CHAPTER IX
POPULATION DYNAMICS
9.1. Introduction

The fish population is highly dynamic due to various types of forces acting on it such as fishing and other fishery independent factors (Banerji, 1967). Successful management of this living resource is required for maintaining the balance of the stock between additive and destructive forces acting on the population. Fish exploitation has been increasing at a very rapid rate to meet the growing demands of the rapidly multiplying human population which in turn has lead to a drastic decline in the abundance of many fish stocks. This situation calls for the development of suitable management strategies for the conservation of fishery resources for their rational use. Studies on population dynamics are essential to formulate fishing strategy to obtain the maximum sustainable yield without disturbing the equilibrium of fish stock. These studies help in evaluating both natural and human forces acting upon a population and fitting them into yield models so as to moderate the dynamic forces through management practices and thereby sustain benefits from the fish population on a long term basis (Bal and Rao, 1984).

Some of the important contributions on fish stock assessment in the tropics were those of Pauly (1980a, b; 1982a, b; 1983a, b; 1984a, b; 1987), Banerji and Chakraborty (1973), Pauly and David (1981), Devaraj (1983b), Sparre and Venema (1992) and Gayanilo and Pauly (1997). Miah et al. (1997) estimated the growth and mortality parameters of Hilsa from Bangladesh. Some of the recent works on the population dynamics of carps include those of Haroon et al. (1999, 2002) on major carps, Alam et


*O. bakeri* is an endemic vulnerable species of Kerala which requires protection and judicious exploitation of stock. Hitherto, no information is available on any aspect of population dynamics of this
endemic species. The present study is aimed at providing information on the mortality parameters and exploitation rate of *O. bakeri* inhabiting river Periyar.

### 9.2. Materials and Methods

A total of 850 individuals, comprising 557 males and 293 females, collected from Periyar river during June 2001 to May 2003 were used for the stock assessment study. Assuming that the growth of this species follows von Bertalanffy growth formula (VBGF), the VBGF parameters, $L_\infty$, $K$ and $t_0$ were estimated using the FiSAT (FAO – ICLARM stock Assessment Tools) computer software package (Gayanilo and Pauly, 1997) as per the procedure mentioned in Chapter 8 and the values were used for the estimation of various parameters given below.

#### 9.2.1. Total mortality coefficient ($Z$)

Total mortality coefficient or instantaneous rate of total mortality, expressed by $Z$, includes both natural mortality coefficient (M) and fishing mortality coefficient (F). Total mortality estimate was done by the methods of Beverton and Holt (1966), the cumulative catch curve method of Jones and van Zalinge (1981), Ssentongo and Larkin method (1973), Pauly’s pile up method (1983) and length converted catch curve method of Gayanilo *et al.* (1996).

\[ Z = K \left( \frac{L_\alpha - L}{\bar{L} - L'} \right) \]

where \( \bar{L} \) = Mean length of fish
\( L' \) = Lower limit of the size group from which length upwards all lengths are under full exploitation.

9.2.1.2. Ssentongo and Larkin method (1973)

\[ Z = K \left( \frac{n}{n + 1} \right) \left( \frac{1}{y - y_c} \right) \]

where \( y = -\ln \left( 1 - l/1_\alpha \right) \)
\( y_c = -\ln \left( 1 - l_c/l_\alpha \right) \)
\( \bar{y} = \sum fy / \sum f \)

where \( n = \sum f, n+1 = \sum f + 1 \)
\( y_c = \) Corresponding to \( l_c \) value
\( n = Number of fish caught from \( y_c \) onwards.
\( l = \) Mid length

9.2.1.3. Pauly's pile up method (1983)

\[ \log_e (N/t) = a - b \ t^* \]

\[ Z = (-b), \ t^* = t_{1+} \frac{1}{2} t \]

\( t = \) Time taken to grow from lower limit of the length class to upper limit.
\( t = 1/K \log_e \left( \frac{L_\alpha - L'}{L_\alpha - L_2} \right) \)
\[ t_1 = \frac{1}{K \log_e (1 - 1/L_\alpha)} \]

\( L \) = Lower limit of length class.

\( t_1 \) = Relative age corresponding to lower limit of length class.

\( t^* \) = Relative age corresponding to the mid length of length-class.

\( N_t \) = Number of individual caught at time 't'.


Jones and van Zalinge found a linear relationship between catch and survivors. This method employs the following formula.

\[ \ln (C_{i, \alpha}) = a + \frac{Z}{K} \times \ln (L_\alpha - L_i) \]

where \( C_{i, \alpha} \) = Cumulative catch corresponding to a given length.

\( i \) = Lower limit of that length class.

\( \alpha \) = Indicates that the catch refers to a range from \( L_1 \) to all larger size.

9.2.1.5. Length converted catch curve method (Gayanilo et al.,1996)

The length converted catch curve was obtained using the following formula:

\[ \ln \left( \frac{N_i}{t_i} \right) = a + b t_i \]

where \( N_i \) = number of specimens in length class \( i \)

\( t_i \) = relative age corresponding to length class \( i \)
9.2.2. Natural mortality coefficient (M)

The methods of Sekharan (1974), Rikhter and Efano (1976) and Pauly’s empirical formula (Pauly, 1980 b) were used for calculating natural mortality coefficient.

9.2.2.1. Sekharan’s method (1974)

This method is based on the assumption that 99% of fish would die if there was no exploitation when they reach $t_{\text{max}}$, which corresponds to $L_{\text{max}}$. $L_{\text{max}}$ is the maximum observed length in the catch.

$$M = -\left(\frac{\log e 0.01}{t_{\text{max}}} \right)$$

where $t_{\text{max}} = \text{Age at } L_{\text{max}} \text{ calculated from VBGE equation}.$

9.2.2.2. Rikhter and Efano method (1976)

This method uses the following formula

$$M = \frac{1.521}{t_{\text{m}}^{0.72}} - 0.155$$

where $t_{\text{m}} = \text{Age at which 50% of the population is mature}.$

In *O.bakeri*, length at which 50% of the individuals mature were 115 mm and 118 mm in males and females respectively (See Chapter V1). The corresponding $t_{\text{m}}$ values were calculated as 1.53 and 0.91 years for males and females respectively.

9.2.2.3. Pauly’s empirical formula (1980)

Natural mortality is given by the following empirical formula:

$$\log_{10} M = 0.0066 - 0.279 \log_{10} L_0 + 0.6543 \log_{10} K + 0.4634 \log_{10} T$$
Where $M = \text{Natural mortality}$

$La$ and $K = \text{Growth parameters of VBGF}$

$T = \text{Annual mean temperature (°C) of the water in which the fish lives.}$

In the present study, $T$ was taken as $27°\text{C}$.  

9.2.3. Fishing Mortality Coefficient ($F$)

Instantaneous rate of fishing mortality ($F$) was computed by subtracting natural mortality ($M$) from total mortality ($Z$).

$$F = Z - M$$

9.2.4. Length based cohort analysis (Jones, 1984)

Cohort analysis is employed to estimate stock sizes and fishing mortalities. In this analysis, the number of fishes in the river that attain $L$, is given by

$$N (L_1) = [N (L_2) S (L_1, L_2) + C (L_1, L_2)] S (L_1, L_2)$$

Where $S (L_1, L_2) = \left[\frac{(L_0 - L_1)}{(L_0 - L_2)}\right]^{M/2K}$

The exploitation rate is determined from the relationship

$$F / Z = C (L_1, L_2) / [N (L_1) - N (L_2)]$$

The fishing mortality was calculated using the formula, $F = M (F/Z) / (1-F/Z)$. In the above expressions, $L_0$, and $K$ are growth parameters of VBGE. $L_1$ and $L_2$ are the lower and upper limits of a length group considered, $N$ is the stock number, $C$ is the number caught, $F$ and $M$ are the fishing and natural mortality coefficients respectively.
9.2.5. Exploitation rate (U)

The rate of exploitation is defined as the fraction of fish present at the start of a year that is caught during the year (Ricker, 1975). This is estimated by the equation given by Beverton and Holt (1957) and Ricker (1975) as:

\[ U = \frac{F (1 - e^{-\frac{F}{Z}})}{Z} \]

9.2.6. Exploitation ratio (E)

It refers to the ratio between fish caught and the total mortality (Ricker, 1975) or the exploitation rate or fraction of death caused by fishing (Sparre and Venema, 1992). It is estimated by the equation:

\[ E = \frac{F}{Z} = \frac{F}{M+F} \]

The ratio gives an indication of the state of exploitation of a stock under the assumption that the optimal value of \( E \) equals 0.5 (\( E = 0.5 \)). This, in turn, is under the assumption that the sustainable yield is optimised when \( F = M \) (Gulland, 1971).

9.2.7. Relative yield per recruit (Y/R) and relative biomass per recruit (B/R)

Y/R and B/R values were determined as a function of \( L_c/L_a \) and \( M/K \) (Pauly and Soriano, 1986). The estimates were made using the FiSAT software.
9.3. Results

The growth parameters used for the stock assessment studies were estimated using ELEFAN 1 programme of FiSAT software (See Chapter 8). \(L_a\) and \(K\) computed in respect of males and females of \(O.bakeri\) were 168 mm, 0.805 yr\(^{-1}\) and 177 mm, 0.645 yr\(^{-1}\) respectively. The \(t_0\) was estimated as 0.0865 in males and -1.0604 in females.

9.3.1. Total mortality coefficient (Z)

Total mortality (Z) of males and females of \(O.bakeri\), estimated following different methods, are presented in Table 9.1. There exists variation in the values of \(Z\) calculated by different methods and therefore, further analysis was carried out based on the average values arrived at from various methods. The total mortality values calculated for males ranged from 4.15 (Pauly’s pile up method, 1983) to 6.53 (Beverton and Holt method, 1966). The average of the estimates by various methods was 5.59. In female population, the values of \(Z\) varied between 2.745 (Pauly’s pile up method, 1983) and 5.49 (Jones and van Zalinge method, 1981), the average being 4.09. The results of the catch curve analysis for male and female \(O.bakeri\) are depicted in Figs.9.1 and 9.2 respectively.

9.3.2. Natural mortality coefficient (M)

Natural mortality coefficient values obtained by different methods along with \(M/K\) values are given in Table 9.2. Sekharan’s method (1974) gave the lowest value of 1.24 while Pauly’s empirical formula (1980)
gave the highest of 1.82 in males, the average being 1.41. In females, the same ranged from 0.99 by Sekharan's method (1974) to 1.55 by Pauly's empirical formula (1980) and the average was found to be 1.2.

9.3.3. Fishing mortality coefficient, Exploitation ratio and Exploitation rate

Fishing mortality coefficient worked out for males and females were 4.18 and 2.89 respectively. The exploitation ratio (E) in male and female *O. bakeri* were 0.72 and 0.68 respectively. Similarly, the exploitation rate (U) was found to be 0.72 in males and 0.67 in females.

9.3.4. Length based cohort analysis

The results of the length based cohort analysis of male population (Fig. 9.3) revealed that the exploitation started at 90 mm and increased upto 140 mm and thereafter decreased. In females (Fig. 9.4) also, the exploitation began from 90 mm and gradually increased upto 150 mm size, followed by a decline.

9.3.5. Relative yield per recruit (Y/R)

The relative yield per recruit (Y/R) and biomass per recruit (B/R) of male and female populations of *O. bakeri* are given in Figs. 9.5 and 9.6 respectively. The Lc/Lα and M/K used for Y/R analysis were 0.6 and 1.83 in males and 0.56 and 2.02 in females. The yield/ recruit reached a maximum at an exploitation rate of 0.94 in males and 0.92 in females and as the exploitation rate increased, the Y/R decreased. The present exploitation rates of 0.72 and 0.67 in males and females respectively did not exceed the optimum exploitation rates (E_{max}) of 0.94 in males and 0.92 in females.
9.4. Discussion

Studies on population dynamics of fishes from tropical waters became popular after the formulation of length based methods and models and the introduction of suitable computer softwares like FiSAT. In India, most of these studies pertain to marine fishes. Non-availability of required number of specimens belonging to different size classes has been the major factor hindering the progress of such studies in freshwater fishes in general and threatened fishes in particular. *O. bakeri* is a vulnerable endemic species of Kerala. Virtually no information is available on the population dynamics of this species and hence the urgency of such a study was felt.

Mortality is caused by natural factors like diseases, predation, environmental changes, senility, etc. in an unexploited stock while in exploited stocks, in addition to natural causes, fishing is the major contributing factor to mortality. Total mortality includes both natural and fishing mortalities. For estimating total mortality, five methods viz., Beverton and Holt method (1966), Jones and van Zalinge method (1981), Ssentongo and Larkin method (1973), Pauly’s pile up method (1983) and length converted catch curve method (Gayanilo et al., 1996) were used. In male *O. bakeri*, Z value was lowest in Pauly’s pile up method (1983) and highest in Beverton and Holt method (1966). The estimate of ‘Z’ was comparable in Jones and van Zalinge method (1981) and length converted catch curve method and was close to the average value of 5.59. The values obtained by Beverton and Holt method (1966) and Ssentongo and Larkin method (1973) were similar and were found to be higher when
compared to other methods. In females, the values arrived at by Beverton and Holt method (1966) and Ssentongo and Larkin method (1973) were comparable. Pauly's pile up method (1983) gave the lowest value while it was highest in Jones and van Zalinge method (1981).

Natural mortality is influenced by several biological and environmental factors and hence an accurate estimation of it is often difficult. (Pauly, 1980 b; Cushing, 1981; Liu and Cheng, 1999). Among the M values arrived at by three methods, the values estimated by Sekharan's method (1974) and Rikhter and Efmanov method (1976) were comparable in male O.bakeri. Interestingly, Pauly's empirical formula (1980) gave the highest while the value from Sekharan's method was the lowest in both males and females. The natural mortality of fish is closely related to age and size as the larger fishes are less prone to predation. Therefore, M can be correlated to longevity of the fish and the latter to growth coefficient K. M/K ratio can be used as an index for checking the validity of M and K values arrived at following different methods and the ratio usually ranged between 1 and 2.5 (Beverton and Holt, 1959). The estimated K values for males and females of O.bakeri were 0.805 and 0.645 respectively. The M values in males were 1.24 (Sekharan's method, 1974), 1.18 (Rikhter and Efmanov method, 1976) and 1.82 (Pauly's empirical formula, 1980) while in females, the values were 0.99, 1.06 and 1.55 respectively. Thus M/K ratios in males were computed as 1.54, 1.47 and 2.26 whereas in females, the values were 1.54, 1.64 and 2.4. Interestingly, the M/K values arrived at using Sekharan's method was exactly the same in both males and females. Thus, in the present
study, the M/K values computed by using M values estimated by the three different methods were within the limits proposed by Beverton and Holt (1959) in both the males and females. It may be inferred that all the three methods presently employed for the estimation of natural mortality can be appropriately used for the computation of M values in both the sexes of *O.bakeri*. M/K ratio is found to be constant among closely related species and sometimes within the similar taxonomic groups (Beverton and Holt, 1959; Banerji, 1973). M/K ratios in male *O.bakeri* were 1.54, 1.47 and 2.26 and in females 1.54, 1.64 and 2.4 by applying Sekharan's method (1974), Rikhter and EfanoV method (1976) and Pauly's empirical formula (1980) respectively. Similar values were reported in *Labeo dussumieri* by Kurup (1998), *L.calbasu* by Alam et al. (2000) and *L.rohita* by Nurulamin et al. (2001).

Fishing mortality was found to be higher in males compared to females. The length converted Cohort analysis showed that in males as well as females, fishes below 90 mm were not exploited. Fishing mortality increased from 90 mm up to 140 mm in males and 150 mm in females and thereafter declined. The present exploitation rate of 0.72 and 0.67 in males and females respectively is less than the respective *E*<sub>max</sub> values of 0.94 and 0.92. This implies that the stocks of *O.bakeri* are not under excess fishing pressure and are well within the optimal level of exploitation. The results of the present study indicate that the harvest of *O.bakeri* can be kept at sustainable level by maintaining the present rate of exploitation.
Table 9.1. Estimates of total mortality coefficient (Z) by different methods for male and female *O.bakeri*.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Method</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Beverton and Holt method</td>
<td>6.53</td>
<td>4.528</td>
</tr>
<tr>
<td>2</td>
<td>Sscentongo and Larkan method</td>
<td>6.2</td>
<td>4.224</td>
</tr>
<tr>
<td>3</td>
<td>Pauly’s pile up method</td>
<td>4.15</td>
<td>2.745</td>
</tr>
<tr>
<td>4</td>
<td>Jones and van Zalinge method</td>
<td>5.77</td>
<td>5.493</td>
</tr>
<tr>
<td>5</td>
<td>Length converted catch curve method</td>
<td>5.31</td>
<td>3.46</td>
</tr>
<tr>
<td></td>
<td><strong>Average</strong></td>
<td><strong>5.59</strong></td>
<td><strong>4.09</strong></td>
</tr>
</tbody>
</table>

Table 9.2. Estimates of natural mortality coefficient (M) by different methods and M/K ratios for male and female *O.bakeri*.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Method</th>
<th>Male</th>
<th>M/K</th>
<th>Female</th>
<th>M/K</th>
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<tr>
<td>1</td>
<td>Sekharan’s method</td>
<td>1.24</td>
<td>1.54</td>
<td>0.99</td>
<td>1.54</td>
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<tr>
<td>2</td>
<td>Rikhter and Efanov method</td>
<td>1.18</td>
<td>1.47</td>
<td>1.06</td>
<td>1.64</td>
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<tr>
<td>3</td>
<td>Pauly’s empirical formula</td>
<td>1.82</td>
<td>2.26</td>
<td>1.55</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td><strong>Average</strong></td>
<td><strong>1.41</strong></td>
<td><strong>1.2</strong></td>
<td></td>
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</table>
Fig. 9.1. Estimation of total mortality (Z) for male *O. bakeri* based on Catch Curve method.

Growth Parameters

<table>
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<th>Value</th>
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<tr>
<td>$L_0$</td>
<td>168.00 mm</td>
</tr>
<tr>
<td>$C$</td>
<td>0.00</td>
</tr>
<tr>
<td>$K$</td>
<td>0.81</td>
</tr>
<tr>
<td>$WP$</td>
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Regression Statistics

<table>
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<tr>
<td>$n$</td>
<td>4</td>
</tr>
<tr>
<td>y-intercept (a)</td>
<td>18.69</td>
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<tr>
<td>slope (b)</td>
<td>-5.31</td>
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<tr>
<td>Corr. Coef. (r)</td>
<td>-0.999</td>
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<tr>
<td>Z from catch curve</td>
<td>5.31</td>
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</tbody>
</table>

(CI of Z: 6.13 to 4.49)

Range of length observations:

- 90 - 160 mm
- Class Size
- 10 mm
Fig. 9.2. Estimation of total mortality (Z) for female *O. bakeri* based on Catch Curve method

**Growth Parameters**

- $L_m = 177.00$ mm
- $K = 0.65$
- $C = 0.00$
- $W_P = 0.00$

**Regression Statistics**

- $n = 3$
- $y$-intercept ($a$) = 16.89
- Slope ($b$) = -3.46
- Corr. Coef. ($r$) = -0.996
- $Z$ from catch curve = 3.46

(CI of $Z$ 7.20 to -0.27)

**Range of length observations**

- 100 - 170 mm
- Class Size
- 10 mm
Fig. 9.3. Length based cohort analysis of males of *O.bakeri*

![Graph showing cohort analysis for males of O.bakeri. Y-axis: Stock number (Thousands); X-axis: Mid length (mm). Legend: Population number, Catch number, Exploitation rate, Fishing mortality, Total mortality.]

Fig. 9.4. Length based cohort analysis in females of *O.bakeri*

![Graph showing cohort analysis for females of O.bakeri. Y-axis: Stock number; X-axis: Mid length (mm). Legend: Population number, Catch number, Exploitation rate, Fishing mortality, Total mortality.]

Fig. 9.5. Relative yield per recruit and biomass per recruit analysis for males of *O. bakeri*

<table>
<thead>
<tr>
<th>Optima:</th>
<th>$E_{\text{inf}}$</th>
<th>$Lc/L_d$ = 0.60</th>
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<td>$E_{-1}$</td>
<td>0.8709</td>
<td>$M/k = 1.83$</td>
</tr>
<tr>
<td>$E_{-5}$</td>
<td>0.3940</td>
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</table>
Fig. 9.6 Relative yield per recruit and biomass per recruit analysis for females of *O. bakeri*

<table>
<thead>
<tr>
<th>Optima</th>
<th>Value 1</th>
<th>Value 2</th>
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<tr>
<td>$E_{nu}$</td>
<td>0.9230</td>
<td>$L_c/L_m$ = 0.56</td>
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<tr>
<td>$E_{-1}$</td>
<td>0.8538</td>
<td>$M/k$ = 2.02</td>
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<td>$E_{-5}$</td>
<td>0.3867</td>
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