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Stevenson,D.K.; Saila,S.B.

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9. ABSTRACT Aritisanal fisheries include a wide range of labor-intensive, low investment harvesting activities along the inland and marine coastal areas in the LDCs of the tropics. These fisheries generally rely on unsophisticated harvesting techniques. The development of artisanal fisheries must consider both the harvesting and marketing sectors. The general objectives of development are to improve the yield of food resources and to maximize the economic and social benefits of the fishery to the human population. The maximization of benefits requires development strategies which promote the efficient allocation of human and capital resources in order to produce the maximum sustained amount of fish protein for the greatest number of people. This paper reviews existing yield models which can be applied to tropical stock assessment surveys and discusses the assumptions, data requirements, strengths and weaknesses of each. Particular emphasis is placed on the Schaefer and Beverton-Holt models. A discussion is offered of published modifications in the Beverton-Holt model which permit the estimation of the necessary parameters from length-frequency measurements without information on the age composition of the catch and in those cases where independent estimates of growth and mortality may be difficult to obtain. Various techniques for estimating model parameters are mentioned, and cases in which these techniques have been test are referenced.

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Yield Models and Tropical Artisanal Fishery Development

D.K. Stevenson and S.B. Saila

I. INTRODUCTION

The term "artisanal fishery" refers to a wide range of labor-intensive, low investment harvesting activities. Artisanal fisheries are widespread along inland and marine coastal areas in the lesser developed countries of the tropics. Although variations in specific gear types and fishing practices are significant, these fisheries generally rely on relatively unsophisticated harvesting techniques. Common gear types include hook and line and many different kinds of traps, nets and empoundments. Vessels are usually small (10 meters or less in length) and powered by sail, oars, outboard or, occasionally, inboard motors. The relative efficiency of the gear is variable and largely unmeasured to date. A large number of operating units can produce a large total catch. Thus, the proportion of the available annual stock which is extracted may be significant in certain instances.

With reference to artisanal fishing gear, the recent "Catalogue of Small-Scale Fishing Gear," edited by Nedelec (1975) provides a reasonable description of types. Relatively little is known regarding the performance of artisanal fishing gear. Some summary material known to the authors is the work of Nikonorov (1973). More work of the type designed by Pope (1966) is required. It is concerned with selectivity studies related to otter trawls for demersal fishes and gill nets as applied primarily to salmonid fishes. Considerably more detailed information, such as that depicting the mode of operation of Antillean fish traps (Munro et.al., 1972; Munro, 1974a), is required for a better understanding of artisanal fishing gears.

Some artisanal fisheries function at subsistence levels, providing fish for direct consumption by the fishermen, their families and neighbors. Artisanal fisheries which operate beyond the subsistence level provide fish which are sold to wholesale and retail markets outside the local fishing community. The distribution and sale are accomplished by another sector of fishery-related activities which depends on adequate roads, communications and port facilities. At the same time, the fishermen are integrated into the money-related economy and employment opportunities in the harvesting and marketing sectors are stimulated.

The development of artisanal fisheries therefore must consider both the harvesting and marketing sectors. The general objectives of development are to improve the yield of food resources and to maximize the economic and social benefits of the fishery to the human population. These benefits include a wide range of options, some of which may be achieved at the expense of others, depending upon national development priorities. It may be considered more important, for instance, to retain a larger number of less efficient vessels in the fishery rather than introduce a technology which increases labor productivity and forces significant numbers of fishermen to emigrate to urban areas seeking employment. In general, however, the maximization of benefits requires development strategies which facilitate the most efficient allocation of human and capital resources in order to produce the maximum sustained amount of fish protein for the greatest number of people.

Development strategies which merely increase yield and improve the efficiency of harvesting and/or marketing practices without considering the productivity of the environment and the capacity of the resource to replenish itself can result in resource depletion and an economically inefficient industry. Development strategies which include management guidelines are more likely to insure that resources are exploited for high biomass yields and optimum economic efficiency on a continual basis. As the pressure to produce more fish protein increases in the less developed world, the probability of widespread resource depletion and diminishing economic returns in these areas seems more certain. Despite this danger, there exists a relatively meager framework upon which to base management policies or to insure high sustained yields. The paucity of management guidelines may be due to a number of factors including:

a) difficulties in estimating vital statistics of exploited tropical species by conventional techniques;

b) the large number of species harvested by the fishery for which management data are required;

c) inadequate or non-existent catch statistics;

d) special problems involved in designing and enforcing management policies which adequately consider biological, economic, social and political factors.

It is recognized that future fisheries management will consider social, economic and biological criteria in very explicit and quantitative ways when evaluating various management options. The complexity of such a decision-making process is considered to be beyond the present abilities of most managers in developing areas which have artisanal fisheries. Therefore, it is expected that each stock or species will be managed by considering only small subsets of the varied criteria necessary for addressing complex management decisions. However, it should be kept in mind from the outset that the objectives of fisheries management will change with the development of fisheries. To a large extent, the nature of a particular objective will dictate the kind of information to be collected, how these data are used to estimate "best" exploitation patterns, and how harvesting operations should be regulated. Thus, it is suggested that the material presented herein is only a first step toward rational management of artisanal fisheries. The dynamic nature of both the fishery and the objectives of management must be kept in mind continually.

Although adequate or even limited catch records may not be available for some artisanal fisheries, the problems involved in the design and analysis of fisheries statistical surveys have been very well addressed by the Food and Agriculture Organization of the United Nations. This work ranges from a manual of sampling methods for fisheries biology

(Gulland, 1962, 1966) to the more recent applied fisheries statistics manual by Bazigos (1974a) and another technical paper by the same author on the design of fisheries statistical surveys for inland waters (Bazigos, 1974b). The latter is believed to be especially useful for application to marine artisanal fisheries. A large number of specialized reports on fisheries statistics are available from the Fisheries Statistics Unit, Department of Fisheries, FAO/UN, Rome, Italy. From the above, it seems clear that the state-of-the-art for gathering and analyzing fisheries statistics is well developed. However, there are some current limitations on economic statistics. Since these data are requisite for the application of any bioeconomic model, it is suggested that future fisheries surveys include those economic elements required for economic assessments.

The special problem involved in designing and enforcing the multidisciplinary management policies cited above are considered to be beyond the scope of this review. However, the procedures for estimating vital statistics of exploited tropical species, and the development or application of yield models are within the terms of reference of this report.

From the point of view of the fisheries biologist, a challenging problem in artisanal fisheries management is the development and application of theoretical models when data are limited and conventional age readings are not possible.

The objective of this paper is to review existing yield models which could be applied to tropical stock assessment surveys and to discuss the assumptions, data requirements, strengths and weaknesses of each. Although it is recognized that many artisanal fisheries consist of a relatively large number of species, the approach to be taken for initial management involves the modification of existing single species population models and parameter estimation procedures. Particular emphasis is placed on the Schaefer and Beverton-Holt models. A discussion is offered of published modifications in the Beverton-holt model which permit the estimation of the necessary parameters from length-frequency measurements without information on the age composition of the catch, and in cases where independent estimates of growth and mortality may be difficult to obtain. Various techniques for estimating model parameters are mentioned, and known cases in which these techniques have been tested are referenced.

The problems of ignoring interspecific competition and interaction are recognized in this management approach which considers only individual species. It is believed that these problems will require another level of effort since multi-species yield models are still largely in the developmental stage. Some important work in this area has already been done. Paulik, Hourston and Larkin(1967) have provided an analytical solution to the problem of finding the common rate of exploitation that maximizes total sustained yield from a mixture of stocks when each stock follows a Ricker type of reproduction curve. However, the data requirements, assumptions and computational requirements limit the utility of this work for artisanal fisheries. A multi-species extension to the Beverton-Holt assessment model provided by Anderson, Lassen and Ursin (1973) also has data requirements such as the natural partitioning of mortality (M) into components due to predation and feeding level which limit its short term applicability for the purposes at hand.

No effort is made at this time to review all the efforts at multi-species modeling and their possible utility. This problem is of current interest in marine ecology and is being actively pursued. Suffice it to say that as reasonable time series of catch and effort by species from tropical artisanal fisheries become available it will at least be possible to derive empirical multivariate autoregression equation predictors of the fluctuations of interacting species which can be used for short-term prediction and control. Such an approach has been suggested by Poole (1976).

In addition, there are a number of less sophisticated approaches to stock assessment which deal with multi-species fishery resources and therefore ignore individual species stocks. One such assessment "model" which has been proposed by Munro & Thompson (1973) requires a series of catch and effort data from a number of different, ecologically similar, fishing grounds. Changes in the response curve of catch per unit area per unit time against effort per unit area indicate the maximum expected catch and the amount of fishing effort that will produce it. This method is being considered by FAO as a convenient means to quickly evaluate the potential for expanded production on a given fishing ground once some basic catch and effort data are collected from several nearby areas. Perhaps the most insurmountable problem with this method is that the different areas must naturally support standing crops of similar magnitude so that observed differences in catch per area per effort actually reflect differences in fishing intensity.

As stated previously, management objectives change with time. The concept of maximum sustainable yield (MSY) has recently lost favor as a management target. However, the criticism directed at MSY as a management objective seems to confuse limitations in the concept with failures in its application. For the purposes at hand, it is believed that yield maximization is a useful first objective in artisanal fisheries. Yield, as a response variable is relatively easily measured in practice and can be handled in the simple mathematical models suggested for initial management tools. In practice, yield can be limited to some fraction of the maximum as a conservative upper limit.

II. TWO THEORETICAL YIELD MODELS

The two theoretical yield models commonly employed in biological stock assessment studies are the so-called Schaefer model and the Beverton-Holt model.

The Schaefer model as first proposed by Schaefer (1954, 1957) does not attempt to distinguish between elemental rates of recruitment, growth and natural mortality, but considers only their resultant effect as a single function of population size. This is sometimes called a lumped parameter model, which may be described as follows:

$$\frac{1}{P}\frac{dP}{dt} = f(P) - F(x) \qquad (1)$$

where P refers to the population biomass and the function F(x) expresses the loss of population biomass as a result of fishing mortality. The utility of this model depends upon being able to apply a simple approximation to f(P). Schaefer expressed the approximation as a power series, $f(P) = k(L-P-dP^2-CP^3...)$, in which L reflects the equilibrium population value. He also assumed that F(P) is linear with P, and Schaefer took only the first two terms of the series such that $FP = KP(L - P)$. This corresponds with the Verhulst-Pearl "logistic" law of population growth in which the deviation of P from the equilibrium value of L results in feedback which returns the population to equilibrium. The logistic function gives a relationship between change in population and population size which is symmetrical with a maximum at L/2. Fox (1970) presented an alternative surplus-yield approach which assumed a Gompertz growth function and results in an asymetrical yield curve.

Although the data demands of this type of model are limited to a time series of catch and effort statistics and an estimate of the catchability or proportion caught by one unit of effort, these are not generally available in artisanal fisheries. Furthermore the model has shortcomings due to the model assumptions that the rate of population increase responds instantaneously to changes in population density, that the rate of natural increase at a given weight of population density and that the rate of natural increase at a given weight of population is independent of the age structure of the population. Recently time lag parameters have been introduced for the Schaefer type models (Walter, 1973; Marchesseault, Saila and Palm, 1976). It is not believed that the model assumptions nor data requirements of this model make it especially attractive for application to artisanal fisheries at this time.

Beverton and Holt (1957) proposed a more analytical method which predicts yield as a function of fishing effort and the mean size of fish captured by the fishery $(l)_c$. For size selective gear, l_c depends on the specifications of the gear in use (e.g. hook or mesh size). Thus, the Beverton-Holt model is more versatile in the sense that it permits assessments of gear regulations and total effort independently (even though a change in one will, to some extent, affect the other). The Beverton-Holt model has the added advantage that it accounts for time delays in recruitment. However, since recruitment is usually not known, yield is often expressed in terms of yield per recruit. The model operates with estimates of growth and mortality rates for each species population. The increased usefulness of the Beverton-Holt model is only achieved under assumptions of steady state conditions, i.e. that growth and mortality rates remain constant throughout the lifespan of the fish. For this purpose, instantaneous rates are averaged for all ages.

The practicality of the Beverton-Holt model depends on the ease with which the necessary population parameters can be estimated. Parameter estimation in tropical waters presents certain unique difficulties which require modifications in the model and present challenges to precise parameter estimation.

The conventional Beverton-Holt yield model depends on the following population parameters:

K = the average instantaneous rate of growth as expressed by the von Bertalanffy growth function, a function which relates length (l) to age (t) over the lifespan of individual fish in the species population.

L_∞ = the asymptotic maximum length attained by in dividuals in the species population.

t_o = the theoretical age at which growth begins, a parameter in the von Bertalanffy growth function.

t_c = the age at first capture, a function of the size selectivity of the gear.

t_r = the age at which fish are first recruited to the fishery, or when they enter the exploitable age phase.

Z = an instantaneous estimate of total mortality from all causes, a function of the exponential decay in numbers from one group to the next in the population.

F = the instantaneous rate of fishing mortality.

M = the instantaneous rate of natural mortality.

Yield forecasts are based on determining:

(1) the yield per recurit as a function of the fishing mortality coefficient F;

(2) the level of fishing mortality (and effort) which produces maximum biomass yield per recruit.

The von Bertalanffy growth function is a standard mathematical expression used by fishery biologists to express the growth of individual fish in species populations. It has repeatedly provided a good fit to observed length-at-age data. It is expressed as

$$l_t = L_\infty (1-e^{-k(t-t_o)}) \tag{2}$$

The exponential function which describes the reduction in population size for a given age class over time or between successive age classes in the fishery during the same time frame is expressed as

$$N_t = N_o e^{-Zt} \tag{3}$$

where N_t = number of fish alive at time t

N_o = number of fish alive at time t = 0

The total mortality rate (Z) is equal to the sum of the fishing and the natural mortalities (F + M).

III. MODIFICATIONS OF THE BEVERTON-HOLT YIELD MODEL

Modifications of the original Beverton-Holt yield equation have been proposed by Holt (1962) and Kutty (1970). These modifications are basically aimed at removing the time dependent (age) terms from the equation and adapting it for use in tropical situations where independent estimates of growth and mortality may be difficult to obtain. These modifications depend on the estimation of mortality/growth ratios and the use of length data in place of age data.

The use of size frequency data is an important advance since tropical fish cannot be reliably aged by standard analyses of growth rings on scales. Tesch (1968) reported that these rings, when they appear, may be formed on estuarine species by alternative periods of drought and rainfall which are not predictably regular from year to year. Various authors (Rodriguez, 1962; Bayagabona, 1966) have reported the successful use of growth rings on otoliths (a bone formed in layers in the inner ear), but the analysis is time-consuming and open to different interpretations.

Modifications of the original Beverton-Holt yield equation have reduced the number of parameters to three. These three parameters are:

1) The parameter c which equals l_c/l_∞ where l_c = length at first capture (a function of size selective gear),

2) the exploitation rate E which equals F/Z under conditions of constant mortality throughout the life of the fish, and

3) the ratio of natural mortality to growth (M/K).

The modified yield equation may be stated as follows:

$$Y' = \frac{Y}{R_o} = W_\infty E(1-c)^{M/K} \sum_{n=0}^{3} \frac{U_n (1-c)^n}{1 = \frac{nK}{M} (1-E)} \qquad (4)$$

Where R_o = the number of recruits produced each year,

W_∞ = the maximum asymptotic weight attained by individuals in the population,

U_n = a summation variable taking values of +1, -3, +3, -1 for n = 0, 1, 2, 3 respectively.

Beverton and Holt (1964) published a set of yield tables which permit the prediction of eumetric yield (i.e. the maximum yield/recruit which can be achieved for given exploitation rates and mean sizes at capture) for given estimates of M/K. Thus, for known values of M/K, the effect of specific changes in the exploitation rate or the mean size at capture (or both) on yield/recruit can be predicted. Appropriate management measures can thus be applied to both underexploited and overexploited species.

Other modifications have been reported which do not require an estimate of E, but do require estimates of F/K, Z/K and Z. All of the different expressions of the yield equation rely on either an estimate of F or F/K and can be related to total fishing effort since

$$F = qf$$

where q = a constant which expresses the vulnerability of a species to capture by a given fishing gear,

and f = fishing intensity or effort.

IV. PARAMETER ESTIMATION

1. Growth

The average instantaneous growth coefficient K can be estimated by fitting the von-Bertalanffy growth function to observed length at age (l_t)data. If $l_t$data are available for sufficiently large range of ages, L_∞ can be estimated from the observed $l_t$data even though the maximum observed length may be considerably less than L_∞. Knight (1968) has warned against extrapolating L_∞ from limited $l_t$data.

Another method for estimating K and L_∞ is the tag and recapture study. The analytical procedures have been described by Gulland and Holt (1959) and Campbell and Phillips (1972). Apparently, the diversity of species encountered, costs and their vulnerability to injury from tagging apparently have discouraged this approach in tropical waters in the past. Randall (1962) reported a limited number of returns from the Virgin Islands and estimated monthly growth increments for a number of species.

The use of tags for growth studies as well as for population estimation and mortality estimation is suggested for the future. It is believed that this method will be extremely useful in spite of the relatively large amount of effort and funding required for such studies. Jones (1976) has clearly described the kinds of information available from mark and recapture studies.

Assuming that each scale grows at a rate proportional to the length of the fish and that each growth ring represents an annual increment, the lenqths which correspond to observed annual growth rings on a scale can be back-calculated when the length of the fish and the scale are recorded. However, as previously mentioned, tropical fish do not grow in a predictable annual cycle and although otoliths have been successfully used to generate l_t data, a more satisfactory method is to estimate K, t and l_∞ from length frequency data.

Ricker (1958) developed a logarithmic transformation of the von Bertalanffy growth function into the following linear regression function:

$$\log_e(L_\infty - l_t) = \log_e L_\infty + kt_o - kt \qquad (5)$$

Where l_t = the mean length of a given size class in a polymodal length frequency distribution at relative sampling time t when t is in terms of months

In this equation, the quantity $\log_e L_\infty + kt_o$ equals the y-intercept and the slope equals -k. On an annual basis K = kt, when t = 12 months. The parameter t can be determined once the y-intercept is known. In practice, this method requires a time series of length frequency data by species, gear type and fishing locations (or any other factor which might affect the frequency distribution of lengths during a given time period) and an objective, convenient method for separating length frequency data into component size groups and determining the mean lengths of each group. A mathematical solution to this problem proposed by Hasselblad (1966) has been transformed into computer programs by Tomlinson (1971) and Yong and Skillman (1975) which have proved more reliable than visual inspection methods. No matter what means are used to identify l_c values from catch data, the more size groups which can be identified and the longer the time period over which each provides mean length data, the more precise will be the estimates of K. An average K growth rate is computed for each species from all individual K estimates for each size group. This method has the added advantage that if L_∞ is unknown, it can be determined by trial and error substitution of L_∞ in equation (5) until the best fit to the data is obtained.

A second graphical technique for estimating K and L_∞ from length frequency data was outlined by Diaz (1963). He calculated the mean lengths of component size groups in commercial catch records at different times of year and plotted the changes in mean length with time against the mean modal lengths for one or more size groups. A straight line with y intercept equal to KL_∞ and slope equal to -K was fitted to the data for each size group and an average K growth rate calculated.

2. Total Mortality

The instantaneous rate of total mortality is estimated from equation (3) once the relative abundance of successive age classes in a single catch sample or of the same age class sampled at different times are known. In its simplest form, equation (3) is transformed into natural logarithms

$$\log_e N_t = \log_e N_o - Zt \qquad (6)$$

so that the y-intercept equals $\log_e N_o$ and the slope equals $-Zt$. For a given sampling period the relative abundance of two adjacent year classes (t and t+1) provides an estimate of total mortality from the following manipulation of equation (6):

$$-Zt = \frac{\log_e N_{t+1}}{\log_e N_t} \qquad (7)$$

A common index of abundance which is used to estimate relative abundance is catch-per-unit-of-effort. In these calculations only relative age information is needed. Use of such simple techniques over a restricted sampling period is dangerous, however, since seasonal changes in the availability of fish (i.e. changes in their vulnerability to capture by a particular gear) can be confused with actual changes in abundance.

Another alternative is to estimate Z directly from size frequency data if K is known. The following equation has been derived by Beverton and Holt (1956) for this purpose:

$$Z = \frac{K(L_\infty - \bar{l})}{\bar{l} - l_c} \qquad (8)$$

Where l_c = the smallest length of fish that is fully represented in the catch

$\bar{l}$ = mean length of fish in the catch from l_c upwards.

This method is sensitive to differences between $\bar{l}$ and l_c and thus to selection of l_c, a value which depends on the size selectivity of the gear and which is not always obvious in catch samples from a restricted period of time. This equation, when used in conjunction with methods based on age composition (see Le Guen, 1971) has produced comparable estimates of Z. When K is unknown, equation (8) can be used to estimate values of Z/K which are useful in predicting yield according to the modified yield equations of Holt (1962) and Kutty (1970).

Ssentongo and Larkin (1973) have derived an unbiased estimate of Z/K as:

$$(\hat{Z}/K) = \frac{n}{n+1} \cdot \frac{1}{\bar{y} - y_c} \qquad (8)$$

Where y is the mean of $\bar{y}$ values calculated from knowledge of the mean length ($\bar{l}_t$) in various samples of individual fish. The quantities y and y_c are defined as:

$$y = -\ln\left(1 - \frac{l_t}{L_\infty}\right) \qquad (9)$$

and

$$y_c = -\ln\left(1 - \frac{l_c}{L_\infty}\right) \qquad (10)$$

where l_c is the length at first capture.

The unbiased estimator for the variance of Z/K is

$$\mathrm{Var}\ (\hat{Z}/K) = \left(\frac{n}{n+1}\right)^2 \cdot \frac{1}{n(\bar{y}-y_c)^2} \qquad (11)$$

Estimates of Z can be made if K is known. The parameter K can be derived from a knowledge of age-size relations and from fitting the von Bertanlanffy equation from tagging data without knowledge of absolute age - only size increments over time. In addition modal progression in length frequency distributions may be used. From a knowledge of K derived by one or more of the above methods, Z is estimated by:

$$\hat{Z} = K\left(\frac{n}{n+1}\right) \cdot \frac{1}{y-y_c} \qquad (12)$$

Perhaps the most difficult problem in solving the Beverton-Holt yield equation is partitioning total mortality into mortality due to natural causes (M) and that due to fishing (F). Since Z = F+M, it is necessary only to estimate either M or F. The ideal situation is to have catch data from a previously unexploited population (F=0), in which case Z as estimated from equation (8) equals M. This situation is unrealistic, since unexploited populations are virtually unknown and since a research vessel would be required to collect the necessary data. An added difficulty is the assumption that M estimated from an unexploited population will be same as M for a different population which is exploited elsewhere. Fishing and natural mortality can also be estimated from tag and recapture studies in which case it is necessary to accurately assess the mortality of tagged fish caused by tagging.

Beverton and Holt (1956) have outlined a number of thecretical bases for estimating F or M from catch samples. The two essential requirements for obtaining these estimates are:

1) there must be changes in fishing intensity, either with time on the stock as a whole or with the age of fish, which are large enough to produce measurable changes in estimates of Z.

2) the different fishing intensities must be known and expressed in standarized units so that they are proportional to the values of F they generate (see equation 4).

Estimates of F and M can be obtained under any of the following situations:

1) When fishing effort is stabilized at two different levels
2) When fishing effort varies continuously with time
3) When fishing intensity varies with the age of the fish.

Another method for estimating F is the "swept-area" technique. If a population of demersal fish is uniformly distributed over a known area (A) and a trawl net of known dimensions, towed at a known speed, sweeps an area (a) in a given time period and captures a fraction of the available population then after (n) hauls (where (n) equals the total number of hauls made by the fleet during the year)

$$N_1 \simeq N_o e - pk \tag{13}$$

where N_1 = number of fish at time t=1

N_0 = number of fish at time t=0

$k = \frac{an}{A}$

and

$$F = \frac{pan}{k} \tag{14}$$

This method can be applied to those species captured by the artisanal fleet which are also captured by trawling gear (e.g. by shrimp boats). The principal problems with this method are:

1) the assumption that fish and fishing are uniformly distributed over the area A.

2) the difficulty in accurately estimating p, the proportion of fish which are available for capture which are actually captured and retained by the net.

V. OTHER YIELD MODELS

This review has placed emphasis on the Beverton-Holt yield equation, but if growth or mortality estimates can be obtained in some objective manner yield estimates are possible by other methods.

Yield can also be estimated by Ricker's (1945, 1975) method. The method involves determining the optimum size corresponding to the mode in a yield-mesh curve, under the assumption of exponential growth and mortality. The computations are carried out in tabular form without any computational complexities. Age differences in growth rate, fishing rate, natural mortality, various minimum size limits, and seasonal distributions of growth, and both fishing and natural mortality can be easily examined. The method is suitable for hand computation but a computer program (Paulik and Bayliff, 1967) is also available.

Kutty (1973) has demonstrated a method for estimating yield through approximate integration. An estimate of the rate of change of yield at a number of equal time intervals within the fishable life span are required. The rate of change of yield (Y_w) is:

$$\frac{dY_w}{dt} = FN_tW_t \qquad (15)$$

where F is fishing mortality, N is the number at time t, and W_t is the weight at time t.

Allen (1953,1954) has developed a relatively simple method for determining the optimum size limit for maximum yield. When the size limit is correctly established:

$$W_c = E'\bar{W} \qquad (16)$$

where W_c is the weight of the typical fish at the limiting size, $\bar{W}$ is the mean weight of fish caught and E' equals F/Z or the proportion of fish reaching the size W_c which are ultimately caught. The method can be easily applied by a mark and recapture program where fish are marked at the current limiting size and recovered over time. The method can also be readily applied if the size composition data for a number of years and average estimates of total and fishing mortality rates are available.

The desirability of utilizing either Ricker's or Allen's methods for the management of tropical artisanal fisheries need further empirical testing.

VI. CONCLUSIONS

The Beverton-Holt yield model, as modified by Holt (1972), Beverton and Holt (1964) and Kutty (1970) is well-adapted to stock assessments of individual species in tropical marine waters. In particular, the substitution of length parameters for age-dependent terms permits the direct of commercial catch records and eliminates the problem of aging fish. The exploitation rate and the mean size at capture which produce maximum yield per recruit for known ratios of natural mortality to growth can be readily determined from tables published by Beverton-Holt (1964). Mean size at capture in many cases is a function of gear type (mesh size, for example). Appropriate adjustments in gear type which will produce maximum yield can be determined. However, without an estimate of the numbers of annual recruits to the fishery the model will not predict absolute maximum yield. It must be emphasized that maximum yield corresponds to some optimum exploitation rate E (equal to fishing mortality F divided by total mortality rate Z), not some optimum fishing effort. Optimum effort can only be determined if total mortality rate Z and the catchability coefficient q of the equation f = qf are known. If Z and q are known, yield-effort curves can be generated in terms of yield/recruit. Direct estimations of recruitment are usually impossible. It seems probable that natural variations in recruitment are damped by physical factors such as water temperature and food supply which directly affect the survival of eggs and larvae and are much more constant in tropical marine waters than they are in temperate regions.

Precise estimation of natural and/or fishing mortality coefficients remains the most challenging aspect of stock assessment surveys which rely on the Beverton-Holt model.

Commercial catch records will provide data on which to base these estimates as long as total fishing intensity (f) is monitored so that changes can be detected, i.e. where f varies with the age of the fish. In this case, catch-per-unit-of-effort for different age groups must also be known. Such information is not difficult to obtain as long as catch-per-unit-effort can be estimated without bias, that is, with a reasonably random sampling program.

Very few comprehensive stock assessment and resource management surveys have been attempted in tropical marine waters, although there have been numerous attempts to estimate growth and mortality parameters from length frequency data. Longhurst (1964) and LeGuen (1971) conducted population studies with various members of the Scianidae exploited by trawlers on the west coast of Africa, but did not apply parameter estimates to yield predictions. Recently, an exhaustive assessment of 24 species landed by the commercial fish pot fishery of Jamaica produced growth and mortality estimates which were applied to the Beverton-Holt equation to estimate total relative yield for all species, by value as a function of mesh size and fishing effort. This work was summarized by Munro (1974 b and c). A similar study of 10 species was conducted in Puerto Rico (Stevenson, Ph.D. Thesis) using natural mortality estimates from the Jamaican reports.

An unavoidable feature of multi-species fishery management studies is that some species are often over-exploited under prevailing conditions of gear type and fishing effort while others are exploited at optimum or sub-optimum levels. Management recommendations which will increase yield for some species will diminish the catch of others. Management policy must therefore be based on certain priorities such as which species are more important economically or what may be the ecological implications of intentional overexploitation and resource depletion of given species. Effective management policy must consider not only questions of optimum resource utilization and maintenance of stocks, but also the economic and social implications of premeditated actions.

The variety of available yield models and the procedures required by each for parameter estimation make a comparative study with a specific artisanal fishery especially attractive. Field work presently underway in Costa Rica will examine alternative data collection systems aimed at estimating parameters for the modified Beverton-Holt yield model. The objective of this study is to produce a manual which can be used by national fishery agencies to direct development/management programs. Although emphasis will be placed on the Beverton-Holt model, conditions under which alternative models may be preferable will be cited. Parameter estimation procedures will be illustrated with empiracal data collected in Costa Rica. Additional examples will be illustrated with hypothetical data. In all cases, the relative effort (manpower, time, costs) required to produce the desired results and the importance of those results will be assessed. In individual cases, national planners should be able to use the manual to evaluate the utility of existing data collection systems and resource development/ management objectives and to design appropriate resource assessment surveys when necessary.

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