# SIMPLE METHODS FOR ESTIMATION OF PARAMETERS FOR ASSESSING EXPLOITED FISH STOCKS

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## ABSTRACT

New methods for estimation of growth and mortality parameters, together with their error estimations, are given, discussing in detail their advantages over the existing ones. A new model called Relative Response model has been designed for estimation of such stocks that are common in tropics where the application of other models are not effective. Demonstrative worksheets are provided to illustrate easy working of the methods. Various proformae for collection of data are appended.

## INTRODUCTION

To assess fish stocks there are different approaches, depending on the condition of stocks and the nature of the data base. Stocks may be broadly grouped into 'virgin' stocks and 'exploited' stocks. Assessment of the virgin stocks may be done by: (1) sweep-out-area method, or area' sampling; (2) production analysis, using biomass and the productivity of the water body ($C_{14}$ technique); (3) comparison method; and (4) aerial and accoustic surveys. For exploited stocks, there are many methods by applying macro- and micro-analytic models. The present account explains some of these.

Fish stocks, coming under renewable resources, have to be scientifically managed, should they return sustainable yields. It is known that unscientific exploitation of stocks, leading to their depletion and eventual disappearance, is but killing the goose that lays the golden eggs; haddock stock in German waters, Californian sardines, Peruvian anchovies and Antartic whales are some of the examples. These stocks would have sustained had there been some control introduced on the rate of their exploitation.

Among the living resources, fishery resources stand apart at least on two accounts. The variations in their availability are not only wide but also wild due to many factors which are not normally encountered in any other living resources, especially in tropical conditions. Secondly, these resources being beyond the visual horizon, many of their behavioural aspects remain unknown. Therefore, to arrive at a reasonable picture of these resources, the foremost requirements are

a sound data base and at least two approaches that will facilitate mutual checks. Uniformity in the method of collection, a well-designed sampling procedure that would minimise any form of bias and a set of proformae are also essential.

## COLLECTION SCHEDULE

The collection schedule is best fixed as follows. A landing centre is to be visited at least two days a week. On each day the duration of observation should be a minimum of 5 h and the number of units observed should be a minimum of ten.

The methods of selection of units, collection of data, estimation of parameters and stock assessment are as follows.

## 1. SELECTION OF UNITS

For the mode of selection of units on each day the following procedure is to be adopted. The total number of units expected to land is to be ascertained beforehand. If the number expected is 15 or less, then all the units should be observed. In other cases the procedure is as follows:

*Case 1—when the number of units expected to land is a multiple of ten*

In case 20 units are expected to land, then one in every two successive units is to be observed. The first unit to be observed in such case is to be selected randomly from the first two units arriving for landing, and then the rest of the units selected systematically keeping a sampling interval of two. For instance, if the second unit among the first two is the one selected the rest of the units selected are the 4th, 6th, 8th, and so on, till the 20th. Similarly, when 50 units are expected to land a unit among the first five arriving is randomly selected and the rest systematically, keeping the sampling interval of five. For example, if the 3rd unit is the one selected randomly, the rest of the units selected are the 8th, 13th, 18th, and so on, till the 48th, keeping the interval systematically five. By this method, as long as the number of units expected to land is a multiple of ten, one can select exactly ten units for observation avoiding any personal bias.

*Case 2—when the number is between 16 and 19*

When the number of units expected to land is between 16 and 19, arrange the numbers in clusters of two consecutive numbers. Select a unit randomly from the first cluster, consisting of 1 and 2, and select the rest of the units systematically keeping the sampling interval of two. Now observe all the two units in the first cluster and all the units in the last cluster, i.e., only one in case the number is odd and two in case the number is even, and all the ones selected systematically. Thus the total number of observed units will be at least ten.

*Example* 1: Suppose 17 units are landing, then the clusters are 1 and 2, 3 and 4, 5 and 6, 7 and 8, 9 and 10, 11 and 12, 13 and 14, 15 and 16, and 17 (the last cluster with only one unit). Now, suppose from the first cluster the second unit is selected, then the rest of the units for observation are the 4th, 6th, 8th, 10th, 12th, 14th and 16th. With these units are added all the units in the first cluster (1 and 2) and all the units of the last cluster (only 17). Thus there are ten selected units for observation. But if 18 units land, the number being even there will be 11 selected units, since the last cluster has two units.

*Case* 3—*when the number is between* 21 *and* 25

Here, too, one in every two, as in Case 1.

*Case* 4—*when the number is between* 26 *and* 29

When the units expected to land are 26-29 divide the number in clusters of three consecutive numbers, viz., 1-3, 4-6, 7-9, 10-12, 13-15, 16-18, 19-21, 22-24, 25-27 and 28-29. Suppose the units expected to land are 26, and suppose the first unit is selected for observation, then the other units selected systematically are the 4th, 7th, 10th, 13th, 16th, 19th, 22nd and 25th, keeping the sampling interval as three. With these selected units are added all the units, 1st to 3rd, in the first cluster and all the units in the last cluster (26th only). Hence there are 12 units selected for observation. In this way, at most 13 units will be selected when the number is 26-29.

*Case* 5—*when the number is* 31 *and above*

When the number of units expected to land is above 31, selection of units is done keeping a sampling interval based on the last of the exact multiples of ten in the number of expected units as follows. Suppose 48 is the number of the expected units, then the last exact multiple of ten in the number is 40 and the sampling intreval for selection of units is $\frac{40}{10} = 4$. From the first four units is selected a unit randomly and the rest systematically keeping the interval of 4. Suppose the third unit is selected randomly, then the systematically selected ones are the 7th, 11th, 15th, and so on, till the 47th. Supposing N = 33, the last multiple of ten being 30, the sampling interval to be kept is 3; and, in case the first unit is selected randomly, the systematically selected units are the 4th, 7th, 10th, and so on, till the 31st. It may be noted that, selecting this way, the total number of units to be observed will not exceed 12.

## 2. COLLECTION OF DATA

From the selected units information is to be obtained on specieswise catch, effort details (length of boat, horsepower, hours of fishing, manpower and number of hauls made), area of fishing and total catch. For biological studies,

a subsample of at least 50 specimens is to be collected, based on which length, weight, sex, stage of maturity and fecundity are recorded. Also, scales|otoliths for aging, wherever possible, are collected.

For the purpose of recording length-frequency data different proformae are given. Proforma I (A for non-selective gears and B for selective gears) is for data on effort and catch. Proforma II is for monthly/specieswise catch and their percentage in the total for the month. Percentage contribution of each species to the resources may be obtained from the total of all the species of the resource then available in the last column of this proforma. Length composition details are recorded in Proforma III A-C. III A is for the details collected on the date of observation. The columns under Sample 1-Sample 5 are to record the length frequencies of the corresponding samples. Final two rows are for the totals, in numbers as well as in weight, of each sample. The column under Total of all Samples is to indicate the sum of the length-frequencies, total numbers and weights for all the samples put together. On the basis of sampling units total weight of the resource for that date is estimated. The raising factor for this estimation is $\frac{N}{n}$ , where N is the number of the units landed on the day and n is number of units observed. This factor is also used to raise each length-frequency of the sampled totals to the day's totals. The last column contains, thus, these estimated length-frequencies, total number and the total weight of the species of the resource. The method of filling up the columns is shown in the work sheets. The daily estimates thus obtained are transferred on to the Proforma III B, wherein monthly estimates are obtained by raising the number of observed days to the number of fishing days in the month. These monthly estimates are posted on Proforma III C, where the last column 'Estimated for the year' is just for the sum of monthly length frequencies. Percentages of length frequencies for each month are to be taken from this and graphed for monthly progression of modes. The details are given in the work sheet.

## 3. ESTIMATION OF PARAMETERS

*Case 1—where age-length distribution available*

Age-length distribution can be found when the stock is exploited fully throughout the stages covering its known life period and well-marked model growths are discernible from length-frequency studies. Hard part studies such as studies on scales and otoliths also serve the purpose where the age marks (ring formation) could be identified.

*Growth (isometric and allometric)*: Growth forms may be divided into two groups, viz., isometric and allometric. Isometric growth is one when growth conforms to dimensional relationship such as between length, height, surface area, weight, etc. However, since parameters such as length and height have single

dimensions, surface area ($=$ length x height) has two dimensions and weight ($=$ volume x density) has three dimensions, in deriving equations between these parameters dimensional equality has to be maintained, so that the number of dimensions involved in the left-hand side of the equation has to be balanced by the number on the right-hand side. For example, the length-weight relationship expressed as

$$W = al^3 \qquad \qquad \ldots\ldots (1)$$

has the left-hand side with three dimensions balanced by three dimensions on the right-hand side, 'a' being a constant with no dimension.

Similarly, the relationship length-surface area(S) is expressed by the equation

$$S \ bl^2 \qquad \qquad \ldots\ldots (2)$$

where the left-hand side has two dimensions (length $\times$ height) balanced by the two-dimensional right-hand side ('b' is a constant).

In the case of length and height (H), the relationship will be in the form

$$H = cl \qquad \qquad . \qquad \ldots\ldots (3)$$

where, 'c' being constant, the single dimensional relationship is maintined on both sides.

When dimensionality is not maintained or not balanced then the growth is said to be allometric. For instance,

$$W = al^n \qquad \qquad \ldots\ldots (4)$$

where n $\neq$ 3 and

$$S = bl^m \qquad \qquad \ldots\ldots (5)$$

where m $\neq$ 2 and

$$H = cl^b \qquad \qquad \ldots\ldots (6)$$

where b $\neq$ 1 are examples of allometric growth.

*Growth model*: In the case of fishes it is found, more often than not, that length-weight relationship is allometrie. Using $W = al^n$ and $S = bl^m$ in the usual notation of von Bertalanffy's growth model (VBC) we get the equation.

$$W_t = W\infty \ (1 - e^{-kd(t-t_o)})^{n/d} \qquad \qquad \ldots\ldots (7)$$

where $d = n - m$. Expressing in terms of length (Alagaraja and Jingran 1976)

$$l_t = l\infty \, (1 - e^{-kd(t-t_o)})^{1/d} \qquad \ldots \ldots (8)$$

follows usual time-length relationship in isometric growth, when $d = 1$. In other words,

$$l_t = l\infty \, (1 - e^{-k(t-t_o)}) \qquad \ldots \ldots (9)$$

Hence equation (9) is more general than normally thought of as mentioned by Alagaraja et al (op. cit.) in that, even when growth is allometric, the usual time-length relationship, equation (9) holds good as long as $n - m = 1$. However, in general, VBG in length follows equation (8) and hence has four parametres $l\infty, k, t_o$ and d. In the particular equation (9) VBG has three parameters only.

Under isometric or particular condition $(d = 1)$ solving (9) is well known using

$$l_{t+1} = l\infty \, (1 - e^{-k}) + l_t \, e^{-k} \qquad \ldots \ldots (10)$$

which is linear and $e^{-k}$ and $l\infty$ are estimated using least square method. With the estimates of $l\infty$ and k obtained from (10), using

$$\frac{1}{k} \, \log_e (1 - l_t / l\infty) = t_o - t \qquad \ldots \ldots (11)$$

which is also linear, $t_o$ is estimated.

In the above case equation (10) is autoregressive and hence estimation of variances of the parameters is not straight forward. However to get variance estimates, let us use, from equation (10)

$$\frac{l_{t+1} - l_t}{l_t - l_{t-1}} = e^{-k} \qquad \ldots \ldots (12)$$

If there are n length groups then there are $n - 2$ estimates of $e^{-k}$ available from equation (12). From these estimates, mean and variance estimates of $e^{-k}$ may be obtained. Similarly an estimate of $l\infty$ may be obtained from

$$\frac{l_{t-1} \cdot l_{t+1} - l_t{}^2}{l_{t-1} + l_{t+1} - 2l_t} = l\infty \qquad \qquad \dots\dots \quad (13)$$

Since

$$\frac{l\infty - l_t}{l\infty - l_{t-1}} = \frac{l\infty - l_{t+1}}{l\infty - l_t} \qquad \dots\dots \quad (13.A)$$

for all 't' in the given range. In the case of n length groups there exist n-2 estimates of $l\infty$. Hence mean and variance estimates for $l\infty$ can be obtained from these n-2 estimates. Using the estimates of k and $l\infty$ in equation (11) estimate for $t_0$ and its variance estimate can be obtained. Thus the statistical problem of estimation of the parameters $l\infty$, k and $t_0$ and their variances could be solved having the above procedure. Work sheet II contains the details of this procedure.

In (4) the exponent n is estimated using

$$\log W = \log a + n \log l. \qquad \dots\dots \quad (14)$$

In the case of allometric growth n ≠ 3. This can be tested. If the test does show n ≠ 3, then allometric growth equation (8) having four parameters has to be taken into consideration. As n is estimated in equation (14) m can also be estimated once effective surface areas could be measured. Assuming effective surface area is proportional to the surface area of a fish Alagaraja et al (op.cit) have indicated a method of measuring outer surface area as follows. A fish is taken, completely wiped to remove water, placed on a plain sheet of paper with one side of it resting on the paper. Starting from the snout the upper part is traced out up to the point from where caudal fin starts. Similarly, from the snout the lower part is traced reaching the point where caudal fin starts. Then the figure is completed by joining the upper and lower caudalfin-starting points by a single straight line. The figure drawn is as shown on the next page, indicating the measurements of $i^{th}$ fish, where $l_i$ = length, $W_i$ = weight, and $s_i$ = one side surface area. Such figures are obtained after cutting them, and each of these figures is weighed in chemical balance. Let gi be the weight of the figure of the $i^{th}$ fish In the same sheet where such figures are cut out, a known area (s) is cut out and its weight (g) is obtained. Then the surface area (of course, of one side) of the $i^{th}$ fish is obtained from $\frac{s}{g}$ . gi = si. Using (4) and (5) n and m can be estimated after logarithmic transformation as done in (14). Thus d ( = n - m ) is obtained. Now re-writing equation (8) as

$$I_t^d = I_\infty^d \left[ 1 - e^{-kd\,(t-t_0)} \right] \qquad \ldots\ldots \text{(8')}$$

we get

$$I_{t+1}^d = I_\infty^d \left[ 1 - e^{-kd} \right] + I_t^d e^{-kd} \qquad \ldots\ldots \text{(10')}$$

and

$$\frac{1}{kd} \log_e \left( 1 - I_t^d \Big/ I_\infty^d \right) = t_0 - t \qquad \ldots\ldots \text{(11')}$$

As before, using

$$\frac{I_{t+1}^d - I_t^d}{I_t^d - I_{t-1}^d} = e^{-kd} \qquad \ldots\ldots \text{(12')}$$

and

$$\frac{I_{t+1}^d \cdot I_{t-1}^d - I_t^{2d}}{I_{t-1}^d + I_{t+1}^d - 2I_t^d} = I_\infty^d \qquad \ldots\ldots \text{(13')}$$

along with (11'), the estimates of $I_\infty$ , k and $t_0$ and their variance estimates can be obtained. The detail procedure of this approach is given in Work sheet III.
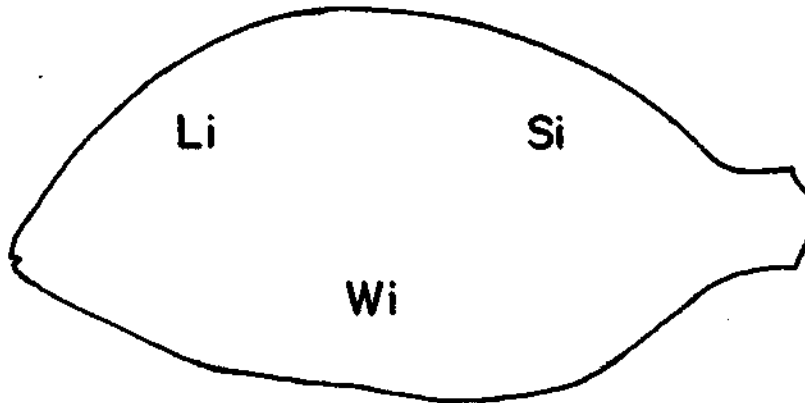
*Estimation of instantaneous rate of total mortality*: Dissolution of multinormal distribution into uninormal ones through graphical methods has been pointed out by Harding (1949), Cassey (1945), Battacharya (1967) and others. These procedures allot numbers to each modal class representing different ages. Using the negative exponential model,

$$N_t = N_o \ e^{-Zt} \qquad \qquad \dots\dots (15)$$

where it is assumed that there is constant recruitment or a single cohart is traced, we have the catch curve (Ricker 1975) given by

$$\log_e N_t = \log_e N_o. - Zt \qquad \dots\dots (16)$$

which is linear in t and $\log_e N_t$ . As indicated by Ricker (op.cit.) the right limb in the graph from equation (16) may be considered for the estimation of 'Z' the instantaneous rate of total mortality. The variance estimate of Z can be obtained in the usual way.

Z can be estimated using length-frequency table also as follows:

$$N_{t+\Delta t} = N_{t_1} e^{-Z\Delta t} \qquad \dots\dots (15^1)$$

In the case of isometric growth from equation (9) we get

$$\frac{l_\infty - l_{t+\Delta t}}{l_\infty - l_t} = e^{-k\Delta t} \qquad \dots\dots (17)$$

Hence

$$\frac{N_{t+\Delta t}}{N_t} = e^{-Z\Delta t} = \left[\frac{l_\infty - l_{t+\Delta t}}{t_\infty - l_t}\right]^{Z/k} \qquad \dots\dots (18)$$

Thus

$$\log( N_{t+\Delta t} / N_t ) = \frac{Z}{k} \log \left[\frac{l_\infty - l_{t+\Delta t}}{l_\infty - l_t}\right] \qquad \dots\dots (19)$$

Since $l_\infty$ and k have already been estimated, Z can be estimated from equation (19) and also its variance. Thus two independant estimates of Z could be obtained for check. Moreover methods of resolving multimodal distribution into

unimodal ones are more subjective and sometimes may not be that easy also. Hence equation (19) can always profitably be used. This method when compared to that of Pauly (1982) and Jones (1981) does not assume anything other than that the growth follows VBG and the calculations are simple and straight forward.

In the case of allometric growth we get

$$\frac{l_\infty^d - l_{t+\Delta t}^d}{l_\infty^d - l_t^d} = e^{-kd\Delta t} \qquad \ldots\ldots\ldots\ldots (17^1)$$

Hence

$$\frac{N_{t+\Delta t}}{N_t} = e^{-Z\Delta t} = \left[\frac{l_\infty^d - l_{t+\Delta t}^d}{l_\infty^d - l_t^d}\right]^{z/kd} \qquad \ldots\ldots\ldots (18^1)$$

and

$$\log\left(\frac{N_{t+\Delta t}}{N_t}\right) = \frac{Z}{kd} \log\left[\frac{l_\infty^d - l_{t+\Delta t}^d}{l_\infty^d - l_t^d}\right] \qquad \ldots\ldots\ldots (19^1)$$

Here also estimates of k, d and $l_\infty$ are already available. Hence estimate of Z and its variance could be obtained. The details of this procedure is presented in Work Sheet IV.

*Case II—where length frequencies alone available*

Under isometric growth we have equations (17) and (19). From equation (17) we get

$$\prod_t \left(\frac{l_\infty - l_{t+\Delta t}}{l_\infty - l_t}\right) = e^{-k\sum_t \Delta t} \qquad \ldots\ldots (20)$$

where L.H.S. is a product taken over the length range observed and $\sum \Delta t$ is the sum of the duration which covers the entire length range under consideration.

Here if we can have an idea about the total duration of the life spent covering the length range under consideration and taking $l\infty$ as the length just above maximum length so far observed for that species in the fishery, then equation (20) gives an estimate of $e^{-k}$ (or $k$). In the cases normally encountered, the values for $l\infty$ and $\Sigma \triangle t$ are not difficult to obtain. Even otherwise the estimate of $k$ thus obtained may be taken as the first approximation. Using this estimate of $k$, the value of $l\infty$ and equation (11) we have

$$\frac{1}{k} \log_e \left[ 1 - l_t / l\infty \right] = t_o - t$$

and

$$\frac{1}{k} \log_e (1 - l_{t+\triangle t} / l\infty) = t_o - (t + \triangle t)$$

Hence the difference of the above two leads to

$$\frac{1}{k} \left[ \log_e (1 - l_t / l\infty) - \log_e (1 - l_{t+\triangle t} / l\infty) \right] = \triangle t \quad \ldots \ldots (21)$$

Equation (21) can also be obtained from equation (17) after taking logarithms, on both sides with base e. Summing such $\triangle t$s over the length range gives an estimate for $\Sigma \triangle t$. This estimate may be substituted for $\Sigma \triangle t$ in equation (20) and another estimate for $k$ may be obtained. This iteration procedure will lead to more precise estimates of $k$. Now using equation (19) estimates of $Z$ could be obtained.

*Data from tagging*: Using equation (17), with a suitable value of $l\infty$, $k$ can be estimated in the isometric case. When information on n and m are available estimates of $k$ can be obtained in the allometric case also using equation (17[1]). Hence estimates on $Z$ from equation (14) or (19[1]) may obtained in these case.

In the case of allometric growth, wherever $k$ appears in the above equations, the same may be replaced by $kd$, where $d = n - m$, and the above procedure may be used to estimate $k$ and $Z$. The details of the procedure are given in Work sheet V.

*Use of modal progressions*: In the well exploited stocks, study of modal progressions indicate the seasons of peak breeding. In tropics there are, in general, two peak periods one in monsoon and another in winter. There may be variations

in this regard. A good data base often is able to throw light on this aspect.
Study of such monthly modal progressions over years and persistence of seasons
of breeding support this statement (e.g., oilsardine and mackerel). However,
owing to continuous breeding, the modes in the latter part of the growth are
rumbled up and hence a definite trend may not be discernible in the later part of
life. Hence using the modes in the earlier period of life one can estimate $t_o$, $k$,
and $l_\infty$ as follows.

*Estimate of* $l_\infty$ *and* $e^{-k}$:    Arrange the modes in an ascending order and let these
be $l_1$, $l_2$, $l_3$ . . . . . . In. Taking the first three modes starting from $l_1$ we have as
before $\dfrac{l_3 - l_2}{l_2 - l_1} = e^{-k}$ , taking next three modes starting from $l_2$ we have $\dfrac{l_4 - l_3}{l_2 - l_1} =$
$e^{-k}$ , and so on. Thus there will be a series of $e^{-k}$ estimates as it is indicated
earlier in (12).    Associated with each such group of these modes an estimate
of $l_\infty$ is also available as seen in (13). From these pairs ($l_\infty$ , $e^{-k}$) the value
of $l_\infty$ may be chosen such that this value is the maximum of the estimates.
Otherwise values of $l_\infty$ may be grouped into sets of more or less equal magni-
tude. For each such homogeneous group mean and variance can be found
wherever possible. In case there are no wide variations among $l_\infty$ values, all
$l_\infty$ values from a single homogeneous group and mean and variance of these
values may be taken. Similarly for the values of $e^{-k}$ estimates of mean and
variances can be had.

*Selection of a straight line: Case*: 1.—When *only one pair* ($l_\infty$ , $e^{-k}$) *is avail-
able*: In this case, one straight line alone is possible having $l_\infty$ ($1-e^{-k}$) and
$e^{-k}$ as its intercept and slope respectively, and almost all the modes will be
on this straight line.

*Case*: 2.—*When more than one pair* ($l_\infty$ , $e^{-k}$ ) *are available, each pair
representing homogeneous group of* ( $l_\infty$ , $e^{-k}$ ) *values*: As in the case 1 each pair
($l_\infty$ , $e^{-k}$ ) represents a straight line. The line on which maximum number of
modes fall is to be selected. This is similar to Pauly's method of selecting a
suitable pair ( $l_\infty$ , $e^{-k}$ ). However, in Pauly's approach, the pair ( $l_\infty$ $e^{-k}$ )
need not be obtained from the data directly and approximate values are seeded.
Added advantage in the present approach is the availability of their variance
estimates whenever possible.

It may not be difficult, from experience, to have an idea about the time
at which peak breeding and the appearance of the first mode takes place. This
information helps to fix the age of the first mode approximately. For all practical
purposes, this approximate value is enough to estimate $t_o$. The length for the

subsequent modes may be available from the data or this can be obtained using equation (10) and the corresponding age then can be fixed. Then using equation (11), an estimate for $t_o$ can be obtained. Thus VBG is fully described by this method. The details of the same are given in Work sheet VI.

In the case of allometric growth also same steps as above are used, but $l_t$ is replaced by, $l_t^d$ for all t and k is replaced by kd. In this way VBG curve is completely determined. Once VBG is completely determined, estimate of Z can be obtained as indicated earlier.

*Estimation of M., the instaneous rate of natural mortality using standard effort*: Splitting up of total mortality into that of fishing and natural mortality is really a problem. Experimental fishing during non-fishing season is expected to yield an estimate of M. In heavily exploited stocks this is out of question. However, relating Z with effective effort expended, we have

$$Z = M + qf \qquad\qquad \dots\dots \quad (22)$$

where q is the catchability coefficient and f is the effective effort. Equation (22) may not hold good in all cases. This may be due to (i) 'f', the effective effort, not being correctly assessed; (ii) the relationship (22) being absent; and (iii) insufficient data base. Normally one does not come across case (ii). Insufficient data base can be overcome by proper sampling as mentioned earlier. Correct assessment of effective effort may also be done. For instance, trawlers catch good quantities of prawns during its peak season. Other times they bring good quantities of threadfin breams. Hence taking effort of trawlers both the occasions as such may reflect on effective effort. To avoid this, standardising trawls on the basis of their CPUE obtained in the peak season will improve the situation. Thus strengthening the data base and proper evaluation of effort will go a long way in obtaining an estimate of M. An ingenious way of assessing M (Sekharan 1975) is as follows. Suppose a stock is supposed to live for four years (in tropics fish normally have relatively short span of life compared to that in temperate zone), then, even when the fishing is absent, most of the stock would die after attaining 4 years. Assuming that 99% of the stock die by the time it reaches 4 years we have

$$\frac{N_4}{N_o} = \frac{1}{100} = e^{-4M} \qquad\qquad \dots\dots \quad (23)$$

Equation (23) given an estimate for M. This approach can profitably be used for assessing maximum life span of the stock, using the estimate of Z for M in (2) and comparing this estimate of life span with the expected life span of the stock.

*Estimation of M., using* $l_\infty$ *and* $k$: (a) *Analytical method*—Once we get an estimate of age when $l_t$ reaches $l_\infty$ then at this age it may be assumed that the survival is either five or one percent. Using equation (23) corresponding 'M' can easily be estimated. Now we know

$$\frac{1}{k} \log_e \left[ 1 - l_t / l_\infty \right] = t_o - t \qquad \qquad \dots\dots (11)$$

Putting $l_T = l_\infty - 0.50$ cm the relative age $T$ can be obtained from (11). Using (23), at 5% survival.

$$\frac{N_T}{N_o} = \frac{5}{100} = e^{-TM}$$

gives an estimate for M.

(b) *Graphical method*— When successive modes at unit intervals of time are available $l_\infty$ is estimated using Ford-Walford graph. The relative age 'T' at which $l_\infty - 0.50$ is attained can be graphically determined by extropolation. Using this T in (23) the corresponding value of M can be found at five and one percent levels of survival.

(c) *Estimation of correct age*— For this purpose estimate of $t_o$ is required. Once the time (the peak breeding month) at which breeding takes place is known and the month at which first mode $l_1$ appears then

$$\frac{1}{k} \log_e \left[ 1 - l_t / l_\infty \right] = t_o - t_1$$

where $t_1$ is no. of months required to reach $l_1$ This gives an estimate for $t_o$. Using this estimate of $t_o$ the actual age of fish can be fixed.

Instead of using $M + F = Z = \log_e (N_i / N_{i+1})$, the actual abundance, in continuous fishery it is better to use mean abundance (Beverton and Holt 1956), leading to

$$M + qf = \log_e (\bar{N}_i / \bar{N}_{i+1})$$

This may be tried under Case II. The method of approach for estimating M is shown in Work sheet VII.

*Estimation of Z using* lc *and* $\bar{l}$

From the length samples using the mean length in the catch containing all lengths starting from lc and above

$$\bar{l} = \sum_i N_i\, l_i\, /\, \sum_i N_i\,,\; i \geq c \qquad\qquad \dots\dots\dots (24)$$

where $l_i$ is the mean length of $i^{th}$ class interval containing $N_i$ individuals and lc the length at entry at fully exploited phase, we get (Beverton and Holt 1956)

$$Z = k\,(l_\infty - \bar{l})\, /\, (\bar{l} - lc) \qquad\qquad \dots\dots\dots\dots (25)$$

where k and $l_\infty$ are parameters in VBG.

In the same notation Ssentengo and Larkin (1973) have shown (Pauly 1982) that

$$Z = (\frac{nk}{n+1})/\log_e (\frac{l_\infty - lc}{l_\infty - \bar{l}}) \qquad\qquad \dots\dots\dots (26)$$

Now

$$\log_e (\frac{l_\infty - lc}{l_\infty - \bar{l}}) \;=\; \log_e (\frac{l_\infty - \bar{l} + \bar{l} - lc}{l_\infty - \bar{l}})$$

$$= \log_e (1 + \frac{\bar{l} - lc}{l_\infty - \bar{l}})$$

$$\simeq (\bar{l} - lc)\, /\, (l_\infty - \bar{l}) \qquad\qquad \dots\dots\dots (27)$$

when $(\bar{l} - lc)\,/\,(l_\infty - \bar{l})$ is small ( $\frac{\bar{l} - lc}{l_\infty - \bar{l}}$ ) becomes negligible for all n $\geq$ 2.

Hence, when n is sufficiently large that ( n/n + 1) $\simeq$ 1 and ( $\frac{\bar{l} - lc}{l_\infty - \bar{l}}$ )$^n$ is negligible for all n $>$ 2, equation (26) approximates to equation (25).

In the above two cases estimates of both k and l∞ are assumed to be available. Let $l_c$ and $l_m$ be the minimum and maximum lengths fully represented in the catch and 'a' is the life span of fish in between $l_c$ and $l_m$, Then Srinath and Alagaraja (1981) following Ssentango et al (op. cit.) have shown that

$$Za[(\bar{l} - l_c) / (l_m - l_c)] = 1 - \frac{e^{za}}{e^{za} - 1} \qquad \qquad \cdots \cdots \cdots (28)$$

where $\bar{l}$ is the mean length as defined earlier.

The estimation of Z on the basis of different formulae given above is shown in the Work sheet VIII.

## 4. STOCK ASSESSMENT

Now there are two models generally employed to assess the exploited fish stocks. The first is based on Beverton and Holt's yield per recruit model (Beverton and Holt 1956). Since this assumes the knowledge of the estimates of vital parameters such as Z and F, this model comes under micro-analytic model. The second one is based on catch and effort only (Schaeffer 1957), hence called macro-analytic model. In the first model, it may be noted, the stock assessment becomes species-specific or it is applicable to the stocks having more or less the same Z, F, k and l∞. The second model may be used for groups of fishes exploited by the same type of gears. If there are gears of more than one type employed and if there is no problem in estimating the effective effort, then also this model can be used. Hence this second model is gear or effort specific. However, in the tropics, multispecies exploited by multigears being ubiquitous, the estimation of effective effort may not be that easy. So, in such cases a third model, called Relative Response model, as described below, is suggested.

### Relative Response model

Relative Response model is a new model advanced to estimate a stock when the estimation of effective effort becomes difficult owing to the ubiquitous exploitation of multispecies by multigears, assuming the following. (1) Stocks existing in a particular area are exploited by various types of gear that are not species specific. This implies that the effect of fishing a mixture of stocks by these gears is proportional to the relative abundance of stocks in the mixture. For instance, if prawns, sciaenids and catfishes are in the ratio 1:2:3 in the mixed stock the catch too will have these species in the same ratio. (2) The fishing is increased over a period of time (year) till the optimum level is

achieved. This assumption implies that once that effort reaches a stage econo-mically not viable, the level of effort would decline to allow the stock to so readjust as to remain in a given level of abundance, or the effort and the stock both would crash down due to overfishing. However, in practice what is found is that the effort adjusts to its optimum level. (3) The third assumption is that when the effort is increased the catches are also increased till a maximum level is reached but the rate of increase increases first, then decreases and finally reaches to nil. At this later stage two things may happen: self regulatory measures on effort may be brought in and the catches kept at a constant level, or, if the price of the fish goes up, making the increased effort economically viable, the effort is increased beyond the safe level, forgetting its ill effects, and the stock is almost annihilated..

In the first stage, when the rate of increase is increasing, more removal leads to better survival and growth in the residual stock resulting in more catch. This stage, in which the response of the stock (to the fishing effort) is positive, continues till the carrying capacity of the water body reaches its maximum. But, when the exploitation exceeds this level, although the response of the stock continues to be positive, the stock is unable to cope up with the increased fishing effort and the rate of increase starts declining and finally reaches nil, after which the response of the stock to the effort is negative. In other words the catches of successive periods in well-exploited stocks are all interrelated. Hence in the absence of fishery independent factors, under the above assumption, the difference in the catches between two successive periods starts declining and finally the catches reach a plateau. This model fits well in majority of the cases in tropical condition where exploitation of stocks is in progress.

The mathematical model fitting the above approach may be as follows

$$C_t - C_{t-1} = f(C_{t-1}) \qquad \dots\dots\dots (29)$$

Where $C_t$ and $C_{t-1}$ are catches at successive periods, $f(C_{t-1})$ is a function of $C_{t-1}$. One of the curves fitting the relative response theory is the sigmoid curve. Hence relationship between $C_t$ and $C_{t+1}$ in equation (29) is similar to that in VBG for $l_t$ and $l_{t+1}$

That is

$$C_{t+1} = a + b\, C_t \qquad \dots\dots\dots (30)$$

This leads to sigmoid curve where $Ct$ reaches an asymptotic maximum. As stated earlier more fishing pressure at this level may lead either to decreased CPUE, when constant recruitment is maintained, or to overfishing, when recruitment is also affected. In the progressive fishery the level of maximum catch can be predicted by this method and suitable management measures may be suggested in advance to get sustainable yield from the fishery.

The second model indicates that effort-catch curve is parabolic in that

$$C = a f = b f^2 \qquad \qquad \ldots \ldots \quad (31)$$

where f is effective effort, C the catch and a and b are constants. Theoretically C = o when f = o and C attains maximum when f = a/2b, which is exactly the mid point of (0, a/b) and the effort-catch curve is smooth on both the sides of a/2b. The smoothness of the curve in the left hand limb is understandable whereas the same on the right hand side, the decreasing phase, does not appear to be reasonable, since the fisheries that have experienced overfishing did not linger on but disappear suddenly. Also, except in the case of high prize-low size compatibility such as in shrimps, fisheries that experience less returns start regulating themselves by adjusting effort so that effort pressure is reduced and the economic viability of operations is maintained. In these cases right hand side of equation (31) is always incomplete with the points lying nearer to the maximum level only. Hence estimation of parameters on the basis of such incomplete data or onesided data may not be precise. Thirdly, in the case of progressing fisheries almost all the points will be on the left side of a/2b. In this case no inference could be drawn about the maximum catch level by using (31). Hence no suggestion to the management. These shortfalls could be overcome by the approach of the theory of Relative Response as shown in the examples given in the Work sheet IX.

## ACKNOWLEDGEMENT

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# WORK SHEET I A

*Size distribution of fishes (species) on sampling days.*

No. of units operated: 20

Centre:                    Craft:                    Resource:
Date:                      Gear:                     Species:

| Size (mm) | Sample | Unit 1 | Sample | Unit 2 | Sample | Unit 3 | Sample | Unit 4 | Sample | Unit 5 | Total for five units | Estimates for the day |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-5 | 1 | 7 | — | — | — | — | — | — | 1 | 10 | 17 | 68 |
| 5-10 | 2 | 14 | — | — | — | — | — | — | 2 | 20 | 34 | 136 |
| 10-15 | 3 | 21 | 2 | 16 | — | — | — | — | 1 | 10 | 47 | 188 |
| 15-20 | 5 | 36 | 4 | 32 | — | — | — | — | 1 | 10 | 78 | 312 |
| 20-25 | 7 | 50 | 6 | 48 | — | — | — | — | 2 | 20 | 118 | 472 |
| 25-30 | 4 | 29 | 5 | 40 | — | — | 1 | 7 | 2 | 20 | 96 | 384 |
| 30-35 | 2 | 14 | 3 | 24 | 2 | 12 | — | — | 3 | 30 | 80 | 320 |
| 35-40 | 1 | 7 | 4 | 32 | 5 | 30 | 1 | 7 | 6 | 60 | 136 | 544 |
| 40-45 | 6 | 43 | 2 | 16 | 7 | 42 | 2 | 12 | 7 | 70 | 183 | 732 |
| 45-50 | 2 | 14 | 1 | 8 | 6 | 36 | 2 | 12 | 6 | 60 | 130 | 520 |
| 50-55 | 1 | 7 | 1 | 8 | 5 | 30 | 3 | 20 | 5 | 50 | 115 | 460 |
| 55-60 | — | — | 1 | 8 | 4 | 24 | 8 | 52 | 8 | 80 | 164 | 656 |
| 60-65 | — | — | 3 | 24 | 3 | 18 | 7 | 45 | 3 | 30 | 117 | 468 |
| 65-70 | — | — | 2 | 16 | 2 | 12 | 6 | 39 | 2 | 20 | 87 | 348 |
| 70-75 | — | — | 1 | 8 | 1 | 6 | 5 | 33 | 1 | 10 | 57 | 228 |
| 75-80 | — | — | — | — | 1 | 6 | 4 | 26 | — | — | 32 | 128 |
| 80-85 | — | — | — | — | 1 | 6 | 1 | 7 | 1 | 10 | 23 | 92 |
| 85-90 | — | — | — | — | 1 | 6 | 1 | 7 | 7 | 10 | 23 | 92 |
| 90-95 | — | — | — | — | — | — | 1 | 7 | — | — | 7 | 28 |
| 95-100 | — | — | — | — | 1 | 6 | 1 | 6 | — | — | 12 | 48 |
| Total No. | 34 | 249 | 35 | 280 | 39 | 234 | 43 | 280 | 52 | 520 | 1556 | 6224 |
| Weight (gm) | 140 | 1000 | 150 | 1200 | 250 | 1500 | 300 | 1950 | 500 | 5000 | | |

ALAGARAJA

# WORK SHEET I B

*Size distribution of fishes (species) for the month of* ........

Centre:                Craft:

Date:                  Gear:                                      Resource:

| Size (mm) | Estimated numbers on sampling days in the month | | | | | | | | Total of estimates | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Date 1st day | Date 2nd day | Date 3rd day | Date 4th day | Date 5th day | Date 6th day | Date 7th day | Date 8th day | sampled days | month | % |
| 0-5 | 68 | 105 | 15 | 46 | 74 | 28 | 33 | 12 | 381 | 1048 | 1.36 |
| 5-10 | 136 | 25 | 25 | 83 | 104 | 72 | 51 | 56 | 552 | 1518 | 1.96 |
| 10-15 | 188 | 34 | 48 | 95 | 106 | 132 | 97 | 73 | 783 | 2153 | 2.78 |
| 15-20 | 312 | 15 | 96 | 106 | 195 | 141 | 138 | 82 | 1085 | 2984 | 3.86 |
| 20-25 | 472 | 46 | 112 | 73 | 178 | 162 | 155 | 95 | 1293 | 3556 | 4.60 |
| 25-30 | 384 | 78 | 178 | 89 | 106 | 178 | 169 | 117 | 1299 | 3572 | 4.63 |
| 30-35 | 320 | 352 | 289 | 98 | 97 | 207 | 213 | 189 | 1765 | 4854 | 6.27 |
| 35-40 | 544 | 436 | 365 | 118 | 68 | 291 | 248 | 216 | 2286 | 6286 | 8.14 |
| 40-45 | 732 | 407 | 418 | 191 | 32 | 326 | 215 | 257 | 2578 | 7090 | 9.17 |
| 45-50 | 520 | 506 | 582 | 242 | 15 | 337 | 198 | 206 | 2606 | 7166 | 9.27 |
| 50-55 | 460 | 540 | 611 | 387 | 18 | 417 | 196 | 191 | 2820 | 7755 | 10 3 |
| 55-60 | 656 | 612 | 407 | 435 | 17 | 305 | 143 | 158 | 2733 | 7516 | 9.72 |
| 60-65 | 468 | 302 | 315 | 364 | 21 | 387 | 128 | 140 | 2125 | 5844 | 7.56 |
| 65-70 | 348 | 258 | 302 | 281 | 32 | 198 | 107 | 131 | 1657 | 4557 | 5.90 |
| 70-75 | 228 | 241 | 285 | 197 | 18 | 126 | 96 | 105 | 1296 | 3564 | 4.61 |
| 75-80 | 128 | 202 | 216 | 165 | 6 | 94 | 69 | 87 | 967 | 2659 | 3.44 |
| 80-85 | 92 | 108 | 198 | 121 | 5 | 83 | 38 | 76 | 721 | 1983 | 2.56 |
| 85-90 | 92 | 75 | 102 | 96 | 8 | 65 | 31 | 63 | 532 | 1463 | 1.90 |
| 90-95 | 28 | 36 | 95 | 83 | 7 | 32 | 25 | 58 | 364 | 1001 | 1.29 |
| 95-100 | 48 | 25 | 48 | 51 | 11 | 23 | 16 | 45 | 267 | 734 | 0.95 |
| Total | 6224 | 4403 | 4707 | 3321 | 1128 | 3604 | 2366 | 2357 | 28110 | 77303 | |

## WORK SHEET II

a.  $\dfrac{l_{t+1} - l_t}{l_t - l_{t-1}} = e^{-k}$

b.  $\dfrac{l_{t-1} \cdot l_{t+1} - l_t^2}{l_{t-1} + l_{t+1} - 2 l_t} = l_\infty$

and

c.  $\dfrac{1}{k} \log_e (1 - l_t/l_\infty) = t_o - t$

Here, for d = 1 (since d = 0.7541), values differ from the earlier data on *Setipinna phasa* : Alagaraja and Jhingran 1976.

| Age (years) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| length (mm) | 76.0 | 121.9 | 162.8 | 201.6 | 231.6 | 259.4 | 285.4 | 303.3 |

$l_\infty = 560.70$      S.E. $(l_\infty) = 90.09$

$e^{-k} = 0.8605$      S.E $(e^{-k}) = 0.0432$

$k = 0.1502$

$t_o = -0.4416$      S.E. $(t_o) = 0.0485$

*Method of estimating the parameters*

Ex: $l_2 = 121.9$  $l_1 = 76.0$ and $l_3 = 162.8$

$\therefore \dfrac{l_3 - l_2}{l_2 - l_1} = \dfrac{162.8 - 121.9}{121.9 - 76.0}$ (when t = 2) $= e^{-k}$

Similarly we can have estimates of $e^{-k}$ from

$\dfrac{l_4 - l_3}{l_3 - l_2}$ , $\dfrac{l_5 - l_4}{l_4 - l_3}$ , $\dfrac{l_6 - l_5}{l_5 - l_4}$ , $\dfrac{l_7 - l_6}{l_6 - l_5}$ & $\dfrac{l_8 - l_7}{l_7 - l_6}$ . Thus we have 6 (n-2) estimates of $e^{-k}$. The means and standard errors (S.E.) are given above. Similarly there are six estimates of $l_\infty$ based on (b) above whose mean and S.E. are given above. Using (c) we get the estimate of $t_o$ as intercept whose estimate and S.E. are given above.

*Note*: The denominator in (b) clearly indicates that if the modal lengths are in arithmetic progression (A.P.), in otherwards, it the differences between $l_t$

and successive values of it remains more or less the same, then $l_\infty$ becomes a vary large quantity $(\infty)$. When the modal lengths are in A.P. then $l_{t+1} + l_{t-1} - 2l_t = 0$. Similarly when the modal lengths are in geometric progression, (G.P). Then the numerator for $l_\infty$ becomes exceedingly small. Hence the modal lengths should not follow either A.P. or G.P. in VBG.

## WORK SHEET III

a. $\dfrac{\overset{d}{l_{t+1}} - \overset{d}{l_t}}{\overset{d}{l_t} - \overset{d}{l_{t-1}}} = e^{-kd}$

b. $\dfrac{\overset{d}{l_{t-1}} \cdot l - \overset{d}{l_{t+1}} - \overset{2d}{l_t}}{\overset{d}{l_{t-1}} + \overset{d}{l_{t+1}} - 2\overset{d}{l_t}} = l_\infty$

and    c. $\dfrac{1}{kd} \log_e (1-l_t \,/\, l_\infty) = t_o - t$

$d = 0.7541$

Data on *Setipinna phasa* : as in Worksheet II.

| | |
|---|---|
| $l_\infty = 456.27$ | S.E. $(l_\infty) = 50.95$ |
| $e^{-k} = 0.7731$ | S.E. $(e^{-k}) = 0.0488$ |
| $k = 0.2574$ | |
| $t_o = -0.8671$ | S.E. $(t_o) = 0.0561$ |

*Note*: If $l_t$ raised to d is in arithmetic progression (A.P.), then $l_\infty$ assumes fantastically large values. It may be further noted that when $l_t$ is in geometric progression (G.P) then the numerator vanishes and $l_\infty$ becomes very small. These observations imply that modal values should not follow both A.P. and G.P. Then estimation of $l_\infty$ becomes reliable. In this case it is pertinent to note that if the time intervals (monthly|weekly) are smaller the average monthly increment may remain the same for few months, following A.P., making the estimate of $l_\infty$ exceedingly large. Hence age intervals should be so determined as not to have A.P. and G.P. This remark holds good when d = 1 also. Please see Worksheet II.

## WORK SHEET IV

$$\log ( N_{t+\triangle t} / N_t ) = \frac{Z}{k} \log ( \frac{l_\infty - l_{t+\triangle t}}{l_\infty - l_t} )$$

Taking $l_\infty = 23.1$ and $k = 0.59$ from Table 8 in 'Some simple methods for the assessment of tropical fish stocks (Pauly, 1983)

| Mid range | N |
|---|---|
| 13.5 | 613 |
| 14.5 | 493 |
| 15.5 | 278 |
| 16.5 | 93 |
| 17.5 | 73 |
| 18.5 | 7 |
| 19.5 | 2 |

$\bar{Z} = 3.23$         S.E. $(\bar{Z}) = 0.94$
There are six Z values

*Calculation of Z values*

For first Z value, $l_t = 13.5$,         $l_{t+\triangle t} = 14.5$
         and $N_t = 613$         $N_{t+\triangle t} = 493$
For Second Z value, $l_t = 14.5$         $l_{t+\triangle t} = 15.5$
         and $N_t = 493$         $N_{t+\triangle t} = 273$, and so on.

## WORK SHEET V

$$\frac{1}{\triangle t} \left[ \log_e ( l_\infty - l_{t+\triangle t}) - \log_e (l_\infty - l_t ) \right] = k$$

Using tables 4 and 5 of Pauly, 1983 (see Tables 1 and 2 in this paper), and assuming $l_\infty$ values to be 20.33 and 52.0, respectively, the k value are 0.4230 (S.E. 0.0550) and 0.5230 (S.E. 0.0440) against 0.4307 and 0.5050 found in Pauly (op.cit).

## WORK SHEET VI

*Modal progression (straight line method)*

Fixing the straight line by using the intercept a and the slope b where $a = l_\infty (1-e^{-k})$ and $b = c^{-k}$, To fix a straight line two points are required. One point is (o, a) and another one some value in the length range less than $l_\infty$ In our case $l_\infty = 312.5$ and $k = 0.05671$ or $e^{-k} = 0.9449$. Below is the table where for different values of $l_\infty$ and $e^{-k}$, including the expected values of $l_\infty$ and $e^{-k}$ pair of values (x, y) are obtained. First pair (o, a) and second pair (300, $l_{t+1}$) where $l_t = 300$ are as follows:

*Pair of Coordinates (x, y) for fitting a straight line*

| $l_\infty$ | 0.943 | 0.944 | $e^{-k}$   0.945 | 0.946 |
|---|---|---|---|---|
| 310.0 | (0,17.67)& | (0.17.36)& | (0,17.05)& | (0,16.74)& |
|  | (300,300.57) | (300,300.56) | (300,300.55) | (300,300.54) |
| 310.5 | (0.17.70)& | (0,17.39)& | (0,17.08)& | (0,16.78)& |
|  | (300,300.60) | (300,300.59) | (300,300.58) | (300,300.57) |
| 311.0 | (0,17.73)& | (0,17.42)& | (0,17.11)& | (0,16.79)& |
|  | (300,300.63) | (300,300.62) | (300,300.61) | (300,300.59) |
| 311.5 | (0,17.76)& | (0,17.44)& | (0,17.13)& | (0,16.82)& |
|  | (300,300.66) | (300,300.64) | (300,300.63) | (300,300.62) |
| 312.0 | (0,17.78)& | (0,17.47)& | (0,17.16)& | (0,16.85)& |
|  | (300,300.68) | (300,300.67) | (300,300.66) | (300,300.65) |
| 312.5 | (0,17.81)& | (0,17.50)& | (0,17.19)& | (0,16.88)& |
|  | (300,300.71) | (300,300.70) | (300,300.69) | (300,300.68) |
| 313.0 | (0,17.84)& | (0,17.53)& | (0,17.22)& | (0,16.90)& |
|  | (300,300.74) | (300,300.73) | (300,300.72) | (300,300.70) |

*Data*

| t (months): | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| $l_t$ (cm): | 33.5 | 49.0 | 63.5 | 77.5 | 90.0 | 102.5 | 114.0 | 125.0 | 135.5 |

| t : | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|
| $l_t$ | 145.0 | 154.5 | 163.0 | 171.0 | 179.0 | 186.5 | 193.5 | 200.0 | 206.0 | 212.0 |

| t : | 20 |
|---|---|
| $l_t$ | 217.5 |

Let us draw 3 st. lines out of 28 st. lines given in the table. For this we shall consider the three following sets.

**Sets**

| | 1 | 2 | 3 |
|---|---|---|---|
| $l_\infty$ | 310.0 | 312.5 | 313.0 |
| $e^{-k}$ | 0.946 | 0.945 | 0.943 |
| Pair of Co-ordinates: | (0,16.74)& | (0.17.19)& | (0.17.84)& |
| | (300,300.54) | (300,300.69) | (300,300.74) |

*Selection of straight line*: The line which accommodates maximum number of modes is to be selected.

*Fixing the cohort*: Modes that do not belong to single cohort may also fall on the st. line. Hence to get the modes of a single cohort, take successive modes (two or three) of a cohort. This could be judged from the modal progression. The region where the ambiguity about cohort is the least may be selected and the modes from this region may be considered for this purpose. Taking the first mode from this group and using this as $l_t$ we can estimate the successive modes of a given cohort as well as its preceding modes using the relationship

$$l_{t+1} = l_\infty (1-e^{-k}) + l_t e^{-k}$$

*Fixing the cohorts*: The above method may also lead to segregation of modes into different cohorts, which have more or less similar parameters such as $l_\infty$ and k.

# WORK SHEET VII

*Example* 1: Let us suppose that for oil sardines the maximum age is four years. Assuming 99% of the population die by the time they reach 5th year, if there is no fishing, we have.

$$\frac{N_4}{N_o} = 0.01 = e^{-4M}$$

Hence M = 1.15

*Example* 2 (*Analytical method*): for the catfish *T. thalassinus* $l_\infty$ = 755 mm, k 20-36. and hence $l_t$ = 750 mm. Hence.

$$\frac{1}{0.36} \log_e [1 - \frac{750}{755}] = -T$$

This gives T = 14.
and $e^{-14M}$ = 0.05

In other words, $M = -\frac{1}{14} \log_e (0.05) = 0.21$

## WORK SHEET VIII

Estimation of 'Z' using $l_c$, $\bar{l}$, $l$ max and duration of life of fish (t) in the fishery. using

$$a) \frac{Z_t \ (\bar{l}-l_c\ )}{(l \ max - l_c\ )} = 1 - \frac{Z_t}{(e^{Z_t}-1)}$$

Values of Z for (a) are taken from the table given in Srinath and Alagaraja (1981).

*Example* 1 (Data are taken from Martin (1978) on *Bagrus docmac*)

   a.   *Kavirando Gulf*:   $l_c$ = 34.5 cm.   l max = 85.0 cm

                                   $\bar{l}$ = 41.9 cm.   l = 7 months

       From (a) Z = 11.6
       From Marten (1978) Z = 11.5

   b.   *Emin Pasha Gulf*:   $l_c$ = 34.5 cm   l max = 85.0 cm.

                                   $\bar{l}$ = 47.4 cm   t = 7 months

       From (a) Z = 6.3
       From Marten (1978) Z = 6.0

*Example* 2 (Data are taken from R. Mallikarjuna Rao, Mss. on growth studies on *Pangasius pangasius*).

       $l_c$ = 12.5 cm   l max = 26.5 cm.
       $\bar{l}$ = 19.1 cm   t = 27 fortnights

       From (a) Z = 0.345
       From actual data Z = 0.345

*Example* 3 (Data from Balan and Raghu 1979 on *Sardinella longiceps*)

       $l_c$ = 10.25 cm   l max = 17.75 cm
       $\bar{l}$ = 13.67 cm   t = One year

       From (a) Z = 0.577
       From the above paper, Z = 0.570

The estimates are so close to each other in the above examples.

## WORK SHEET IX

*Relative Response model*

$$C_{t+1} = a - b \, C_t$$

Applying the model on data on world fish production for 19 years from 1962 to 1980 (Table 3) Max. $C_t$ = 73.2 million tonnes; and ·

**Max. $C_t$ = 73.2 million tonnes.**

on Indian total fish landings including inland catch. Max $C_t$ = 2.76 million tonnes

TABLE 3. *Total fish landings (including inland catch) in million tonnes for the period* 1962-1980.

| Year | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| India | 0.97 | 1.05 | 1.32 | 1.33 | 1.37 | 1.40 | 1.53 | 1.61 | 1.75 | 1.85 | 1.64 | 1.96 |
| World | 47.00 | 48.3 | 52.70 | 53.50 | 57.30 | 60.40 | 63.90 | 62.70 | 65.58 | 66.21 | 62.18 | 62.82 |

| Year | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 |
|---|---|---|---|---|---|---|---|
| India | 2.26 | 2.27 | 2.17 | 2.32 | 2.31 | 2.34 | 2.42 |
| World | 66.60 | 66.49 | 69.87 | 69.17 | 70.55 | 71.29 | 72.19 |

(Source F.A.O. Year Book)

THE SIX PROFORMAE RECOMMENDED FOR RECORDING CATCH (WT.|NOS.) AND
EFFORT DATA FOR STOCK ASSESSMENT

*Estimated catch and effort*

1 & 2.  *Non-selective|selective gears* — PROFORMA 1A|B

Year:                           Centre:                         Resource:

| Names of Gear\|craft: | 1 | | | 2 | | | 3 | | | 4 | | | 5 | | | Total catch of the Resource | % of the re-source in the total landings |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | C | E | C\|E | C | E | C\|E | C | E | C\|E | C | E | C\|E | C | E | C\|E | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |

3.   *Estimated species composition of the resource in the catch* —   PROFORMA II

Year:                           Centre:                         Fishing gear:
                                                                Craft:

| Name of species: | 1 | | 2 | | 3 | | 4 | | 5 | | Monthly total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | C | P | C | P | C | P | C | P | C | P | C | E |
| 1 | 2 | 3 | 4 | 5 | 8 | 9 | 10 | 11 | 10 | 11 | 12 | 13 |

4.  *Size-frequency distribution of species on sampling days* — PROFORMA III A.

Centre:            Craft:            Resource:         No. of units landed
Date:              Gear:             Species:         on the day

|  | Sample | | | | | Total of | Estimated frequencies |
|  | 1 | 2 | 3 | 4 | 5 | all samples | for that day |
| Size class |  | Frequencies | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Total No. |  | | | | | | |
| Wt. |  | | | | | | |

5.  *Size-frequency distribution for the month*—PROFORMA III B.

Centre:            Craft:            Resource:
Month:           Gear:           Species:

| Size class | Estimated frequencies on sampling days | | | | | | | | Total for all sampling days | Estimates for the month | Percentage frequency |
|  | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | 8th | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Total No. |  | | | | | | | | | | |
| Wt. |  | | | | | | | | | | |
| Effort |  | | | | | | | | | | |

6.    *Month-wise estimated size distribution of species* — **PROFORMA III C.**

Centre:                          Craft:                          Resource:
Year:                            Gear:                           Species:

| Size class | Estimated frequencies | | | | | | | | | | | | Total for the year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Total No. | | | | | | | | | | | | | |
| Weight | | | | | | | | | | | | | |
| Effort | | | | | | | | | | | | | |

E = Effort = No. of units operated (Besides no. of units indicate trawling hours in parenthesis).

C = Catch in weight;    C|L = Catch per unit effort;    P = Percentage in the monthly total

Non selective gears : Trawl, purse-seine, shore-seine, boat-seine, bag net etc.

Selective gears : Gill|drift net, hooks and lines etc.

4. *Size-frequency distribution of species on sampling days* — PROFORMA III A.

| Centre:<br>Date: | | Craft:<br>Gear: | | Resource:<br>Species: | | | No. of units landed<br>on the day |
|---|---|---|---|---|---|---|---|

| | | Sample | | | | Total of | Estimated frequencies |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | all samples | for that day |
| Size class | | Frequencies | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Total No. | | | | | | | |
| Wt. | | | | | | | |

5. *Size-frequency distribution for the month*—PROFORMA III B.

| Centre:<br>Month: | | Craft:<br>Gear: | | Resource:<br>Species: | |
|---|---|---|---|---|---|

| Size<br>class | Estimated frequencies on sampling days | | | | | | | | Total for<br>all sampling | Estimates<br>for the | Percentage<br>frequency |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | 8th | days | month | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Total No. | | | | | | | | | | | |
| Wt. | | | | | | | | | | | |
| Effort | | | | | | | | | | | |

6. *Month-wise estimated size distribution of species —* PROFORMA III C.

Centre:                 Craft:                 Resource:
Year:                   Gear:                  Species:

| Size class | Estimated frequencies | | | | | | | | | | | | Total for |
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | the year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Total No. | | | | | | | | | | | | | |
| Weight | | | | | | | | | | | | | |
| Effort | | | | | | | | | | | | | |

E = Effort = No. of units operated (Besides no. of units indicate trawling hours in parenthesis).
C = Catch in weight;   C|L = Catch per unit effort;   P = Percentage in the monthly total
Non selective gears : Trawl, purse-seine, shore-seine, boat-seine, bag net etc.
Selective gears : Gill|drift net, hooks and lines etc.

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