CMFRI

Winter School on

Towards Ecosystem Based Management of Marine Fisheries – Building Mass Balance Trophic and Simulation Models

INFORMATION ONLY

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Technical Notes

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CONCEPTS OF GROWTH & MORTALITY OF FISH STOCKS

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Knowledge of growth and mortality is essential for a meaningful assessment of the exploited stock. The parameters of growth and mortality are components of majority of the yield models used to explain the dynamics of the exploited stocks and the effect of fishing on them.

GROWTH

The most widely used growth model in fish stock assessment is the von Bertalanffy growth function (vBGF) and which has been shown to conform to the observed growth of most fish species. The mathematical model expressing the length, L, as a function of the age (t) of the fish, is given by:

$$L(t) = L? * (1 - \exp(-K*(t-t_o))$$

Where,
L? = the asymptotic (the limiting) length the fish can attain (or the average of the maximum lengths of the fish in the population),
K = the curvature parameter (also known as Brody’s growth coefficient or “shrinkage” factor) that determines how soon or fast L? is reached,
t_o = the age at which the fish has zero length.
The generalised functional form the growth and the one which incorporates seasonal growth are found in Sparre and Venema (1992).

The weight-based von Bertalanffy growth equation

Combining the von Bertalanffy growth equation

$$L(t) = L? * (1 - \exp(-K * (t - t_o))$$

with the length / weight relationship

$$W(t) = a * L^3 (t)$$

gives the weight of a fish as a function of age:

$$W(t) = a*L?^3 * (1 - \exp(-K*(t-t_o))^3$$

The “asymptotic weight”, W?, corresponding to the asymptotic length is given by,

$$W? = a*L?^3$$

The parameter, a, is called the “condition factor”. Thus, “the weight-based von Bertalanffy equation” can be written:

$$W(t) = W? * (1 - \exp(-K*(t-t_o))^3$$

Data required

To estimate the parameters of the von Bertalanffy growth model, the sources of data are,

1) Age reading and length measurements combined
   a) data from resource surveys with a research vessel
   b) data from samples taken from commercial catches
2) Length measurements only
   a) data from resource surveys with a research vessel
   b) data from samples taken from commercial catches
3) Mark-recapture (tagging) experiments, where two (or more) length measurements are obtained, viz. at the time of marking (usually on a research vessel) and the time of recovery (usually by the commercial fishery).

Estimation of growth parameters from length-at-age data

If the pairs of observations of age and length are available then the estimates of the parameters can be obtained by

1. Non-linear regression approach
2. Ford-Walford plot method
3. von Bertallanfy's plot method

If the data from tagging is available then Gulland-Holt plot method cane be used to estimate, $L_?$ and K.

The above estimation procedures described in Sparre and Venema (1992)

Growth as estimated from length-frequency data

The methods conventionally used for the analysis of length-frequency data have been introduced by Petersen and can be reduced to two basic techniques:

- the "Petersen Method", that is the attribution of relative ages to the peaks in a length-frequency sample, and
- the "Modal Class Progression Analysis", that is the linking up of the peaks of length-frequency samples sequentially arranged in time by means of growth segments.

With the first method, the problem consists of identifying those peaks representing broods spawned at known or assumed time intervals. The method generally involves the separation of the length-frequency samples into normally or otherwise distributed subsets by graphical methods, probability plots, parabola plot etc.

The "modal class progression analysis", on the other hand, has its major problems in the identification of those peaks which should be connected (by growth lines) with each other.

However, the need for a rapid, yet reliable and *objective* method for the analysis of length-frequency data led to a radical computer based approach known as ELEFAN (Electronic Length Frequency Analysis) in the analysis of length-frequency data, and such an approach was presented in Pauly and David(see Sparre and Venema (1992). Another such computer based approach is the Sheperd's Length Composition Analysis (SLCA).

ELEFAN I is based on the following steps:

- ? objective identification (definition) of the peaks and the troughs separating peaks of a (set of) length-frequency sample(s)
- ? attribution to the peaks of a certain number of positive "points"
- ? attribution to troughs separating the peaks of a certain number of negative
- ? "points"
- ? iterative identification of those growth parameters generating a growth curve
- ? which, by passing through most peaks and avoiding most troughs,
- ? accumulates the highest number of "points" and thus best explains the specific structure of a (set of) length-frequency sample(s).

Given the assumptions that the sample(s) used represent(s) the population investigated, and that the growth of the fish in question conforms to the vBGF, (seasonalized or not), the method can be used to derive growth parameters that are reproducible. Moreover, an estimator is given of the proportion of the peaks in a (set of) sample(s) that are "explained" by the growth parameters obtained at the end of the iteration process. This estimator is the ratio of a sum called "Explained Sum of Peaks", or ESP, referring to the number of "points" explained by a given growth curve, divided by another sum called" Available Sum of Peaks", or ASP, which refers to the total number of points "available" in a (set of) length-frequency samples).1 (See Sparre and Venema (1992) for details). The method which can be readily implemented on microcomputers, is fast, reliable, and objective.

MORTALITY

Total Mortality

A basic equation used in fishery biology for expressing the mortality of fish is

$$N_t = N_o e^{-Zt}$$

where N_o and N_t are fish numbers at time zero and t, respectively and where Z is the total mortality affecting the stock. Also, we have , Z = F+M ,which states that total mortality is the sum of fishing mortality (F) plus natural mortality (M). If the age frequency data, meaning numbers caught by age are available, estimation Z is straight forward and the methods of estimation are described by Sparre and Venema (1992).

In tropical waters, where obtaining age-frequency data is rather difficult, the mortality is usually estimated from the length frequency data and assuming a suitable growth model for the length such as the von Bertalanffy growth model, with known parametric values.

One of the simplest methods employed to estimate the total mortality (Z) is from the mean length in the catch (Lbar) for a known length at first capture (Lc) or a known length (L') from which the fish are assumed to be fully vulnerable. The equation is given by Beverton and Holt (Gulland, 1983) where

$$Z = K*(L_{?} - Lbar)/(Lbar – Lc)$$

and Pauly suggested using L’ instead of Lc in the equation. ($L_{?}$ and K have their usual meaning and are known). where L’ is “some length for which all fish of that length and longer are under full exploitation”. Note that L’ is the lower limit of the corresponding length interval.

One of the methods commonly applied in temperate waters to estimate total mortality is the “linearized catch curve method with constant time intervals”, which is given by

$$Ln(Ct) = a - Z*t \quad \text{(Ct is numbers caught of age t)}$$

Typically, a catch curve will have an ascending left limb and a descending right limb and Z is estimated from the regression of ‘Ln(Ct)’ on ‘t’ from the points of the right limb.

The linearized catch curve based on length composition data

It is often referred to as the “length-converted catch curve” or the “linearized length-converted catch curve”. What is actually done is to convert length data into age data, using the inverse von Bertalanffy growth equation and the equation used is

$$Ln (Nt/?t) = a – Z* t^{bar}$$

Where, Nt is the number caught in given length class,
?t is the time taken to grow from the lower limit of the length class to the upper limit of the length class and
t^{bar} is the average of the relative ages corresponding to the lower and upper limit of the given length class.
The plot of the curve obtained from above equation will resemble the one of the age based catch curve, and Z is estimated from the regression of ‘Ln(Nt/?t)’ on ‘t^{bar} ‘ from the points on the descending right limb. The procedure of deriving the length catch curve and the estimation of Z is explained in detail by Sparre and Venema(1992).

Another method of estimating Z using length data is by Jones and van Zalinge, which is popularly called the “cumulative catch” curve method.
The “Jones and van Zalinge equation” is:

$$Ln\ C(L, L?) = a + Z/K *Ln (L? - L)$$

Where, C(L, L?) is the cumulative catch from L onwards (L is the lower limit of the length class).

Natural mortality

Natural mortality (M) is a parameter that is generally extremely difficult to estimate, and typically, natural mortality estimates of tropical fish have been obtained from estimates of total mortality in stocks known, or assumed to be unfished.. In a few cases, however, it has been possible to obtain time series of values of Z from the same stock, and to plot these against their corresponding values of effort, with M being obtained from the intercept of the line fitted to these data. The natural mortality is the mortality created by all other causes than fishing, e.g., predation including cannibalism, diseases, spawning stress, starvation, and old age. Predation and starvation mortalities and several others are linked to the ambient ecosystem. The same species may have different natural mortality rates in different areas dependent on the density of predators and competitors whose abundance is influenced by fishing activities. As direct measurements of M are often impossible to obtain, it has been attempted to identify quantities which can be assumed proportional to M and which are easier to measure (or estimate).

Longevity can be considered more closely related to mortality than K, L? or ambient temperature. Alagaraja (1984) suggested another way of illustrating the concept of the mortality coefficient. He tentatively defined the natural life span of fish species (or the longevity) as the age at which 99% of a cohort had died if it had been exposed to natural mortality only (i.e. if Z = M). if Tm stands for longevity and M1% stands for the natural corresponding to a 1% survival, then:

$$M1\% = \ln(0.01)/Tm$$

Pauly (1980) made a regression analysis of M (per year) on K (per year), L? (cm) and T (average annual temperature at the surface in degrees centigrade), based on data from 175 different fish stocks, and estimated the empirical linear relationship.

$$\text{Ln } M = -0.0152 - 0.279 * \ln L? + 0.6543 * \ln K + 0.463 * \ln T$$

Srinath (1998) has derived a simpler empirical equation to estimate M, for the fishes in the temperature range of 26? to 28? C , which represents, in general, mean annual temperature range obtained in the tropical waters. The equation which has better predictability than the one derived by Pauly(1980) is given by

$$M = 0.4615 + 1.4753 * K$$

Rikhter and Efanov (1976) showed a close association between M and Tm50% the age when 50% of the population is mature (also called “the age of massive maturation”):

$$M = 1.521 / (Tm50\%^{0.720}) - 0.155 \quad \text{per year}$$

Tm50% should be equal to the “optimum age” defined as the age at which the biomass of a cohort is maximal.

Fishing mortality

Fishing mortality is the most important parameter that should be known in order to assess the effect of fishing on the exploited stocks and also to estimate the rate of exploitation.

Of the various methods used to estimate fishing mortality, four may be listed here:

- tagging/recapture studies
- subtraction of M from Z
- swept-area method in the case of trawlable demersal stocks
- Virtual Population Analysis (VP A) or Cohort Analysis

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