for each age come from year classes having complete catch histories. The estimates for period three, 1966-72, are based on abbreviated catch histories for all age groups except the 10-year olds.

Figs. 7,8, 9, and 10

Figures 7, 8, 9, and 10 show the average estimated age-specific fishing mortality rates for the second period, 1959-65, based on different assumptions concerning the natural mortality regime and F_o. The rates are given for each quarter-year of life (plotted at the midpoints), but are expressed on an annual basis. Figure 7, with $M = 0.2$, indicates that for F_o of the same order of magnitude estimates of F converge at younger ages. A comparison with Figure 8 suggests that under conditions of variable M, the convergence at younger ages is not as strong as with constant M. When F_o values are of different orders of magnitude, no convergence is obtained with the North Pacific albacore data (Fig. 9).

Figure 10 displays the estimated fishing mortality rates for both $M = 0.2$ and M = variable and with $F_o = 0.10$ in each instance. The age-specific natural mortality vector in this case had an average value higher than 0.2, so of course the estimates of F are greater for the constant-M situation. The difference between the age-dependent M values and the assumed constant M diminishes as age decreases. We thus expected the estimated F values to converge correspondingly. This did not seem to happen.

Earlier we pointed out that the average fishing mortality rate estimated under ($M = 0.2$, $F_o = 0.01$) was practically the same as under (M = variable, $F_o = 0.1$). Here we note, by comparing Figures 8 and 9 that the second set of conditions gives a slightly higher F throughout the age scale, and proportionally greater estimates for older age groups characterized by increasing natural mortality rates.

In all these figures we see that the average fishing mortality estimates for the second 7-year period are highest during the 4th quarter of the 5th year of life (just prior to reaching age 5). This corresponds to the Japanese pole-and-line fishing season. The peaks at ages 4 and 6 are also due to the pole-and-line fishery, while the peak at age 3 is caused by the American fishery. The peaks at ages 6.5 years, 7.7 years, 8.5 years, 9.5 years, and 10.5 years are a result of the longline fishery.

Figures 9 and 10 show that whether the estimate of F at age 6 years exceeds the estimate for ages 3 and 4 years depends on the assumptions concerning M, or, for a particular natural mortality situation, on the order of magnitude of F_o. Thus the choice of both M and F_o affects not only the average level of the fishing mortality vector but its shape as well.

ESTIMATES OF FISHERY-SPECIFIC FISHING MORTALITY RATES

The estimates of aggregate fishing mortality rates were partitioned into fishing mortality rates specific to each of the three fisheries by multiplying the total fishing mortality rate by the ratio of the catch by each fishery to the aggregate catch. This was done for each quarter and each age group.

Table 9 Fishery-specific estimates are shown in Table 9 by year for the principal age groups in each fishery, and under different sets of assumptions of M and F_o. Although estimates were computed for each quarter, only estimates for the main periods of activity are given. For the longline fishery this the first quarter, for the pole-and-line fishery it is the second quarter and for the American fishery, the third quarter.

Table 10 The results in Table 10 are given as averages for each 7-year time period. Keeping in mind the earlier cautionary words about making year-to-year comparisons, we note a decrease in longline mortality rates for age groups 3 through 7 between period 1 and period 2. The fishing rates on ages 8 through 10 appear to be essentially unchanged.

A similar decline is seen in the 2d quarter pole-and-line fishing mortality rates for fish aged 3 to 5 years. We note a far greater apparent reduction in the age 4 fishing mortality rate than in the age 5 rate. This is in keeping with the earlier observation that the pole-and-line fishery took a predominance of 5-year olds in the 1950's, and mainly 4-year old albacore in the 1960's. The shift to more southerly fishing grounds during these years is also indicated by the general increase in fishing mortality rates for age groups 6 and 7, in the face of declines for younger age groups.

The estimates for the 3d quarter American fishery consistently show an apparent reduction in fishing mortality rates for all age groups except 4-year olds.

AVERAGE FISHING MORTALITY RATE OVER THE LIFE OF EACH COHORT

The Gulland-Murphy analysis, providing estimates of F and average population size during each time interval of a cohort's life, allows us to compute the average fishing mortality rate over the life of each cohort, $\bar{F}_N$, such that

$$C_N = \sum_i F_i N_i = \bar{F}_N \sum_i N_i$$

where C_N = total number of albacore caught from a cohort over its life in the fishery

N_i = average number of albacore in the exploitable stock during time period i, and

F_i = fishing mortality rate during period i for members of the cohort.

Thus, $\bar{F}_N = \sum_i F_i N_i / \sum_i N_i$

and the summation is from 1 to 32 for year classes with a complete catch history.

An alternative measure of overall fishing mortality (and one equivalent to $\bar{F}_N$ if F is constant over age) is one weighted by the average biomass during each time period, and satisfies

$$C_w = \bar{F}_w \sum_i B_i$$

Thus, $\bar{F}_w = \sum_i F_i B_i / \sum_i B_i = \sum_i F_i N_i w_i / \sum_i N_i w_i$

where B_i = average biomass of the cohort during period i, and

w_i = average individual weight during the interval.

We note that $\bar{F}_w = \bar{F}_N (w_c / w_p)$ where w_c denotes the average weight of the albacore caught from the cohort over its life and w_p is the average individual weight in the cohort during its history in the fishery.

We computed $\bar{F}_w$ for each cohort beginning with the 1949 group. Estimates of $\bar{F}_w$ for different assumed conditions on natural mortality and F_o are shown in Figures 11, 12, and 13. Repeating the words of caution about comparing cohort-to-cohort changes, we simply note that a general decline in $\bar{F}_w$ is apparent at least through the 1962 year class. Estimates of $\bar{F}_w$ for the more recent year classes are based on incomplete catch histories, so are not so reliable. A consideration of the F_o values in each case and the convergence properties demonstrated in the complete, 32-quarter sequences suggests that for (M = variable, F_o = 0.1, 0.2, 0.4) the indicated upswing after the 1962 year class is "legitimate." For the set of estimates with M = 0.2, the upturn shown for F_o = 0.10 and F_o = 0.20 should be perhaps 10% higher and for F_o = 0.01 about 50% greater than indicated.

Figs. 11, 12, 13

The evidence in Figures 11 and 12 is that the average fishing mortality, while showing rather striking short-term variation, underwent an apparent decline of about 50% from the period of exploitation of the 1949 year class through at least the 1962 year class. There has evidently been an upturn in more recent years.

It is equally revealing to compute average fishing mortality rates within each year over all age groups. We did this for M = 0.20 and F_o = 0.01, for both $\bar{F}_N$ and $\bar{F}_w$ using formulae analagous to those above. The results are shown in Table 11.

Table 11

Whether these trends in average aggregate fishing mortality rate are real or only apparent rests on the validity of assuming that F_o was constant over the years. For the year classes 1949-62, F_o represents the fishing mortality by longliners on 10-year old albacore during the 4th quarter. Thus it is mortality inflicted in the 4th quarter principally in the southernmost limits of the fishing grounds, where the oldest albacore are found. Total longline effort has declined over the years, though with fairly considerable annual variation (Fig. 33). The nominal effort in the 4th quarter, over all areas and between 20° and 25°N has shown no steady increase.

ESTIMATES OF SPAWNING BIOMASS

We computed estimates of spawning biomass assuming the spawning group was composed of albacore 6 years old and older. Under the condition that $M = 0.2$, we implicitly assumed that the entire spawning stock was available to the fishery, or, if there is an emigration of mature albacore to a southern spawning area outside the main fishing grounds, that the natural mortality component of the loss rate decreased with age. Alternatively, we assumed that M was variable, increasing after the onset of sexual maturity, due to a progressive increase both in natural mortality and emigration from the fishing grounds. The second condition seems to be the more tenable.

In either case, if the loss rate includes an emigration component (and a permanent departure of the emigrants from the fishable stock) then the spawning stock estimates computed from the cohort analysis biomass statistics will be underestimates. Under average, equilibrium conditions, the total spawning stock will exceed the nominal spawning biomass from the cohort analysis by 100 (λ/θ) percent, where λ is the average rate of emigration from the exploitable spawning fish to the spawning refugium, and θ is the total loss rate from this unavailable group (Fig. 6).

The estimated spawning biomass during the 2d quarter of each

Figs. 14, 15, 16

year, 1952-68, is shown in Figures 14, 15, and 16. The 2d quarter is assumed to be the period of peak spawning activity in North Pacific albacore (Ueyanagi 1957; Otsu and Uchida 1959). The spawning biomass estimates for this 17-year period are based on complete catch sequences. Assuming F_o was constant over the period the figures indicate a decrease in the early 1950's, a rather steady spawning biomass through 1965 and then beginning in 1966 a definite increase in the spawning stock.

This pattern is remarkably consistent with indices of the spawning biomass reported by Otsu and Sumida (1970). They studied the albacore fishery statistics for Hawaii for 1948-68. The Hawaiian longline fishery harvests very large, mature albacore assumed to be part of the spawning segment of the North Pacific stock. Otsu and Sumida gave statistics on total landings (MT) and catch rate (tons

Fig. 17

per boat per year) in the Hawaiian fishery. In Figure 17 we have plotted the catch rate along with the estimated spawning biomass computed under M = 0.2 and F_o = 0.01. The close correspondence between the two lends credibility to the cohort analysis and particularly to the conclusion that there was an increase in spawning biomass in the late 1960's.

ESTIMATES OF RECRUITMENT

The cohort analysis produced estimates of the number of albacore in the exploited stock at the beginning of each time interval (each of the 32 quarters in the case of cohorts with complete catch histories). We assumed the birthdate of each cohort was July 1 (beginning of the 3d quarter) so that the albacore were first considered exploitable at age 2.5 years, i.e., on January 1 in the third year following their birth year. Our recruitment estimates are therefore estimates of abundance at age 2.5 years for each cohort.

Fig. 18, 19, 20

Figures 18, 19, and 20 show estimates of recruitment for year classes 1949 through 1969. Only estimates through 1962 are based on complete, 32-quarter catch histories. However, the estimates from the reverse iterative solution of the catch equation converge in such a way that even estimates for 1968 are not greatly affected by the shorter catch history. The exception is the figure for F_o = 0.01, M = 0.20. In this case the indicated recruitment estimates for 1965-68 are perhaps 50% too high.

The pattern displayed in Figures 18 and 19 is one of moderate fluctuation, indicating perhaps a fivefold variation in strength of year classes, with peak recruitments occurring every 4 years or so. Estimates generated under assumption of constant M indicate the possibility of a slight increase in recruitment during the 1960's, relative to the 1950's. This is especially the case when $F_o = 0.01$ or less. For variable M, such an increase is not clearly shown.

RELATION BETWEEN RECRUITMENT AND SPAWNING BIOMASS

One consequence of increased exploitation on a stock is a reduction in stock biomass, other things being unchanged, and consequently a decline in spawning biomass. The extent to which this reduction in spawning stock affects the regenerative capacity of the stock and recruitment to the fisheries is of course a fundamental issue in fishery biology. Spawner-recruit relationships, as derived empirically, are very often extremely untidy, yet can be the most critical determinants of the behavior of population simulation models which we use as tools for management analysis (Walters 1969).

Figs. 21, 22, 23

In Figures 21, 22, and 23 we have plotted the corresponding pairs of estimates of 2d quarter spawning biomass (1952-66) and subsequent recruitment at age 2.5 years (1955-69). The most recent four pairs of estimates are based on shorter catch sequences, but this should not seriously affect the results. We note that aside from being based on common specifications for M and F_o, the spawning biomass and recruitment figures are estimated independently.

The plots show no clear pattern. With the proviso that a reproduction curve pass through the origin, the data points are so scattered that a wide range of models based on different sets of assumptions could fit the points equally well. Two such models are the asymptotic reproduction curve of Beverton and Holt (1957) and the dome-shaped spawner-recruit function of Ricker (1975).

Suda (1966b), having constructed indices of spawning stock and recruitment using longline hooking rate satistics, fit several alternative reproduction curves and found that the Ricker function gave the best fit to his 7 data points (based on the 1952-59 spawning years). But the improvement over fitting to the mean recruitment was only marginal. We fit the Ricker model to 15 data points (from our data set, different from Suda's) covering the 1952 through 1966 spawning seasons. Parameter estimates under the various specifications

Table 12

for M and F_o are given in Table 12. We note that better fits are obtained under the assumption of a progressive increase in natural mortality in spawning-age fish than under the constant M hypothesis (roughly twice as much variation in LN (R/B_s) is explained by the model.)

ESTIMATES OF THE YIELD PER RECRUIT

The total harvests from each year class, 1949 through 1966, were divided by the estimated initial cohort strengths to give estimates

Figs. 24, 25, 26

of yield per recruit. Results are shown in Figures 24, 25, and 26. Considerable variation in yield per recruit is seen under the variable

M hypothesis, and under the constant M hypothesis with low F_o. Assuming constant F_o over the years, the results indicate a slight reduction in yield per recruit from the mid-1950's through the mid-1960's. Under the low F_o, constant M assumptions, the decline is particularly dramatic. If F_o had in fact been decreasing over the period, then the estimates of yield per recruit would show an even steeper decline.

The greater reduction in yield per recruit for the constant M situation relative to the case of variable M corresponds to the sharper decline in average fishing mortality for the constant M case. (Compare Fig. 11 and Fig. 12.) The greatest apparent reduction in yield per recruit is seen for low F_o, and again here there is a clear correspondence with a sharper decline in average fishing mortality rate.

ANALYSIS OF YIELD PER RECRUIT

A key objective of our work is to establish the status of the North Pacific albacore fisheries in terms of some measure of exploitation efficiency. While some complex set of economic and political criteria would need to be considered in achieving an optimal usage of the albacore stock, some relatively simple biological measures are clearly useful in an assessment of the fisheries' vitality.

Here we consider a widely used yardstick, the yield per recruit. This measures our efficiency in harvesting the biomass generated by a cohort through its life, in competition with other sources of mortality. In a multi-gear fishery the list of competitors for each gear includes, of course, the other gears as well as agents of natural mortality. The differential response of the yield per recruit in the American, pole-and-line and longline fisheries to

Fig. 30 changes in the level of fishing mortality is demonstrated in Figure 30. Here the base F vector, corresponding to a multiplier of 1.0, was computed assuming M = variable and $F_o = 0.20$.

Disregarding momentarily the division of yield among competing sectors of the albacore fishery, we consider the aggregate yield per recruit. With given growth and natural mortality schedules for a fish stock, maximization of the yield per recruit involves the adjustment of factors affecting both the level and timing or age-distribution of fishing mortality. In the classical analytical yield models with constant parameters and knife-edge recruitment, these adjustable parameters are the constant F and the age at recruitment or first capture. In the more elaborate, computer-implemented models now in general use, the fishing mortality coefficient is considered age-dependent and the age at first capture is in many cases not as relevant a control parameter as in the constant F situation. Perhaps a better set of interpretive parameters would be the expected age at capture and the average F over the life of the cohort.

We studied the response of the total yield per recruit to changes in the average level and age-distribution of the fishing mortality. The computer program MGEAR, written by W. H. Lenarz (NMFS, La Jolla) was employed. The program permits the use of age-specific natural mortality rates and age-specific F for as many as four competing fishing gears. We used as baseline fishing mortality vectors the

Table 13 average vectors computed over the second period, 1959-65 (Table 13). The aggregate fishing mortality vectors for the period are displayed in Figures 9 and 10.

Figs. 27, 28, 29 In Figures 27, 28, and 29 we have plotted total yield per recruit (Y/R, in kg) against a multiplier of the fishing mortality vectors, applied to each gear, for different minimum ages at first capture. The results are given for different levels of F_o and for both constant M and age-dependent natural mortality. Clearly we would prefer to use a more contemporary base fishing mortality vector for the analysis, but the average vector for the 1966-72 period is constructed from biased estimates.

With the minimum age of capture (denoted tmin) assumed to be 2.5 years the assessment of the fisheries' welfare vis-a-vis yield per recruit clearly depends on the assumed values of M and F_o. If M = 0.20 for all exploitable ages and if F_o (or F_{32}) was constant at 0.01 during the period then an average yield per recruit of 4.4 kg could be obtained, and a doubling of fishing mortality in all fisheries would increase the aggregate yield per recruit to 6.0 kg. The yield per recruit to all three fisheries would increase as well. If the doubling of fishing mortality were accompanied by an increase in tmin to 3.5 years, this would bring a marginal increase in yield per recruit, to 6.1 kg.

If M = 0.20 and F_o = 0.10, Figure 29 indicates that the fishery was taking, on the average, just slightly less than the maximum yield per recruit for tmin = 2.5 years. An increase in yield per recruit could be achieved only by increasing tmin.

If M = 0.20 and F_o = 0.20, an unlikely condition, our analysis shows that the fishery was harvesting virtually the maximum yield per recruit for the prevailing tmin.

Under the hypothesized age-specific schedule for natural mortality and F_o = 0.10, the status of the fishery, in terms of overall yield per recruit, was about the same as with M = 0.20 and F_o = 0.01.

The situation in the mid-1960's, which we portrayed above by an F multiplier of 1.0, undoubtedly no longer prevails. Nominal effort in the longline fishery has decreased (Figure 33 and Table 19) and it has increased in both surface fisheries. We looked at the response of yield per recruit to the following two sets of hypotheses, taking the mid-1960's yield per recruit as a point of reference:

1) Fishing mortality has increased by 50% in the two surface fisheries and decreased by 50% in the longline fishery.
2) Fishing mortality has trebled in the surface fisheries and remained unchanged in the longline fishery.

We computed the percentage changes in the yield per recruit for each fishery individually and for all fisheries combined, under two sets of conditions: M = 0.20, F_o = 0.01, and M = variable, F_o = 0.10.

Under the first hypothesis, the average yield per recruit increased in the American fishery by 37% with ($M = 0.20$, $F_o = 0.01$) and by 36% assuming (M = variable, $F_o = 0.10$). Yield per recruit increased in the pole-and-line fishery by 30% and by 28%. Under both sets of conditions on M and F_o, yield per recruit to the longline fishery decreased by 58%, and the aggregate yield per recruit increased only marginally, by 5% and 4%.

Under the second hypothesis, the American fishery shows increases in yield per recruit of 110% and 103%, and the pole-and-line yield per recruit is greater by 54% and by 43%. The yield per recruit to longliners is reduced by 60% and 64%. Overall, the yield per recruit increases by 36% and 30%.

If our choices of M and F_o are correct, this analysis indicates that the North Pacific albacore stock was underfished, in a yield per recruit sense, in the mid-1960's. Further, since the second hypothesis assumes increases in average fishing mortality which are probably unrealistically high, and even greater increases in $\bar{F}$ would bring slightly larger yield per recruit, the analysis suggests that the stock is probably not overexploited now, according to the yield per recruit criterion. The response of recruitment to such increases in fishing mortality as assumed above is unknown, but average spawning biomass would certainly decline substantially.

The competitive relationship between surface and longline tuna fisheries is well-documented (e.g., Hayasi and Kikawa 1970; Lenarz and Zweifel 1974). In Table 14 we illustrate for the North Pacific albacore stock the response of yield per recruit to hypotheses concerning elimination of various combinations of the fisheries. Under each assumed set of M and F_o, the table gives the yield per recruit, to each sector individually and in the aggregate, at multipliers of 1.0 and 2.0. The basic second period fishing mortality vectors are assumed. The main entries in the table are the yield per recruit in each fishery under the particular elimination hypothesis (indicated by zeroes in appropriate columns) relative to the base yield per recruit.

Table 14

Table 14 shows that in every case the elimination of one or more fisheries increases the yield per recruit to each remaining fishery. As we would expect, the greatest increases occur in the longline fishery and the lowest in the American surface fishery. However, the elimination of any fishery reduces the overall yield per recruit in virtually all cases examined. The only exceptions are seen under relatively high levels of assumed fishing mortality, and in these cases the increase in total yield per recruit is usually achieved, as expected, by elimination of the American fishery.

CHOICE OF F_o AND AVERAGE EXPLOITATION RATES

In the results above we have seen that a variety of conclusions can be drawn concerning the status of the albacore stock and its fisheries depending on the assumed conditions for M and F_o. Concerning the natural mortality rate, we assume that the age-variable M hypothesis is most reasonable, though it may be impossible to verify that the natural mortality schedule is as we have supposed.

Regarding the fishing mortality rate, we have two kinds of information to assist in determining which set of conclusions is appropriate. The first is the regression estimates of total mortality rate and fishing mortality rates discussed earlier. These were based on longline hooking rate data for 4-year, 5-year, and 6-year old albacore. We estimated F_4 and F_5 to be in the neighborhood

Table 15 of 0.4-0.5 during the 1952-71 period. In Table 15 we have listed cohort analysis estimates of F_4 and F_5 for a 6-year period in the late 1950's corresponding to two different sets of assumptions on M and F_o. These are estimates of the fishing mortality rate generated by all gears in all quarters, so in theory are comparable to the regression estimates.

For $M = 0.2$ and $F_o = 0.10$ the average estimates of F_4 and F_5 from the cohort analysis, over the 1955-60 period are 0.62 and 0.80, respectively. These seem too high to us. More reasonable average estimates of $F_4 = 0.34$ and $F_5 = 0.39$ are obtained under the conditions

$M = 0.2$ and $F_o = 0.01$. The estimates of F_4 and F_5 for M = variable and $F_o = 0.10$ would be only slightly higher than these and equally reasonable.

The second source of information on the level of fishing mortality is the tag recovery data produced in the cooperative albacore studies of NMFS and the American Fishermen's Research Foundation (Laurs and Associates 1974). Extensive tagging of albacore is also done by the Japanese Government. The Japanese data are not available to us, but we have a summary of recovery information from the NMFS-AFRF program, courtesy of R. M. Laurs. In the 1971-74 seasons 7,264 albacore were tagged in the American fishery. Through 20 October 1975 there had been 404 reported recoveries. Fifty-eight tags were recovered from catches of the Japanese pole-and-line fleet, 5 were taken by Japanese longliners and 1 tagged albacore was reported by a Korean longliner. The remaining 340 recoveries have been made by the jig and bait vessels of the American commercial fleet, by American sport fishing boats, and odd seiners.

The overall recovery percentages to date (including the relatively small number of sport recoveries) have been 3.7% for 1971 releases, 8.3% for 1972 tags, 5.5% for 1972 fish and 4.0% for tagged albacore released in 1974. While a complete analysis of the tag recovery data remains to be done, the observed recovery rates suggest that the albacore stock is not being very heavily exploited.

Of course, the observed recovery rates give lower bounds to actual exploitation rates, and if we correct for non-reporting, tagging-induced mortality, and tag shedding a higher apparent rate of exploitation will be indicated. We estimated exploitation rates in the albacore stock under various sets of M and F_o and assuming the second period fishing mortality vector applied. We computed P_{ij} (i = 1, 2,..., 32 and j = i, i + 1,..., 32), defined as the probability that an albacore alive at the beginning of the i-th quarter of its exploitable life is caught by the end of the j-th quarter of the exploitable period. In addition, under various assumptions concerning rates of non-reporting and tag loss we computed the corresponding P'_{ij}, the probability that a tag released at the beginning of the i-th quarter is recovered (and reported) by the end of the j-th quarter.

Table 16 An abbreviated list of P_{ij} and P'_{ij} is given as Table 16. In computing the P'_{ij} for Table 16 we assumed a combined Type-I loss rate of 28% and a Type-II loss of 25% annually. For Type-I losses, no quantitative estimates are available for non-reporting of albacore recaptures or of immediate tagging mortality. On the basis of

Footnote 2 double-tagging experiments Laurs, Lenarz and Nishimoto (MS)[2] estimated the retention rate following Type-I shedding to be about 90%, and the Type-II shedding rate to be about 10% per year. No estimates of long-term tagging mortality have been made for albacore. We assume this source of tag loss is included in the 25% annual rate.

Table 16 gives the expected cumulative exploitation rates and recovery rates for albacore tagged as either 3-year olds or 4-year olds in the 3d quarter of the year. Although we have not estimated actual recovery rates on the same basis, we feel it is reasonable to conclude that ($M = 0.20$, $F_o = 0.10$) gives expected recovery rates which are too high. The other two sets of conditions ($M = 0.20$, $F_o = 0.01$) and (M = variable, $F_o = 0.10$) give results which are probably closer to the true picture, allowing for even higher loss rates than we assumed. If we consider further that the average fishing mortality rate has increased significantly since the mid-1960's, the expected recovery rates would be even greater than those indicated in Table 16. Thus we feel safe in adopting the F vector estimated under ($M = 0.20$, $F_o = 0.01$) or (M = variable, $F_o = 0.10$).

ESTIMATES OF CATCHABILITY COEFFICIENTS IN THE LONGLINE FISHERY

When the only fishery statistics available are estimates of catch and nominal effort, production models, or simple empirical examinations of catch and catch per unit of effort statistics, provide useful first-cut assessment of a fish stock and guidelines for management. As these analyses are normally applied they assume a constant catchability coefficient, q, so that mean catch per unit effort, appropriately standardized, provides an index of stock size.

The validity of this assumption is often open to question. The proportionality of the mean catch per unit effort statistic to average stock size may vary with stock size itself, or with the level of fishing activity, the geographical distribution of the fleet relative to the stock, the average age of fish in the exploitable stock, with developments in fishing technology and tactics and numerous other factors.

There have been attempts recently (Fox 1974) to accommodate stock-dependent changes in q. These embellishments of the standard production model allow a greater variety of hypotheses to be tested--or a broader class of explanations to be fitted to the data--but at some sacrifice in degrees of freedom. One or two additional parameters must be estimated from the very same set of data. Unless some independent information is brought to bear on the estimation problem there must be some loss in confidence accompanying results of the more elaborate production model analyses.

Where, in addition to catch data, enough detailed information on age-composition is available to permit a cohort analysis, estimates of fishing mortality rates may be made independently of effort data. Together with nominal effort statistics, the fishing mortality estimates allow estimates of q to be made on at least an age-specific basis. Under stronger assumptions on the temporal pattern of F_o, the cohort analysis provides a basis for estimating time-specific changes in q as well. Assumptions underlying analyses which depend on constant q may therefore be tested.

We estimated q on an annual basis for the North Pacific albacore longline fishery. Our estimates were constructed as

$$q_i = 100 \times C_i \ / \ \bar{N}_i \ H_i$$

where C_i = total longline catch in year i (number of albacore)

$\bar{N}_i$ = estimated average stock size during year i (from cohort analysis)

and H_i = number of hooks fished during year i in the principal longline grounds (130°-180°E, 20°-40°N)

Our estimates of overall longline q (based on the condition

Fig. 31 $M = 0.2$, $F_o = 0.01$) are plotted against years in Figure 31. If our assumption of constant F_o is valid, the analysis indicates a steady decrease in q over the years (at least from 1952 through 1962, estimates of F for more recent years are based on shorter catch histories).

Analyses of average hooking rates in the longline fishery, assuming constant q, have indicated an apparent decline in the stock

Fig. 32 levels (Rothschild and Yong 1970). In Figure 32 we show our estimates

Fig. 33 of mean catch per 100 hooks over 1952-72. In Figure 33 we show estimated hooks fished each year during the first quarter, the peak of the albacore longline season. There has indeed been a reduction in both hooking rate and nominal effort over the years. But if the assumptions of the cohort analysis are correct the decline in catch rates does not reflect a decline in stock size, but rather a decrease in catchability.

Fig. 34 Figure 34 shows the estimated annual average stock levels under the assumption M = 0.2, F_o = 0.01. Estimates for 1952 through 1965 are based on complete catch histories, but more recent figures are overestimated. If the assumptions, including constant F_o, are valid the cohort analysis indicates virtually no change in average abundance from 1952 through 1962, and then a steep increase at least through 1965 (approximately a doubling in the average number of albacore). Even with another set of conditions (M = variable, F_o = 0.10, constant over years) the average abundance does not show a decline.

The catchability coefficients estimated here are products of two independent factors:

1. The average availability of albacore to the longline fleet (or of the fleet to the albacore), and
2. the fishing effectiveness of 100 longline hooks.

In seeking an explanation for the decline in q we assumed there had been no significant change in fishing efficiency. However, we considered that the distribution of hooking effort relative to albacore distribution had perhaps changed over the years in a steady manner. We thus computed a concentration coefficient for each year, on a quarterly basis. We used as this concentration index the ratio-of-averages catch per unit effort statistic divided by the average-of-ratios catch per unit effort.

Table 17 The coefficient varied widely from year to year (Table 17). There was a slight downward trend in quarters 2, 3, and 4, and a slight increase over the years in the first quarter, owing to very high estimates in the mid-1960's. The analysis of concentration coefficients does not seem to provide an explanation for the apparent reduction in q.

Still, part of the decline in overall average catch per unit effort must be related to an increasing concentration of nominal effort in the second half of the year, which is characterized by lower average

Fig. 35 catch rates than the first half. Figure 35 shows that the proportion of total hooks fished in the second half has increased steadily from 25% to 50% over the years.

CATCHABILITY COEFFICIENTS IN THE AMERICAN FISHERY

We estimated annual catchability coefficients for the American fishery in a manner similar to the one employed for the longline fishery. Very approximate estimates of coastwide nominal effort (boat-days of fishing) were taken from an unpublished report by Living

Footnote 3 Marine Resources, San Diego California (1974)[3].

Fig. 36 Figure 36 indicates that for the American fishery q increased over the 1952-62 period. Pointing out again that estimates of average stock size for more recent years are based on shorter catch histories, we note a cluster of low q estimates since 1964.

In the American fishery year-to-year changes in availability, related to oceanic temperature regimes, are widely assumed. The other principal component of q, fishing effectiveness of a boat-day of nominal effort, is thought to have increased over the years along with improved navigational aids, better inter-vessel communication, and other factors.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Our analysis has suggested that during the 1959-65 period the North Pacific albacore stock was underharvested in a yield per recruit sense, and that with a doubling of the fishing mortality rate in all fisheries (over the 1959-65 level) an increase in aggregate yield per recruit of about 35% would be achieved. Further, the yield per recruit to each fishery would increase as well. The analysis showed that with a threefold increase in the average fishing mortality rate of the two surface fisheries and no change in the longline mortality rate an increase in total yield per recruit of the same magnitude would occur. However, the distribution of yield per recruit among the fisheries would change, the surface fisheries showing increases and yield per recruit to longliners decreasing by roughly 60%. The average stock biomass would be reduced by about 60% also.

These conclusions, which we consider quite tentative, are based on a number of critical assumptions. Among these are:

1. The catch histories, derived from the catch and length composition statistics and a particular age-length relation are reasonably accurate.
2. The natural mortality rates used in the cohort analysis are approximately correct.
3. The fishing mortality rate on 10-year old albacore during the 4th quarter (F_{32}) of each year, 1959-72, was about 0.1 under the condition M = 0.2, or 0.10 under the M = variable hypothesis.

Assumptions 1 and 3 would appear to be the most important. A different procedure for estimating the overall length composition of the catches and a different growth model might produce markedly different results, and a critical examination of both aspects should be undertaken.

The choice of the level of F_{32} was based on

1. a comparison of rather crude estimates of average fishing mortality coefficients determined from longline catch rates and the corresponding coefficients expected under different F_{32}'s, and
2. a consideration of observed tag recovery rates in recent years and expected rates of recovery generated under various F_{32} assumptions.

Of these two approaches for measuring the average exploitation rates the second presumably holds the most promise. The tagging results are from the recent period of increased catches in the Japanese pole-and-line fishery, yet recovery rates have been even lower than those expected under the assumed base period conditions. Either our assessment is conservative or we have grossly underestimated the factors which reduce reported rates of recapture--tag loss, tagging mortality, non-reporting, and possible behavioral changes in tagged fish leading to reduced vulnerability to capture (perhaps gear-specific). We strongly recommend a more complete analysis of recent tagging experiments with a view toward estimating exploitation rates.

Another key assumption on F_{32}, a mortality rate inflicted by longliners, was that it remained constant over 1959-72. If it decreased over the period, our estimates of the base period fishing mortality rates would be lower. The long-term trend in longline nominal effort over the period was downward, and we have no evidence of an increase in F_{32}.

Along with estimates of fishing mortality rates, and dependent upon them, the cohort analysis produced a description of secular trends in other population features:

1. Under the assumptions listed above, the average spawning biomass was found to have been fairly constant from 1952 through 1965, and to have increased markedly from 1966 at least through 1968. The increase was consistent with a substantial (and independently observed) rise in catch rates of sexually mature albacore in the Hawaiian longline fishery during this period, and a similar increase in hooking rates of spawning-age albacore in the Japanese longline fishery.
2. If the assumptions of the cohort analysis are valid, the increased spawning biomass beginning in 1966 resulted from a rise in recruitment beginning in 1963 and extending for at least the next few years. Since spawning biomass was estimated to have been fairly constant until 1966, conditions for survival of young albacore were apparently exceptionally favorable during the early 1960's.

The value of the yield per recruit criterion as a sole measure of harvest efficiency (and as a goal quantity for management) depends, of course, on the independence of recruitment and stock biomass. The relationship between recruitment and spawning biomass derived from the cohort analysis showed the wide scatter of points typical of tuna stocks. Thus there is a reasonable basis for adopting a yield per recruit criterion.

However, any substantial increase in fishing mortality rate, particularly among the immature age groups (as has recently happened), might reduce spawning biomass to critically low levels, levels at which reduced recruitment could be a distinct possibility. We thus recommend that further studies be undertaken with the objective of coupling the yield per recruit model to various spawner-recruit relations and determining the impact of changes in fishing mortality on total yield. In addition, we suggest the development of stock-fecundity indices for North Pacific albacore.

A particularly intriguing product of the cohort analysis is the conclusion that the catchability coefficient in the longline fishery decreased from 1952 at least through 1962, and probably into more recent years. A steady catchability coefficient over the years would have been estimated only with a substantial increase in the value of F_{32} during the period, which we have ruled out. A partial explanation for the apparent decline in longline catchability is the redistribution of effort; a progressively higher proportion of effort has been expended in the second half of the year, when longline catch rates for albacore are relatively low.

If the longline catchability coefficient has in fact been declining, then, of course, analyses which assume its constancy will be misleading. We refer particularly to production model analyses utilizing data on catch and nominal effort.

In this regard, we recommend a careful development of various kinds of nominal effort measures in the two surface fisheries and the estimation of temporal patterns in catchability coefficients for each. Estimates of this sort will be essential for assessing the impact of changes in fishing effort on the stock and on catch levels.

The analyses presented in this paper, treating catch data from 1952-72, did not directly address the matter of recent increases in landings. Instead, in the cohort analysis we generated estimates of average fishing mortality rates during the mid-1960's, when a relatively stable situation prevailed. Then in the yield per recruit analysis we estimated the effects of increases in fishing mortality rates, above the base period levels, on the aggregate yield per recruit. Though we have no direct measure of the recent rise in fishing mortality rate, our analyses indicate that the new catch level of about 100,000 MT annually is less, but not much less, than the maximum sustainable average yield. Here we assume there has been no reduction in expected recruitment, and no significant change in expected age at capture.

If recruitment holds up, the analysis suggests that a further increase in fishing mortality could produce a somewhat greater harvest providing it was applied to increasingly older age groups. Without an increase in recruitment, the present trend of increasing fishing mortality on the younger age groups, if sustained, could well result in a reduction of total yield below the 100,000 MT level.

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TEXT FOOTNOTES

[2]LAURS, R. M., W. H. LENARZ, and R. N. NISHIMOTO. Manuscript in preparation. 1975. Estimates of rates of tag shedding by North Pacific albacore, Thunnus alalunga (Bonnaterre), 12 p. Southwest Fisheries Center, National Marine Fisheries Service, NOAA, La Jolla, CA 92038.

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Table 1.--Kinds of North Pacific albacore data used in the cohort analysis, their completeness, and source.

Fishery	Type of data	Temporal and spatial completeness	Source
Japanese pole-and-line	Total landings	By year, 1952-72 All areas combined	Far Seas Fisheries Research Laboratory, Shimizu, Japan (FSFRL) (Courtesy of S. Morita and T. Shiohama)
	Yaizu sample catch and nominal effort	By year, 1955-72 By month, Mar.-Sept. By 5° lat., 10° long. areas (25°-35°N, 130°-180°E; and 35°-45°N, 140°-180°E)	FSFRL
	Sample length composition	By year, 1952-64 By month, May-July By 10° long. bands (North of 25°N, 130°-160°E)	1952-59 in Suda (1963) 1960-64 in Koto and Hisada (1966)
		By year, 1965-71 By month, Jan.-Dec. By 5° lat., 10° long. areas (North of 25°N, east of 120°E)	Shiohama (1973)
		1972 By month, Mar.-Oct. By 5° lat., 10° long. areas (North of 25°N, east of 130°E)	FSFRL
Japanese longline	Total catch and nominal effort	By year, 1952-72 By month, Jan.-Dec. By 5° lat., 5° long. areas (North of 20°N, east of 120°E)	FSFRL magnetic tape Also, 1962-72 published by year in "Annual Report of Effort and Catch Statistics by Area on Japanese Tuna Longline Fishery" Fisheries Agency of Japan
	Sample length composition	By year, 1952-64 By month, Dec.-Feb. By 10° long. bands (North of 25°N, 130°-180°E)	1952-59 in Suda (1963) 1960-64 in Koto and Hisada (1966)
		By year, 1965-72 By month, Jan.-Dec. By 5° lat., 10° long. areas (North of 25°N, east of 120°E)	1965-71 in Shiohama (1973) 1972 from FSFRL
American	Total landings	By year 1952-72 By month, by state (California, Oregon and Washington)	California Department of Fish and Game, Long Beach, California (CFG) (Courtesy of H. B. Clemens and C. H. Hooker)
	Length composition	By year, 1952-72 for California and Oregon (except 1964 for Oregon); By year, 1952-68 for Washington (several years of Washington size compositions estimated from Oregon data)	CFG Also, California data for 1952-61 published in Clemens and Craig (1965); Oregon data for 1952-60 published in Ayers and Meehan (1963); Oregon data for 1961-67 published in Meehan and Hreha (1969); Oregon data for 1968-72 published in Hreha (1974).

Table 2A.--Sample mean fork lengths (cm) for North Pacific albacore taken in Japanese pole-and-line fishery by latitude, 1951-73.

Year	Latitudinal band				All latitudes
	25°-30°N	30°-35°N	35°-40°N	40°-45°N	
1951	--	--	--	--	82.3
1952	--	--	--	--	74.7
1953	--	--	--	--	79.6
1954	--	--	--	--	82.5
1955	--	--	--	--	79.4
1956	--	--	--	--	74.4
1957	--	--	--	--	78.0
1958	--	--	--	--	79.0
1959	--	--	--	--	83.7
1960	--	--	--	--	78.6
1961	--	--	--	--	78.2
1962	--	--	--	--	88.6
1963	--	--	--	--	78.5
1964	--	--	--	--	79.3
1965	86.6	78.5	--	--	82.6
1966	89.5	78.7	77.4	--	81.2
1967	90.8	82.0	67.2	--	83.0
1968	94.0	82.1	71.4	--	84.7
1969	86.0	81.0	57.1	51.3	73.7
1970	89.6	84.3	71.7	56.3	82.0
1971	87.0	83.6	67.7	--	81.6
1972	86.8	79.5	61.4	53.5	75.5
1973	90.6	86.4	67.0	49.7	80.4

Table 2B.--Sample mean fork lengths (cm) for North Pacific albacore taken in Japanese pole-and-line fishery by longitude, 1951-73.

Year	Longitudinal band						All longitudes
	120°-130°E	130°-140°E	140°E-150°E	150°-160°E	160°-170°E	170°-180°E	
1951	--	--	--	--	--	--	82.3
1952	--	--	--	--	--	--	74.7
1953	--	--	--	--	--	--	79.6
1954	--	--	--	--	--	--	82.5
1955	--	--	--	--	--	--	79.4
1956	--	--	--	--	--	--	74.4
1957	--	--	--	--	--	--	78.0
1958	--	--	--	--	--	--	79.0
1959	--	--	--	--	--	--	83.7
1960	--	80.2	78.8	76.6	--	--	78.6
1961	--	87.0	78.4	73.7	--	--	78.2
1962	--	89.9	86.6	90.3	--	--	88.6
1963	--	78.4	78.6	--	--	--	78.5
1964	--	87.4	79.5	70.8	--	--	79.3
1965	84.0	83.6	81.1	--	--	--	82.6
1966	--	85.1	80.6	82.0	70.0	--	81.2
1967	--	88.2	79.4	86.8	--	83.6	83.0
1968	--	83.3	86.0	89.2	86.2	80.1	84.7
1969	85.0	82.9	74.2	68.6	50.9	--	73.7
1970	--	86.6	84.4	76.6	56.3	--	82.0
1971	--	85.0	82.3	75.2	83.2	--	81.6
1972	--	85.3	73.8	68.8	--	--	75.5
1973	--	88.4	85.5	70.2	79.6	64.4	80.4

Table 3A.--Sample mean fork lengths (cm) for North Pacific albacore taken in Japanese longline fishery by latitude, 1948-73.

Year	Latitudinal band			All latitudes
	25°-30°N	30°-35°N	35°-40°N	
1948	--	--	--	87.3
1949	--	--	--	85.6
1950	--	--	--	85.7
1951	--	--	--	87.6
1952	--	--	--	83.9
1953	--	--	--	88.8
1954	--	--	--	84.9
1955	--	--	--	86.0
1956	--	--	--	85.5
1957	--	--	--	90.0
1958	--	--	--	88.3
1959	--	--	--	92.3
1960	--	--	--	88.7
1961	--	--	--	92.9
1962	--	--	--	89.6
1963	--	--	--	87.9
1964	--	--	--	87.5
1965	88.1	84.0	85.4	86.1
1966	88.6	82.4	91.5	86.5
1967	92.9	91.7	93.4	92.5
1968	88.8	89.0	101.6	90.2
1969	93.1	93.0	102.6	94.3
1970	86.8	92.7	102.2	90.5
1971	98.7	95.6	102.6	98.1
1972	94.4	93.1	102.3	95.8
1973	97.8	95.5	--	97.2

Table 3B.--Sample mean fork lengths (cm) for North Pacific albacore taken in Japanese longline fishery by longitude, 1948-73.

Year	Longitudinal band						All longitudes
	120°-130°E	130°-140°E	140°-150°E	150°-160°E	160°-170°E	170°-180°E	
1948	--	--	83.0	--	87.6	91.3	87.3
1949	--	85.8	76.1	86.9	86.4	93.0	85.6
1950	--	82.5	80.8	89.8	83.2	89.5	85.7
1951	--	83.6	81.7	90.3	89.8	90.6	87.6
1952	--	80.5	77.1	85.9	86.5	89.7	83.9
1953	--	93.9	85.4	88.4	85.3	91.0	88.9
1954	--	92.6	83.0	80.1	80.2	88.3	84.9
1955	--	93.6	88.5	82.5	79.1	85.2	86.0
1956	--	89.2	86.1	84.9	82.0	85.2	85.5
1957	--	90.6	87.0	94.9	88.5	89.0	90.0
1958	--	91.0	87.5	87.9	91.4	83.5	88.3
1959	--	93.4	90.7	94.2	91.8	91.1	92.3
1960	--	92.2	86.1	90.9	87.3	88.1	88.7
1961	--	93.8	93.0	89.3	93.6	96.2	92.9
1962	--	90.3	81.9	91.7	94.3	94.5	89.6
1963	--	92.8	82.6	88.2	89.9	84.2	87.9
1964	--	87.9	80.4	90.0	77.6	106.3	87.5
1965	90.7	87.4	79.9	89.1	82.8	106.7	86.1
1966	--	88.5	80.7	87.3	86.5	87.5	86.5
1967	101.7	94.8	91.1	93.5	86.5	91.9	92.5
1968	--	81.3	85.8	96.3	94.5	91.7	90.2
1969	--	87.9	90.3	96.0	94.3	98.3	94.3
1970	95.0	76.6	89.9	94.2	94.5	90.7	90.4
1971	--	100.7	102.8	96.8	97.8	86.3	98.1
1972	--	85.3	93.7	103.5	93.7	94.0	95.8
1973	100.3	95.7	103.7	95.3	88.3	107.0	97.2

Table 4.--Estimates of mean fork length (cm) of North Pacific albacore taken in American and Japanese fisheries, 1952-73.

Year	Japanese pole-and-line	Japanese longline	American
1952	74.7	81.6	68.5
1953	79.6	87.5	66.7
1954	82.5	84.5	65.6
1955	79.4	87.9	63.5
1956	74.4	85.4	68.0
1957	78.0	84.7	71.9
1958	79.0	87.0	70.0
1959	83.7	91.2	66.3
1960	79.0	89.5	70.2
1961	82.6	90.1	73.7
1962	89.3	88.0	65.2
1963	78.6	87.4	67.5
1964	76.2	86.8	70.2
1965	83.5	84.9	71.1
1966	82.6	86.1	69.9
1967	84.2	89.0	68.0
1968	82.6	87.0	68.0
1969	81.7	92.0	69.3
1970	74.4	87.9	69.0
1971	76.7	96.3	65.9
1972	83.2	92.7	71.5
1973	77.8	--	--

Table 5.--Estimated percentage age structure of North Pacific albacore catches, by number and weight for selected years.

Age group	American		Japanese pole-and-line		Japanese longline		Total	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
1952								
LT 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	6.2	2.8	1.8	0.6	1.9	0.5	3.4	1.3
3	62.3	52.6	32.5	20.8	19.3	9.7	40.9	28.6
4	25.7	33.6	44.1	45.7	41.0	33.3	36.9	39.2
5	5.0	9.1	19.5	28.8	21.8	26.7	14.7	22.0
6	0.8	1.8	2.1	4.1	9.3	15.2	2.9	5.7
7	0.0	0.1	0.0	0.1	4.3	8.6	0.8	1.9
8	0.0	0.0	0.0	0.0	1.3	3.1	0.2	0.7
9	0.0	0.0	0.0	0.0	0.7	1.8	0.1	0.4
10	0.0	0.0	0.0	0.0	0.3	0.9	0.1	0.2
GT 10	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
1957								
LT 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	3.4	1.4	2.1	0.6	1.0	0.2	2.3	0.7
3	53.4	40.9	19.8	11.3	16.8	7.1	29.6	18.4
4	31.4	37.4	42.1	38.8	29.9	21.2	37.0	35.2
5	10.2	16.8	30.9	40.6	24.0	25.1	23.6	31.4
6	1.6	3.3	5.0	8.7	15.8	22.3	5.6	9.7
7	0.1	0.2	0.0	0.0	8.2	14.5	1.3	2.7
8	0.0	0.0	0.0	0.0	2.7	5.7	0.4	1.0
9	0.0	0.0	0.0	0.0	1.1	2.5	0.2	0.5
10	0.0	0.0	0.0	0.0	0.5	1.2	0.1	0.2
GT 10	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
1962								
LT 2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
2	10.6	5.4	0.6	0.1	0.8	0.1	7.8	3.0
3	74.9	71.4	0.0	0.0	24.4	9.1	57.7	41.4
4	11.8	17.4	5.5	3.4	13.6	8.5	11.4	12.5
5	2.6	5.3	38.1	33.0	14.2	13.4	8.5	12.5
6	0.2	0.5	53.2	60.2	18.0	21.7	9.1	17.2
7	0.0	0.0	2.4	3.3	18.9	28.3	3.6	8.3
8	0.0	0.0	0.0	0.0	6.5	11.5	1.2	3.1
9	0.0	0.0	0.0	0.0	2.8	5.7	0.5	1.5
10	0.0	0.0	0.0	0.0	0.7	1.5	0.1	0.4
GT 10	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0

Table 5.--Continued.

Age group	American		Japanese pole-and-line		Japanese longline		Total	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
1967								
LT 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	6.7	3.1	1.3	0.3	0.8	0.1	3.6	1.1
3	64.8	55.7	6.6	2.9	4.9	1.8	32.8	19.7
4	22.9	30.7	9.7	6.9	27.3	16.4	19.8	17.6
5	5.1	9.5	65.7	67.0	25.7	23.5	28.7	35.0
6	0.4	1.0	15.0	19.9	21.7	25.9	9.9	15.7
7	0.0	0.0	1.7	2.8	11.7	17.4	3.3	6.4
8	0.0	0.0	0.0	0.0	4.9	8.5	1.1	2.6
9	0.0	0.0	0.0	0.0	2.0	3.9	0.5	1.2
10	0.0	0.0	0.0	0.0	0.9	2.1	0.2	0.6
GT 10	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.1
1972								
LT 2	0.0	0.0	0.7	0.1	0.0	0.0	0.4	0.0
2	1.4	0.6	15.4	5.0	0.0	0.0	10.0	3.2
3	50.0	38.4	14.9	9.4	3.3	1.2	25.9	17.4
4	42.2	50.4	38.0	38.7	29.4	16.0	39.0	40.1
5	6.3	10.5	27.3	39.5	13.6	10.9	19.6	28.0
6	0.0	0.1	3.0	5.6	15.7	16.6	2.7	5.0
7	0.0	0.0	0.7	1.7	20.5	26.3	1.5	3.5
8	0.0	0.0	0.0	0.0	9.7	14.8	0.5	1.4
9	0.0	0.0	0.0	0.0	4.2	7.3	0.2	0.7
10	0.0	0.0	0.0	0.0	3.3	6.4	0.2	0.6
GT 10	0.0	0.0	0.0	0.0	0.3	0.6	0.0	0.1

Table 6.--Catch histories for the 1949-62 year classes of North Pacific albacore, beginning with catches in the first quarter of the second year following the birth year and extending through 9 full fishing years. The estimated catches are given in number of fish.

CATCH HISTORY FOR NORTH PACIFIC ALBACORE YEAR CLASS 1962 ACCORDING TO AGE MODEL 3

FISHING YEAR	QUARTER	CALIF	OREGON	WASH	POLELINE	LONGLINE	TOTAL
1964	1	0	0	0	0	0	0
1964	2	0	0	0	3828	0	3828
1964	3	45965	5901	0	314185	0	366051
1964	4	11920	2303	0	0	0	14223
1964	TOTAL	57885	8204	0	318013	0	384102
1965	1	0	0	0	4324	39850	44174
1965	2	0	0	0	86844	142	86986
1965	3	374396	622808	63681	7	219	1061111
1965	4	127538	76916	0	0	9868	214322
1965	TOTAL	501934	699724	63681	91175	50079	1406593
1966	1	0	0	0	26437	444895	471332
1966	2	0	0	0	284273	49274	333547
1966	3	408963	248056	18919	11179	3661	690778
1966	4	79603	46212	0	0	83185	209000
1966	TOTAL	488566	294268	18919	321889	581015	1704657
1967	1	0	0	0	1298	275880	277178
1967	2	0	0	0	1497560	46559	1544119
1967	3	66339	89241	4235	24713	5754	190282
1967	4	7181	8653	0	0	120833	136667
1967	TOTAL	73520	97894	4235	1523571	449026	2148246
1968	1	0	0	0	3820	197441	201261
1968	2	0	0	0	237570	5483	243053
1968	3	738	0	0	248	3831	4817
1968	4	220	0	0	0	50513	50733
1968	TOTAL	958	0	0	241638	257268	499864
1969	1	0	0	0	118	119068	119186
1969	2	0	0	0	3325	4546	7871
1969	3	104	0	0	0	3289	3393
1969	4	36	0	0	0	67148	67184
1969	TOTAL	140	0	0	3443	194051	197634
1970	1	0	0	0	0	15520	15520
1970	2	0	0	0	142	992	1134
1970	3	0	0	0	0	1152	1152
1970	4	0	0	0	0	22114	22114
1970	TOTAL	0	0	0	142	39778	39920
1971	1	0	0	0	0	17102	17102
1971	2	0	0	0	83	446	529
1971	3	0	0	0	0	739	739
1971	4	0	0	0	0	9048	9048
1971	TOTAL	0	0	0	83	27335	27418
1972	1	0	0	0	0	8599	8599
1972	2	0	0	0	0	305	305
1972	3	0	0	0	0	221	221
1972	4	0	0	0	0	9486	9486
1972	TOTAL	0	0	0	0	18611	18611

CATCH HISTORY FOR NORTH PACIFIC ALBACORE YEAR CLASS 1961 ACCORDING TO AGE MODEL 3

FISHING		CATCH BY FISHERY					
YEAR	QUARTER	CALIF	OREGON	WASH	POLELINE	LONGLINE	TOTAL
1963	1	0	0	0	0	900	900
1963	2	121	0	0	0	183	304
1963	3	183974	15742	858	0	30	200604
1963	4	49921	2906	0	0	391	53218
1963	TOTAL	234016	18648	858	0	1504	255026
1964	1	0	0	0	0	34771	34771
1964	2	0	0	0	7890	1981	9871
1964	3	1144903	146979	55020	370455	449	1717806
1964	4	296920	57383	0	0	4035	358338
1964	TOTAL	1441823	204362	55020	378345	41236	2120786
1965	1	0	0	0	22511	214352	236863
1965	2	0	0	0	516151	11145	527296
1965	3	483182	190576	55959	203	6926	736846
1965	4	164597	23536	0	0	169728	357861
1965	TOTAL	647779	214112	55959	538865	402151	1858866
1966	1	0	0	0	5693	205404	211097
1966	2	0	0	0	1017986	36285	1054271
1966	3	88735	23780	2081	41989	8258	164843
1966	4	17272	4431	0	0	144256	165959
1966	TOTAL	106007	28211	2081	1065668	394203	1596170
1967	1	0	0	0	11161	252391	263552
1967	2	0	0	0	336055	10486	346541
1967	3	12966	0	0	0	5233	18199
1967	4	1404	0	0	0	110435	111839
1967	TOTAL	14370	0	0	347216	378545	740131
1968	1	0	0	0	5672	94856	100528
1968	2	0	0	0	68275	2541	70816
1968	3	217	0	3089	42	4537	7885
1968	4	65	0	0	0	91369	91434
1968	TOTAL	282	0	3089	73989	193303	270663
1969	1	0	0	0	0	59063	59063
1969	2	0	0	0	76	2198	2274
1969	3	0	0	0	0	2198	2198
1969	4	0	0	0	0	33753	33753
1969	TOTAL	0	0	0	76	97212	97288
1970	1	0	0	0	0	6970	6970
1970	2	0	0	0	0	668	668
1970	3	0	0	0	0	763	763
1970	4	0	0	0	0	18035	18035
1970	TOTAL	0	0	0	0	26436	26436
1971	1	0	0	0	0	4086	4086
1971	2	0	0	0	0	107	107
1971	3	0	0	0	0	220	220
1971	4	0	0	0	0	8939	8939
1971	TOTAL	0	0	0	0	13352	13352

CATCH HISTORY FOR NORTH PACIFIC ALBACORE YEAR CLASS 1949 ACCORDING TO AGE MODEL 3

FISHING		CATCH BY FISHERY					
YEAR	QUARTER	CALIF	OREGON	WASH	POLELINE	LONGLINE	TOTAL
1951	1	0	0	0	0	0	0
1951	2	0	0	0	0	0	0
1951	3	0	0	0	0	0	0
1951	4	0	0	0	0	0	0
1951	TOTAL	0	0	0	0	0	0
1952	1	0	0	0	18330	260351	278681
1952	2	59804	0	0	1427014	13227	1500045
1952	3	1568176	88468	3562	26636	598	1687440
1952	4	363968	78985	5763	0	53672	502388
1952	TOTAL	1991948	167453	9325	1471980	327848	3968554
1953	1	0	0	0	20670	268286	288956
1953	2	7776	0	0	1609136	5752	1622664
1953	3	228707	2272	89	30036	1209	262313
1953	4	0	273	726	0	48586	49585
1953	TOTAL	236483	2545	815	1659842	323833	2223518
1954	1	0	0	0	12264	281904	294168
1954	2	0	0	0	954897	22827	977724
1954	3	49752	253	16	17822	1077	68920
1954	4	4698	138	628	0	83077	88541
1954	TOTAL	54450	391	644	984983	388885	1429353
1955	1	0	0	0	661	163345	164006
1955	2	0	0	0	51415	10880	62295
1955	3	19	0	0	960	1980	2959
1955	4	5	0	0	0	44865	44870
1955	TOTAL	24	0	0	53036	221070	274130
1956	1	0	0	0	169	44184	44353
1956	2	0	0	0	5038	13267	18305
1956	3	0	0	0	468	538	1006
1956	4	0	0	0	0	16275	16275
1956	TOTAL	0	0	0	5675	74264	79939
1957	1	0	0	0	0	18848	18848
1957	2	0	0	0	0	1121	1121
1957	3	0	0	0	0	576	576
1957	4	0	0	0	0	14547	14547
1957	TOTAL	0	0	0	0	35092	35092
1958	1	0	0	0	0	7552	7552
1958	2	0	0	0	0	512	512
1958	3	0	0	0	0	107	107
1958	4	0	0	0	0	4795	4795
1958	TOTAL	0	0	0	0	12966	12966
1959	1	0	0	0	0	3727	3727
1959	2	0	0	0	0	116	116
1959	3	0	0	0	0	82	82
1959	4	0	0	0	0	2529	2529
1959	TOTAL	0	0	0	0	6454	6454

CATCH HISTORY FOR NORTH PACIFIC ALBACORE YEAR CLASS 1950 ACCORDING TO AGE MODEL 3

FISHING		CATCH BY FISHERY					
YEAR	QUARTER	CALIF	OREGON	WASH	POLELINE	LONGLINE	TOTAL
1952	1	0	0	0	989	22046	23035
1952	2	5877	0	0	76796	1234	83907
1952	3	154100	10044	346	1432	53	165975
1952	4	35766	8966	558	0	9506	54796
1952	TOTAL	195743	19010	904	79217	32839	327713
1953	1	0	0	0	2687	178125	180812
1953	2	48379	0	0	209356	3969	261704
1953	3	1422713	29069	188	3908	838	1456716
1953	4	0	3529	1526	0	54423	59478
1953	TOTAL	1471092	32598	1714	215951	237355	1958710
1954	1	0	0	0	13792	232786	246578
1954	2	0	0	0	1073727	18408	1092135
1954	3	159194	621	24	20041	868	180748
1954	4	15034	338	948	0	46168	62488
1954	TOTAL	174228	959	972	1107560	298230	1581949
1955	1	0	0	0	5073	440558	445631
1955	2	206	0	0	394841	29900	424947
1955	3	20164	0	0	7370	5446	32980
1955	4	5922	0	0	0	68089	74011
1955	TOTAL	26292	0	0	407284	543993	977569
1956	1	0	0	0	5938	74753	80691
1956	2	148	0	0	176898	24381	201427
1956	3	1525	0	0	16442	992	18959
1956	4	270	0	0	0	31172	31442
1956	TOTAL	1943	0	0	199278	131298	332519
1957	1	0	0	0	6	64191	64197
1957	2	59	0	0	932	3489	4480
1957	3	1586	0	0	0	1798	3384
1957	4	227	0	0	0	36604	36831
1957	TOTAL	1872	0	0	938	106082	108892
1958	1	0	0	0	0	24363	24363
1958	2	0	0	0	0	1667	1667
1958	3	0	0	0	0	347	347
1958	4	0	0	0	0	15788	15788
1958	TOTAL	0	0	0	0	42165	42165
1959	1	0	0	0	0	16559	16559
1959	2	0	0	0	0	489	489
1959	3	0	0	0	0	344	344
1959	4	0	0	0	0	8573	8573
1959	TOTAL	0	0	0	0	25965	25965
1960	1	0	0	0	0	3743	3743
1960	2	0	0	0	0	357	357
1960	3	0	0	0	0	116	116
1960	4	0	0	0	0	1459	1459
1960	TOTAL	0	0	0	0	5675	5675

CATCH HISTORY FOR NORTH PACIFIC ALBACORE YEAR CLASS 1951 ACCORDING TO AGE MODEL 3

FISHING		CATCH BY FISHERY					
YEAR	QUARTER	CALIF	OREGON	WASH	POLELINE	LONGLINE	TOTAL
1953	1	0	0	0	53	10402	10455
1953	2	13020	0	0	4071	249	17340
1953	3	382895	29504	400	73	50	412922
1953	4	0	3583	3241	0	5077	11901
1953	TOTAL	395915	33087	3641	4197	15778	452618
1954	1	0	0	0	137	241369	241506
1954	2	0	0	0	10499	18660	29159
1954	3	1293919	14231	558	195	882	1309785
1954	4	122196	7756	22341	0	29009	181302
1954	TOTAL	1416115	21987	22899	10831	289920	1761752
1955	1	0	0	0	22041	155483	177524
1955	2	756	0	0	1716041	11202	1727999
1955	3	73823	298	7	32029	2041	108198
1955	4	21685	576	307	0	63945	86513
1955	TOTAL	96264	874	314	1770111	232671	2100234
1956	1	0	0	0	8858	222130	230988
1956	2	1278	0	0	263374	43199	308351
1956	3	13126	235	24	24526	1758	39669
1956	4	2323	45	0	0	39190	41558
1956	TOTAL	16727	280	24	297258	306277	620566
1957	1	0	0	0	1548	145026	146574
1957	2	1292	0	0	234926	7170	243388
1957	3	34604	0	0	33	3694	38331
1957	4	4962	0	0	0	48975	53937
1957	TOTAL	40858	0	0	236507	204865	482230
1958	1	0	0	0	8	71205	71213
1958	2	6	0	0	2450	4620	7076
1958	3	5124	0	0	0	966	6090
1958	4	385	0	0	0	35700	36085
1958	TOTAL	5515	0	0	2458	112491	120464
1959	1	0	0	0	0	44367	44367
1959	2	0	0	0	0	1324	1324
1959	3	0	0	0	0	934	934
1959	4	0	0	0	0	24533	24533
1959	TOTAL	0	0	0	0	71158	71158
1960	1	0	0	0	0	10423	10423
1960	2	0	0	0	0	990	990
1960	3	0	0	0	0	324	324
1960	4	0	0	0	0	8829	8829
1960	TOTAL	0	0	0	0	20566	20566
1961	1	0	0	0	0	2124	2124
1961	2	0	0	0	0	272	272
1961	3	0	0	0	0	50	50
1961	4	0	0	0	0	2290	2290
1961	TOTAL	0	0	0	0	4736	4736

CATCH HISTORY FOR NORTH PACIFIC ALBACORE YEAR CLASS 1952 ACCORDING TO AGE MODEL 3

FISHING YEAR	QUARTER	CATCH BY FISHERY: CALIF	OREGON	WASH	POLELINE	LONGLINE	TOTAL
1954	1	0	0	0	0	18902	18902
1954	2	0	0	0	0	1493	1493
1954	3	281623	13394	240	0	68	295325
1954	4	26597	7299	9639	0	3337	46872
1954	TOTAL	308220	20693	9879	0	23800	362592
1955	1	0	0	0	78	121570	121648
1955	2	16632	0	0	6075	9396	32103
1955	3	1623683	16934	472	113	1709	1642911
1955	4	476961	32778	17608	0	29053	556400
1955	TOTAL	2117276	49712	18080	6266	161728	2353062
1956	1	0	0	0	90419	286089	376508
1956	2	55508	0	0	2693387	43341	2792236
1956	3	570113	20921	3992	250334	1765	847125
1956	4	100913	4009	0	0	33208	138130
1956	TOTAL	726534	24930	3992	3034140	364403	4153999
1957	1	0	0	0	9501	254576	264077
1957	2	8409	0	0	1441252	11366	1461027
1957	3	224952	705	253	203	5856	231969
1957	4	32235	266	268	0	38539	71308
1957	TOTAL	265596	971	521	1450956	310337	2028381
1958	1	0	0	0	310	167085	167395
1958	2	49	0	0	109499	10097	119645
1958	3	37632	151	77	0	2109	39969
1958	4	2827	7	18	0	53950	56802
1958	TOTAL	40508	158	95	109809	233241	383811
1959	1	0	0	0	101	90416	90517
1959	2	6	0	0	7040	2575	9621
1959	3	514	0	0	824	1812	3150
1959	4	16	0	0	0	45548	45564
1959	TOTAL	536	0	0	7965	140351	148852
1960	1	0	0	0	0	32065	32065
1960	2	0	0	0	0	2940	2940
1960	3	0	0	0	0	962	962
1960	4	0	0	0	0	10973	10973
1960	TOTAL	0	0	0	0	46940	46940
1961	1	0	0	0	0	7002	7002
1961	2	0	0	0	0	816	816
1961	3	0	0	0	0	148	148
1961	4	0	0	0	0	6132	6132
1961	TOTAL	0	0	0	0	14098	14098
1962	1	0	0	0	0	4787	4787
1962	2	0	0	0	0	195	195
1962	3	0	0	0	0	59	59
1962	4	0	0	0	0	1010	1010
1962	TOTAL	0	0	0	0	6051	6051

CATCH HISTORY FOR NORTH PACIFIC ALBACORE YEAR CLASS 1953 ACCORDING TO AGE MODEL 3

FISHING		CATCH BY FISHERY					
YEAR	QUARTER	CALIF	OREGON	WASH	POLELINE	LONGLINE	TOTAL
1955	1	0	0	0	0	3721	3721
1955	2	1761	0	0	0	273	2034
1955	3	171949	2588	65	0	47	174649
1955	4	50509	5010	2401	0	1045	58965
1955	TOTAL	224219	7598	2466	0	5086	239369
1956	1	0	0	0	35152	84418	119570
1956	2	125710	0	0	1047098	10170	1182978
1956	3	1291172	236131	39844	97320	413	1664880
1956	4	228543	45263	0	0	6197	280003
1956	TOTAL	1645425	281394	39844	1179570	101198	3247431
1957	1	0	0	0	12947	341985	354932
1957	2	25225	0	0	1964246	11957	2001428
1957	3	674997	17142	2319	279	6161	700898
1957	4	96729	6511	2460	0	27159	132859
1957	TOTAL	796951	23653	4779	1977472	387262	3190117
1958	1	0	0	0	1651	234497	236148
1958	2	245	0	0	583240	14502	597987
1958	3	187995	21750	4365	0	3029	217139
1958	4	14119	1047	1014	0	88187	104367
1958	TOTAL	202359	22797	5379	584891	340215	1155641
1959	1	0	0	0	2094	116950	119044
1959	2	29	0	0	145336	3092	148457
1959	3	2312	753	136	17006	2181	22388
1959	4	71	35	0	0	39504	39610
1959	TOTAL	2412	788	136	164436	161727	329499
1960	1	0	0	0	2	65796	65798
1960	2	0	0	0	743	5964	6707
1960	3	0	0	0	0	1950	1950
1960	4	0	0	0	0	35765	35765
1960	TOTAL	0	0	0	745	109475	110220
1961	1	0	0	0	0	20510	20510
1961	2	0	0	0	0	2308	2308
1961	3	0	0	0	0	422	422
1961	4	0	0	0	0	16486	16486
1961	TOTAL	0	0	0	0	39726	39726
1962	1	0	0	0	0	20363	20363
1962	2	0	0	0	0	842	842
1962	3	0	0	0	0	257	257
1962	4	0	0	0	0	4120	4120
1962	TOTAL	0	0	0	0	25582	25582
1963	1	0	0	0	0	688	688
1963	2	0	0	0	0	156	156
1963	3	0	0	0	0	28	28
1963	4	0	0	0	0	2206	2206
1963	TOTAL	0	0	0	0	3078	3078

CATCH HISTORY FOR NORTH PACIFIC ALBACORE YEAR CLASS 1954 ACCORDING TO AGE MODEL 3

FISHING		CATCH BY FISHERY					
YEAR	QUARTER	CALIF	OREGON	WASH	POLELINE	LONGLINE	TOTAL
1956	1	0	0	0	450	7642	8092
1956	2	7983	0	0	13442	1083	22508
1956	3	82000	19929	2397	1248	42	105616
1956	4	14515	3819	0	0	754	19088
1956	TOTAL	104498	23749	2397	15140	9521	155304
1957	1	0	0	0	6094	194109	200203
1957	2	38317	0	0	924326	6119	968762
1957	3	1025260	120739	11636	131	3148	1160914
1957	4	146924	45862	12352	0	14358	219496
1957	TOTAL	1210501	166601	23988	930551	217734	2549375
1958	1	0	0	0	2876	184391	187267
1958	2	416	0	0	1016123	10757	1027296
1958	3	322243	64101	12434	0	2247	401025
1958	4	24203	3085	2890	0	42503	72681
1958	TOTAL	346862	67186	15324	1018999	239898	1688269
1959	1	0	0	0	6681	346867	353548
1959	2	1127	0	0	463373	8328	472828
1959	3	92079	14956	8331	54221	5868	175455
1959	4	2842	690	0	0	69241	72773
1959	TOTAL	96048	15646	8331	524275	430304	1074604
1960	1	0	0	0	201	105198	105399
1960	2	354	0	0	73454	9336	83144
1960	3	9948	0	0	42	3054	13044
1960	4	634	0	0	0	49820	50454
1960	TOTAL	10936	0	0	73697	167408	252041
1961	1	0	0	0	119	72944	73063
1961	2	0	0	0	4414	8724	13138
1961	3	0	0	0	0	1593	1593
1961	4	0	0	0	0	69483	69483
1961	TOTAL	0	0	0	4533	152744	157277
1962	1	0	0	0	0	47624	47624
1962	2	0	0	0	0	1989	1989
1962	3	0	0	0	0	607	607
1962	4	0	0	0	0	9507	9507
1962	TOTAL	0	0	0	0	59727	59727
1963	1	0	0	0	0	3312	3312
1963	2	0	0	0	0	789	789
1963	3	0	0	0	0	147	147
1963	4	0	0	0	0	12271	12271
1963	TOTAL	0	0	0	0	16519	16519
1964	1	0	0	0	0	8185	8185
1964	2	0	0	0	0	486	486
1964	3	0	0	0	0	111	111
1964	4	0	0	0	0	986	986
1964	TOTAL	0	0	0	0	9768	9768

CATCH HISTORY FOR NORTH PACIFIC ALBACORE YEAR CLASS 1955 ACCORDING TO AGE MODEL 3

FISHING		CATCH BY FISHERY					
YEAR	QUARTER	CALIF	OREGON	WASH	POLELINE	LONGLINE	TOTAL
1957	1	0	0	0	637	11081	11718
1957	2	2397	0	0	96492	352	99241
1957	3	64165	9228	332	16	177	73918
1957	4	9196	3505	355	0	809	13865
1957	TOTAL	75758	12733	687	97145	12419	198742
1958	1	0	0	0	921	131169	132090
1958	2	1060	0	0	324815	7589	333464
1958	3	819204	508457	56670	0	1584	1385915
1958	4	61526	24470	13168	0	27839	127003
1958	TOTAL	881790	532927	69838	325736	168181	1978472
1959	1	0	0	0	5375	96282	101657
1959	2	1664	0	0	372761	2168	376593
1959	3	135690	33903	25746	43618	1531	240488
1959	4	4189	1558	0	0	16522	22269
1959	TOTAL	141543	35461	25746	421754	116503	741007
1960	1	0	0	0	715	295313	296028
1960	2	6698	0	0	340447	26962	374107
1960	3	188874	3419	1555	403	8812	203063
1960	4	12037	569	200	0	139077	151883
1960	TOTAL	207609	3988	1755	341565	470164	1025081
1961	1	0	0	0	2792	117835	120627
1961	2	192	0	0	133837	11432	145461
1961	3	5475	83	0	3961	2087	11606
1961	4	255	17	0	0	61156	61428
1961	TOTAL	5922	100	0	140590	192510	339122
1962	1	0	0	0	241	142865	143106
1962	2	0	0	0	13248	5648	18896
1962	3	0	0	0	0	1723	1723
1962	4	0	0	0	0	23802	23802
1962	TOTAL	0	0	0	13489	174038	187527
1963	1	0	0	0	0	19533	19533
1963	2	0	0	0	0	4179	4179
1963	3	0	0	0	0	784	784
1963	4	0	0	0	0	25536	25536
1963	TOTAL	0	0	0	0	50032	50032
1964	1	0	0	0	0	20993	20993
1964	2	0	0	0	0	1275	1275
1964	3	0	0	0	0	290	290
1964	4	0	0	0	0	2594	2594
1964	TOTAL	0	0	0	0	25152	25152
1965	1	0	0	0	0	4144	4144
1965	2	0	0	0	0	27	27
1965	3	0	0	0	0	63	63
1965	4	0	0	0	0	1559	1559
1965	TOTAL	0	0	0	0	5793	5793

CATCH HISTORY FOR NORTH PACIFIC ALBACORE YEAR CLASS 1956 ACCORDING TO AGE MODEL 3

FISHING		CATCH BY FISHERY					
YEAR	QUARTER	CALIF	OREGON	WASH	POLELINE	LONGLINE	TOTAL
1958	1	0	0	0	22	2435	2457
1958	2	101	0	0	7149	137	7387
1958	3	79063	66726	7344	0	28	153161
1958	4	5939	3211	1707	0	688	11545
1958	TOTAL	85103	69937	9051	7171	3288	174550
1959	1	0	0	0	37	43628	43665
1959	2	23276	0	0	2577	886	26739
1959	3	1899117	707572	165994	303	626	2773612
1959	4	58621	32561	0	0	5377	96559
1959	TOTAL	1981014	740133	165994	2917	50517	2940575
1960	1	0	0	0	3916	169499	173415
1960	2	17483	0	0	1905355	14519	1937357
1960	3	493003	89759	11443	2337	4747	601289
1960	4	31421	14945	1473	0	46503	94342
1960	TOTAL	541907	104704	12916	1911608	235268	2806403
1961	1	0	0	0	11464	333536	345000
1961	2	5130	0	0	781912	29613	816655
1961	3	145078	9136	1452	38980	5411	200057
1961	4	6793	1835	0	0	82194	90822
1961	TOTAL	157001	10971	1452	832356	450754	1452534
1962	1	4	0	0	4226	132936	137166
1962	2	145	0	0	295791	5327	301263
1962	3	5565	0	151	1653	1625	8994
1962	4	668	0	0	0	25491	26159
1962	TOTAL	6382	0	151	301670	165379	473582
1963	1	0	0	0	22	39042	39064
1963	2	0	0	0	1021	8453	9474
1963	3	0	0	0	0	1582	1582
1963	4	0	0	0	0	53385	53385
1963	TOTAL	0	0	0	1043	102462	103505
1964	1	0	0	0	0	25412	25412
1964	2	0	0	0	0	1537	1537
1964	3	0	0	0	0	349	349
1964	4	0	0	0	0	3132	3132
1964	TOTAL	0	0	0	0	30430	30430
1965	1	0	0	0	0	9918	9918
1965	2	0	0	0	0	96	96
1965	3	0	0	0	0	237	237
1965	4	0	0	0	0	2125	2125
1965	TOTAL	0	0	0	0	12376	12376
1966	1	0	0	0	0	9271	9271
1966	2	0	0	0	0	73	73
1966	3	0	0	0	0	169	169
1966	4	0	0	0	0	2115	2115
1966	TOTAL	0	0	0	0	11628	11628

CATCH HISTORY FOR NORTH PACIFIC ALBACORE YEAR CLASS 1957 ACCORDING TO AGE MODEL 3

FISHING		CATCH BY FISHERY					
YEAR	QUARTER	CALIF	OREGON	WASH	POLELINE	LONGLINE	TOTAL
1959	1	0	0	0	1	148	149
1959	2	2385	0	0	99	1	2485
1959	3	194679	16574	2725	12	1	213991
1959	4	6010	763	0	0	75	6848
1959	TOTAL	203074	17337	2725	112	225	223473
1960	1	0	0	0	79	19913	19992
1960	2	44348	0	0	31853	1540	77741
1960	3	1250579	151164	13805	25	504	1416077
1960	4	79705	25170	1779	0	4292	110946
1960	TOTAL	1374632	176334	15584	31957	26249	1624756
1961	1	0	0	0	3507	148396	151903
1961	2	27721	0	0	420586	12613	468920
1961	3	783913	87186	10460	20366	2307	904232
1961	4	36702	17504	0	0	31970	86176
1961	TOTAL	848336	104690	10460	452459	195286	1611231
1962	1	50	0	0	3258	89358	92666
1962	2	2073	0	0	210409	4298	216780
1962	3	80192	1154	1033	2514	1312	86205
1962	4	9642	250	0	0	35913	45805
1962	TOTAL	91957	1404	1033	216181	130881	441456
1963	1	0	0	0	1278	22225	23503
1963	2	2	0	0	60828	5220	66050
1963	3	1750	0	0	15	976	2741
1963	4	474	0	0	0	76403	76877
1963	TOTAL	2226	0	0	62121	104824	169171
1964	1	0	0	0	20	45101	45121
1964	2	0	0	0	230	2694	2924
1964	3	0	0	0	0	610	610
1964	4	0	0	0	0	5480	5480
1964	TOTAL	0	0	0	250	53885	54135
1965	1	0	0	0	0	10639	10639
1965	2	0	0	0	0	692	692
1965	3	0	0	0	0	239	239
1965	4	0	0	0	0	6054	6054
1965	TOTAL	0	0	0	0	17624	17624
1966	1	0	0	0	0	19706	19706
1966	2	0	0	0	0	174	174
1966	3	0	0	0	0	365	365
1966	4	0	0	0	0	5776	5776
1966	TOTAL	0	0	0	0	26021	26021
1967	1	0	0	0	0	11534	11534
1967	2	0	0	0	0	214	214
1967	3	0	0	0	0	284	284
1967	4	0	0	0	0	4288	4288
1967	TOTAL	0	0	0	0	16320	16320

CATCH HISTORY FOR NORTH PACIFIC ALBACORE YEAR CLASS 1958 ACCORDING TO AGE MODEL 3

FISHING		CATCH BY FISHERY					
YEAR	QUARTER	CALIF	OREGON	WASH	POLELINE	LONGLINE	TOTAL
1960	1	0	0	0	1	191	192
1960	2	408	0	0	471	12	891
1960	3	11518	0	0	1	4	11523
1960	4	733	0	0	0	35	768
1960	TOTAL	12659	0	0	473	242	13374
1961	1	0	0	0	0	19805	19805
1961	2	15001	0	0	0	1976	16977
1961	3	424208	82472	13959	0	360	520999
1961	4	19858	16557	0	0	4863	41278
1961	TOTAL	459067	99029	13959	0	27004	599059
1962	1	214	0	0	52	103166	103432
1962	2	8869	0	0	25838	4351	39058
1962	3	343254	20295	16916	5506	1323	387294
1962	4	41274	4396	0	0	16055	61725
1962	TOTAL	393611	24691	16916	31396	124895	591509
1963	1	0	0	0	5457	96288	101745
1963	2	96	0	0	328963	18865	347924
1963	3	144968	281	0	749	3529	149527
1963	4	39336	52	0	0	73905	113293
1963	TOTAL	184400	333	0	335169	192587	712489
1964	1	0	0	0	11394	82738	94132
1964	2	0	0	0	157158	4884	162042
1964	3	277	35	0	3387	1108	4807
1964	4	71	14	0	0	9934	10019
1964	TOTAL	348	49	0	171939	98664	271000
1965	1	0	0	0	3157	18015	21172
1965	2	0	0	0	8730	1097	9827
1965	3	104	0	0	0	599	703
1965	4	35	0	0	0	33204	33239
1965	TOTAL	139	0	0	11887	52915	64941
1966	1	0	0	0	24	24270	24294
1966	2	0	0	0	0	273	273
1966	3	0	0	0	0	413	413
1966	4	0	0	0	0	18015	18015
1966	TOTAL	0	0	0	24	42971	42995
1967	1	0	0	0	0	24312	24312
1967	2	0	0	0	0	209	209
1967	3	0	0	0	0	492	492
1967	4	0	0	0	0	9022	9022
1967	TOTAL	0	0	0	0	34035	34035
1968	1	0	0	0	0	2970	2970
1968	2	0	0	0	0	44	44
1968	3	0	0	0	0	77	77
1968	4	0	0	0	0	2136	2136
1968	TOTAL	0	0	0	0	5227	5227

CATCH HISTORY FOR NORTH PACIFIC ALBACORE YEAR CLASS 1959 ACCORDING TO AGE MODEL 3

FISHING		CATCH BY FISHERY					
YEAR	QUARTER	CALIF	OREGON	WASH	POLELINE	LONGLINE	TOTAL
1961	1	0	0	0	0	1038	1038
1961	2	1848	0	0	0	103	1951
1961	3	52301	5969	575	69216	18	128079
1961	4	2448	1199	0	0	247	3894
1961	TOTAL	56597	7168	575	69216	1406	134962
1962	1	1033	0	0	0	195757	196790
1962	2	43015	0	0	0	7901	50916
1962	3	1664642	695280	7725	0	2412	2370059
1962	4	200153	150648	0	0	18578	369379
1962	TOTAL	1908843	845928	7725	0	224648	2987144
1963	1	0	0	0	29483	135672	165155
1963	2	300	0	0	2064050	24490	2088840
1963	3	449888	160880	13735	6874	4582	635959
1963	4	122079	29732	0	0	81614	233425
1963	TOTAL	572267	190612	13735	2100407	246358	3123379
1964	1	0	0	0	54169	245060	299229
1964	2	0	0	0	757713	14661	772374
1964	3	54186	6955	404	68126	3328	132999
1964	4	14053	2716	0	0	29839	46608
1964	TOTAL	68239	9671	404	880008	292888	1251210
1965	1	0	0	0	42643	31009	73652
1965	2	0	0	0	280303	3810	284113
1965	3	2031	0	0	137	1311	3479
1965	4	692	0	0	0	41912	42604
1965	TOTAL	2723	0	0	323083	78042	403848
1966	1	0	0	0	406	76433	76839
1966	2	0	0	0	8134	586	8720
1966	3	0	0	0	0	1563	1563
1966	4	0	0	0	0	20843	20843
1966	TOTAL	0	0	0	8540	99425	107965
1967	1	0	0	0	0	56486	56486
1967	2	0	0	0	417	927	1344
1967	3	0	0	0	0	1028	1028
1967	4	0	0	0	0	26737	26737
1967	TOTAL	0	0	0	417	85178	85595
1968	1	0	0	0	129	9521	9650
1968	2	0	0	0	0	230	230
1968	3	0	0	0	0	207	207
1968	4	0	0	0	0	6887	6887
1968	TOTAL	0	0	0	129	16845	16974
1969	1	0	0	0	0	1405	1405
1969	2	0	0	0	0	50	50
1969	3	0	0	0	0	215	215
1969	4	0	0	0	0	2780	2780
1969	TOTAL	0	0	0	0	4450	4450

CATCH HISTORY FOR NORTH PACIFIC ALBACORE YEAR CLASS 1960 ACCORDING TO AGE MODEL 3

FISHING		CATCH BY FISHERY					
YEAR	QUARTER	CALIF	OREGON	WASH	POLELINE	LONGLINE	TOTAL
1962	1	168	0	0	66	6588	6822
1962	2	6971	0	0	3445	269	10685
1962	3	269767	51426	19576	0	81	340850
1962	4	32437	11140	0	0	626	44203
1962	TOTAL	309343	62566	19576	3511	7564	402560
1963	1	0	0	0	397	69079	69476
1963	2	1207	0	0	19063	11458	31728
1963	3	1811831	674137	20191	7	2146	2508312
1963	4	491653	124594	0	0	24330	640577
1963	TOTAL	2304691	798731	20191	19467	107013	3250093
1964	1	0	0	0	823	315303	316126
1964	2	0	0	0	36773	18623	55396
1964	3	833109	106953	17404	546433	4226	1508125
1964	4	216056	41757	0	0	37895	295708
1964	TOTAL	1049165	148710	17404	584029	376047	2175355
1965	1	0	0	0	83706	121347	205053
1965	2	0	0	0	2130443	19878	2150321
1965	3	76861	8616	1676	759	3967	91879
1965	4	26185	1064	0	0	41154	68403
1965	TOTAL	103046	9680	1676	2214908	186346	2515656
1966	1	0	0	0	2132	117719	119851
1966	2	0	0	0	248790	946	249736
1966	3	5596	0	0	2723	6271	14590
1966	4	1090	0	0	0	92475	93565
1966	TOTAL	6686	0	0	253645	217411	477742
1967	1	0	0	0	2176	128795	130971
1967	2	0	0	0	37813	2181	39994
1967	3	299	0	0	0	3551	3850
1967	4	32	0	0	0	69959	69991
1967	TOTAL	331	0	0	39989	204486	244806
1968	1	0	0	0	1290	24522	25812
1968	2	0	0	0	496	677	1173
1968	3	0	0	0	0	1224	1224
1968	4	0	0	0	0	28895	28895
1968	TOTAL	0	0	0	1786	55318	57104
1969	1	0	0	0	0	20065	20065
1969	2	0	0	0	0	816	816
1969	3	0	0	0	0	1781	1781
1969	4	0	0	0	0	13522	13522
1969	TOTAL	0	0	0	0	36184	36184
1970	1	0	0	0	0	896	896
1970	2	0	0	0	0	170	170
1970	3	0	0	0	0	153	153
1970	4	0	0	0	0	8417	8417
1970	TOTAL	0	0	0	0	9636	9636

Table 7.--Estimated annual landings of North Pacific albacore in numbers and weight (kg), and mean weights (kg), by fishery, 1952-72.

Year		Japanese pole-and-line	Japanese longline	American	Total
1952	W	39,914,600	17,937,000	27,251,500	85,103,100
	N	4,525,500	1,696,400	3,480,600	9,702,500
	$\bar{w}$	8.82	10.57	7.83	8.77
1953	W	31,174,800	23,229,300	17,188,100	71,592,200
	N	2,998,400	1,752,100	2,424,300	7,174,800
	$\bar{w}$	10.40	13.26	7.09	9.98
1954	W	26,452,300	15,991,900	13,357,100	55,801,300
	N	2,304,000	1,340,100	2,032,800	5,676,900
	$\bar{w}$	11.48	11.93	6.57	9.83
1955	W	22,446,400	18,412,300	16,769,900	57,628,600
	N	2,237,800	1,377,200	2,543,100	6,158,100
	$\bar{w}$	10.03	13.37	6.59	9.36
1956	W	42,020,300	12,423,100	21,225,300	75,668,700
	N	4,731,100	1,029,200	2,871,700	8,632,000
	$\bar{w}$	8.88	12.07	7.39	8.77
1957	W	46,491,600	15,437,500	22,455,200	84,384,300
	N	4,693,600	1,293,900	2,625,500	8,613,000
	$\bar{w}$	9.91	11.93	8.55	9.80
1958	W	20,695,900	15,256,400	18,706,100	54,658,400
	N	2,049,100	1,157,800	2,354,800	5,561,700
	$\bar{w}$	10.10	13.18	7.94	9.83
1959	W	13,765,400	15,075,900	23,275,300	52,116,600
	N	1,121,400	1,003,800	3,437,000	5,562,200
	$\bar{w}$	12.28	15.02	6.77	9.37
1960	W	23,359,000	15,454,100	20,086,900	58,900,000
	N	2,360,000	1,082,900	2,463,000	5,905,900
	$\bar{w}$	9.90	14.27	8.16	9.97
1961	W	17,744,200	15,698,800	16,160,700	49,603,700
	N	1,499,200	1,078,700	1,775,300	4,353,200
	$\bar{w}$	11.84	14.55	9.10	11.39

Table 7.--Continued.

Year		Japanese pole-and-line	Japanese longline	American	Total
1962	W	8,539,100	12,614,400	25,343,000	46,496,500
	N	566,800	919,400	3,690,100	5,176,300
	$\bar{w}$	15.07	13.72	6.87	8.98
1963	W	24,712,300	11,444,700	32,250,600	68,407,600
	N	2,518,200	824,500	4,341,500	7,684,200
	$\bar{w}$	9.81	13.88	7.43	8.90
1964	W	23,776,400	11,558,100	25,147,000	60,481,500
	N	2,332,600	929,000	3,061,300	6,322,900
	$\bar{w}$	10.19	12.44	8.21	9.57
1965	W	40,089,000	10,004,100	19,512,200	69,605,300
	N	3,255,500	806,100	2,314,000	6,375,600
	$\bar{w}$	12.31	12.41	8.43	10.92
1966	W	22,108,000	18,998,900	20,320,800	61,427,700
	N	1,826,200	1,495,400	2,524,400	5,846,000
	$\bar{w}$	12.11	12.70	8.05	10.57
1967	W	29,622,900	24,780,500	26,052,500	80,455,900
	N	2,320,500	1,745,400	3,426,800	7,492,700
	$\bar{w}$	12.77	14.20	7.60	10.74
1968	W	15,860,600	17,827,400	27,921,800	61,609,800
	N	1,321,800	1,362,700	3,770,000	6,454,500
	$\bar{w}$	12.00	13.08	7.41	9.55
1969	W	31,183,400	16,202,600	24,016,400	71,402,400
	N	2,636,700	1,020,200	3,064,700	6,721,600
	$\bar{w}$	11.83	15.88	7.84	10.62
1970	W	23,960,900	10,890,600	28,342,700	63,194,200
	N	2,524,800	788,300	3,570,100	6,883,200
	$\bar{w}$	9.49	13,82	7.94	9.18
1971	W	51,795,300	9,682,200	25,879,800	87,357,300
	N	5,181,800	530,500	3,733,400	9,445,700
	$\bar{w}$	10.00	18.25	6.93	9.25
1972	W	59,660,500	9,306,700	30,003,200	98,970,400
	N	6,642,400	564,100	3,545,800	10,752,300
	$\bar{w}$	8.98	16.50	8.46	9.20

Table 8.--Estimates of total instantaneous mortality rate of 5-year-old North Pacific albacore (Z_5), based on catch rates in the longline fishery.

Year i	I_{5i}	$I_{6(i+1)}$	$\frac{I_{6(i+1)}}{I_{5i}}$	Z_{5i}	f_i
1952	0.5564	0.6038	1.085	-0.082	356
1953	0.8836	0.1924	0.218	1.525	466
1954	0.5027	0.2441	0.486	0.722	435
1955	0.6587	1.2431	1.887	-0.635	113
1956	0.3694	0.2350	0.636	0.452	867
1957	0.4127	0.2671	0.647	0.435	410
1958	0.3748	0.1662	0.443	0.813	363
1959	0.4927	0.1381	0.280	1.272	722
1960	0.3877	0.1570	0.405	0.904	393
1961	0.4444	0.1793	0.404	0.908	134
1962	0.1207	0.0367	0.304	1.190	2,306
1963	0.1592	0.1306	0.820	0.198	561
1964	0.3870	0.0502	0.130	2.042	903
1965	0.1963	0.2170	1.105	-0.100	283
1966	0.3788	0.3235	0.854	0.158	203
1967	0.3536	0.2758	0.780	0.248	213
1968	0.3192	0.1341	0.420	0.867	441
1969	0.1316	0.1192	0.906	0.099	423
1970	0.2197	0.1025	0.466	0.762	774
1971	0.0684	0.0715	1.045	-0.044	2,362

Table 9.--Estimates of fishing mortality rates on principal age groups of North Pacific albacore by each fishery during its quarter of greatest activity. Given for different sets of M and F_o, 1952-72.

M = 0.2 and F_o = 0.01

Fishing year	American		Pole-and-line			Longline				
	3	4	4	5	6	4	5	6	7	8
1952	0.600	0.484	1.048	1.115	0.241	0.258	0.256	0.206	0.136	0.022
1953	0.775	0.154	0.887	1.212	0.122	0.124	0.405	0.658	0.376	0.159
1954	0.556	0.154	0.861	0.901	0.401	0.156	0.220	0.200	0.273	0.148
1955	0.546	0.057	1.086	0.565	0.075	0.081	0.520	0.217	0.226	0.209
1956	0.556	0.450	1.470	0.267	0.383	0.121	0.200	0.143	0.078	0.050
1957	0.661	0.484	1.067	1.899	0.339	0.152	0.246	0.186	0.180	0.042
1958	0.789	0.427	0.877	0.585	0.302	0.134	0.202	0.401	0.132	0.090
1959	0.956	0.173	0.295	0.773	0.227	0.069	0.470	0.166	0.341	0.106
1960	0.502	0.395	1.005	0.414	0.207	0.074	0.310	0.265	0.129	0.169
1961	0.319	0.468	0.199	0.764	0.262	0.063	0.272	0.206	0.268	0.051
1962	0.731	0.319	0.020	0.144	0.476	0.074	0.057	0.187	0.368	0.251
1963	0.416	0.363	0.962	0.364	0.054	0.053	0.095	0.019	0.080	0.067
1964	0.232	0.224	0.008	0.636	0.260	0.063	0.176	0.124	0.048	0.067
1965	0.180	0.172	0.112	0.682	0.348	0.043	0.034	0.035	0.036	0.014
1966	0.250	0.154	0.060	0.308	0.111	0.087	0.056	0.049	0.119	0.062
1967	0.223	0.196	0.056	0.441	0.139	0.094	0.072	0.096	0.069	0.112
1968	0.222	0.103	0.030	0.159	0.096	0.038	0.072	0.074	0.047	0.016
1969	0.206	0.082	0.038	0.331	0.051	0.024	0.016	0.041	0.057	0.037
1970	0.181	0.126	0.091	0.096	0.050	0.020	0.018	0.016	0.019	0.009
1971	0.219	0.066	0.224	0.268	0.059	0.008	0.007	0.011	0.022	0.025
1972	0.185	0.149	0.235	0.319	0.042	0.010	0.008	0.010	0.015	0.009

American in 3d quarter

Pole and line in 2d quarter

Longline in 1st quarter

Table 9.--Continued.

M = 0.2 and F_o = 0.10

Fishing year	American		Pole-and-line			Longline				
	3	4	4	5	6	4	5	6	7	8
1952	0.926	0.742	1.468	1.984	0.652	0.340	0.402	0.509	0.571	0.165
1953	1.108	0.326	1.657	2.466	0.386	0.209	0.686	1.736	1.406	0.878
1954	0.889	0.276	1.410	2.599	1.533	0.237	0.500	0.628	1.171	0.806
1955	0.627	0.129	2.106	1.303	0.397	0.138	1.023	0.995	1.250	1.299
1956	0.797	0.593	1.804	0.718	1.288	0.142	0.487	0.410	0.503	0.377
1957	0.844	0.940	1.778	3.021	1.266	0.230	0.340	0.588	0.826	0.330
1958	1.201	0.640	1.222	1.465	0.793	0.178	0.442	0.920	0.684	0.558
1959	1.331	0.306	0.498	1.398	0.966	0.113	0.759	0.606	1.256	0.727
1960	1.210	0.708	1.601	0.851	0.541	0.110	0.582	0.631	0.721	0.992
1961	0.641	1.664	0.579	1.751	0.811	0.172	0.532	0.567	0.871	0.372
1962	1.093	0.730	0.043	0.711	1.954	0.158	0.254	0.609	1.575	1.347
1963	0.898	0.738	1.692	1.012	0.342	0.085	0.240	0.112	0.448	0.408
1964	0.567	0.591	0.019	1.741	1.204	0.153	0.407	0.484	0.372	0.518
1965	0.473	0.513	0.311	2.574	1.486	0.116	0.101	0.126	0.201	0.116
1966	0.785	0.479	0.176	1.158	0.647	0.247	0.188	0.260	0.678	0.419
1967	0.795	0.813	0.210	1.824	0.770	0.336	0.248	0.469	0.491	0.804
1968	1.008	0.450	0.122	0.865	0.634	0.154	0.347	0.437	0.321	0.142
1969	0.800	0.478	0.207	1.878	0.355	0.125	0.075	0.268	0.443	0.318
1970	0.679	0.628	0.411	0.663	0.400	0.086	0.112	0.123	0.151	0.083
1971	1.049	0.347	1.028	1.815	0.506	0.035	0.038	0.084	0.199	0.221
1972	1.536	1.270	1.488	2.242	0.391	0.054	0.043	0.087	0.138	0.088

American in 3d quarter

Pole and line in 2d quarter

Longline in 1st quarter

Table 9.--Continued.

M = variable and F_o = 0.1

Fishing year	American 3	American 4	Pole-and-line 4	Pole-and-line 5	Pole-and-line 6	Longline 4	Longline 5	Longline 6	Longline 7	Longline 8
1952	0.660	0.524	1.117	1.183	0.268	0.272	0.268	0.217	0.188	0.049
1953	0.807	0.178	1.008	1.360	0.146	0.139	0.444	0.735	0.509	0.316
1954	0.599	0.164	0.908	1.083	0.516	0.164	0.257	0.240	0.398	0.292
1955	0.549	0.064	1.198	0.610	0.102	0.088	0.556	0.279	0.358	0.444
1956	0.597	0.456	1.485	0.304	0.458	0.122	0.226	0.161	0.127	0.113
1957	0.657	0.543	1.172	1.937	0.427	0.164	0.249	0.220	0.261	0.096
1958	0.826	0.423	0.869	0.676	0.339	0.133	0.230	0.424	0.203	0.188
1959	1.017	0.184	0.311	0.762	0.297	0.073	0.465	0.203	0.468	0.234
1960	0.599	0.436	1.093	0.443	0.220	0.080	0.330	0.268	0.204	0.345
1961	0.355	0.585	0.243	0.869	0.311	0.077	0.304	0.231	0.342	0.116
1962	0.791	0.360	0.022	0.186	0.616	0.083	0.073	0.225	0.534	0.482
1963	0.492	0.410	1.067	0.418	0.076	0.058	0.109	0.025	0.125	0.141
1964	0.278	0.273	0.009	0.744	0.334	0.076	0.202	0.149	0.081	0.152
1965	0.221	0.212	0.136	0.863	0.456	0.052	0.042	0.043	0.056	0.033
1966	0.450	0.193	0.074	0.388	0.157	0.108	0.070	0.065	0.189	0.135
1967	0.563	0.389	0.107	0.569	0.195	0.178	0.092	0.127	0.117	0.253
1968	0.806	0.292	0.082	0.341	0.139	0.104	0.150	0.101	0.080	0.039
1969	0.751	0.357	0.158	1.070	0.125	0.096	0.047	0.094	0.099	0.089
1970	0.679	0.576	0.381	0.469	0.202	0.080	0.082	0.061	0.057	0.022
1971	1.049	0.347	1.028	1.604	0.357	0.035	0.034	0.058	0.112	0.105
1972	1.536	1.270	1.488	2.242	0.356	0.054	0.043	0.076	0.111	0.065

American in 3d quarter

Pole and line in 2d quarter

Longline in 1st quarter

Table 10.--Average age-specific fishing mortality rates on North Pacific albacore during successive 7-year periods, for each fishery during its quarter of peak activity. Given for various sets of M and F_o.

$M = 0.2$ and $F_o = 0.1$

	Age groups							
	3	4	5	6	7	8	9	10
Japanese longline (1st quarter)								
Period 1	0.083	0.211	0.554	0.827	0.916	0.630	0.448	0.225
Period 2	0.024	0.130	0.411	0.448	0.778	0.640	0.433	0.240
Period 3	0.024	0.148	0.150	0.247	0.346	0.296	0.224	0.123
Japanese pole-and-line (2d quarter)								
Period 1	0.279	1.635	1.937	0.902	0.034	0	0	0
Period 2	0.010	0.678	1.434	1.044	0.073	0	0	0
Period 3	0.189	0.520	1.492	0.529	0.113	0.003	0.0001	0
American (3d quarter)								
Period 1	0.913	0.521	0.451	0.162	0.016	0	0	0
Period 2	0.887	0.750	0.412	0.033	0.002	0	0	0
Period 3	0.950	0.638	0.196	0.010	0.002	0	0	0

Period 1 = 1952-58

Period 2 = 1959-65

Period 3 = 1966-72

Table 10.--Continued.

$M = 0.2$ and $F_o = 0.01$								
	Age groups							
	3	4	5	6	7	8	9	10
Japanese longline (1st quarter)								
Period 1	0.061	0.147	0.293	0.287	0.200	0.103	0.057	0.024
Period 2	0.014	0.063	0.202	0.143	0.181	0.104	0.153	0.026
Period 3	0.007	0.040	0.036	0.042	0.050	0.039	0.026	0.013
Japanese pole-and-line (2d quarter)								
Period 1	0.206	1.042	0.935	0.266	0.006	0	0	0
Period 2	0.004	0.371	0.540	0.262	0.015	0	0	0
Period 3	0.040	0.105	0.275	0.078	0.015	0	0	0
American (3d quarter)								
Period 1	0.640	0.316	0.186	0.049	0.003	0	0	0
Period 2	0.476	0.302	0.146	0.009	0	0	0	0
Period 3	0.212	0.125	0.030	0.002	0	0	0	0

M = variable and $F_o = 0.1$								
	Age groups							
	3	4	5	6	7	8	9	10
Japanese longline (1st quarter)								
Period 1	0.064	0.154	0.319	0.325	0.292	0.214	0.192	0.145
Period 2	0.016	0.071	0.218	0.163	0.258	0.215	0.182	0.156
Period 3	0.019	0.094	0.074	0.083	0.109	0.101	0.095	0.079
Japanese pole-and-line (2d quarter)								
Period 1	0.215	1.108	1.022	0.322	0.010	0	0	0
Period 2	0.005	0.412	0.612	0.330	0.024	0	0	0
Period 3	0.183	0.474	0.955	0.219	0.043	0.001	0	0
American (3d quarter)								
Period 1	0.671	0.336	0.205	0.061	0.005	0	0	0
Period 2	0.536	0.351	0.162	0.011	0.001	0	0	0
Period 3	0.834	0.489	0.115	0.003	0.001	0	0	0

Period 1 = 1952-58

Period 2 = 1959-65

Period 3 = 1966-72

Table 11.--Estimates of average aggregate fishing mortality rates on North Pacific albacore, during years 1952-72, based on weightings by number ($\bar{F}_N$) and by biomass ($\bar{F}_W$).

Year	$\bar{F}_N$	$\bar{F}_W$
1952	0.2876	0.1852
1953	0.2456	0.1723
1954	0.2190	0.1879
1955	0.2170	0.1905
1956	0.2941	0.2329
1957	0.3453	0.2754
1958	0.2443	0.1876
1959	0.2028	0.1660
1960	0.2121	0.1866
1961	0.1707	0.1591
1962	0.1570	0.1322
1963	0.1641	0.1470
1964	0.1080	0.1050
1965	0.0988	0.0999
1966	0.0835	0.0754
1967	0.0829	0.0797
1968	0.0565	0.0492
1969	0.0531	0.0475
1970	0.0470	0.0353
1971	0.0577	0.0432
1972	0.0617	0.0447

Table 12.--Estimates of parameters of the Ricker spawner-recruit model for North Pacific albacore, for different sets of M and F_o. The model is $\ln (R/Bs) = \ln \alpha - \beta\, Bs$, where R is recruitment (millions of 2.5-year old albacore) and Bs is spawning biomass (10^9 kg) during second quarter of birth year.

M	F_o	$\hat{\alpha}$	$\hat{\beta}$	$\bar{Bs}$	r	Data points
Variable	0.10	399.7	9.778	0.0844	-0.62	15
Variable	0.20	531.7	15.894	0.0515	-0.61	15
Variable	0.40	689.9	23.389	0.0352	-0.57	15
0.2	0.001	76.7	0.125	1.7329	-0.08	15
0.2	0.01	138.8	1.172	0.1840	-0.13	15
0.2	0.10	543.6	15.776	0.0295	-0.34	15
0.2	0.20	794.5	26.949	0.0205	-0.38	15

Table 13.--Estimates of age-specific (by quarter) and fishery-specific fishing mortality rates used in the North Pacific albacore yield-per-recruit analysis. Rates are on annual basis, are averages for the period 1959-65, and are given for different sets of M and F_o.

$M = 0.2$ and $F_o = 0.01$

Age*	Quarter	American	Japanese pole-and-line	Japanese longline	Total
3	1	0.0000	0.0001	0.0142	0.0143
	2	0.0058	0.0041	0.0009	0.0108
	3	0.4764	0.0091	0.0003	0.4858
	4	0.0645	0.0	0.0030	0.0675
4	1	0.0000	0.0033	0.0629	0.0662
	2	0.0043	0.3714	0.0052	0.3809
	3	0.3020	0.0268	0.0017	0.3306
	4	0.0471	0.0	0.0273	0.0744
5	1	0.0000	0.0127	0.2020	0.2147
	2	0.0024	0.5395	0.0169	0.5588
	3	0.1461	0.0322	0.0058	0.1841
	4	0.0185	0.0	0.0942	0.1127
6	1	0.0000	0.0114	0.1430	0.1545
	2	0.0002	0.2620	0.0114	0.2736
	3	0.0090	0.0067	0.0036	0.0193
	4	0.0008	0.0	0.0831	0.0839
7	1	0.0	0.0011	0.1814	0.1825
	2	0.0000	0.0154	0.0140	0.0294
	3	0.0004	0.0005	0.0043	0.0052
	4	0.0000	0.0	0.1313	0.1313
8	1	0.0	0.0	0.1037	0.1037
	2	0.0	0.0	0.0083	0.0083
	3	0.0	0.0	0.0025	0.0025
	4	0.0	0.0	0.0532	0.0532
9	1	0.0	0.0	0.0526	0.0526
	2	0.0	0.0	0.0037	0.0037
	3	0.0	0.0	0.0012	0.0012
	4	0.0	0.0	0.0376	0.0376
10	1	0.0	0.0	0.0256	0.0256
	2	0.0	0.0	0.0015	0.0015
	3	0.0	0.0	0.0005	0.0005
	4	0.0	0.0	0.0100	0.0100

*"Age" is number of years following birth year. Thus "Age" 3, quarter 1 refers to albacore aged 2.5 years.

Table 13.--Continued.

		$M = 0.2$ and $F_o = 0.10$			
Age*	Quarter	American	Japanese pole-and-line	Japanese longline	Total
3	1	0.0001	0.0003	0.0239	0.0242
	2	0.0104	0.0095	0.0016	0.0215
	3	0.8874	0.0223	0.0005	0.9102
	4	0.1386	0.0	0.0061	0.1447
4	1	0.0000	0.0063	0.1297	0.1360
	2	0.0099	0.6775	0.0108	0.6983
	3	0.7499	0.0665	0.0040	0.8204
	4	0.1259	0.0	0.0707	0.1966
5	1	0.0000	0.0309	0.4107	0.4417
	2	0.0056	1.4341	0.0413	1.4810
	3	0.4115	0.0838	0.0154	0.5108
	4	0.0648	0.0	0.2756	0.3404
6	1	0.0000	0.0415	0.4477	0.4893
	2	0.0007	1.0435	0.0401	1.0844
	3	0.0329	0.0307	0.0141	0.0778
	4	0.0036	0.0	0.3628	0.3664
7	1	0.0	0.0059	0.7778	0.7837
	2	0.0000	0.0734	0.0682	0.1417
	3	0.0016	0.0022	0.0213	0.0251
	4	0.0001	0.0	0.6803	0.6804
8	1	0.0	0.0	0.6399	0.6399
	2	0.0	0.0	0.0562	0.0562
	3	0.0	0.0	0.0172	0.0172
	4	0.0	0.0	0.3901	0.3901
9	1	0.0	0.0	0.4326	0.4326
	2	0.0	0.0	0.0315	0.0315
	3	0.0	0.0	0.0102	0.0102
	4	0.0	0.0	0.3215	0.3215
10	1	0.0	0.0	0.2401	0.2401
	2	0.0	0.0	0.0150	0.0150
	3	0.0	0.0	0.0047	0.0047
	4	0.0	0.0	0.0999	0.0999

*"Age" is number of years following birth year. Thus "Age" 3, quarter 1 refers to albacore aged 2.5 years.

Table 13.--Continued.

M = variable and F_o = 0.10

Age*	Quarter	American	Japanese pole-and-line	Japanese longline	Total
3	1	0.0000	0.0001	0.0157	0.0158
	2	0.0065	0.0049	0.0010	0.0124
	3	0.5361	0.0109	0.0003	0.5473
	4	0.0748	0.0	0.0034	0.0782
4	1	0.0000	0.0037	0.0713	0.0750
	2	0.0050	0.4116	0.0059	0.4225
	3	0.3513	0.0317	0.0020	0.3850
	4	0.0557	0.0	0.0319	0.0875
5	1	0.0000	0.0146	0.2177	0.2323
	2	0.0026	0.6122	0.0188	0.6337
	3	0.1625	0.0349	0.0064	0.2038
	4	0.0216	0.0	0.1042	0.1258
6	1	0.0000	0.0139	0.1633	0.1772
	2	0.0003	0.3301	0.0136	0.3439
	3	0.0112	0.0091	0.0046	0.0248
	4	0.0011	0.0	0.1135	0.1147
7	1	0.0	0.0017	0.2584	0.2601
	2	0.0000	0.0239	0.0219	0.0458
	3	0.0006	0.0008	0.0073	0.0087
	4	0.0000	0.0	0.2396	0.2397
8	1	0.0	0.0	0.2146	0.2146
	2	0.0	0.0	0.0195	0.0195
	3	0.0	0.0	0.0065	0.0065
	4	0.0	0.0	0.1574	0.1574
9	1	0.0	0.0	0.1816	0.1816
	2	0.0	0.0	0.0146	0.0146
	3	0.0	0.0	0.0053	0.0053
	4	0.0	0.0	0.1894	0.1894
10	1	0.0	0.0	0.1560	0.1560
	2	0.0	0.0	0.0111	0.0111
	3	0.0	0.0	0.0041	0.0041
	4	0.0	0.0	0.0999	0.0999

*"Age" is number of years following birth year. Thus "Age" 3, quarter 1 refers to albacore aged 2.5 years.

Table 14.--Estimated yield per recruit of North Pacific albacore under various hypotheses concerning elimination of fisheries, relative to yield per recruit with all fisheries present. Given for various sets of M and F_o, and based on average 1959-65 fishing rates.

	American		Japanese pole-and-line		Japanese longline		Total	
F-mult	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0
Base Y/R	1.411	2.289	1.642	2.183	1.406	1.551	4.459	6.024
(kg)	1.02	1.04	1.08	1.142	0	0	0.72	0.81
	1.08	1.14	0	0	1.27	1.54	0.74	0.83
M = 0.2	0	0	1.22	1.48	1.28	1.61	0.85	0.95
and	0	0	0	0	1.63	2.53	0.51	0.65
F = 0.01	0	0	1.46	1.87	0	0	0.54	0.68
	1.21	1.30	0	0	0	0	0.38	0.49
Base Y/R	2.473	3.422	2.522	2.262	1.928	1.119	6.922	6.803
(kg)	1.04	1.06	1.18	1.28	0	0	0.80	0.96
	1.17	1.24	0	0	1.85	2.36	0.93	1.01
M = 0.2	0	0	1.54	2.16	1.72	2.54	1.04	1.13
and	0	0	0	0	3.26	6.93	0.91	1.14
F = 0.10	0	0	2.05	3.19	0	0	0.75	1.06
	1.29	1.40	0	0	0	0	0.46	0.70
Base Y/R	2.600	3.532	2.594	2.213	1.919	1.033	7.113	6.779
(kg)	1.05	1.06	1.20	1.30	0	0	0.82	0.97
	1.18	1.25	0	0	2.00	2.43	0.97	1.02
M = 0.2	0	0	1.60	2.27	1.80	2.67	1.07	1.15
and	0	0	0	0	3.72	7.85	1.00	1.20
F = 0.20	0	0	2.17	3.43	0	0	0.79	1.12
	1.32	1.42	0	0	0	0	0.48	0.74
Base Y/R	1.563	2.484	1.761	2.232	1.444	1.466	4.767	6.181
(kg)	1.02	1.04	1.08	1.16	0	0	0.74	0.84
M =	1.09	1.15	0	0	1.31	1.62	0.75	0.84
variable	0	0	1.26	1.56	1.32	1.70	0.87	0.97
and	0	0	0	0	1.74	2.83	0.53	0.67
F_o = 0.10	0	0	1.51	2.00	0	0	0.56	0.72
	1.22	1.31	0	0	0	0	0.40	0.53
Base Y/R	1.905	2.878	2.060	2.316	1.627	1.365	5.592	6.558
(kg)	1.03	1.05	1.11	1.20	0	0	0.76	0.88
M =	1.11	1.18	0	0	1.44	1.84	0.80	0.90
variable	0	0	1.35	1.75	1.44	1.97	0.92	1.03
and	0	0	0	0	2.09	3.80	0.61	0.79
F_o = 0.20	0	0	1.66	2.35	0	0	0.61	0.97
	1.26	1.36	0	0	0	0	0.43	0.60

Table 15.--Estimates of aggregate annual fishing mortality rates on 4-year old North Pacific albacore (F_4) and 5-year olds (F_5), 1955-60, based on two sets of assumptions on M and F_o.

Fishing year	$M = 0.2$, $F_o = 0.01$		$M = 0.2$, $F_o = 0.10$	
	F_4	F_5	F_4	F_5
1955	0.350	0.358	0.692	0.827
1956	0.624	0.162	0.777	0.348
1957	0.470	0.725	0.810	1.180
1958	0.392	0.306	0.557	0.800
1959	0.153	0.473	0.263	0.876
1960	0.399	0.328	0.654	0.696

Table 16.--Estimates of cumulative exploitation rates (top line) and expected tag recovery rates (bottom line) for North Pacific albacore, beginning at age 3 or 4. Based on average 1959-65 fishing rates and given for different sets of M and F_o.

	Age at tagging	Quarter of tagging year		Quarter of tagging year + 1				Quarter of tagging year + 2				Quarter of tagging year + 3				Quarter of tagging year + 4				Over all years
		3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
M = 0.2	3	0.11	0.12	0.14	0.20	0.25	0.26	0.29	0.35	0.37	0.38	0.39	0.41	0.41	0.41	0.42	0.42	0.42	0.43	0.44
and		0.08	0.09	0.10	0.14	0.16	0.17	0.18	0.20	0.21	0.22	0.22	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
F_o = 0.01	4	0.08	0.09	0.13	0.23	0.26	0.27	0.29	0.32	0.32	0.33	0.34	0.35	0.35	0.36	0.36	0.36	0.36	0.37	0.37
		0.06	0.07	0.09	0.15	0.16	0.17	0.18	0.19	0.19	0.19	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.21	0.21
M = 0.2	3	0.20	0.22	0.25	0.35	0.44	0.46	0.50	0.59	0.61	0.62	0.64	0.67	0.67	0.68	0.69	0.69	0.69	0.70	0.71
and		0.14	0.16	0.17	0.23	0.28	0.29	0.31	0.35	0.36	0.36	0.37	0.38	0.38	0.38	0.38	0.38	0.38	0.39	0.39
F_o = 0.10	4	0.18	0.22	0.29	0.47	0.52	0.54	0.57	0.63	0.63	0.65	0.67	0.68	0.68	0.69	0.70	0.70	0.70	0.71	0.72
		0.13	0.15	0.20	0.30	0.33	0.34	0.36	0.38	0.38	0.39	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.41	0.41
M = variable	3	0.12	0.14	0.15	0.22	0.28	0.29	0.32	0.38	0.40	0.41	0.42	0.44	0.44	0.45	0.46	0.46	0.46	0.47	0.48
and		0.09	0.10	0.11	0.15	0.18	0.18	0.20	0.23	0.23	0.24	0.24	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.26
F_o = 0.10	4	0.09	0.11	0.15	0.26	0.28	0.30	0.32	0.35	0.35	0.36	0.38	0.38	0.38	0.39	0.40	0.40	0.40	0.40	0.41
		0.06	0.08	0.10	0.16	0.18	0.19	0.20	0.21	0.21	0.22	0.22	0.22	0.22	0.22	0.23	0.23	0.23	0.23	0.23

Table 17.--Aggregate concentration coefficients (ratio of averages CPUE/average of ratios CPUE) in the North Pacific albacore longline fishery, computed on a quarterly basis over the area lat. 20°-40°N, long. 130°-180°E.

Year	1st quarter	2d quarter	3d quarter	4th quarter	All quarters
1952	1.09	0.94	1.28	1.34	1.42
1953	1.19	0.80	1.02	1.11	1.51
1954	1.04	0.73	0.46	1.39	1.34
1955	1.23	2.71	2.45	1.38	1.59
1956	1.05	2.51	2.37	0.91	1.33
1957	1.11	0.53	3.91	1.16	1.32
1958	0.87	0.71	2.21	0.88	1.01
1959	1.03	0.89	1.34	1.31	1.30
1960	1.04	0.27	0.97	0.98	0.93
1961	1.04	1.13	1.05	1.20	1.18
1962	1.42	1.57	1.33	1.55	1.83
1963	1.46	2.17	1.41	1.26	1.55
1964	1.89	2.52	1.47	1.15	2.08
1965	1.70	1.81	1.61	1.39	1.75
1966	1.58	1.02	1.04	1.00	1.44
1967	1.22	1.39	1.10	1.02	1.34
1968	1.36	1.35	1.29	1.04	1.48
1969	1.22	1.14	1.06	1.10	1.40
1970	1.42	0.88	0.86	0.63	1.29
1971	1.29	0.76	0.76	1.09	1.26
1972	1.11	0.88	0.69	1.05	1.15
Average	1.26	1.27	1.41	1.14	1.41

Table 18.--Aggregate average of ratios catch per 100 hooks in the North Pacific albacore longline fishery, computed on a quarterly basis over the area lat. 20°-40°N, long. 130°-180°E.

Year	1st quarter	2d quarter	3d quarter	4th quarter	All quarters
1952	3.15	0.54	0.02	1.50	1.69
1953	2.77	0.28	0.04	1.50	1.49
1954	1.89	0.55	0.07	1.10	1.08
1955	1.60	0.12	0.09	0.68	0.83
1956	1.47	0.29	0.06	0.64	0.84
1957	1.97	0.45	0.23	0.64	1.10
1958	2.09	0.42	0.11	0.98	1.19
1959	1.70	0.10	0.07	0.52	0.77
1960	1.30	1.02	0.14	0.74	0.93
1961	1.38	0.21	0.05	0.56	0.72
1962	1.23	0.12	0.08	0.34	0.57
1963	0.86	0.22	0.10	0.81	0.61
1964	1.44	0.16	0.05	0.36	0.66
1965	0.93	0.15	0.04	0.68	0.53
1966	2.05	0.76	0.14	1.08	1.20
1967	2.08	0.42	0.08	0.90	1.09
1968	1.91	0.32	0.08	0.50	0.90
1969	1.22	0.29	0.07	0.60	0.70
1970	1.27	0.15	0.09	0.58	0.68
1971	0.78	0.12	0.07	0.36	0.45
1972	1.11	0.11	0.11	0.36	0.59
Average	1.63	0.32	0.08	0.74	0.89

Table 19.--Total hooks fished (millions) by Japanese longliners in the North Pacific in the area lat. 20°-40°N, long. 130°-180°E, on a quarterly basis, 1952-72.

Year	1st quarter	2d quarter	3d quarter	4th quarter	Total
1952	36.455	11.335	3.903	17.587	69.286
1953	39.870	11.538	3.393	18.799	73.600
1954	51,149	19.436	4.895	14.046	89.526
1955	52.131	21.213	2.680	22.924	98.948
1956	47.822	18.684	2.000	21.427	89.933
1957	46.943	14.849	2.256	21.832	85.880
1958	44.410	1.5991	2.790	28.704	91.895
1959	41.983	13.594	10.633	28.150	94.360
1960	51.008	21.587	10.085	36.384	119.064
1961	48.299	23.013	12.731	22.932	106.975
1962	40.327	15.340	6.347	16.703	78.717
1963	29.188	13.868	5.155	23.304	71.515
1964	27.833	10.415	9.024	15.927	63.199
1965	27.415	10.914	12.728	22.656	73.713
1966	30.387	11.291	10.698	27.412	79.788
1967	47.609	13.307	13.560	38.291	112.767
1968	38.540	9.414	9.594	34.461	92.009
1969	40.300	7.146	7.822	29.767	85.035
1970	26.032	6.715	7.607	25.280	65.634
1971	26.517	5.818	8.686	24.256	65.277
1972	18.359	4.525	5.152	15.703	43.739

LIST OF FIGURES

12. Estimated average aggregate fishing mortality rate, $\bar{F}_w$, by year class, based on M = 0.20 and F_o = 0.001, 0.01, 0.10, 0.20 or 0.40.

13. Estimated average aggregate fishing mortality rate, $\bar{F}_w$, by year class, based on M = 0.40 and F_o = 0.001, 0.01, 0.10, 0.20 or 0.40.

14. Estimated spawning biomass (10 ** 9 kg) by year, 1952-72, based on M = variable and F_o = 0.10, 0.20 or 0.40.

15. Estimated spawning biomass (10 ** 9 kg) by year, 1952-72, based on M = 0.20 and F_o = 0.10, 0.20 or 0.40.

16. Estimated spawning biomass (10 ** 9 kg) by year, 1952-72, based on F_o = 0.01 and M = 0.20 or 0.40.

17. Comparison of estimated spawning biomass of North Pacific albacore (10 ** 6 MT) (based on M = 0.20 and F_o = 0.01) and average annual catch of albacore per boat (MT) in the Hawaiian longline fishery, 1952-68.

18. Estimated recruitment of North Pacific albacore at beginning of third year following birth year (at age 2.5 years), by year class, for M = variable and F_o = 0.10, 0.20 or 0.40.

19. Estimated recruitment of North Pacific albacore at beginning of third year following birth year (at age 2.5 years), by year class, for M = 0.20 and F_o = 0.10, 0.20 or 0.40.

20. Estimated recruitment of North Pacific albacore at beginning of third year following birth year (at age 2.5 years), by year class, for F_o = 0.01 and M = 0.20 or 0.40.

21. Relationship between recruitment and spawning biomass for North Pacific albacore, for spawning years 1952-66, based on M = variable and F_o = 0.10.

22. Relationship between recruitment and spawning biomass for North Pacific albacore, for spawning years 1952-66, based on M = 0.2 and F_o = 0.10.

23. Relationship between recruitment and spawning biomass for North Pacific albacore, for spawning years 1952-66, based on M = 0.20 and F = 0.01.

24. Estimated yield per recruit (kg) by year class, based on M = 0.20 and F = 0.001, 0.01, 0.10, 0.20 or 0.40.

25. Estimated yield per recruit (kg) by year class, based on M = 0.40 and F_o = 0.001, 0.01, 0.10, 0.20 or 0.40.

26. Estimated yield per recruit (kg) by year class, based on M = variable and F_o = 0.10, 0.20 or 0.40.

27. Expected yield per recruit (kg) of North Pacific albacore as a function of fishing mortality rates (F-multiplier) and minimum age in catch (tmin, years), based on M = variable and F_o = 0.10, and same gear composition as in base period (GF = 1.0, 1.0, 1.0).

28. Expected yield per recruit (kg) of North Pacific albacore as a function of fishing mortality rates (F-multiplier) and minimum age in catch (tmin, years), based on M = 0.20 and F_o = 0.01.

29. Expected yield per recruit (kg) of North Pacific albacore as a function of fishing mortality rates (F-multiplier) and minimum age in catch (tmin, years), based on M = 0.20 and F_o = 0.10.

30. Expected yield per recruit (kg) of North Pacific albacore as a function of F-multiplier, by fishery, with tmin = 2.5 years and based on M = 0.20 and F_o = 0.20.

31. Estimated catchability coefficient in the North Pacific albacore longline fishery by year, 1952-72, based on M = 0.20 and F_o = 0.01.

32. Estimated average catch per 100 hooks in the North Pacific albacore longline fishery, by year, 1952-72.

33. Estimated number of hooks fished during the first quarter of each fishing year, 1952-72, in the North Pacific albacore longline fishery.

34. Estimated average abundance of North Pacific albacore by year, 1952-72, based on M = 0.2 and F_o = 0.01 (figures for 1966-70 are positively biased).

35. Estimated proportion of hooks fished during the second half of each year, 1952-72, in the North Pacific albacore longline fishery.

36. Estimated catchability coefficient in the American North Pacific albacore fishery (per boat-day), by year, 1952-70. Based on M = 0.20 and F_o = 0.01, and approximate levels of nominal effort.

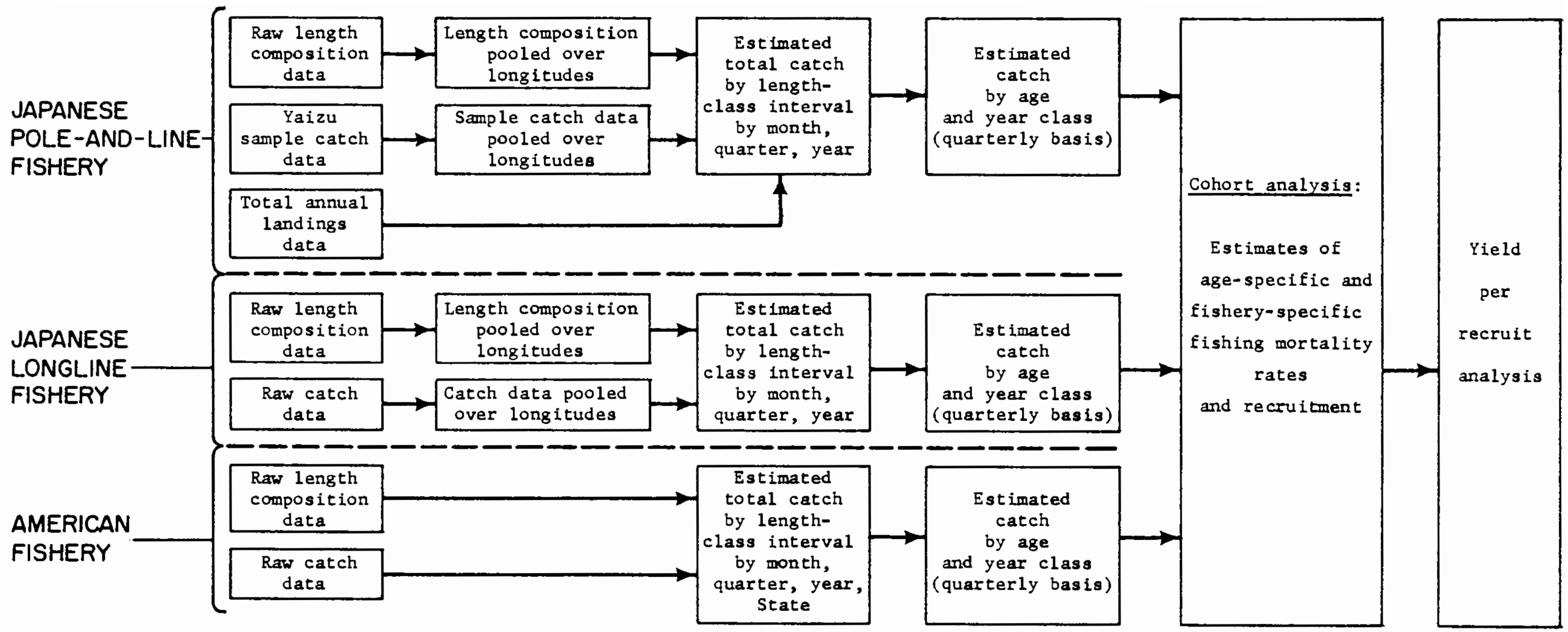
JAPANESE POLE-AND-LINE FISHERY
Raw length composition data
Length composition pooled over longitudes
Yaizu sample catch data
Sample catch data pooled over longitudes
Total annual landings data
Estimated total catch by length-class interval by month, quarter, year
Estimated catch by age and year class (quarterly basis)
JAPANESE LONGLINE FISHERY
Raw length composition data
Length composition pooled over longitudes
Raw catch data
Catch data pooled over longitudes
Estimated total catch by length-class interval by month, quarter, year
Estimated catch by age and year class (quarterly basis)
AMERICAN FISHERY
Raw length composition data
Raw catch data
Estimated total catch by length-class interval by month, quarter, year, State
Estimated catch by age and year class (quarterly basis)
Cohort analysis:
Estimates of age-specific and fishery-specific fishing mortality rates and recruitment
Yield per recruit analysis

Figure 1

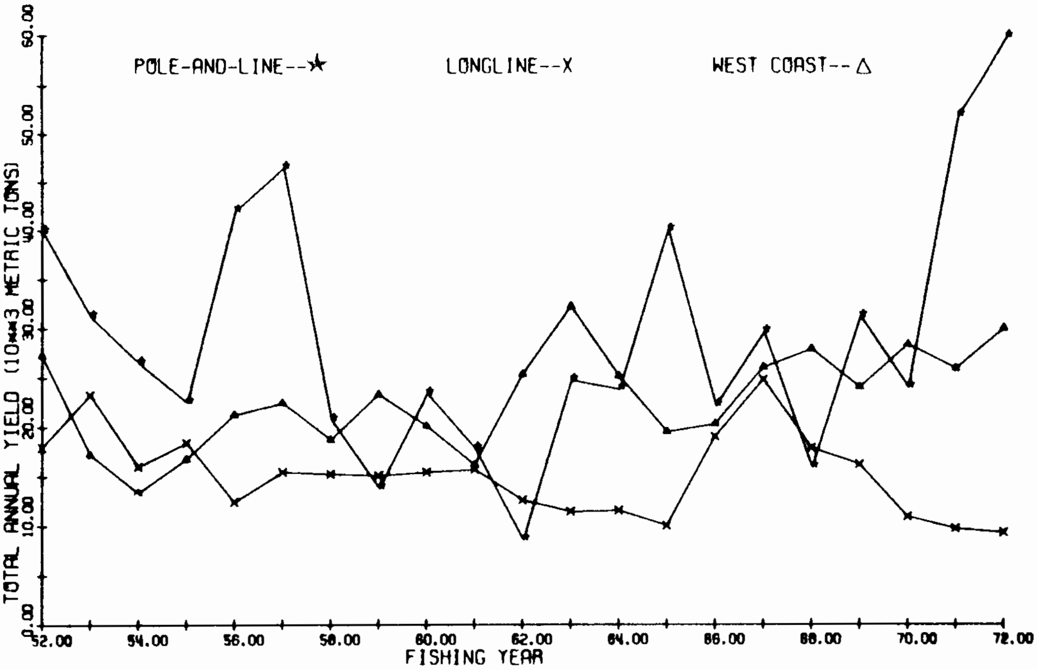

Figure 2

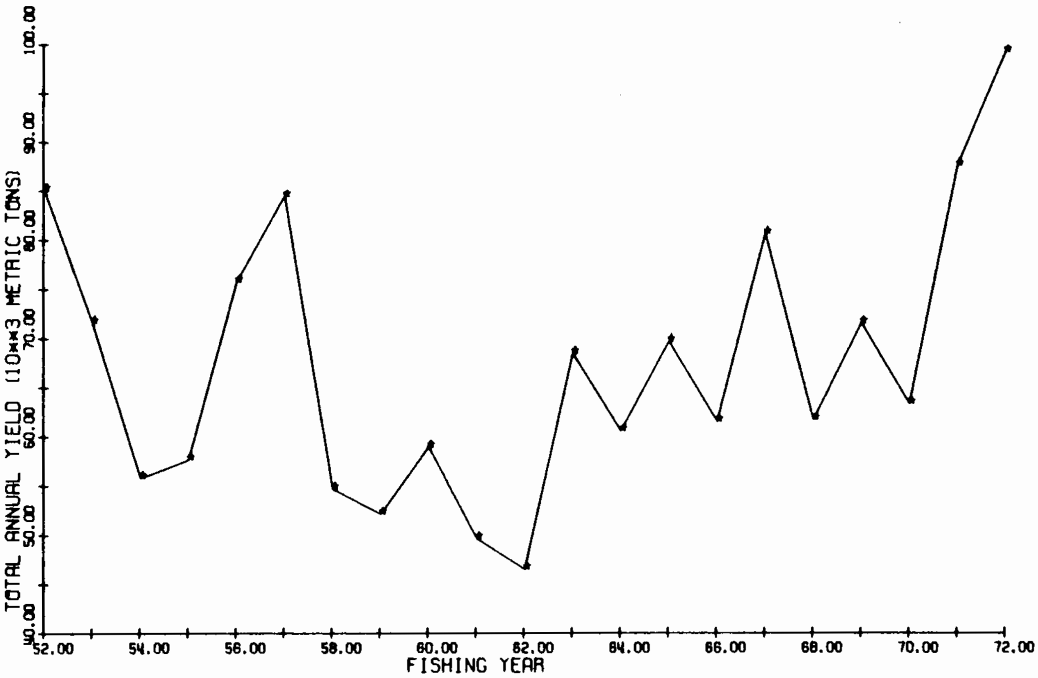

Figure 3

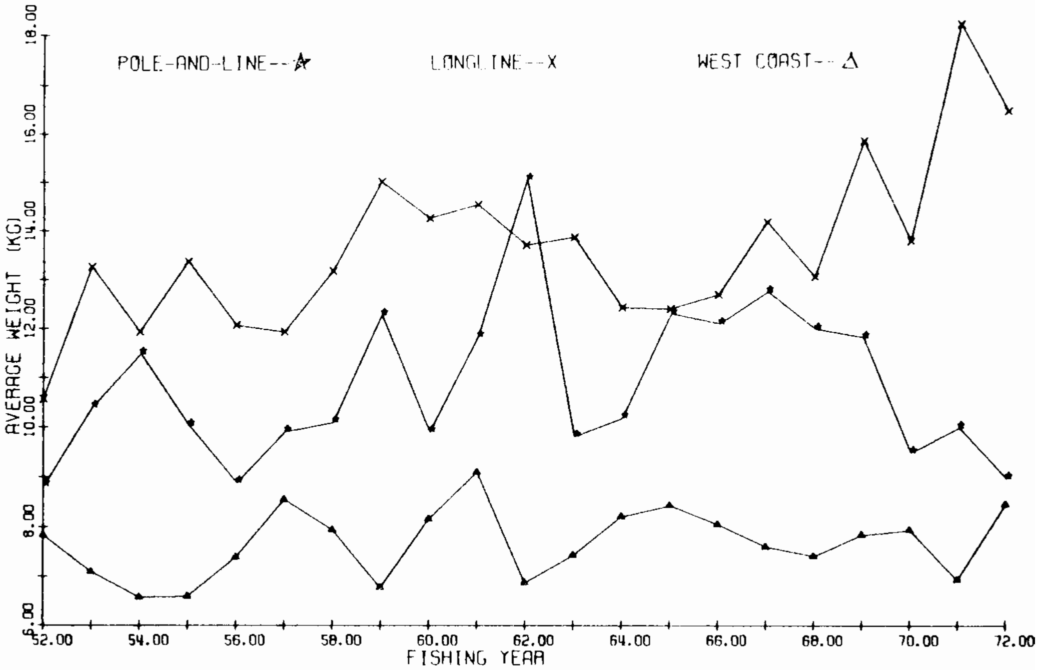

Figure 4

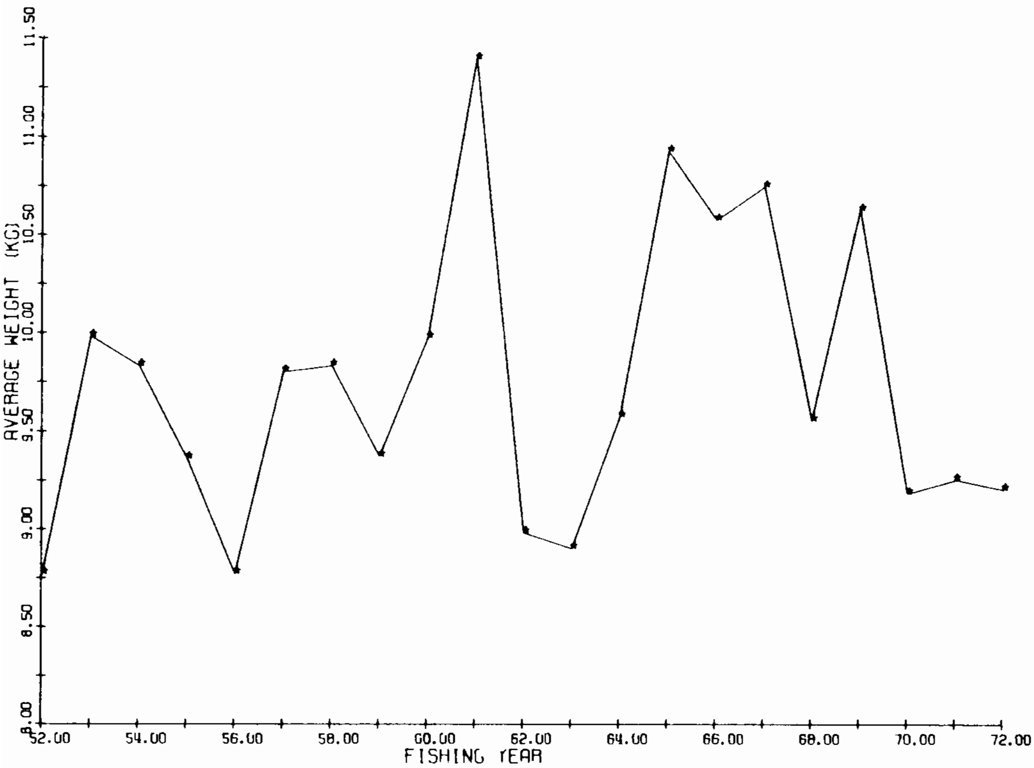

Figure 5

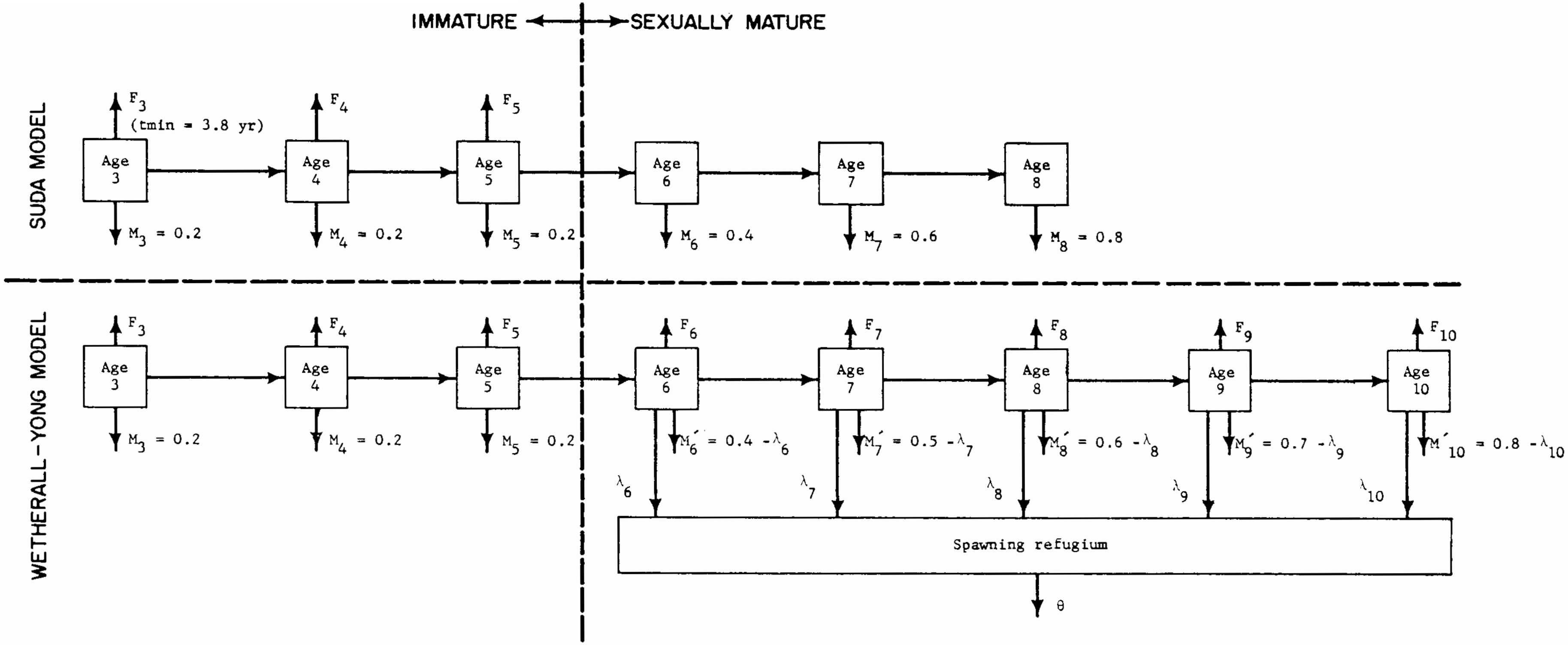
IMMATURE
SEXUALLY MATURE
SUDA MODEL
WETHERALL-YONG MODEL
F3
(tmin = 3.8 yr)
F4
F5
F6
F7
F8
F9
F10
Age 3
Age 4
Age 5
Age 6
Age 7
Age 8
Age 9
Age 10
M3 = 0.2
M4 = 0.2
M5 = 0.2
M6 = 0.4
M7 = 0.6
M8 = 0.8
M′6 = 0.4 - λ6
M′7 = 0.5 - λ7
M′8 = 0.6 - λ8
M′9 = 0.7 - λ9
M′10 = 0.8 - λ10
λ6
λ7
λ8
λ9
λ10
Spawning refugium
θ

Figure 6

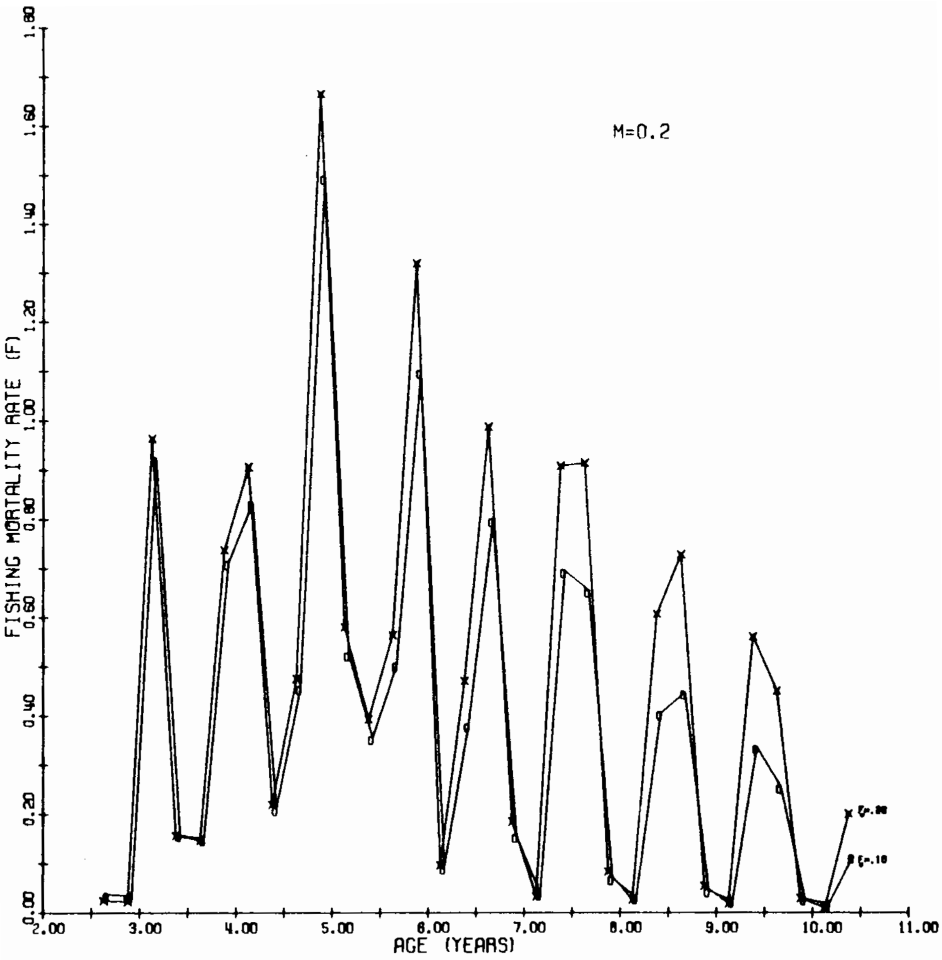
M=0.2
FISHING MORTALITY RATE (F)
AGE (YEARS)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
11.00
ξ=.10

Figure 7

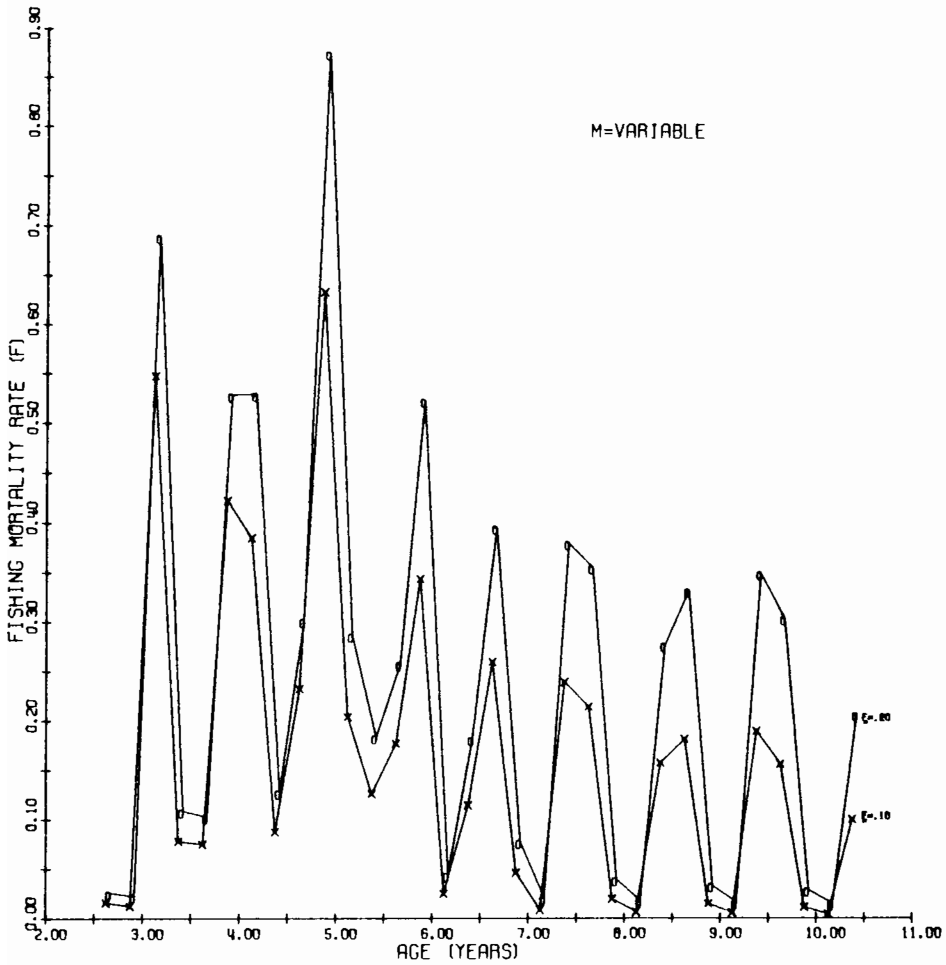
M=VARIABLE
FISHING MORTALITY RATE (F)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
AGE (YEARS)
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
11.00
ξ=.20
ξ=.10

Figure 8

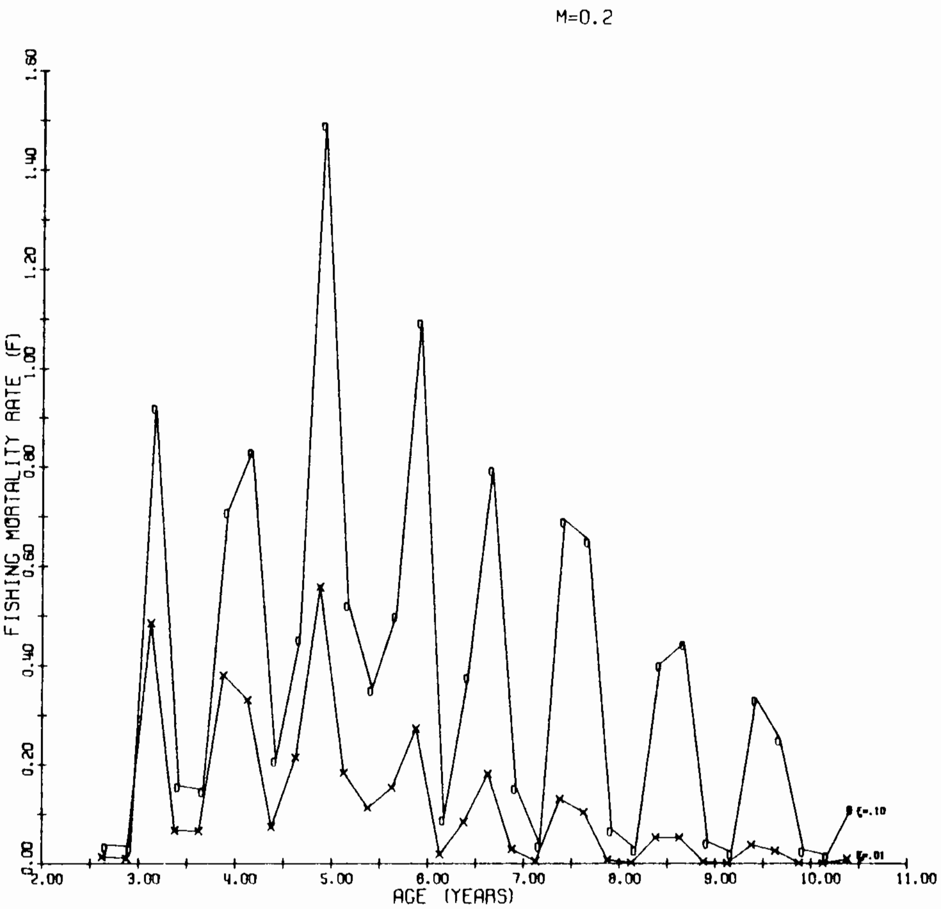
M=0.2
FISHING MORTALITY RATE (F)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
11.00
AGE (YEARS)
=.10
=.01

Figure 9

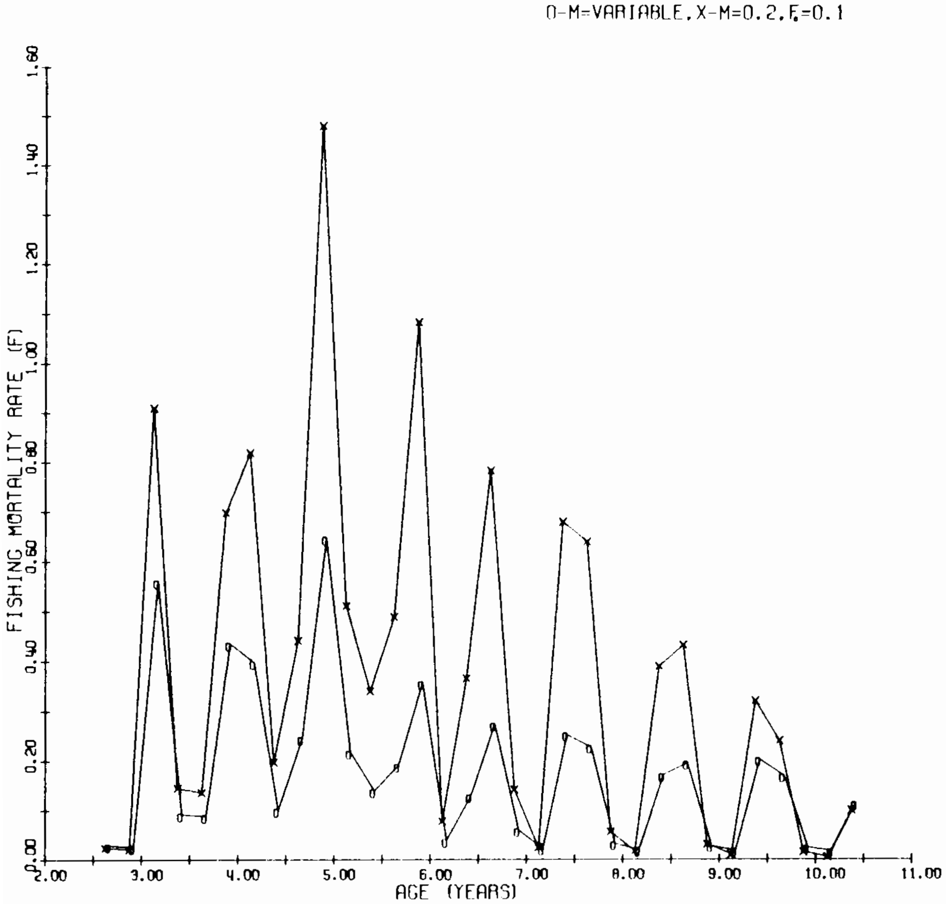
O-M=VARIABLE, X-M=0.2, F=0.1
FISHING MORTALITY RATE (F)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
11.00
AGE (YEARS)

Figure 10

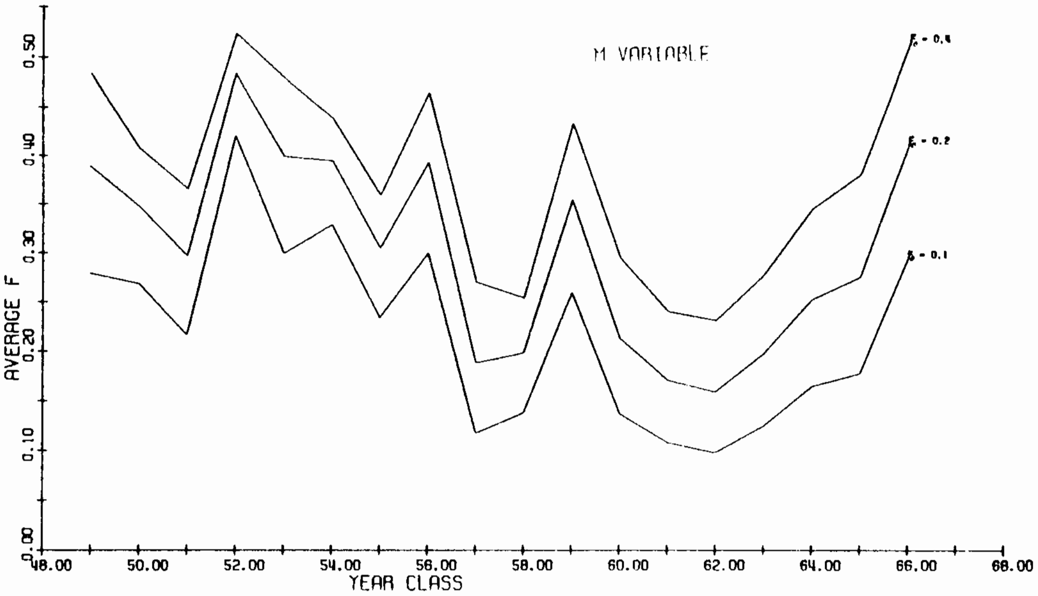

Figure 11

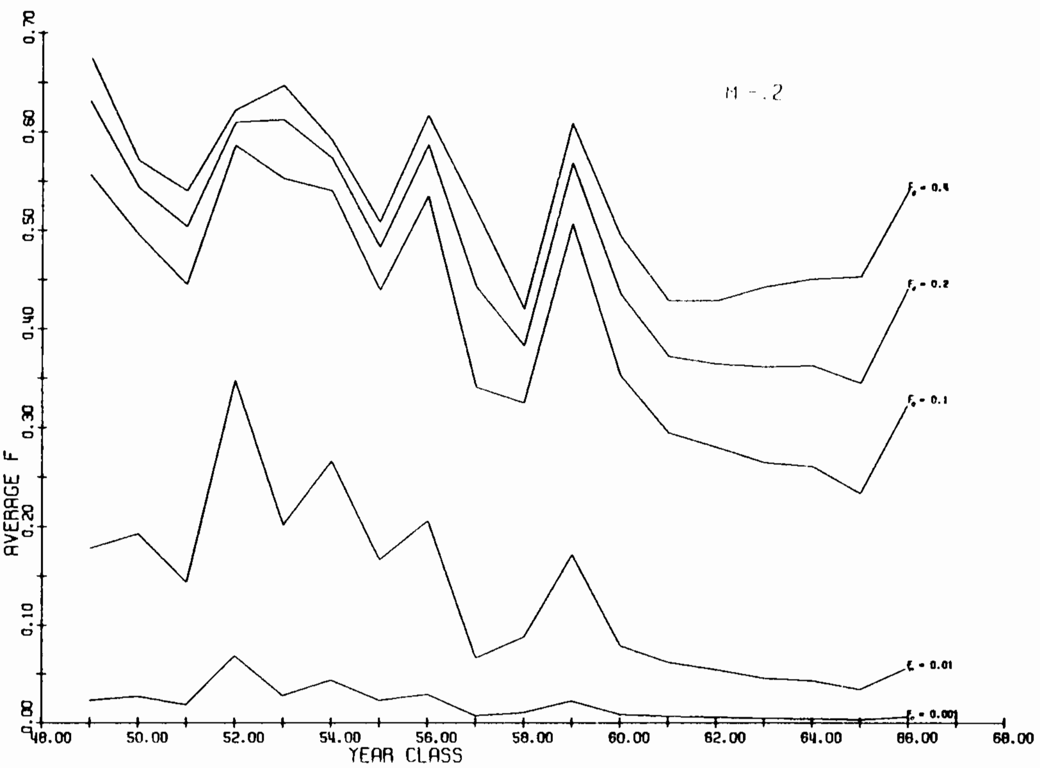

Figure 12

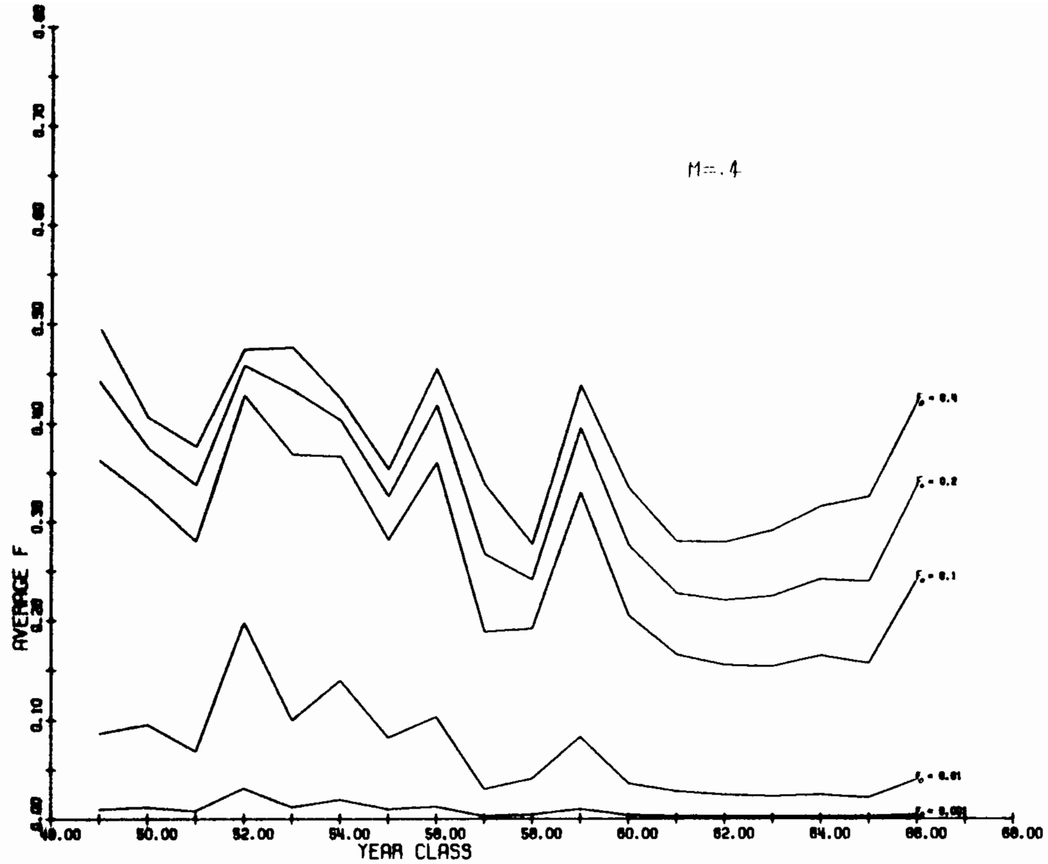
M=.4
AVERAGE F
YEAR CLASS
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
48.00
50.00
52.00
54.00
56.00
58.00
60.00
62.00
64.00
66.00
68.00

Figure 13

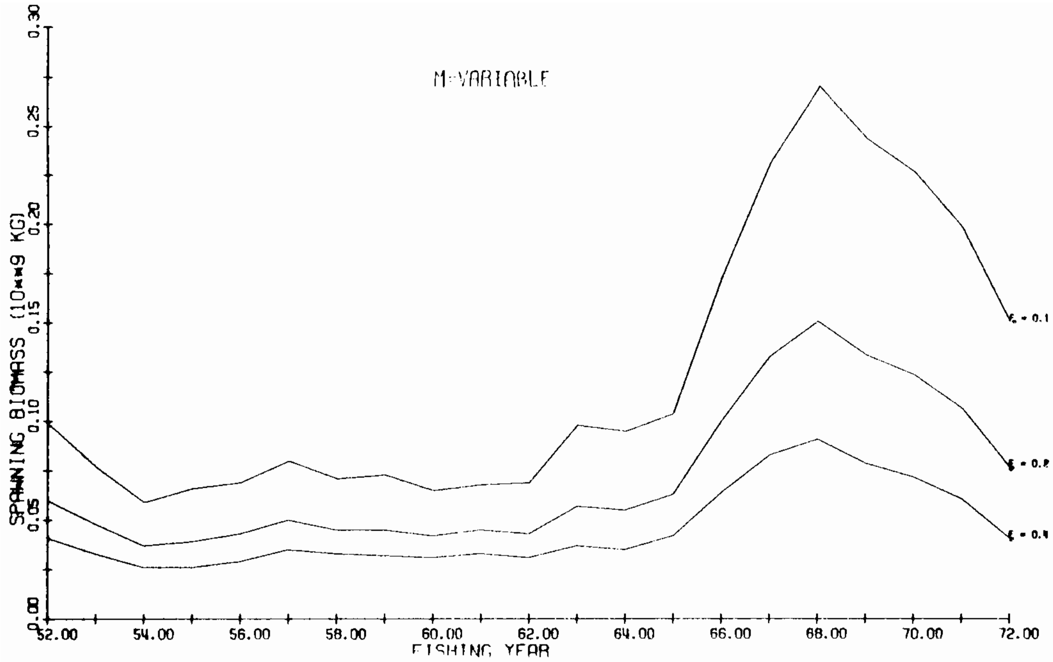

Figure 14

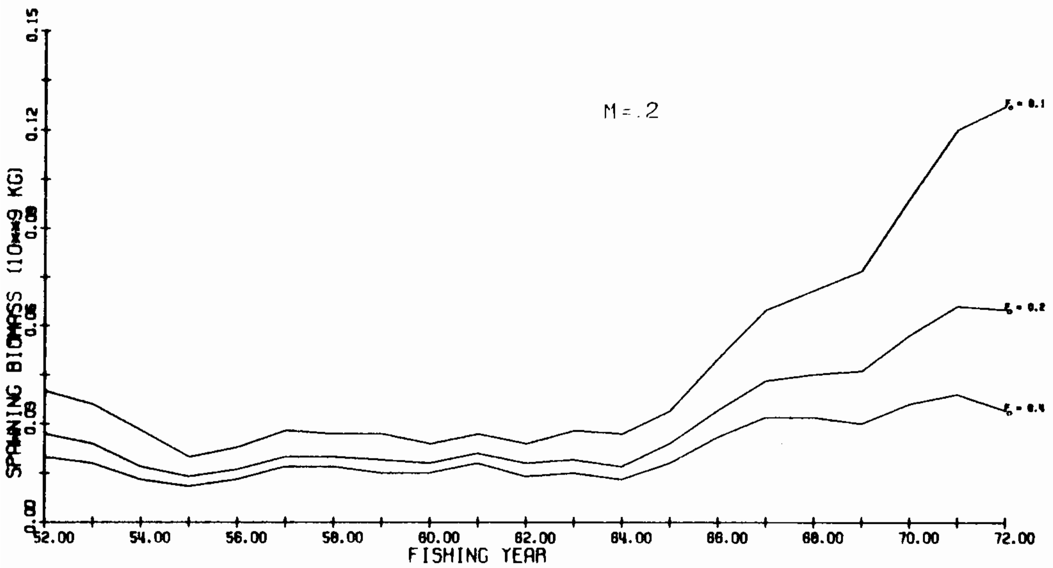

Figure 15

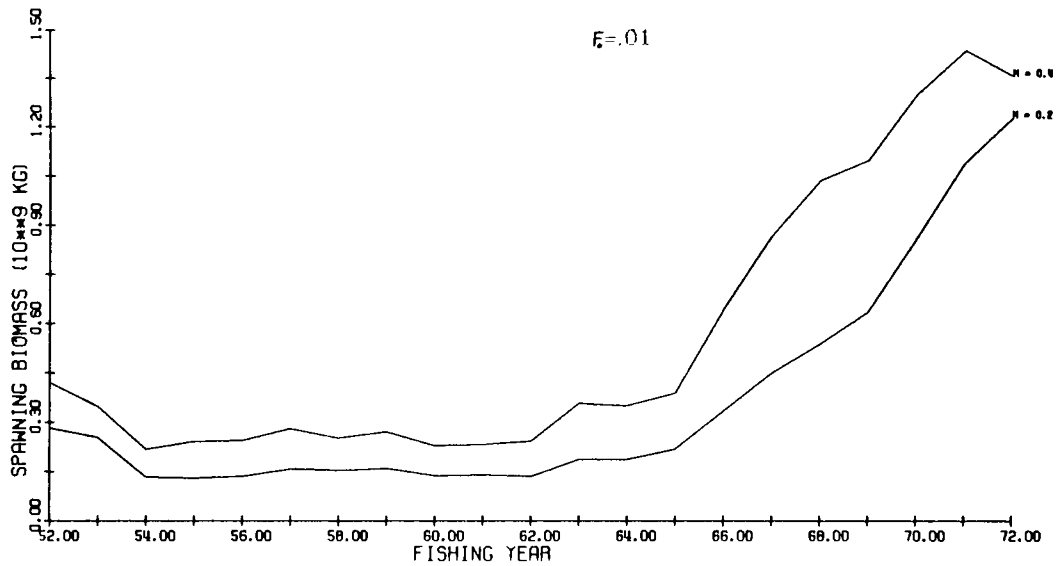

Figure 16

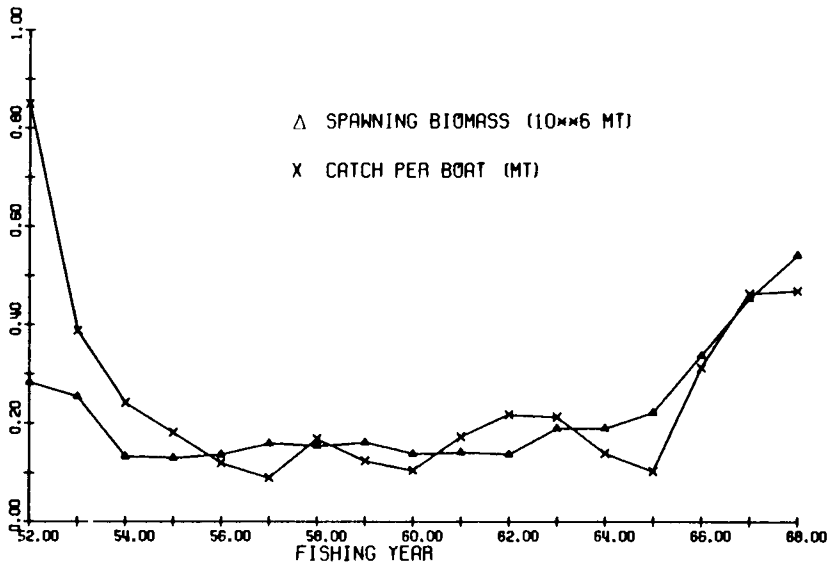

Figure 17

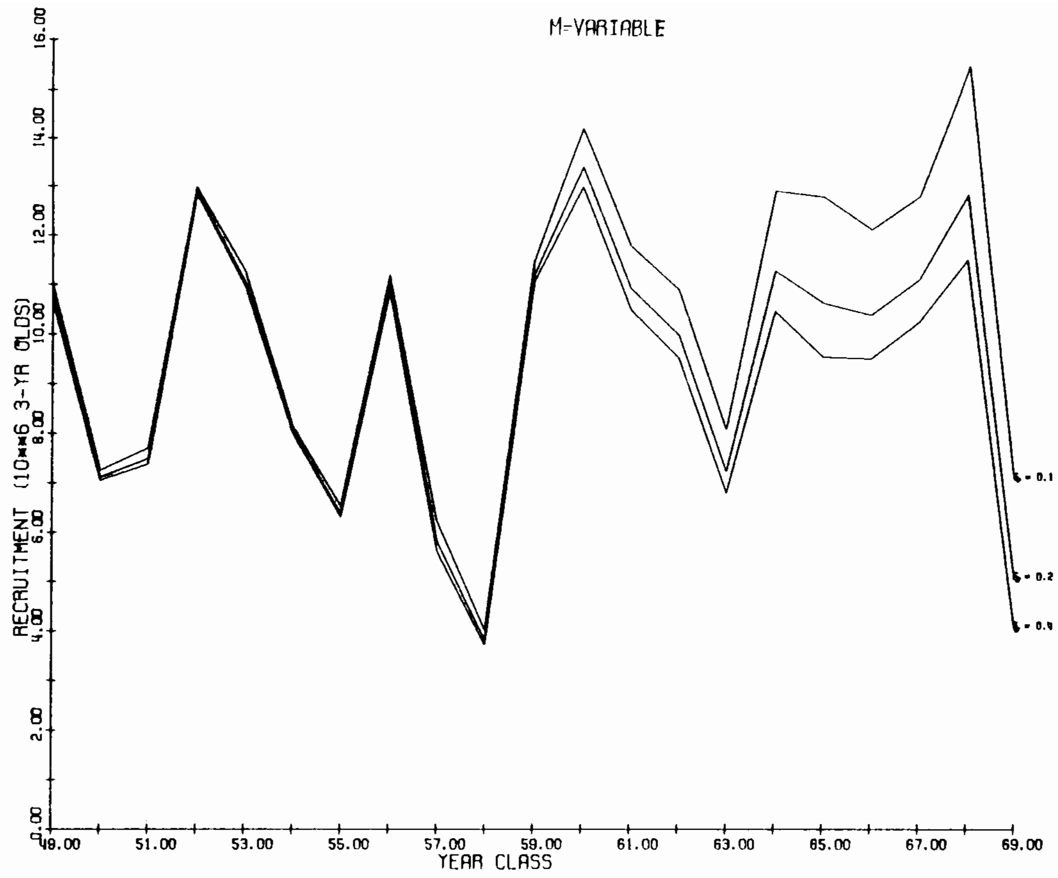

Figure 18

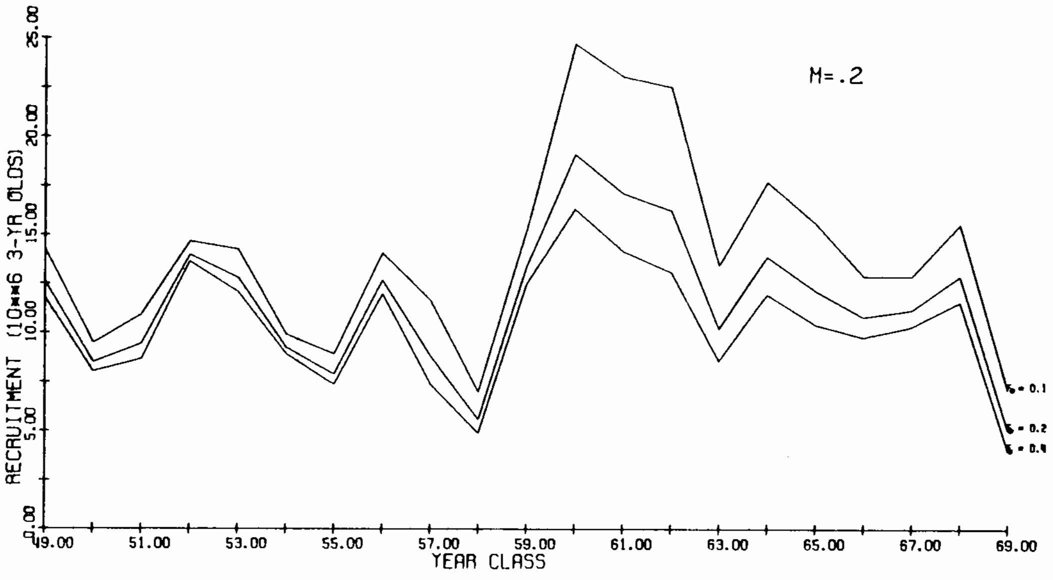

Figure 19

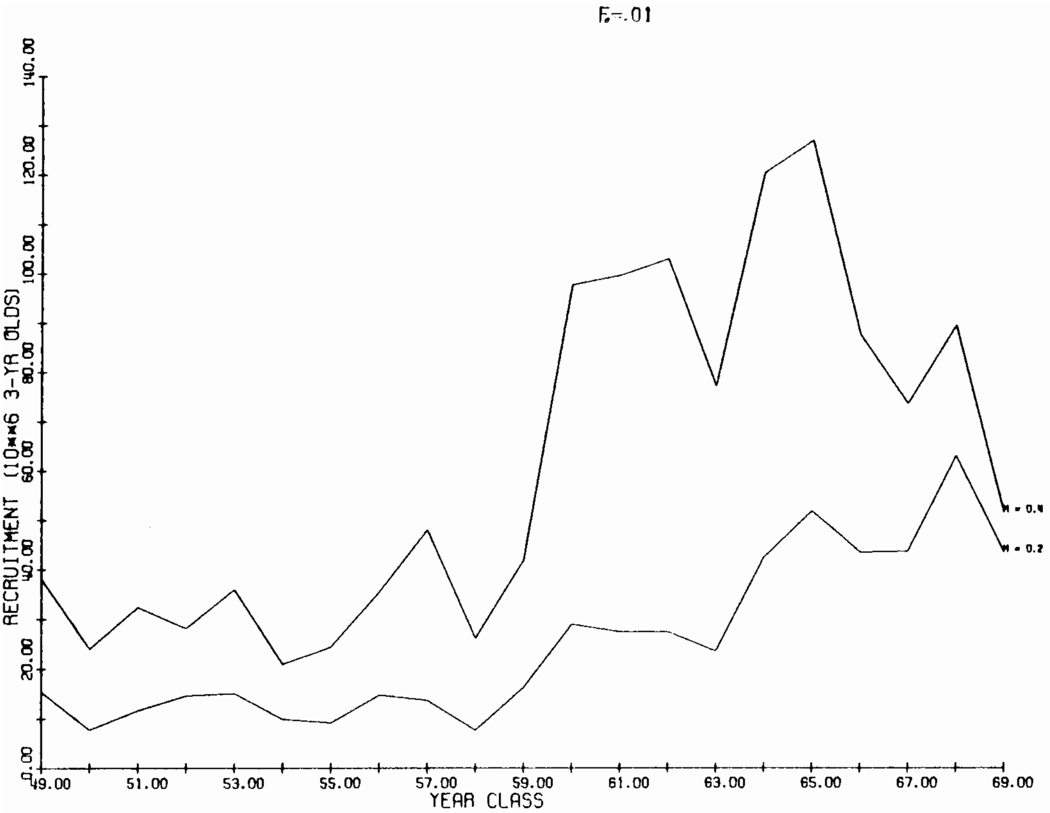
F=.01
RECRUITMENT (10**6 3-YR OLDS)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
49.00
51.00
53.00
55.00
57.00
59.00
61.00
63.00
65.00
67.00
69.00
YEAR CLASS
M = 0.4
M = 0.2

Figure 20

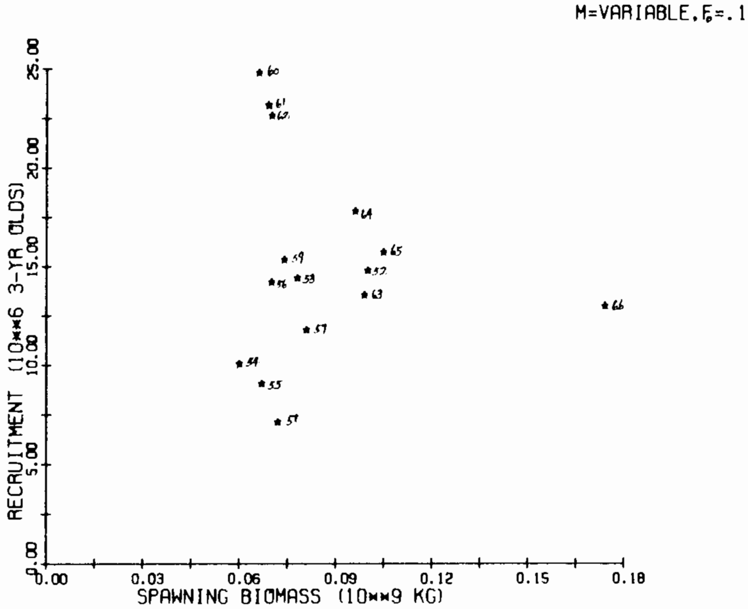
M=VARIABLE,F=.1
RECRUITMENT (10**6 3-YR OLDS)
SPAWNING BIOMASS (10**9 KG)
0.00
5.00
10.00
15.00
20.00
25.00
0.00
0.03
0.06
0.09
0.12
0.15
0.18

Figure 21

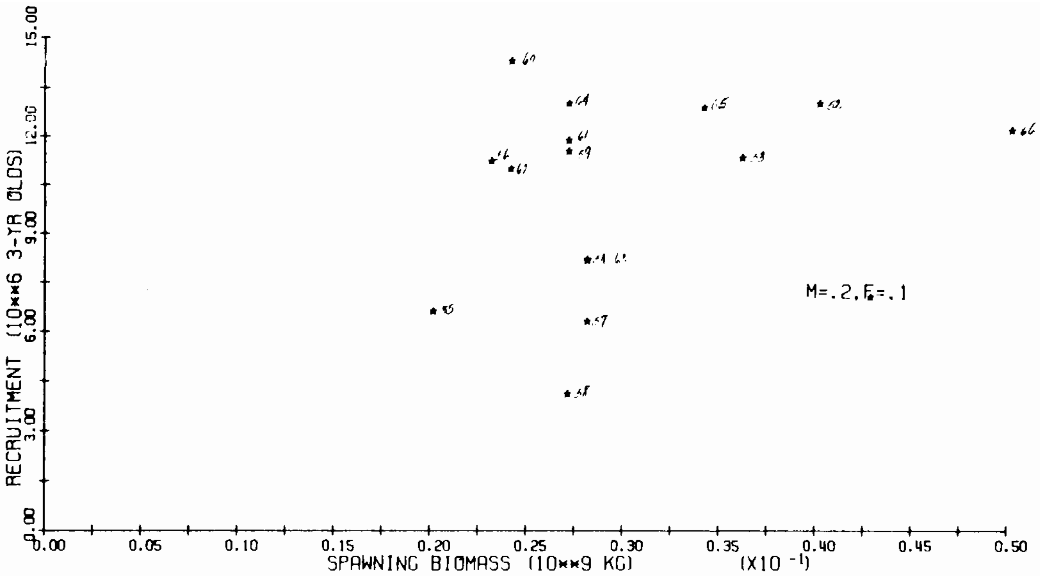

Figure 22

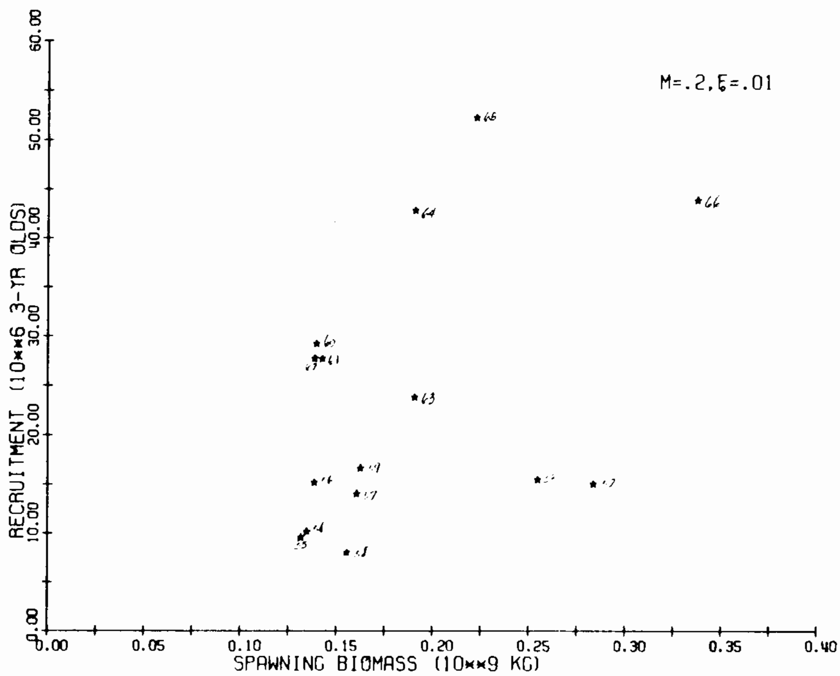

Figure 23

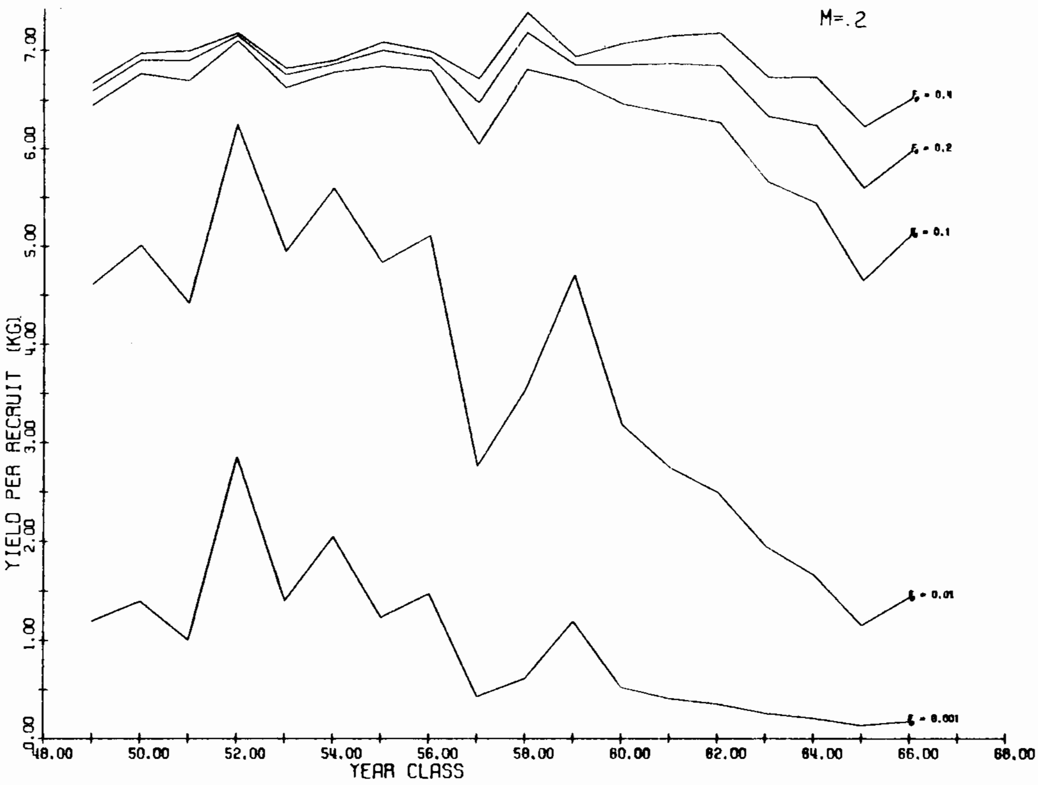

Figure 24

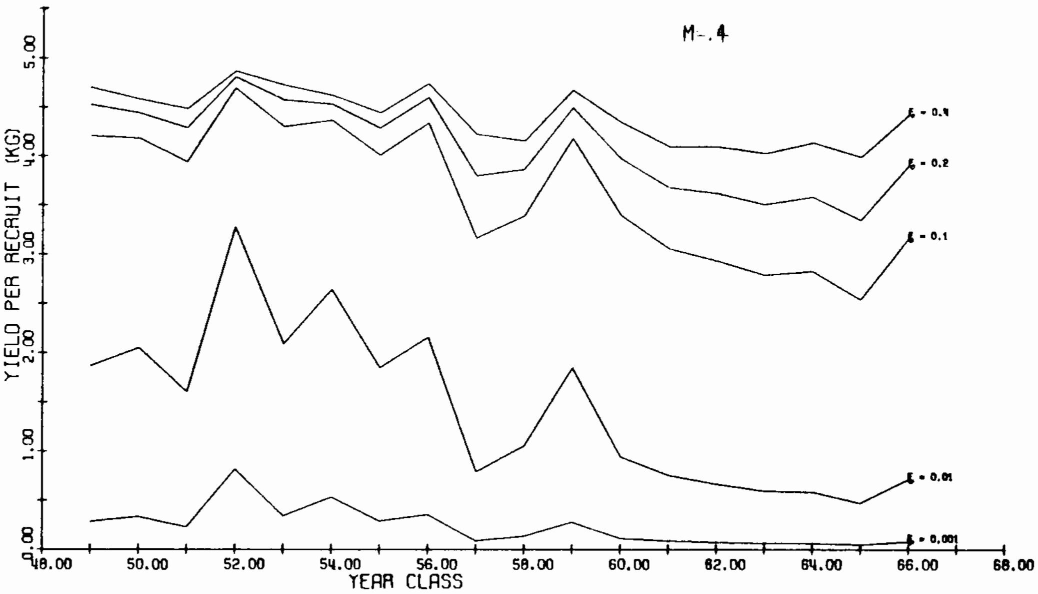

Figure 25

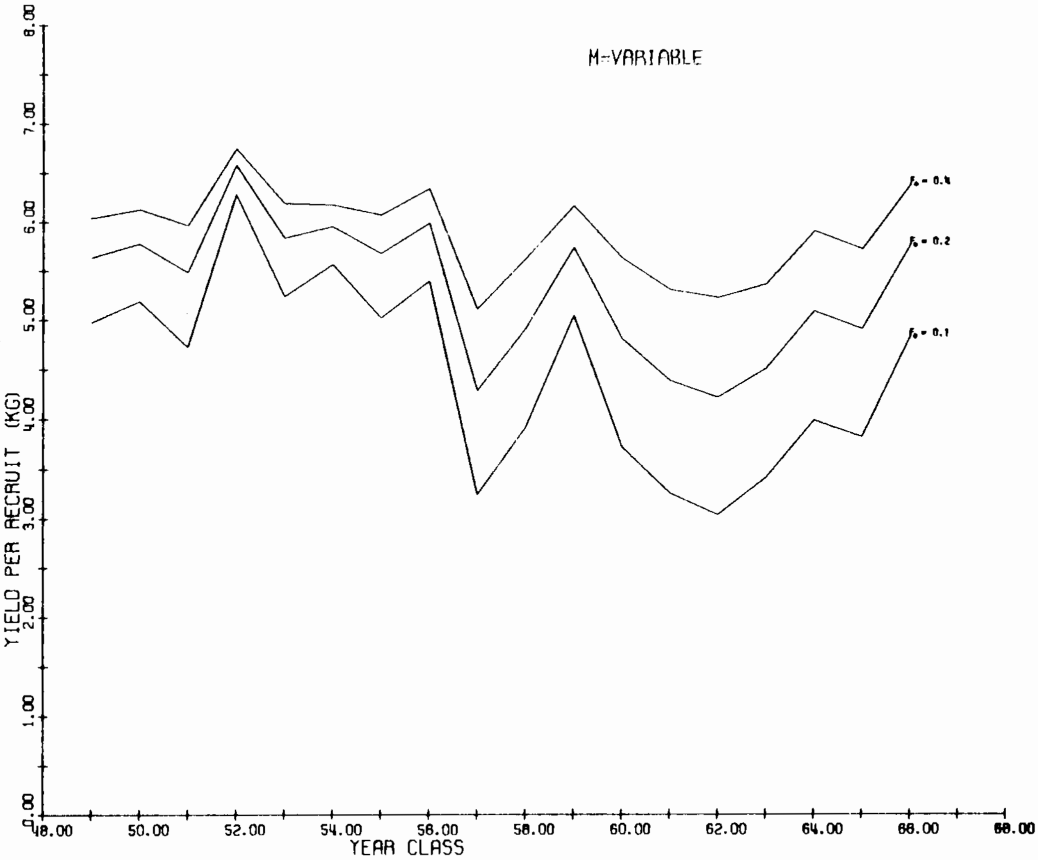
M=VARIABLE
YIELD PER RECRUIT (KG)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
YEAR CLASS
48.00
50.00
52.00
54.00
56.00
58.00
60.00
62.00
64.00
66.00
68.00
F0 = 0.4
F0 = 0.2
F0 = 0.1

Figure 26

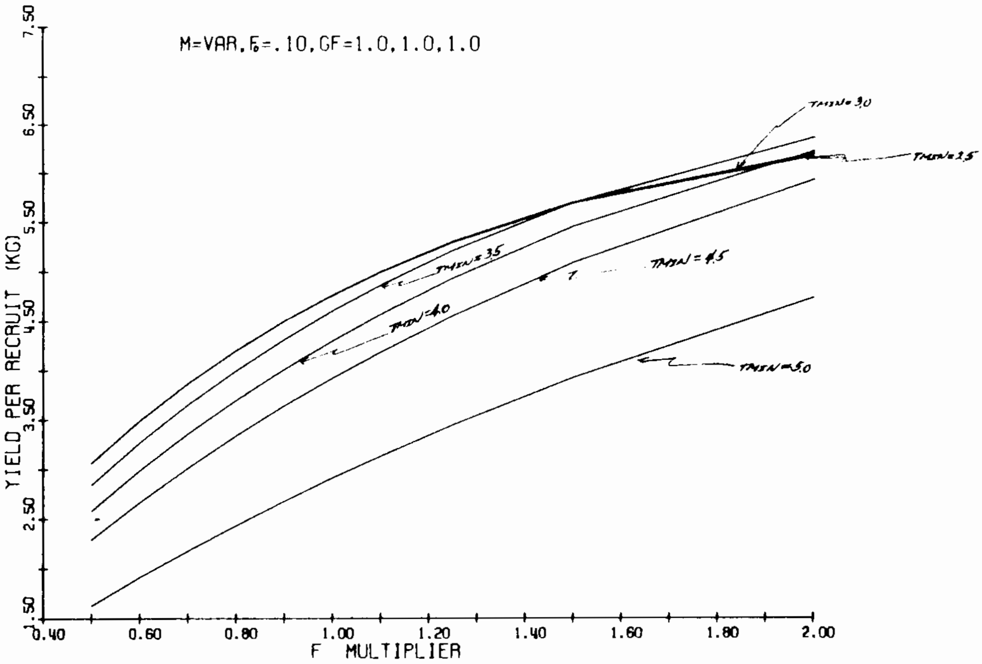

Figure 27

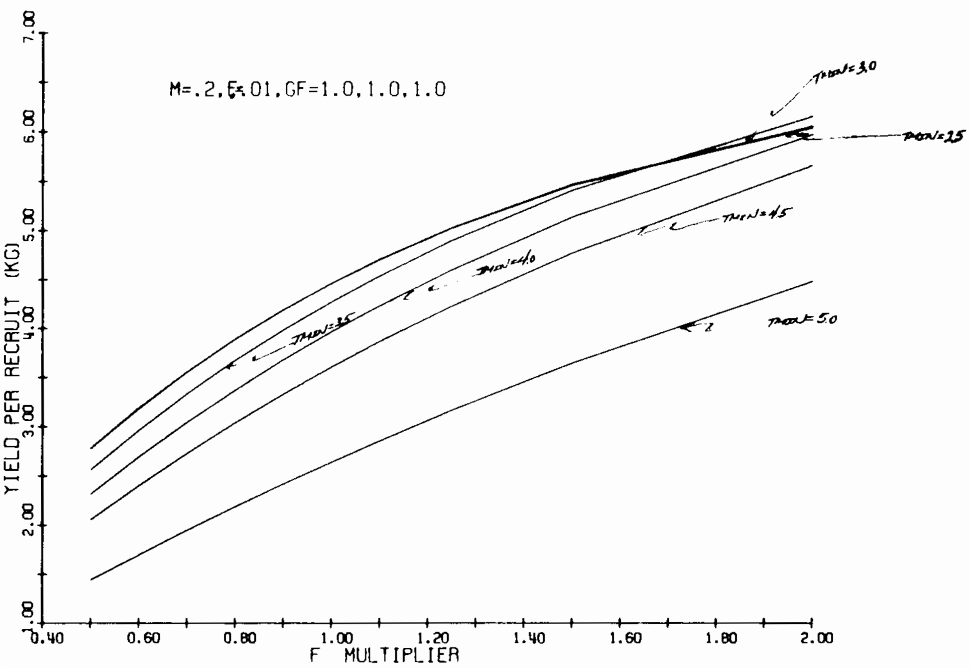

Figure 28

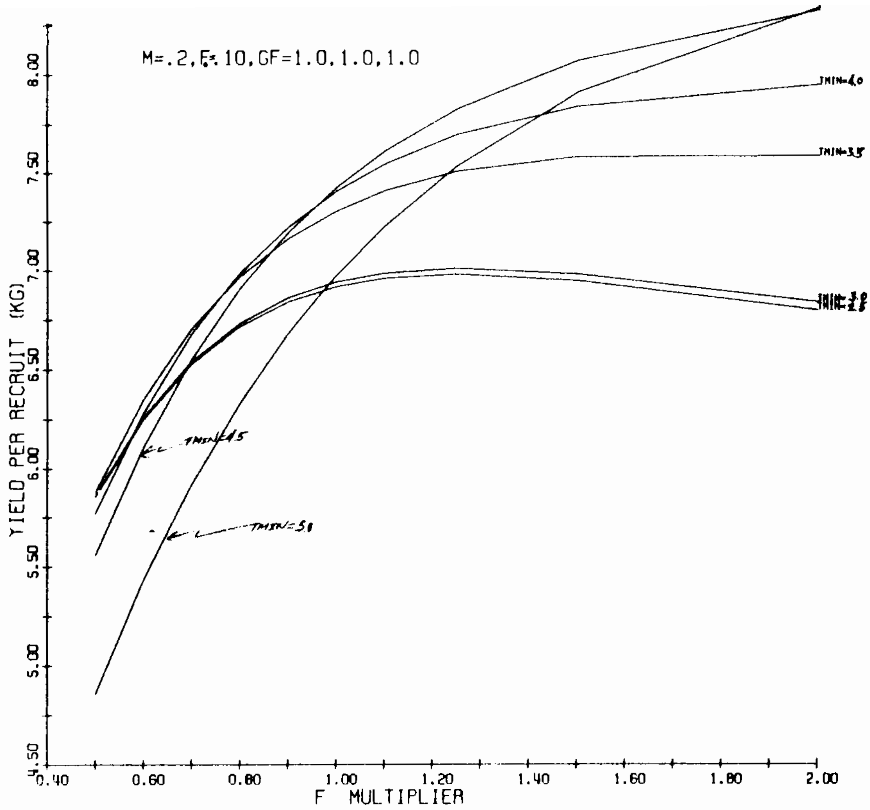

Figure 29

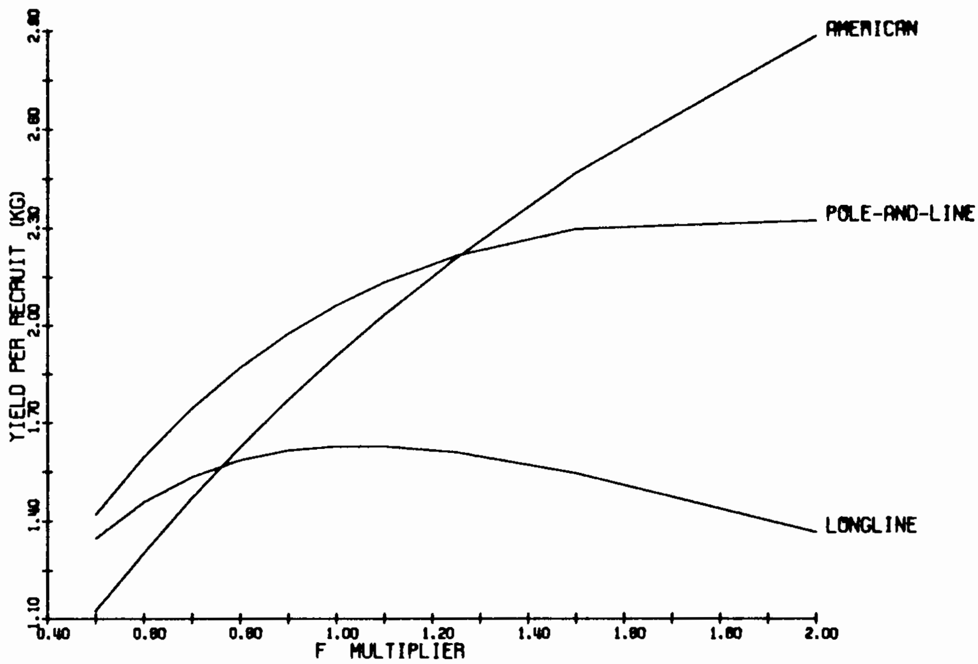

Figure 30

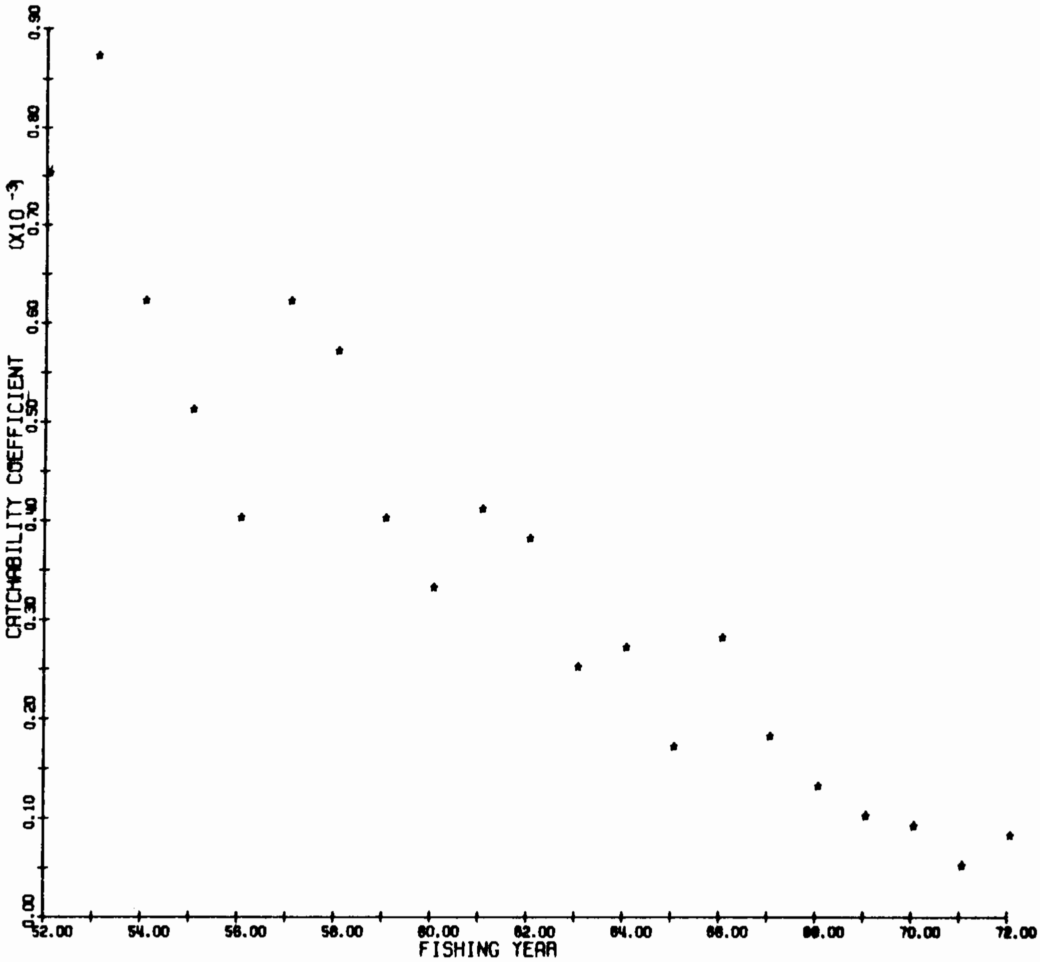

Figure 31

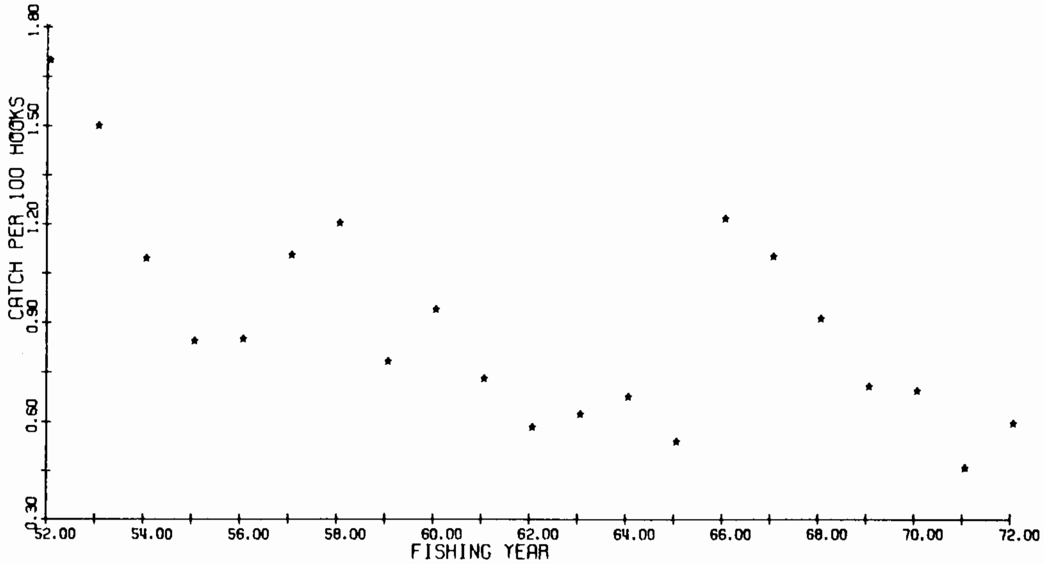

Figure 32

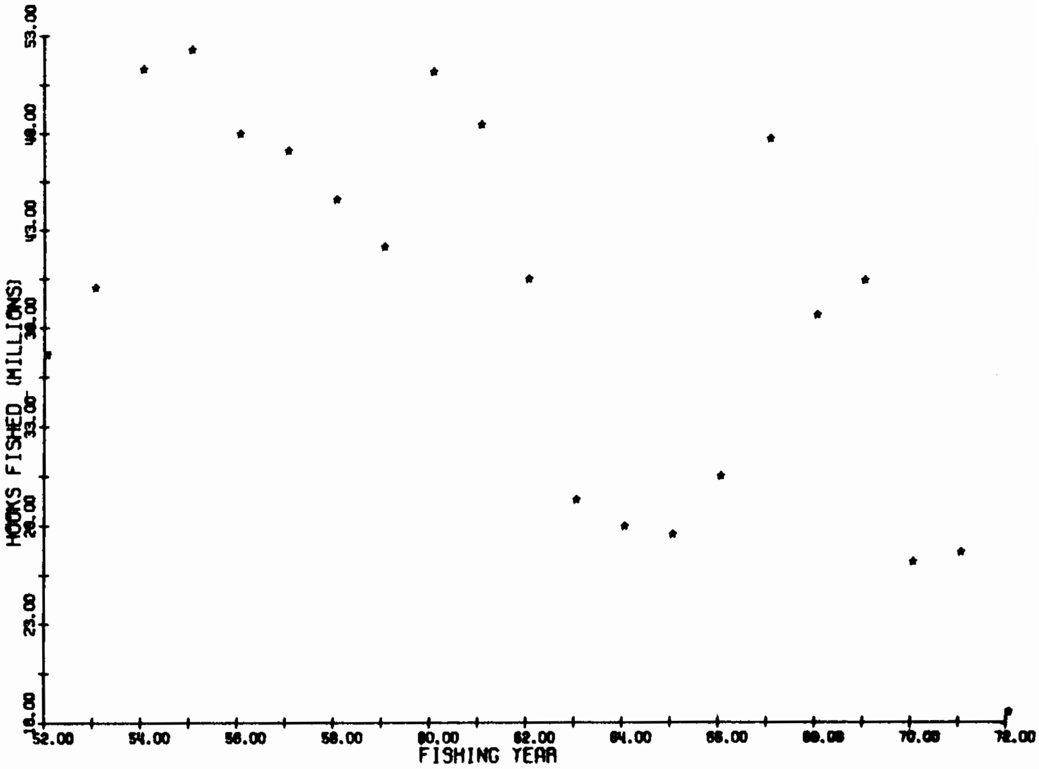

Figure 33

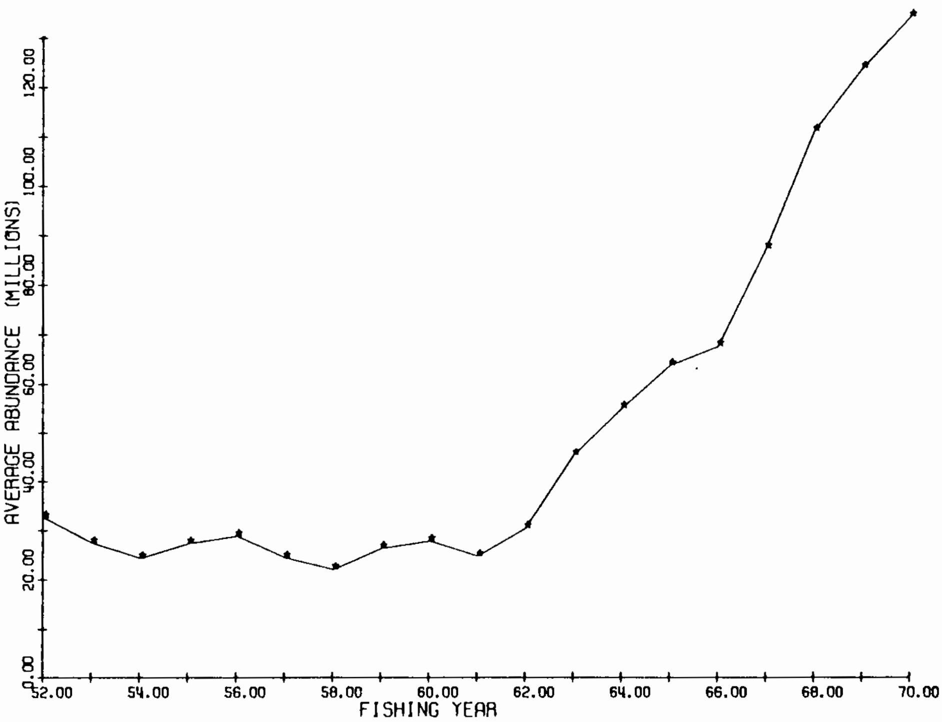

Figure 34

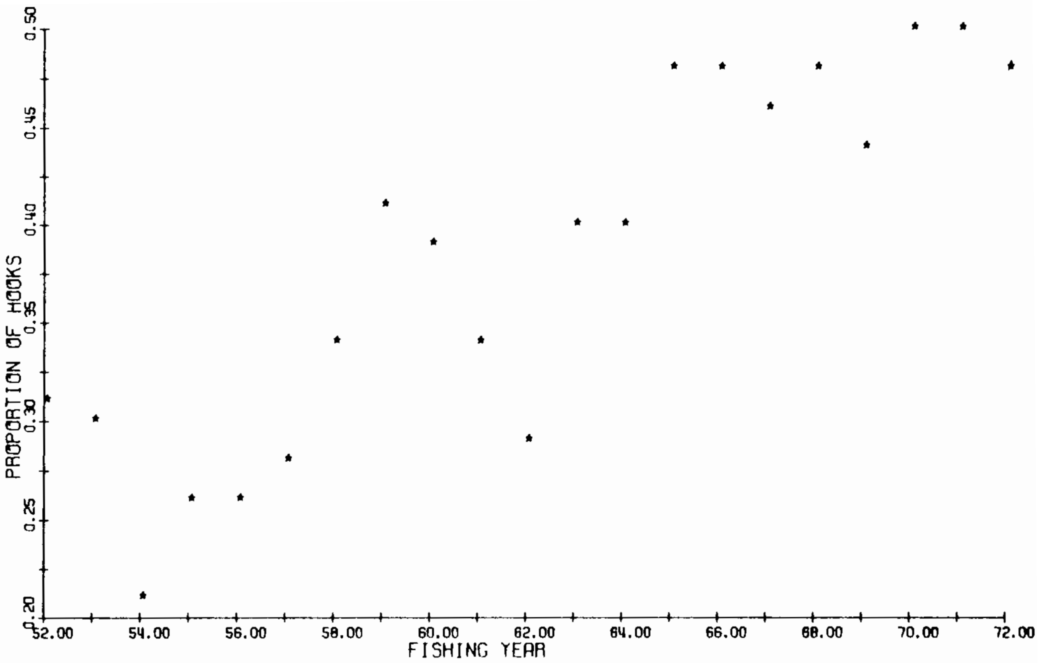

Figure 35

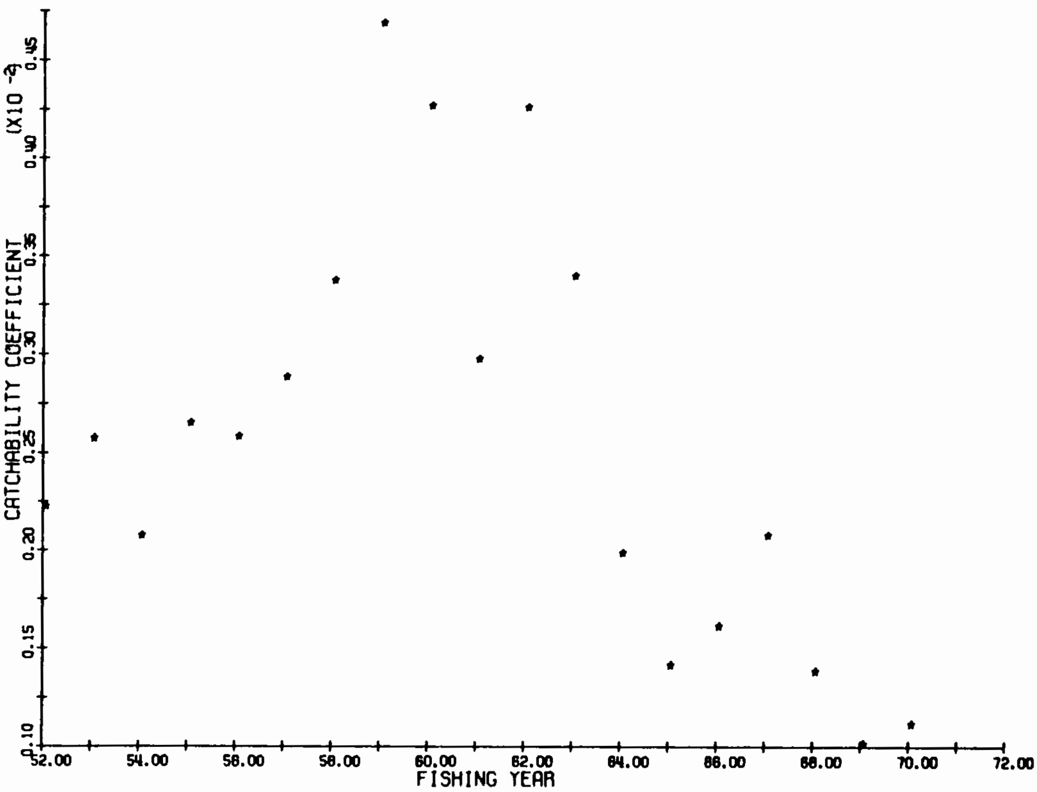

Figure 36

A COHORT ANALYSIS OF THE NORTH PACIFIC ALBACORE STOCK
AND AN ASSESSMENT OF YIELD PER RECRUIT
IN THE AMERICAN AND JAPANESE FISHERIES

Jerry A. Wetherall and Marian Y. Y. Yong

APPENDIX

Sustainable Yields

In our main working document we discussed the assessment of the North Pacific albacore stock in terms of the yield per recruit criterion . In adopting this criterion we assumed that recruitment is not affected by stock size, and that the only concern in setting harvest policy is to avoid "growth overfishing."

If recruitment is dependent on stock size then of course the yield per recruit analysis, per se, is only of secondary interest and our key objectives are to assess the status of the fisheries with respect to "recruitment overfishing" (as discussed by Cushing 1973), and to determine the fishing policy which maximizes total yield.

Invariably the fishing mortality rate which maximizes yield per recruit (and also average total yield when recruitment and stock are independent) is greater than the level which maximizes the total harvest under this second circumstance. Thus if the "dependent" model is used as a guide for setting fishing policy, but is the incorrect model, "growth underfishing" might occur, accompanied by significant economic loss. On the other hand, if the less conservative approach is taken when in fact recruitment depends critically on stock size, the productivity of the stock and the existence of the fisheries may be put at considerable risk.

Below we present a comparison of total sustainable yield surfaces for North Pacific albacore generated under two alternative assumptions on stock and recruitment:

1. <u>Ricker Model</u>

$$R = 399.7 * B_s \, EXP \, (-9.78 * B_s)$$

where R = recruitment in millions of 2.5-year old albacore

and B_s = second quarter spawning biomass in the birth year, in millions of metric tons

2. <u>Linear-segmental Model</u>

$$R = 600 * B_s \qquad B_s < 0.025$$

$$R = 15 \qquad B_s \geq 0.025$$

and the same units apply.

In the linear-segmental model we assume recruitment is a constant 15 million fish as long as spawning biomass is not less than 25,000 metric tons (MT). Below this stock level recruitment is reduced sharply. The value of 15 million is the maximum recruitment obtained in the Ricker model, at a spawning stock of about 100,000 MT. We arbitrarily set the cut-off point in the linear-segmental model to 25% of this level.

Total sustainable yields were computed for each of these models employing the age-specific M vector used in the cohort analyses, a linear-segmental version of the adjusted Clemens growth model, and a variety of age-specific fishing mortality vectors. The population simulator POPSIM, developed and coded in FORTRAN by Walters (1969) was used. The program was modified to permit quarterly variation in the age-specific fishing mortality rates and to compute two interpretive parameters:

1) the average annual fishing mortality rate, weighted by biomass, defined as

$$\bar{F}_w = \sum_{ij} F_{ij} B_{ij} / \sum_{ij} B_{ij} \qquad \begin{array}{l} i = 3,\ldots,10 \\ j = 1,\ldots,4 \end{array}$$

where B_{ij} = average biomass of the i-th age group in the j-th quarter

and F_{ij} = fishing mortality rate on i-year olds during the j-th quarter.

2) the average age of capture, weighted by yield, defined as

$$\bar{t} = \sum_{ij} t_{ij} F_{ij} B_{ij} / \sum_{ij} F_{ij} B_{ij}$$

where the new variable, t_{ij}, is the age at the midpoint of each quarter-year interval of exploitable life, i.e.,

$$t_{ij} = -0.625 + i + 0.25\, j \qquad \begin{array}{l} i = 3,\ldots 10 \\ j = 1,\ldots,4 \end{array}$$

A-Fig. 1 The yield isopleths are shown in Appendix Figure 1, plotted against average age at capture and the average fishing mortality rate. The choice of these two variables introduces some minor interpretational difficulties, since average age at capture is not independent of $\bar{F}_w$. (In general, average age at capture will decrease with an increase in $\bar{F}_w$ unless the distribution of F is shifted toward the older age groups.)

The hatched areas in each graph indicate the conditons under which sustainable yields cannot be expected, i.e., the conditions leading to "recruitment overfishing." Under the linear-segmental stock-recruitment model, the maximum sustainable yield is about 10,000 MT greater than under the Ricker model, and is achieved at a significantly greater $\bar{F}_w$ and a lower average age at capture.

Sustainable yields expected under several sets of conditions on $\bar{F}_w$ and $\bar{t}$ are indicated by letters in Appendix Figure 1, and the

A-Table 1 corresponding conditions are given in Appendix Table 1. Point "A" corresponds to the estimated base level conditions in the mid-1960's (assuming F_o = 0.10 and age-specific M). The yield at point "A" is the same under both stock-recruitment models. At point "C," the yields are again the same and correspond to a 50% increase in the surface fisheries and a 50% reduction in longline fishing mortality.

At point "D," with a doubling in longline fishing mortality over the base level, the sustainable yield under the linear-segmental model is 91,000 MT, but only 83,000 MT under the Ricker model. Points "B" and "E" show yields obtained when the surface fisheries are eliminated and fishing mortality is increased in the longline fishery.

At point "F" the fishing mortality vectors were selected to produce approximately the maximum sustainable yields under each stock-recruitment assumption. Clearly the greatest yields are sustained with intense fishing on the older age groups and little or no harvest of immature albacore (in this example slight fishing was allowed on the younger fish for computational convenience).

One of the unlabeled cases in Appendix Table 1 shows the expected outcome when fishing mortality is trebled in the surface fisheries and reduced by 50% in the longline fishery relative to the base period conditions. Here a sustainable yield of about 90,000 MT is achieved under the linear-segmental option, whereas if the Ricker model holds the stock is depleted--recruitment declines steadily, as does yield.

In recent years the total yield from the North Pacific albacore stock has increased from a level of about 70,000 MT to the 100,000 MT level. The increase was brought about primarily by an increase in nominal effort and fishing mortality in the pole-and-line fishery. Assuming no further increases in fishing mortality, we would expect annual yields to decrease from the recent high levels until a new equilibrium age structure was established in the stock. Indeed, it appears that the 1975 catch will be only about 80,000 MT, though it is not yet known whether there was also a reduction in fishing mortality.

Using POPSIM we studied the transient behavior of total yield following a sudden 50% increase in fishing mortality rate (in all fisheries). Under the linear-segmental model, yield rose from the equilibrium 70,000 MT base period level to just over 10,000 MT in the first year of increased fishing mortality, then declined in subsequent years, reaching a new equilibrium level of 85,000 MT in the 8th year of the higher fishing rates. Under the Ricker option the response was similar, the yield rising to 100,000 MT but leveling off at about 81,000 MT.

After the new equilibrium was established we increased the fishing mortality again, so that this time the mortality rate was twice as great as during the base period. Under the linear-segmental stock-recruitment relationship total yield increased from the 85,000 MT level to 108,000 MT and settled at 92,000 MT after 8 years (the assumed number of age groups in the exploited stock was 8). When the Ricker model was assumed the yield rose at first to 104,000 MT. But it then dropped steadily as recruitment was eroded under continued application of the increased fishing mortality and no equilibrium was achieved.

We emphasize that these results are quite preliminary and a more definitive assessment of the North Pacific albacore stock vis-a-vis either "growth overfishing" or "recruitment overfishing" must await a more reliable estimation of fishing mortality rates. Here we refer not only to the base period conditions but also to the recent changes brought about by increased nominal effort.

In the meantime, our analysis suggests that the limits to productivity of the stock are being approached, unless a radical redistribution of fishing mortality to older age groups is feasible.

In summarizing the analyses two other points, both well known, may be made. First, under steady increases in fishing mortality the resulting yields will be greater than the sustainable yields expected under those fishing conditions. Second, though the response of sustainable yield to increased fishing mortality depends critically on the stock-recruitment relation assumed, the observed variance about our fitted models is so great that a stock-dependent decrease in recruitment may not be reliably detected until several years of additional data (at one point per year) are accumulated. Thus, in the linear-segmental model especially, a sequence of environmental conditions favorable to the survival of pre-recruit albacore could mask a really significant reduction in stock-dependent recruitment potential.

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