Preliminary Assessment of the Yield Potential of the Skipjack Tuna (*Katsuwonus pelamis*) in the Central Pacific Ocean.

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ABSTRACT

A preliminary assessment of the yield potential of the skipjack tuna in the central Pacific Ocean is based on the hypothesis that those skipjack which are exploited in the eastern Pacific Ocean are born in the central Pacific, migrate to the eastern Pacific, remain there for a relatively short time, and then return to the central Pacific to spawn. Intensive fisheries for skipjack are, however, conducted only in the eastern Pacific. Therefore, a portion of those skipjack that inhabit the central Pacific can be considered as escapement from the eastern Pacific fishery. A component of the yield potential of the escapement stock is estimated from the ratio of yield-per-recruit under the assumption that the skipjack are fished throughout their entire post-recruitment life span to the yield-per-recruit under the present fishing conditions where the skipjack are only exploited for a relatively short portion of their post-recruitment life span. This ratio is applied to a present steady-state yield to obtain yield potential in absolute rather than in relative terms. Estimation of the various parameters of the yield equation is discussed. Since these estimates are largely conjectural, the yield predictions must be considered tentative.

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INTRODUCTION

One of the goals of the first Governor's Conference On Central Pacific Resources was to obtain estimates of the magnitude of the skipjack resources of the Central Pacific. The present paper is a formulation of some of these estimates. It is based on the hypothesis that the skipjack tuna (Katsuwonus pelamis) taken in the coastal fisheries of the eastern Pacific undergo natality in the equatorial central Pacific, migrate to the eastern Pacific fishery areas, remain in the fishery areas for a relatively short time, and then emigrate to the central Pacific where they spawn (see Kawasaki, 1964 and Rothschild, 1965). This hypothesis implies that the skipjack that enter the eastern Pacific are subject to fishing mortality only during the interval that they are actually in the eastern Pacific fishery areas since we assume that the numbers of skipjack taken in the high-seas areas of the central Pacific are negligible. Therefore, those skipjack that leave the eastern Pacific fishery area can be considered as an escapement stock that inhabits the central Pacific. The primary objective of the present paper is to consider the yield potential of this escapement stock should the fishery be modified so that it would continue to harvest these skipjack during their movement to, and in, the central Pacific. It will be evident that there is

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not yet sufficient information to provide a point estimate of the yield potential of the escapement stock, let alone for the entire Pacific. The approach taken here then, will be to attempt to select a reasonable range within which the yield potential of the escapement stock is likely to fall and then to briefly comment on the possible relation between the yield potential of the eastern Pacific escapement stock and the skipjack stocks for the entire Pacific Ocean.

YIELD POTENTIAL OF THE ESCAPEMENT STOCK

For this preliminary assessment, conjectured coefficients of growth and mortality are employed to estimate yield by means of the equation developed by Beverton and Holt (1957). The yield function for various combinations of the coefficients is conveniently tabulated in Beverton and Holt (1964). The following notation will be used:

- M - Instantaneous coefficient of natural mortality
- F - Instantaneous coefficient of fishing mortality
- Z - Instantaneous coefficient of total mortality
- E - Rate of exploitation
- K, L_∞ - Constants of the von Bertalanffy growth equation
- c - Ratio of mean selection length to L_∞
- A_0 - Set of population parameters $\{M_0, E_0, L_{\infty_0}, K_0\}$
- Y'_0 - A dimensionless index of yield per recruit, under assumption A_0, given by Beverton and Holt (1964).

In order to assess the yield potential of the escapement stock Y'_0 is computed under two conditions:

1. Under the first condition Y'_0 is computed over the interval between age (size) at recruitment and age (size) at escapement. Under this condition Y'_0 is denoted by Y'_{01}.

2. Under the second condition Y'_0 is computed over the interval between age (size) at recruitment and maximum age (size). Under this condition Y'_0 is denoted by Y'_{02}.

Clearly, the ratio $R_0 = Y'_{02}/Y'_{01}$ gives a measure of the relative change in yield that can be expected should a fishery continue to harvest---under a fixed A_0--- the escapement stock. Application of R_0 to the yield of an existent steady-state fishery that operates under A_0 and condition 1 would provide a measure of potential yield should the fishery continue to operate under A_0 but extend its fishing, under condition 2, to the larger and older members of the escapement stocks.

Parameter for the Yield Equation

In order to obtain values of R_0 we need to obtain reasonable A_0 and the size ranges over which the fish are exposed to fishing. It must be emphasized that at this stage of our understanding of skipjack biology, the choice of A_0, recruitment size, and escapement size is largely conjectural. The choice of growth coefficients, size at recruitment and escapement, and mortality coefficients will be discussed.

Growth Coefficients

The von Bertalanffy growth coefficients of $K = 0.7$, $L_\infty = 85$ cm, and $t_0 = 0$ will be used throughout this paper. These are similar to those given by Rothschild (Shomura, 1966). Although Rothschild's estimates were based on incremental growth from a relatively few tag returns and must be considered tentative since the growth estimation study is not yet complete, it appears that the growth curve with these coefficients as parameters is in good agreement with other estimates of growth from tag returns (Schaefer, Chatwin, and Broadhead, 1961) and modal progressions (Kawasaki, 1963). The growth curve given by Brock (1954), however, exhibits a faster rate of growth than that tentatively proposed by Rothschild; therefore if Brock's curve is a more accurate estimate of growth, use of Rothschild's curve for yield calculations would have a tendency to produce conservative estimates.

Recruitment and Escapement Sizes

The size at recruitment and the size at escapement are critical parameters in making the yield estimates since the amount of time a fish spends in the fishery area, susceptible to fishing mortality, is a function of recruitment and escapement sizes. A notion of these sizes for the northern fishery area of the eastern Pacific can be obtained from graphs presented by Broadhead and Barrett (1964). We note that length distributions of the catch in the southern fishery area (south of the Gulf of Tehuantepec) are not available in the literature and therefore we must assume that the length distribution of the catch in the southern area is approximated by the size distribution of the northern area. The Broadhead and Barrett graphs show that the minimum fork length of skipjack in the Baja California region, for example, is about 41 cm and the maximum fork length is about 65 cm. The mean fork length appears to be about 53 cm. A striking feature of these lengths is that they appear to vary very little among the quarter-years for which the length frequencies are presented. One of several possible interpretations of this phenomenon (Rothschild, 1965) is that it reflects size (or age) specific movements through the fishery. The difference between the maximum size and minimum size provides an estimate of the amount of time a skipjack spends in the eastern Pacific. This estimate would be the amount of time it would take a 41 cm skipjack to attain a fork length of 65 cm. According to our assumed von Bertalanffy growth curve, the time interval for a 41 cm skipjack to attain 65 cm would be slightly more than one year. If we interpret the apparent stability in size distribution as a result of size (or age) specific movement, then an estimate of slightly more than one year must be an upper bound on the eastern Pacific sojourn time. A more accurate estimate of sojourn time might be obtained from the mortality coefficients of skipjack. (Only Z will be considered in this paper since it is the only parameter that we will use, explicitly, to obtain yield from R_0 and estimation of Z alone requires less restrictions than an estimate of both F and M.) Estimates of skipjack survival rates are provided by Schaefer, Chatwin, and Broadhead (1961). The Schaefer, Chatwin, and Broadhead estimation procedure was modified by Fink (1965) to account for variations in fishing intensity upon the tagged fish. He used their data and additional data to provide two estimates of Z (corrected for tag shedding by assuming that the coefficient of tag shedding in the skipjack is the same as that estimated for the yellowfin tuna). For 1957 taggings in the Baja California area he obtained a Z of 5.92 and for 1955-1960 taggings off of Northern Peru he obtained a Z of 3.96. The latter estimate was annotated as "unreliable". As Fink notes, these rather high values of Z are probably the result of emigrations from the fishery as well as actual deaths. We will therefore denote a Z that represents emigration losses as well as mortality decrements as $\tilde{Z}$. If we take Fink's estimate at face value to represent the loss of tagged fish from all causes other than tag shedding, and we assume that the behavior of the tagged fish is not different than that of the untagged fish, then we can use $\tilde{Z}$ to estimate the average sojourn time (sojourn time is defined as the amount of time a fish spends in the fishery area regardless of whether it leaves as a result of mortality or emigration) in the eastern Pacific. This estimate can be made if we assume that the waiting time until a tagged fish leaves the fishery, either as the result of death or emigration, follows the exponential probability law (this is analogous to the usual deterministic assumption that the rate of loss is proportional to the number present) with parameter $\tilde{Z}$. The mean of this law is $\tilde{Z}^{-1}$ and therefore with $\tilde{Z} = 5.92$, the average sojourn time in the fishery is roughly 2 months. Correspondingly, an average sojourn time for the northern Peru data (1955-1960) would be roughly 3 months. In order to translate the average sojourn time into a recruitment and escapement size we make use of the expression $t' = \bar{t} - Z^{-1}$ (Beverton and Holt, 1956) where t' is the average size at recruitment, $\bar{t}$ is the average length of the fish in the fishery. Using Fink's not-unreliable $\tilde{Z}$ and taking $\bar{t}$ to correspond with a length of 53 cm (1 year and five months) gives us a t' of 1 year and three months which corresponds to a length of 50 cm. A 50 cm skipjack grows, according to our growth assumption, about 3 cm in two months and therefore we take the average size at entrance and exit, to the nearest tabulated value as $.58\ L_{\infty}$ and .62 respectively.

Since an average eastern Pacific sojourn time of 2 months seems rather short and is based on only one year's tag returns, we will also make yield computations for comparative purposes with a perhaps more conservative, but arbitrarily selected, sojourn interval of about six months which would correspond to an average entrance size of $.54\ L_{\infty}$ and an exit size of $.68\ L_{\infty}$.

Total Mortality Rates

Two approaches can be considered for the estimation of total mortality rate Z. In the first we can attempt to determine the amount by which $\tilde{Z}$ overestimates Z. For example, owing to a lack of data, it was necessary for Fink to apply the instantaneous tag shedding coefficient (Q = 1.06) determined for yellowfin to skipjack. Clearly, if Q is larger than 1.06 for skipjack, then this will produce a positive bias in the estimate of Z. Unfortunately no data are available to determine if $\tilde{Z}$ is positively or, for that matter, negatively biased as the result of using the coefficient obtained from yellowfin. Another clue to a component of $\tilde{Z}$ which might cause overestimation may be obtained from the assertion, which needs to be studied critically, that the size distribution of skipjack in the eastern Pacific is relatively stable. Stability in size could be utilized to provide a lower bound estimate of an average instantaneous rate of emigration. In order to make this estimate in a simple fashion we assume that the stable size distribution has an approximately normal distribution with a mean length corresponding to the mean length of the catch (53 cm) and a standard deviation (6 cm) which is approximately $\frac{1}{4}$ of the range of fish lengths. According to the growth curve which we have adopted in this paper a 53 cm skipjack would grow about 2 cm in a month. From tables of the normal probability distribution we can ascertain that a normal distribution ($\mu = 55$, $\sigma = 6$) would extend about 13 percent of its area to the right of a normal distribution with $\mu = 53$, $\sigma = 6$. This would correspond to a loss by growth alone of 13 percent per month or an instantaneous loss rate coefficient of 1.7 per year.

In the second approach we can attempt to obtain a direct estimate of Z. We again use the relationship that $Z = (t' - \bar{t})^{-1}$. Clearly we have, at present, no way of estimating the average age in the population or at recruitment, but from our knowledge of the structure of the population we could surmise what might be a likely range. For example, the average length of the population is probably in the 60-65 cm range and the average size at recruitment is probably in the 45-50 cm range. Using the assumed growth curve and $Z = (t' - \bar{t})^{-1}$ we find that these ranges correspond to $1 \leq Z \leq 2$. This of course requires the assumption that Z is constant throughout the life of the steady-state population.

Yield Estimates

Values of R_0 for various Z and average sojourn times of approximately 2 and 6 months are given in Figure 1. If we take the average sojourn time to be nearer to 2 months than to 6 months and Z to be of the order of magnitude of 1 or 2, then

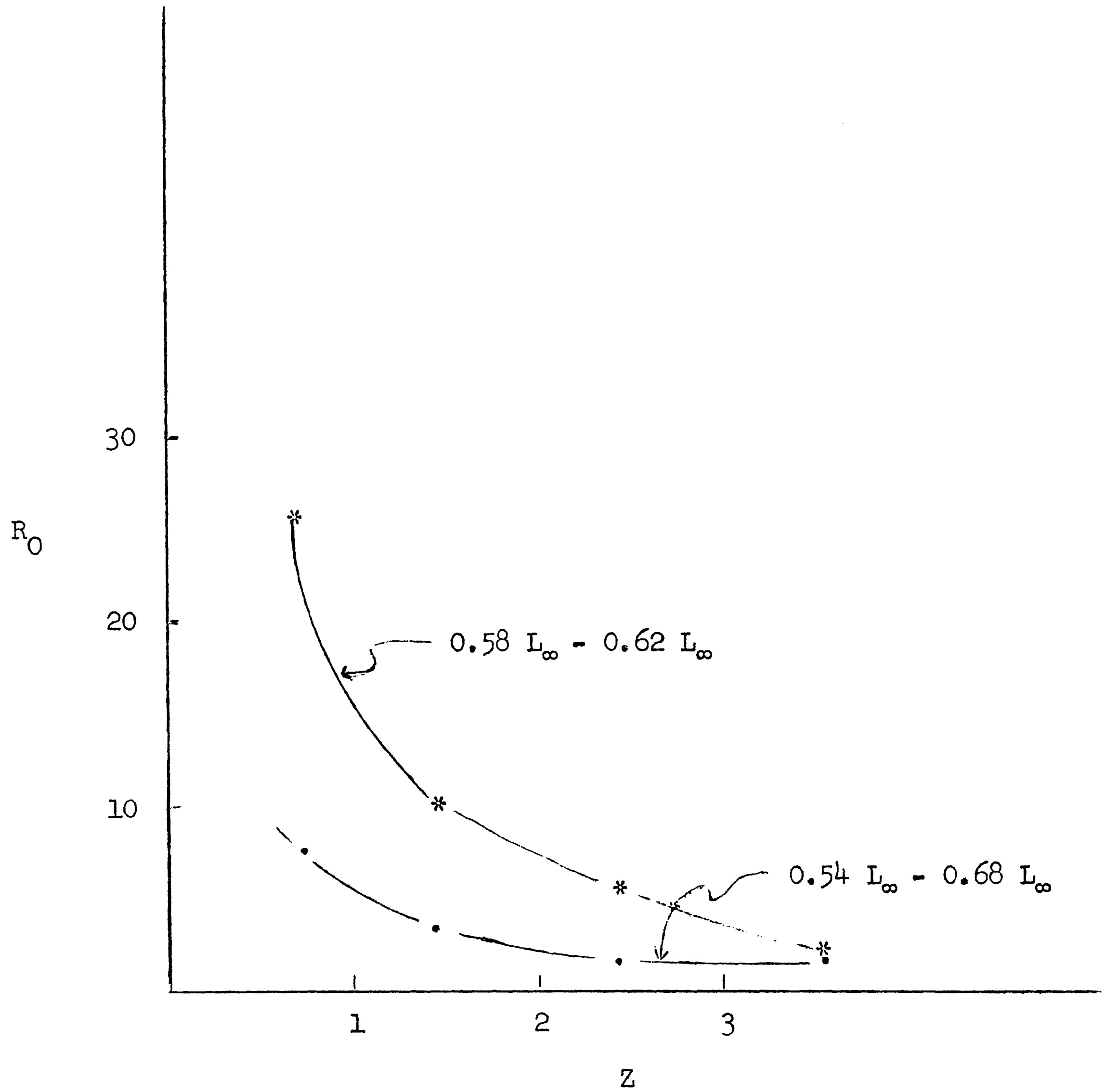

Figure 1. Values of R_0 (ratio of whole-life exploitation to limited-life exploitation) as a function of Z under two recruitment-escapement size assumptions.

we could triple or quadruple our present catch of approximately 75,000 tons per year by harvesting the escapement stock. This would amount to a catch of between 225,000 and 300,000 tons per year. A catch of 300,000 tons of skipjack would be roughly double the present eastern Pacific catch of both skipjack and yellowfin tuna.

DISCUSSION

It is obvious that at the present time we do not have enough of the right kinds of data to provide firm estimates of the magnitude of the escapement stock. We have relied on a tentative estimate of growth, a single "mortality" coefficient to estimate immigration-emigration sizes, and surmised estimates of total mortality. In addition it was necessary to apply length frequency distributions from the Baja California region to both the southern and northern fishery areas of the eastern Pacific. For this preliminary assessment, we have not considered the effects of varying A_0 as the fish move from the eastern to the central Pacific, the effect that fishing in the central Pacific might have on recruitment to the eastern Pacific, or the problem of optimum yields.

Emphasis is placed on the fact that these estimates of yield potential are strictly of the escapement stock and therefore must be underestimates of the yield potential for the central Pacific, since this area is almost certainly inhabited by skipjack that do not circulate through the eastern Pacific fishery areas. In this connection, Rothschild (1965) has hypothesized that the skipjack of the Marquesas-Tuamotu region do not enter the eastern Pacific fisheries. If this hypothesis is correct, then the skipjack that inhabit this vast area of the south Pacific must comprise an as yet unexploited population.

The actual harvesting of the escapement skipjack raises certain practical problems connected with the logistics of the fisheries. One of these problems involves the density of the escapement skipjack in the central Pacific. There are at least two factors that may tend to reduce the density of the skipjack in the central Pacific relative to the density levels in the eastern Pacific. The first is, since the escapement fish are older than the exploited fish, their numbers are certainly less. The second is, since the area of the central Pacific is larger than the eastern Pacific fishery area, it is conceivable that the escapement skipjack are spread over a much larger area than the exploited fish. On the other hand, the biomass of the escapement fish might be larger than that of the exploited fish, congregating mechanisms which would tend to increase density almost certainly operate in the central Pacific (see, for example, Sette, 1955) and the escapement fish might be mixed with non-escapement skipjack to provide densities which would enable profitable fishing.

Finally it is interesting to note that the dynamics of the skipjack, when interpreted on a recruitment-escapement basis, generate a set of problems similar to those that occur in the interpretation of salmon dynamics (see Hirschhorn,1966). It is of further interest to note that the emigration of skipjack from the fishery area appears correlated with the onset of sexual maturity (Rothschild, 1965) and we thus have a phenomenon in skipjack which is the reverse of that described by Beverton (1963) for clupeids, where the entrance of certain clupeids into the fishery is correlated with the onset of sexual maturity.

In conclusion, we can note that there is limited information available to estimate the yield potential of the escapement stock, but nevertheless it can be seen that the escapement fish could contribute to a possibly substantial increase in the present catch of skipjack tuna. The largest unknown remains, however, and that is the proportion of marketable-size skipjack biomass of the central Pacific that are escapement fish. A perhaps more direct approach to the problem would be to devise a method for a direct estimation of the skipjack biomass in the central Pacific and its size composition.

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