An approach to estimate the natural mortality rate in fish stocks

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Abstract

A simple approach is introduced to estimate the natural mortality rate (M) of fish stocks. The approach is based on the age at maximum cohort biomass, or critical length (L^*) concept. The ratio of the critical length to the asymptotic length ($\omega = L^*/L_\infty$) is relatively constant in 141 fish stocks at 0.62 (CV = 21.4 per cent) and the relationship $M = 3K(1\text{-}\omega)/\omega$ is derived and could be used to estimate M, where K is the growth coefficient of the von Bertalanffy growth function. Average values of ω are given for the various Families of fish in order to estimate M based on closely related species.

Introduction

In exploited marine resources, natural mortality is related to all possible causes of death except fishing. However, estimates for the instantaneous natural mortality rate will always be subjected to large uncertainties in population dynamics of marine animals (Vetter 1988).

Usually, natural mortality estimates can be obtained by one or more of the following methods: (i) catch-curve analysis for lightly exploited stocks (Robson and Chapman 1961; Ricker 1975); (ii) a plot of total mortality rate (fishing and natural mortality) against fishing effort (Beverton and Holt 1957; Paloheimo 1961); (iii) techniques for direct estimation, usually limited and expensive (i.e., tagging); and (iv) life history parameters and environmental variables using empirical relationships or models (Beverton 1963; Rickhter and Efanov 1976; Pauly 1980; Hoening 1983; Gunderson and Dygert 1988).

The objective of this paper is to develop a relationship to estimate the natural mortality rate (M) in fish stocks by using the life history parameters approach.

Materials and Methods

Alverson and Carney (1975) formulated an equation to estimate the age at maximum cohort biomass or critical age (t^*) expressed as:

$$t^* = t_0 + \frac{1}{K}\ln\left[\frac{3K}{M}+1\right]$$

…1)

where t_0 and K are von Bertalanffy growth parameters and M is the natural mortality rate. The constant 3 comes from the exponent of the length-weight relationship (b = 3). If t_0 is ignored, the equation becomes:

$$t^* = \frac{1}{K}\ln\left[\frac{3K}{M}+1\right]$$

…2)

Solving for M, the following equation is obtained:

$$M = \frac{3K}{(\exp(Kt^*)-1)}$$

…3)

In Equation (3), natural mortality is dependent on both K and t^*. In order to obtain an estimation for t^*, data for 175 fish stocks analyzed by Pauly (1980) were used. Then, the critical length (L^*) was obtained for each fish stock by using the von Bertalanffy growth function (VBGF)

$$L^* = L_\infty\,(1-\exp(-Kt^*))$$

…4)

where L_∞ is the asymptotic length. Equation (4) can be reformulated to obtain:

$$\frac{L^*}{L_\infty} = (1-\exp(-Kt^*))=\omega$$

…5)

and then solve for the critical age t^* by the following equation:

$$t^* = -\frac{1}{K}\ln(1-\omega)$$

…6)

where ω is the ratio of L^* to L_∞. Then, t^* is used to estimate M using Equation (3). Alternatively, ω can be used to estimate M directly by combining Equation (3) and Equation (6) to obtain:

$$M = \frac{3K(1-\omega)}{\omega}$$

…7)

Results

Critical length (L^*) was related linearly to L_∞ for 141 fish stocks (Figure 1) and the estimated mean of the ratio L^* to L_∞ (= ω) was equal to 0.62 (Table 1). In this fashion, according to Equation (7), the general relationship to estimate the natural mortality rate can be expressed as:

$$M = \frac{3K(1-0.62)}{0.62}$$

…8)

By simplifying Equation (8), then estimates of M = 1.839K (i.e. $M \approx$ 1.5 or 2 times K). This generalization is consistent with earlier studies by Beverton and Holt (1959), Charnov (1993), and Jensen (1996). However, better application of the approach (Equation 7) should be obtained by using an estimation of ω from related fish species (Table 1).

Discussion

Vetter (1988) indicates that methods that use parameters of the life history present two advantages: (i) require a minimal quantity of data, and (ii) are useful in demonstrating trends between species and in the development of ecological theory. Nevertheless, due to the fact that they only generate a simple estimate of

Table 1. Mean critical length to asymptotic length ratio (ω) by Families ($n \geq 3$) and total based on 141 fish stocks (data from Pauly, 1980). : SD = standard deviation, CV = coefficient of variation, Max = Maximum, Min = Minimum.

Family	**Mean ω**	**n**	**SD**	**CV (%)**	**Max**	**Min**
Acipenseridae	0.834	3	0.118	14.1	0.938	0.706
Cichlidae	0.521	6	0.108	20.7	0.642	0.324
Clupeidae	0.741	16	0.092	12.4	0.854	0.561
Cottidae	0.635	4	0.062	9.7	0.711	0.571
Engraulidae	0.648	9	0.153	23.6	0.808	0.363
Gadidae	0.669	17	0.115	17.3	0.824	0.452
Lutjanidae	0.480	7	0.061	12.7	0.547	0.365
Merlucciidae	0.487	5	0.103	21.2	0.616	0.375
Myctophidae	0.533	3	0.136	25.6	0.646	0.382
Nemipteridae	0.572	12	0.113	19.7	0.762	0.421
Percidae	0.618	3	0.129	20.9	0.709	0.470
Pleuronectidae	0.639	16	0.117	18.3	0.870	0.500
Salmonidae	0.587	11	0.108	18.4	0.725	0.366
Sciaenidae	0.607	5	0.117	19.3	0.750	0.474
Scombridae	0.628	16	0.093	14.9	0.750	0.429
Scorpaenidae	0.632	3	0.049	7.7	0.688	0.597
Serranidae	0.638	5	0.142	22.2	0.808	0.514
All species	**0.620**	**141**	**0.133**	**21.4**	**0.938**	**0.323**

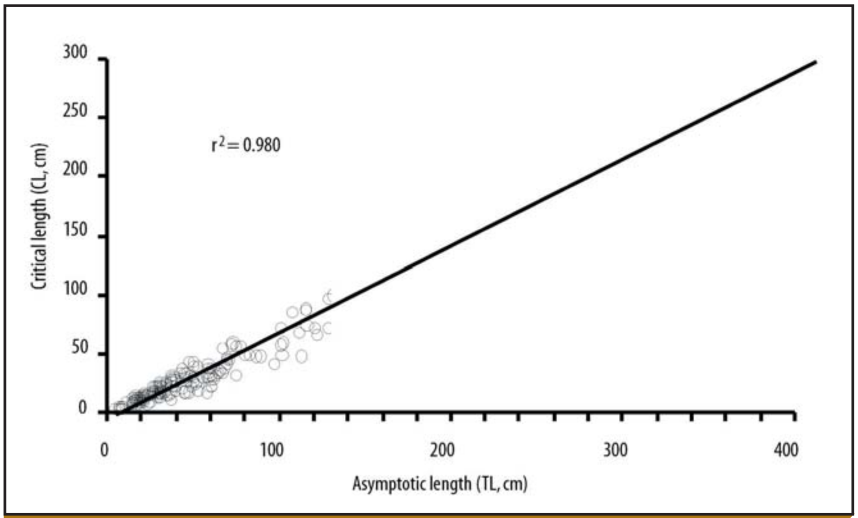

Figure 1. Critical length-asymptotic length relationship from 175 fish stocks (data from Pauly 1980).The relationship is showed for fish having L_∞ <=350 cm TL.

M for any given group of fish, and are not effective to generate precise estimates of *M* (see Pascual and Iribarne 1993; Cubillos et al. 1999), or to determine the existence or extent of trends and variability in *M* for a given stock. Furthermore, the extrapolations will not be better than the parameters used to estimate the values of *M* in the regressions. Pascual and Iribarne (1993) evaluated the predictive power of the most commonly used empirical models and concluded that the forecast errors of the estimates of the natural mortality is substantial. This study then proposes that the predictive power of an empirical model must be evaluated with adequate methods since the criterion based on the coefficient of determination only describes the relationships found.

The underlying assumptions in the estimate of *M* with the method developed here include an assumption that the critical size is a constant proportion of the asymptotic length. In this study, where t^* is unknown, it is approximated through reparameterization of the Alverson and Carney (1975) method which enabled the estimation of t^* based on closely related species, i.e. from an average of ω. Natural mortality and growth parameters are usually similar among related species (Pauly 1980). Most applications of empirical models incorporate parameters from a range of species, but sometimes an entire family can act as an "outlier" and affect estimates of *M* (Pascual and Iribarne 1993).

It must be mentioned that when the method is used, it is assumed that the ratio of the age at maximum biomass to the maximum age ($t^*/Tmax$) or the ratio of the critical size to the asymptotic size (L^*/L_∞) are constants. Beverton and Holt (1959) and Beverton (1963) discovered several patterns in growth and mortality parameters across fish species (see also Charnov 1993; Jensen 1996). One pattern was the relation between the size at first maturity and the asymptotic length ($Lm_{50}/L_\infty = C_1$), a second pattern was the relation between natural mortality and the von Bertalanffy growth coefficient ($M/K = C_2$), and the third pattern was an inverse relation between natural mortality and the age at maturity ($Tm_{50} = C_3/M$). According to Jensen (1996), these relationships were called the Beverton and Holt invariants by Charnov (1993). Jensen (1996) postulates that the three Beverton and Holt invariants are not just statistical relations, but rather a result of an expression of fundamental ecological relations. In this context, the approach here could be a direct consequence of those three Beverton and Holt invariants.

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