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

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

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

$$S \, bl^2 \qquad\qquad \dots\dots (2)$$

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

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

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,

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

where n $\neq$ 3 and

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

where m $\neq$ 2 and

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

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.

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

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 $l\infty, k, l_o$ 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

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

Since

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

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

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

In the case of allometric growth n $\neq$ 3. This can be tested. If the test does show n $\neq$ 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 ith 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 ith 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 ith fish is obtained from $\frac{s}{g} \cdot gi = si$. 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

$$I_t^d = I_\infty^d \left[1 - e^{-kd \, (t-t_o)} \right] \qquad \ldots\ldots \text{ (8}^1\text{)}$$

we get

$$I_{t+1}^d = I_\infty^d \left[1 - e^{-kd} \right] + I_t^d e^{-kd} \qquad \ldots\ldots \text{ (10}^1\text{)}$$

and

$$\frac{1}{kd} \log_e \left(1 - I_t^d \Big/ I_\infty^d \right) = t_o - t \qquad \ldots\ldots \text{ (11}^1\text{)}$$

As before, using

$$\frac{I_{t+1}^d - I_t^d}{I_t^d - I_{t-1}^d} = e^{-kd} \qquad \ldots\ldots \text{ (12}^1\text{)}$$

and

$$\frac{I_{t+1}^d \cdot I_{t-1}^d - I_t^{2d}}{I_{t-1}^d + I_{t+1}^d - 2I_t^d} = I_\infty^d \qquad \ldots\ldots \text{ (13}^1\text{)}$$

along with (11^1), the estimates of I_∞ , k and t_o and their variance estimates can be obtained. The detail procedure of this approach is given in Work sheet III.
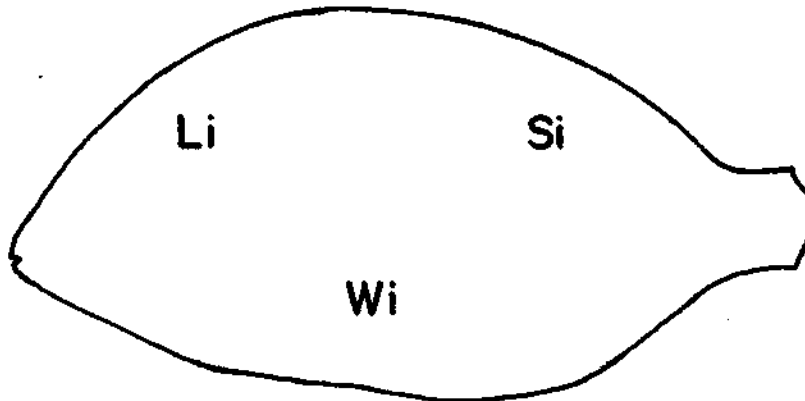
Estimation of instantaneous rate of total mortality: Dissolution of multinormal distribution into uninormal ones through graphical methods has been pointed out by Harding (1949), Cassey (1945), Battacharya (1967) and others. These procedures allot numbers to each modal class representing different ages. 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

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

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:

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

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

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

Hence

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

Thus

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

Since l_∞ 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

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

Hence

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

and

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

Here also estimates of k, d and l_∞ 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

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

Equation (21) can also be obtained from equation (17) after taking logarithms, on both sides with base e. Summing such $\triangle ts$ 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_∞ as follows.

Estimate of l_∞ *and* e^{-k}: Arrange the modes in an ascending order and let these be $l_1, l_2, l_3 \ldots \ldots$ In. Taking the first three modes starting from l_1 we have as before $\frac{l_3 - l_2}{l_2 - l_1} = e^{-k}$, taking next three modes starting from l_2 we have $\frac{l_4 - l_3}{l_2 - l_1} = e^{-k}$, 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_∞ is also available as seen in (13). From these pairs (l_∞, e^{-k}) the value of l_∞ may be chosen such that this value is the maximum of the estimates. Otherwise values of l_∞ may be grouped into sets of more or less equal magnitude. For each such homogeneous group mean and variance can be found wherever possible. In case there are no wide variations among l_∞ values, all l_∞ 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_∞, e^{-k}) *is available*: In this case, one straight line alone is possible having l_∞ $(1-e^{-k})$ 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_∞, e^{-k}) *are available, each pair representing homogeneous group of* (l_∞, e^{-k}) *values*: As in the case 1 each pair (l_∞, 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_∞, 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

$$Z = M + qf \qquad \qquad \ldots \ldots \text{(22)}$$

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

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

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_∞ *and* k: (a) *Analytical method*—Once we get an estimate of age when l_t reaches l_∞ 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

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

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_∞ 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 l_c *and* $\overline{l}$

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

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

where l_i is the mean length of ith class interval containing N_i individuals and l_c the length at entry at fully exploited phase, we get (Beverton and Holt 1956)

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

where k and l_∞ are parameters in VBG.

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

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

Now

$$\log_e (\frac{l_\infty - l_c}{l_\infty - \overline{l}}) = \log_e (\frac{l_\infty - \overline{l} + \overline{l} - l_c}{l_\infty - \overline{l}})$$

$$= \log_e (1 + \frac{\overline{l} - l_c}{l_\infty - \overline{l}})$$

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

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

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

In the above two cases estimates of both k and I∞ 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

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

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 I∞. 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 con-tinues 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 differ-ence 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

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

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

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

This leads to sigmoid curve where C_t 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

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

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		

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_∞ 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_∞ becomes a vary large quantity (∞), 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_∞ 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. $\dfrac{\overset{d}{l_{t-1}} \cdot \overset{d}{l_{t+1}} - \overset{2d}{l_t}}{\overset{d}{l_{t-1}} + \overset{d}{l_{t+1}} - 2\overset{d}{l_t}} = l_\infty$

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_∞ 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_∞ becomes very small. These observations imply that modal values should not follow both A.P. and G.P. Then estimation of l_∞ 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_∞ 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

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

Taking $l_\infty \simeq 23.1$ 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, $l_t = 13.5$, $l_{t+\Delta t} = 14.5$
        and $N_t = 613$ $N_{t+\Delta t} = 493$
For Second Z value, $l_t = 14.5$ $l_{t+\Delta t} = 15.5$
        and $N_t = 493$ $N_{t+\Delta t} = 273$, and so on.

WORK SHEET V

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

Using tables 4 and 5 of Pauly, 1983 (see Tables 1 and 2 in this paper), and assuming l_∞ 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).

TABLE 1. (*Table 4 of Pauly* 1983). *Length at tagging* (L_1), *length at recapture* (L^2) *and time at large in tagged ocean surgeon fish* (Acanthurus bahianus) *from the Virgin Islands.*

Number	L_1 (cm)	L_2	Days out
1	9.7	10.2	53
2	10.5	10.9	33
3	10.9	11.8	108
4	11.1	12.0	102
5	12.4	15.5	272
6	12.8	13.6	48
7	14.0	14.3	53
8	16.1	16.4	73
9	16.3	16.5	63
10	17.0	17.2	106
11	17.7	18.0	111

TABLE 2 (*Table 5 of Pauly* 1983). *Length at tagging* (L_1), *length at recapture* (L_2) *and days at large of tagged queen parrot fish* (Scarus vetula) *from the Virgin Islands.*

Number	L_1 (cm)	L_2	Days out	$\bar{L}$	cm|day
1	14.0	16.9	48	15.45	0.0604
2	20.8	27.6	189	24.2	0.0360
3	24.8	26.5	48	25.65	0.0354

means: $\bar{x}$ = 21.27 $\bar{y}$ = 0.0439

Calculation of 'k' values

From Table 1. For first k value; l_t = 9.7, $l_{t+\Delta t}$ = 10.2 and Δt = 53
For the second k value; l_t = 10.5, $l_{t+\Delta t}$ = 10.9 and Δt = 33
For the last k value; l_t = 17.7 and $l_{t+\Delta t}$ = 18.9 and Δt = 111

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 $b = e^{-k}$, 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_∞ 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_∞ and e^{-k}, including the expected values of l_∞ 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_∞	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_∞	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_∞ 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_∞ = 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. Ct = 73.2 million tonnes; and ·

Max. Ct = 73.2 million tonnes.

on Indian total fish landings including inland catch. Max Ct = 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

Size class	Sample					Total of all samples	Estimated frequencies for that day
	1	2	3	4	5		
		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	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total for 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.

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

Size class	Sample					Total of all samples	Estimated frequencies for that day
	1	2	3	4	5		
		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 |
	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.

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