

# **Mortality parameters**

# Mortality parameters

## Total Instantaneous mortality

### Introduction

Fish mortality is a term widely used in fisheries science that denotes the loss of fish from a stock through death.

### Types of Mortality:

**Natural mortality:** the removal of fish from the stock due to causes not associated with fishing. Such causes can include disease, competition, cannibalism, old age, predation, pollution or any other natural factor that causes the death of fish. In fisheries population dynamics, natural mortality is denoted by  $(M)$ .

**Fishing mortality:** the removal of fish from the stock due to fishing activities using any fishing gear. It is denoted by  $(F)$  in fisheries models.

### Total Instantaneous Mortality

The removal of fish from the stock due to natural causes  $(M)$  and fishing activities  $(Z)$ .

(M) and (F) are additive instantaneous rates that sum up to (Z), the instantaneous total mortality coefficient; that is,  $Z=M+F$ . These rates are usually calculated on an annual basis.

### **Application of mortality parameters**

Estimates of fishing mortality rates are often included in mathematical yield models to predict yield levels (Yield per recruit) obtained under various exploitation scenarios. These are used as resource management indices or in bioeconomic studies of fisheries.

They are used as input data in the Analytical Model of Beverton and Holt in estimating Maximum Sustainable Yield per Recruit. Further, this model predicts the effect of changes in fishing effort on future yields. In addition to the application in stock production modelling, they are also used as input data in cohort analysis, and in estimating standing stock biomass of aquatic animals.

### **Estimation of total instantaneous mortality (Z)**

Mortality parameters are extremely difficult to estimate precisely in aquatic animals. This is because of mortality rate, the rate at which the animals are removed from the population by death, is a parameter of population and not of individuals. To estimate mortality rate, it is therefore necessary to examine a group of aquatic animals.

Fishery scientists divide the instantaneous total mortality rate ( $Z$ ) of a population into two parameters i.e., instantaneous fishing mortality ( $F$ ) and instantaneous natural mortality ( $M$ ). An advantage of total instantaneous mortality is that they can be added or subtracted.

Thus, we have

$$Z = F + M$$

Where,  $Z$  is total instantaneous mortality coefficient

$F$  is instantaneous fishing mortality coefficient and

$M$  is instantaneous natural mortality coefficient

In unexploited stock,  $F=0$  then,  $Z=M$ . This means total mortality will have the same value when there is no fishing mortality.

## Estimation of Z by exponential equation

In fishery biology, the most useful manner of expressing the decrease of the age group of fishes through time is by means of exponential equation. For example, if we put a group of fish in a pond and sampled the fish over a long period of time, the number of survivors of the original group decline over time as shown in the following figure.

This can be modeled in the following equation.

$$N_t = N_0 e^{-Zt} \dots\dots\dots (1)$$

Where  $N_t$  = Number of survivors after 't' units of time

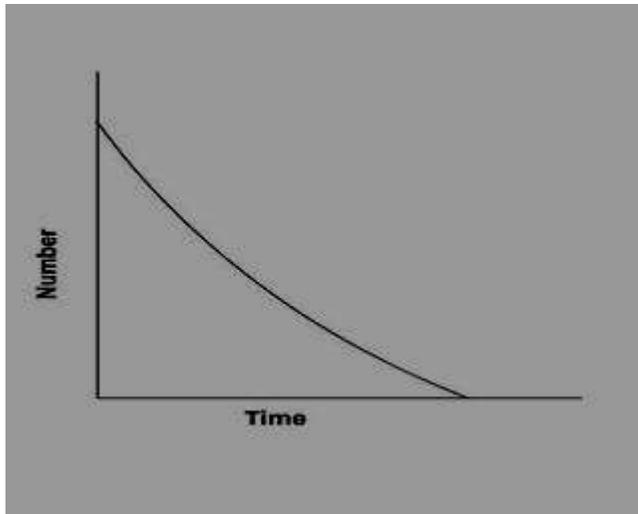
$N_0$  = Original number of fish

$e$  = Constant equal to 2.7182818

( $e$  is the base of natural logarithm)

$Z$  = Total instantaneous mortality rate in units of time  $-1$  (eg 1/yr.)

$N_t$  = the number of fishes remaining at the end of time 't'.



'Z' is most often reported in units of  $(\text{yr})^{-1}$ . It is also reported in other units such as  $1/\text{month}$ . To convert 'Z' to units of  $\text{yr}^{-1}$ , the equation (1) must be in units of months if 'Z' is in units of  $1/\text{month}$ . If 't' is used as units of one year, then the number of time units is one twelfth ( $1/12$ ) as large. (12 units of 1 month would become 1 unit of 1 year). So one should multiply Z by 12 in order for the answer ( $Nt$ ) to stay the same. For example Z is  $0.2 / \text{month}$ , the Z in units of  $\text{Yr}^{-1}$  will be  $2.4 \text{ yr}^{-1}$  ( $12 \times 0.2 = 2.4 \text{ yr}^{-1}$ ).

### a) Annual survival rate (S)

The proportion of the population that will survive after one unit of time has passed is known as annual survival rate (if time is expressed in years). The annual survival rate is denoted by 'S'. The relationship between annual survival rate (S) and the total instantaneous mortality rate (Z) is described by the following notion.

$$S = e^{-Z} \dots\dots\dots (2)$$

### b) Annual mortality rate (A)

The proportion of the population that does not survive is known as 'annual mortality rate' if time is expressed in years. It is designated by 'A'.

$$A = 1 - S \dots\dots\dots (3)$$

The annual mortality rate (A) and total instantaneous mortality rate (Z) will be more or the less the same to begin within a stock, but they progressively diverge as the mortality rate increases.

## Estimation of 'Z' by age composition data

### (a) Heincke's method

This method is the oldest method. This method could be applied for short lived species (fish or shrimp or exploited aquatic animal) whose life span is more or less 2 years. Further '0' year class should constitute the fully recruited group.

$$A = \frac{N_0}{\sum N} \dots \dots \dots (1)$$

$N_0$  is the number of 0 year old fish and  $\sum N$  is the total number of fish comprising all age groups.

From the annual mortality rate, S could be calculated as  $S = 1 - A$ . ..... (2)

Z could be estimated by the following equation,

$$S = e^{-Z} \dots \dots \dots (3)$$

$$(-Z = \log_e S ; Z = - \log_e S)$$

**(b) Jackson method**

In this method, 'Z', could be estimated between two adjacent age groups in a given year or between the abundance of the same year class in two adjacent years using the following formula.

$$S = \frac{N_{t+1}}{N_t} \dots\dots\dots (4)$$

Since the annual mortality rate (A) is the complement of S i.e.,  $A = 1 - S$ , 'Z' could be estimated by passing equations 3 and 4.

$$Z = -\log_e \left\{ \frac{N_{t+1}}{N_t} \right\} \text{ or } Z = \log_e \left\{ \frac{N_t}{N_{t+1}} \right\} \dots\dots\dots (5)$$

**(c) Estimation of Z (if more than 3 age groups are represented in the fishery).**

If in a species more than 5 age groups (year classes) are represented in the fishery, the following formula is used.

$$S = \frac{\{N_1 + N_2 + N_3 + N_4 + N_5\}}{\{N_0 + N_1 + N_2 + N_3 + N_4 + N_5\}} \dots\dots\dots (6)$$

$$Z = -\log_e S$$

**(d) Robson and Chapman's method**

The 'Z' could be estimated from age composition data i.e., the numbers caught per age group.

$$Z = - \ln \left\{ \frac{A}{B+A-1} \right\} \dots\dots\dots (7)$$

Where,

$$A = N_1 + 2*N_2 + 3*N_3 + 4*N_4 + 5*N_5 + \dots\dots\dots$$

$$B = N_0 + N_1 + N_2 + N_3 + N_4 + N_5 + \dots\dots\dots$$

**(e) Cushing method**

When incomplete age composition data are available for a fish stock, for example only 2nd and 4th year age groups are available, Z could be calculated from the following relation.

$$Z = \frac{1}{3} \times \log_e \left\{ \frac{N_2}{N_4} \right\} \dots\dots\dots (8)$$

## **Estimation of Z from CPUE**

### **Paloheimo (1961) method :**

A plot of monthly CUPE against the respective months for a fishery prosecuted nearly all through the year may take the shape of a near normal curve, with the ascending phase including the peak falling in one half of the year and the descending phase in the other half. From this data, CUPE is derived separately for the descending phase  $(c/f)_2$  and ascending phase,  $(c/f)_1$ , and Z estimated using the expression.

$$Z = - \log_e (c/f)_2 / (c/f)_1$$

### **Estimation of Z using LFD and selection parameters**

Four methods namely Rickers Catch Curve, CPUE, Beverton Holt equation and by Powell – Wetherall methods are used in the estimation of Z. In these methods, LFD and selection parameters are the data needed.

### **Estimation of Z by means of a catch curve**

This method is usually referred to as the length converted catch curve or linearized length converted catch curve. In this method, Z is estimated by sampling a multiaged population of fishes. Plotting the natural logarithm ( $\log_e$ ) of the number of fishes

in the sample (N) against their respective age (t) is called catch curve, and this is of the following equation.

$$\ln N = a + bt \dots\dots\dots (1)$$

Where, the value of b with sign changed, provides an estimate of Z.

## Requirements to be met by 'b' to be a good estimator of Z

According to Pauly, 1984, the requirements to be met by 'b' to be a good estimator of Z should include the followings:

- The values of  $\log_e N$  should include the age group of fishes fully vulnerable to the gear in question and this corresponds to using only the descending part of the catch curve and it should be larger than the  $L'$  . (Smallest length of animals that are fully represented in the catch samples).
- All age groups used in the plot are recruited with the same abundance or the variations in recruitment fluctuations should be small and of random character.
- All age groups used in the plot should be equally vulnerable to the gear used for sampling.
- The samples used should be large and it should cover all age groups and it should represent average population structure over the period considered.
- Inclusion of fish whose size close to that of their asymptotic size must be avoided as this will result in their age being closely overestimated.
- Since 'Z' is equal to slope (with sign changed) of the catch curve, the real age which requires an estimate of  $T_0$  can be replaced by relative age i.e. by setting 't' =  $T_0$ .

The equation - 1 can be rewritten as

$$\log_e(N/D t) = a + bt$$

Where,  $\triangle t$  is the time needed to grow from lower ( $t_1$ ) to the upper ( $t_2$ ) limit of a given length class.

$t$  = relative age corresponding to mid range of the length class in question.

### **Input data needed**

a) LFD data and the catch in numbers in the respective length group.

b) Values of  $L_{\infty}$  and  $K$  needed for catch curve analysis, estimated from growth equations.

## Estimation of Z by growth and selection parameters (Beverton and Holt equation)

In this method, Z is estimated from the mean length of the fish in the catch and from von Bertalanffy's parameters i.e.,  $L_{\infty}$  and K. Input data for the estimation in this method is less compared to length based linearised catch curve methods.

The equation  $Z = K * \frac{L_{\infty} - \overline{L}}{L - L'}$ ..... (1)

$\overline{L}$  is the mean length of fish of length  $L'$  and longer. While  $L'$  is some length for which all fish of that length and longer are under full exploitation (According to Beverton and Holt,  $L'$  is the smallest length of animals that are fully represented in catch samples). K and  $L_{\infty}$  are von Bertalanffy's parameters.

The equation is also be used based on length at first capture. This equation could also be written with the following notion. Here,  $L_c < L'$

Hence,  $Z = K * \frac{L_{\infty} - \overline{L_c}}{\overline{L_c} - L'}$ ..... (2)

$L_c$  is the length at which 50% of the fish entering the gear are retained and  $\overline{L_c}$  is the average length of entire catch. When  $\overline{L}$  and  $L'$  are not available, the above equation could be used for estimation of Z (when  $L_c$  and  $\overline{L_c}$  are known). (For calculation of Z, by this method, refer to the Practical Section.

## **Powell – Wetherall method**

In this method, plotting of  $\overline{L_c} - L'$  against  $L'$  gives a linear equation from which 'a' and 'b' can be estimated,  $L_{\infty} = -a/b$ ; and slope  $b = -K / (Z+K)$  slope. This method is more suitable for situations where little or nothing is known about the fish stock in question.

### **Input data needed.**

1. LFD data
  2. The number caught for each length interval are to be recorded
- (For calculation of Z by this method, refer to practical section.)

# Natural mortality

## Introduction

Estimating natural mortality is one of the most difficult and critical elements of stock assessment. Natural mortality is denoted as 'M'. It will be high in larval and in early juvenile stages of fish. However, once the fish attain a certain age or size, natural mortality rate becomes much lower and much steadier and is generally considered to be constant. The von Bertalanffy's growth parameters, 'K' and 'L  $\infty$ ' are closely linked to M. As a rough generalization, fish species with a high K value have a high M value and fish species with low M will have low 'K' value. The ratio of 'M/K' value will be mostly in the range of 1.5 to 2.5 (Beverton and Holt, 1959). Natural mortality is linked to L  $\infty$  or the maximum weight of the species W  $\infty$ , as the large fish have fewer predators than small fish. According to Rikhter and Efanov (1976), fish with high natural mortality mature early in life and compensates the high 'M' by starting to reproduce earlier. Natural mortality also has close relationship with the ratio of gonad weight to somatic weight in fishes. Thus, fish with high M may compensate by producing more eggs. As most biological processes go faster at higher temperature, M is also related to environmental temperature.

## **Application**

This parameter is used in the estimation of yield / recruit (Beverton of Holt model) in fishes. This parameter also goes as an input datum in cohort analysis and in estimation of standing stock biomass of aquatic animals. If 'M' and 'Z' are estimated, 'F' could be estimated by the relation  $F = Z - M$ .

## **Estimation of 'M'**

When values of 'Z' are available for several years pertaining to different annual values of effort (f), the value of 'M' can be calculated from

$$Z = M + qf$$

Where (q) is the 'catchability coefficient' or 'proportionality coefficient', which relates fishing effort (f) and fishing mortality (F). The fishing mortality (F) is almost always assumed to be proportional to effort and is mathematically expressed as,

$$F = q * f$$

The more efficient the gear is, the higher the value of 'q' because 'q' is the measure of the ability of the gear to catch the fish.

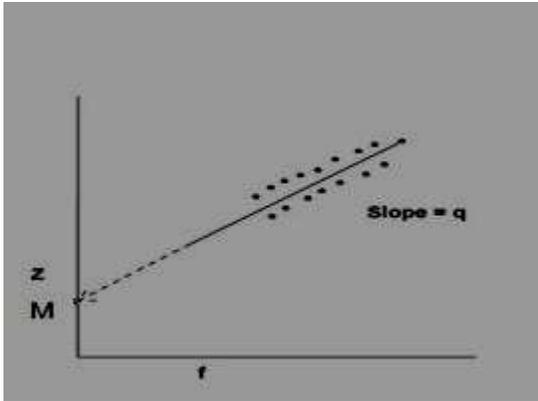
When series of 'Z' (mean annual) values are plotted against their corresponding values of 'f', a straight line can be fitted to the points by means of linear regression technique. This results in a regression line with the equation

$$y = a + bx$$

The slope of the line is an estimate of 'q' and the 'y' the intercept is an estimate of 'M'. Sometimes, a regression line fitted to data of this type will give an estimate of 'M' which is negative. But 'M' cannot be negative. In such case, one makes an estimate of 'M' and then forces the regression line to have an intercept equal to 'M'.

If only one value of 'Z' and 'f' are available, or when there are only few values of 'Z' and 'f' are available, reasonable values of 'M' and 'q' could be obtained. In such case, the 'q' is estimated through

$$q = \frac{\overline{z} - m}{\overline{f}}$$



Where ' $\overline{z}$ ' is the mean of the available values of 'Z' (or a single value of Z) and ' $\overline{f}$ ' is the mean of the values of 'f' (or a single value of f), 'M' being an independent estimate of Natural mortality.

## Pauly's empirical formula

Natural mortality in fishes can also be correlated to mean environment temperature. The interrelationships can be expressed for length growth data by the multiple regressions as below:

For length-growth data

$$\log_{10} M = -0.0066 - 0.279 \log_{10} L + 0.6543 \log_{10} K + 0.4634 \log_{10} T$$

For weight – growth data

$$\log_{10} M = -0.2107 - 0.0824 \log_{10} W + 0.6757 \log_{10} K + 0.4687 \log_{10} T$$

'M' is the natural mortality in a given stock, 'L' (total length in cm) and 'W' (live weight in g) being the asymptotic size of the fishes of that stock and 'K' the growth co-efficient. The value of 'T', is the annual mean temperature in °C of the water in which the stock is found.

The above two equations give reasonable estimate of 'M' for about any set of growth parameters and temperature value. However for certain schooling pelagic fishes particularly for clupeoid fishes, the 'M' is generally overestimated by the above two equations. In such cases, it might be appropriate to reduce the estimate of 'M' by multiplying K by 0.8 (Pauly, 1983).

The equation should be avoided for crustaceans and molluscs or any other invertebrates. Pauly's formula does not cover these groups.

### **Correlation of 'M' with longevity of fishes (Pauly's method)**

The growth co-efficient in fishes is closely linked with their longevity. In nature, the oldest fishes of a given stock grow to about 95 percent of their asymptotic size length. Thus,

$$L_t = L_{\infty}(1 - e^{-k(t-t_0)})$$

$$t - t_0 = \frac{\log_e(1 - \{L_t / L_{\infty}\})}{-k}$$

If 95 percent of  $L_{\infty}$  is inserted for the oldest fish

$$t - t_0 = \frac{2.9977}{-k}$$

$$t_{\max} \approx \frac{3}{K}$$

't max' is the longevity of the fishes in question.

Thus, natural mortality is correlated with size, since large fishes should have, as a rule, fewer predators than small fishes.

## Rikhter and Efanov's formula

Rikhter and Efanov (1975) showed a close association between 'M' and 'Tm 50%', the age when 50% of the population is mature (also called the age of massive maturation)

$$M = 1.521 / (Tm\ 50\%^{0.720}) - 0.155 \text{ per year}$$

'Tm 50%' is equal to the optimum age defined as the age at which the biomass of a cohort is maximal.

# Fishing mortality

## Introduction

Fishing mortality (F) is the rate at which the fishes are removed from the population by fishing activity. Fishing mortality is almost assumed to be proportional to fishing effort.

## Estimation of 'F'

When 'Z' and 'M' are available, 'F' could be estimated from the relation

$$Z - M = F$$

In fully exploited stock,  $Z = F$  as 'M' is negligible and in unexploited stock 'Z' is an estimate of 'M'.