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Empirical relationships to estimate the instantaneous rate of natural mortality

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ABSTRACT

Problems in estimation of the instantaneous rate of natural mortality in exploited fish populations have been mentioned and improved estimators of the natural mortality rate (M) are empirically derived as functions of the von Bertalanffy growth parameter K. Alternative methods are also suggested.

Introduction

Information on mortality is critical to the study of population dynamics of exploited fish stocks. This forms an important input to the analytical models to derive the yield functions. There are two ways of expressing numerically the mortality in a population, the annual absolute rate of mortality and the instantaneous mortality rate. In fish population studies, it is the latter which is extensively used. The total instantaneous rate of mortality, Z, is composed of two components one due to fishing F and other due to natural causes M (Gulland, 1983). The total instantaneous rate of mortality is the sum of mortalities due to fishing and all factors other than fishing usually termed as natural mortality. Deaths due to predation, old age, disease etc. are all classified under natural mortality. This particular parameter is one of the most important inputs to almost all the structural models in fish stock assessment and also the most difficult to estimate. There is no direct method of estimating this parameter especially in exploited fish populations. As fishing and natural mortality are assumed to concurrently affect the exploited stocks it is extremely difficult to make direct estimates of natural mortality. Since there is no direct method of estimating M, proxy or auxiliary variables are used to derive estimates of M based on certain assumptions and some of those methods are reviewed hereunder.

In exploited fish populations the estimate of M can be obtained from the values of total mortality Z minus the fishing mortality or by plotting Z against effort and the intercept of such a plot gives an estimate of M (Sparre and Venema, 1992). This method of estimating M is not easy to follow in practice because more often than not, a good estimate of effective effort targetted at the exploited stock may not be available. Besides, in multispecies and multigear systems such as those prevalent in Indian waters, estimation of effective effort is quite impracticable. Thus the practical difficulty of estimating M from traditional and direct method has prompted many workers exploring comparative approaches which attempt to relate M to parameters easy to estimate or proxy variables.

Beverton & Holt (1959) and Holt (1960, 1962) demonstrated the relationship between maximum age and the asymptotic size (T_{max} and L_∞) as well as between M and K (the parameter of vBGF). Tanaka (1960) as quoted by Saville (1977) has given a relationship between maixmum age and M which can be used as a first approximation of M. Rikhter and Efanov (1976) observed a close association between M and age at sexual maturity and also age when 50 % of the population was mature. One of the most commonly used estimates of M is due to Pauly (1980), which he has developed compiling the information on 175 different stocks distributed in 84 species ranging from polar to tropical waters. He formulated an empirical relationship depicting M as a function of L_∞, K and T (mean annual temperature). Alagaraja (1984) proposed an alternative method of estimating M by relating to the natural life span of fish which was defined as an age at which 99 % of a cohort died if it had been exposed to natural mortality only. More recently, Gunderson and Dygert (1988) estimated M as a function of reproductive effort and found that the commonly used reproductive effort index (Gonado–Somatic Weight Index) was superior to many of the life parameters as a better predictor of M.

Ursin (1984) and Alagaraja (1989) expressed doubts about the statistical validity of the Pauly's empirical equation to estimate M. Keeping in view the fact that in tropics the variations in sea temperatures are of lesser magnitude than prevalent in the temperate waters, the data given by Pauly (1980) was reanalysed by taking into consideration only groups which belonged to the temperature range of 26–28° C which represents in general, the mean annual temperature range obtained in the tropical waters.

Method

The following equations were fitted to the data,

$$y = b_0\, x_1^{b1}\, x_2^{b2} + \varepsilon \qquad \text{............ (1)}$$

$$y = b_{01}\, x_2^{b21} + \varepsilon' \qquad \text{............ (2)}$$

$$y = c_0 + c_1.x_1 + c_2.x_2 + \delta \qquad \text{........... (3)}$$

$$y = c_{01} + c_{21}.x_2 + \delta' \qquad \text{............ (4)}$$

where $y = M$, $x_1 = L_\infty$ and $x_2 = K$; b_0, b_1,b_2,b_{01},b_{21},c_{01}, c_{21},c_0,c_1 and c_2 are the parameters to be estimated and ε, ε', δ and δ' are the error terms.

For estimating the parameters in the equations (1)-(4) the linear and the non-linear regression algorithms as given in the SPSS/PC ver IV were used. The adequacy of the models were tested using the R^2, MAE (Mean Absolute Error), MAPE (Mean Absolute Percent Error) and the Durbin-Watson statistics.

As the temperature range was narrow and correlated with K (Ursin, 1984) it was not considered in the above equations.

Results and discussion

The results of regression analysis for the two equations are summarised in Tables 1 to 4.

Kvalseth (1985) cautioned against the use of R^2 alone for comparing the

TABLE 1. *Results of regression analysis for equation 1*

Coefficient	Estimate	Standard error	Remarks
b_0	2.333	0.797	S
b_1	-0.0225	0.102	N S
b_2	0.758	0.051	H S
R^2 (%)	85.66		
MAE	0.4547		
MAPE (%)	48.08		
Durbin-Watson	2.34		

S = significant, NS = Not significant HS = Highly significant

TABLE 3. *Results of regression analysis for equation 3*

Coefficient	Estimate	Standard error	Remarks
c_0	0.6446	0.1737	H S
c_1	−0.0029	0.002095	N S
c_2	1.4331	0.0939	H S
R^2 (%)	85.00		
MAE	0.4552		
MAPE (%)	48.78		
Durbin-Watson	2.57		

S = Significant, NS = Not significant.

models of linear and non-linear forms. Keeping this in view the other indices of testing the adequacy were also used in the analysis.

From the above tables it is clear that in the chosen temperature range the contribution of L was not significant and K alone could be considered as a predictor of M. It is also notable that the non-linear form with K alone fitted the data better than the corresponding linear equation.

An alternative form of the above relationship was also derived by forcing the line to pass through the origin, and the relationship now takes the form,

$$M = \underset{(0.081)}{1.68}\ K \text{ with } R^2 = 89.4\ \% \quad \ldots\ldots\ldots \quad (5)$$

(The figure in parenthesis indicates the standard error of the estimate).

The equations 2, 4 and 5 are better fits to the data in the chosen temperature range than Pauly's equation whose R^2 was about 71 % only. Thus, in the tropics above relationships could profit-

TABLE 2. *Results of regression analysis for equation 2*

Coefficient	Estimate	Standard error	Remarks
b_{01}	2.165	0.715	S
b_{21}	0.758	0.044	H S
R^2 (%)	85.65		
MAE	0.4560		
MAPE (%)	48.73		
Durbin-Watson	2.36		

S = Significant, HS = Highly significant.

TABLE 4. *Results of regression analysis for equation 4*

Coefficient	Estimate	Standard error	Remarks
c_{01}	0.4615	0.1107	H S
c_{21}	1.4753	0.0897	H S
R^2 (%)	84.40		
MAE	0.4718		
MAPE (%)	56.69		
Durbin-Watson	2.54		

HS = Highly significant.

ably be used to estimate the natural mortality rate.

It is worth noting here that by following the approach of Alagaraja (1989) assuming that, 99 % of the stock die when they reach 95 % of L , under no exploitation, it is easy to verify that $M/K \approx 1.54$. This can also be obtained from the concept of T_{max} which according to Pauly (1980) is approximately equal to 3/K. Thus if we assume that 99 % of the stock (in the unexploited case) die when they reach T_{max}, we will obtain $M/K \approx 1.535$. The derivation is quite straightforward and is given below :

$$N_{Tmax}/N_0 = \exp(-M.\ T_{max})$$

$$0.01 = \exp(-3M/K)$$

from which it is easy to verify that

$$M = 1.535\ K.$$

This equation and the equation (5) result in constant M/K ratio irrespective of the magnitude of K which may be true in the case of more or less homogeneous groups or species sharing a common habitat. However, for all practical purposes the equations (2) or (3) can be used to estimate M.

Since these relationships are also derived from the data set presented in Pauly (1980), the observations made by Ursin (1984) on Pauly's equation are equally applicable to the equations derived above especially with reference to the precision of the estimates of M used taken from other studies and used in building the equation. Nonetheless, these equations serve as better approximations of M and statistically more valid than (in terms of higher R^2) the one proposed by Pauly (1980). Besides it is not proper to estimate the mortality of the groups habitating a relatively narrow temperature range such as the one occurring in the tropics, from an equation which is built by taking into consideration highly heterogeneous temperature ranges, some of which never are obtained in the tropics.

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