Chapter 11

POPULATION DYNAMICS
11.1. INTRODUCTION

Owing to lucrative price, higher export value and heavy demand from the world's major seafood markets, the deep sea prawns have gained a prime position among the exploited marine fishery resources of Kerala within a short span of three years. Indiscriminate exploitation patterns such as exerting 80% of the total fishing efforts in the inshore waters coupled with over-dependence in shrimp trawlers have adversely affected the stocks of coastal penaeid prawns, resulted in their stock depletion (Devaraj and Vivekanandan, 1999). This situation has tempted the shrimp trawlers to shift their area of operation to increasingly deeper parts of the oceans targeting deep sea prawns during late 90's. However, the shrimp trawlers carried out the fishing for deep sea prawns almost on par with the coastal shrimps, regardless of the stock size and regeneration capability of the former groups. Besides, their unique biological features such as low fecundity, sexual segregation and slow growth rates make them vulnerable to high and uncontrolled levels of fishing pressures in the deeper waters of Kerala. As a result, the total deep sea prawn landings showed a drastic decline from 48675t in 2000-01 to 19285 tonnes in 2001-02, thus registering a reduction to the tune of 60.35% in the total deep sea prawn landings of Kerala (refer chapter 5 for details).
It would thus appear that enforcement of strict management measures is warranted for the sustenance of the stock of deep sea prawns. For adoption of successful management practices, knowledge on the dynamics of fish population is essential to understand the stock position from time to time, which is the net result of various dynamic forces acting on the population. This information is vital in regulating the exploitation level of the stock as a measure of conservation.

The earlier attempts to estimate stock assessment of crustaceans were mostly on penaeid prawns which restricted to the study of mortality rates based on tagging experiments (Lindner and Anderson, 1956; Klima, 1965; Kutkunh, 1966) and catch composition (Neal, 1968; Berry, 1970; Garcia, 1977; Jones and Van Zalinge, 1981; Pauly et al., 1984).

Studies on the population dynamics of deep sea prawns are very scanty and are confined to a few species viz., *Aristomorpha foliacea* and *Aristeus antennatus* (Yahiaoui, et al., 1986; Orsi and Relini, 1988; Demestre and Martin, 1993; Yahiaoui, 1994; Ragonese and Bianchini, 1995; Ragonese et al., 1994; Spedicato et al., 1994; Donghia et al., 1998), *Pandalus borealis* (Anderson, 1991; Bergström, 1992; Cessay, 2000) and *Heterocarpus laevigatus* (Dailey and Ralston, 1986).

Studies on the dynamics of population of marine prawns of Indian waters were confined to coastal Penaeid and Solenocerid prawns.
Notable works among them are on *Penaeus* spp. (Banerji and Geroge, 1967; Kurup and Rao, 1974; Lalitha Devi, 1986; Rao, 1988; Rao et al., 1993) *Metapenaeus dobsoni* (Ramamurthy et al., 1978; Alagaraja et al., 1986; George et al., 1988), *Parapenaeopsis stylifera* (Ramamurthy, 1980; Alagaraja et al., 1986; Suseelan and Rajan, 1989; George et al., 1980) *M. monoceros* (Lalitha Devi, 1987; Rao, 1994), *Solenocera crassicornis* (Chakraborty et al., 1997) and *P. merguiensis* (Bhadra and Biradar, 2000).

Information on the dynamics of *Heterocarpus gibbosus* and *H. woodmasoni* from any part of the world is not available. Against this background, a maiden attempt is made to estimate the mortality parameters and stock assessment of two most commercially important species *Heterocarpus gibbosus* and *H. woodmasoni* off Kerala coast.

### 11.2. MATERIALS AND METHODS

The detailed methodology is described in chapter 10 on age and growth. The materials used for age and growth and population dynamics are same. For the estimation of total instantaneous rate of mortality
coefficient (Z), among the various methods available, the following four methods were employed in the present study.

1. **Beverton and Holt method (1957)**

   \[
   Z = \frac{K \cdot L_a - L}{L - L'}
   \]

   Where \( L \) is the mean length of prawn of length \( L' \) and larger. \( L' \) is the lower limit of the size group from which length upwards, all lengths are under full exploitation.

2. **Ssentongo and Larkin method (1973)**

   \[
   Z = K \frac{n}{n + 1} \frac{1}{\bar{y} - y_c}
   \]

   where \( y = -\log (1 - I/L) \)
   \( y_c = -\log (1 - I_c/L) \)
   \( \bar{y} = \frac{fy}{f} \) where \( n=f, n+1 = f+1 \)
   \( y_c = \) corresponding \( I_c \) value
   \( n = \) number of prawn caught from \( y_c \) onwards

   \( I = \) mid length
3. Length converted catch curve method (Gayanilo et al., 1996)

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

where \( N \) = number in length class \( i \)

\( t \) = time needed to grow through length class \( i \)

\( t_i \) = the age corresponding to the mid length class \( i \)

(relative age computed with \( t_0 = 0 \))

\( b \) = estimate of \( Z \) when sign altered.

4. Pauly’s pile up method (1983)

\[
\log_e \left( \frac{N_t}{t} \right) = a - bt^*
\]

\( Z = -(-b) \), \( t^* = t_1 + \frac{1}{2} \ t \)

\[ t = \frac{1}{k} \log_e \frac{(L-L_1)}{(L-L_2)} \]

\[ t_1 = \frac{1}{k} \log_e \frac{(t^* - L_1)}{L} \]

where \( L \) = 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’.

To estimate natural mortality coefficients the following three methods are employed:

1. Rickter and Effanov method

\[ M = 1.521 \left( t_m - 0.72 \right) - 0.155 \]
Where $t_m$ is the age at which 50% of the population is mature.

2. **Sekharans' method (t max method) (1975)**

$$M = \frac{- (\ln 0.01)}{t_{max}}$$

Where $t_{max} \equiv 3/K$

$t_{max}$ is the age at $l_{max}$ assuming that 99% of fish in the exploited population die when they reach $t_{max}$ or the longevity of the prawn stock in question.

3. **Pauly's empirical method**

Pauly (1980) developed an empirical relationship between $L_\alpha$, $K$ and mean sea surface temperature ($T$) and natural mortality as:

$$\log_{10}(M) = -0.0066 - 0.279 \log_{10}L_\alpha + 0.6543 \log_{10}K + 0.4653 \log_{10}T$$

$L_\alpha$ = asymptotic length (in cm)

$K$ = annual growth coefficient

$T$ = mean sea surface temperature in °C.

The annual mean temperature of sea in which deep sea prawn stock lives is taken as 12°C based on the present study (refer Chapter 3)
Fishing mortality estimation

Instantaneous rate of fishing mortality rate (F) was estimated by simple expression

\[ F = Z - M \]

Stock assessment

For the purpose of stock assessment studies, the following parameters are considered:

Jones' (1984) length based cohort analysis

In Jones' length cohort analysis, an assumption is made that the picture presented by all size (age) classes caught during one year reflects that of a cohort during its life span. This length base cohort analysis is written as

\[ N(L_1) = \left[ N(L_2) X (L_1, L_2) + C (L_1, L_2) \right] X (L_1, L_2) \]

Where \( N(L_1) = \) the number of fish that attains length \( L_1 \)

\[ N(L_2) = \] the number of fish that attains length \( L_2 \)
C \( (L_1, L_2) \) = the number of fish caught of length between \( L_1 \) and \( L_2 \)

\[ X \ (L_1, L_2) = \left( \frac{(\alpha L - L_2)}{(L_1 - L_2)} \right)^{M2K} \]

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 above equations \( \alpha \) and \( K \) are growth parameters of VBGE, \( L_1 \) and \( L_2 \) are lower and upper limits of the length group considered, \( N \) is the stock number, \( C \) is the number caught, \( F \) and \( M \) are fishing and natural mortality coefficient respectively.

Exploitation rate (U)

The rate of exploitation (U) is defined as the fraction of fish present at the start of a year that is caught during the year (Ricker, 1975). It is estimated by the equation given by Beverton and Holt (1957) and Ricker (1975) as
\[ U = \frac{F}{Z} (1 - e^{-Z}) \]

**Exploitation ratio (E)**

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

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

The ratio gives an indication whether a stock is overfished or not, under the assumption that the optimal value of E equals to 0.5 which in turn is under the assumption that the sustainable yield is optimized when \( F = M \) (Gulland, 1971).

**Recruitment patterns**

The method described by Pauly restructures the recruitment pulses from a time series of length frequency data to determine the relative strength and number of young ones per year. It involves backward projection of length frequency in time series as defined by Von Bertalanffy growth function (Bertalanffy, 1938).
11.3. RESULTS

11.3.1. Mortality coefficients

The growth parameters of \textit{H. woodmasoni} estimated are: males $L_\alpha$ -161mm, $K$ - 0.82 yr$^{-1}$, $t_0$ - 0.97; females $L_\alpha$ - 188mm, $K$ - 0.60 yr$^{-1}$, $t_0$ - 0.96 (refer chapter 10 for details). The total mortality coefficients of male and female population of \textit{H. woodmasoni} are given in Table 11.1. The $Z$ values calculated by different methods in males varied from 2.77 to 8.30. Beverton and Holt method gave the lowest value while the estimate by Jones and Van Zalinge was the highest. In females, the lowest $Z$ value was estimated by Pauly's pile up method while the highest was obtained by Jones Zalinge method. Since the $Z$ values obtained were not closer to each other, the $Z$ estimate was calculated from the average of the 3 methods, which were taken for further analysis.

The natural mortality coefficient values estimated by different methods in males and females of \textit{H. woodmasoni} are given in Table 11.2. In females, the values were 1.37 by Rikhtar and Effanov method, 0.92 by Sekharan's method and 1.19 by Pauly's empirical formula. While in males, the estimated $M$ value was maximum by Rikhtar and Effanov method (1.37), followed by 1.19 by Pauly's empirical formula and 0.92 by
Sekharan’s method. The average values were taken in males and females for further analysis.

Between the two sexes studied, the total mortality was obviously high in females. On the contrary, the natural mortality was slightly higher in males than females. The mortality due to fishing (F) is estimated as 3.43 in females and 1.73 in males of *H. woodmasoni*, which were far exceeded the natural mortality, which is indicative of heavy exploitation level of *H. woodmasoni*, especially in female population.

The growth parameters of *H. gibbosus* used for stock assessment studies are: males $L_\alpha$ - 200mm, $K$ - 0.73 yr$^{-1}$, $t_0$ - 0.98; females $L_\alpha$ - 203mm, $K$ - 0.53 yr$^{-1}$, $t_0$ - 0.86 (refer Chapter 10 for details). The total mortality (Z) and natural mortality (M) of male and female population of *H. gibbosus* are given in Tables 11.3 and 11.4. Amongst the mortality rates, the M value obtained in females by Jones Zalinge method appeared as the highest (5.17) while it was lowest in Pauly’s pile up method. In males also, the lowest M value was estimated by the same method (2.65) while it was highest while estimating with Beverton and Holt method (6.88). The natural mortality estimates based on Pauly’s empirical formula were lower in males and females with 1.10 and 0.81 respectively. Whereas the highest M values were estimated based on Rikhtor and Effanov method. It would thus appear that the values of Z and
M estimated using different method for *H.gibbosus* were not closer, and therefore the average was computed and used for further analysis. Among the two sexes studied, the Z and M values were glaringly high in males and in compliance with this, the F value was also apparently high in male population when compared to their counterparts, being 3.91 in males against 2.47 for females.

11.3.2. Exploitation rate (U) and Exploitation rate (E)

The exploitation rate (U) in males of *H.woodmasoni* was 0.5311 while the exploitation ratio (E) was 0.5563. Whereas in females, the U and E values were 0.7389 and 0.7468 for the period 2000-02.

The exploitation rate of male *H.gibbosus* was estimated at 0.7483 while the exploitation ratio was 0.7527. In females, the U and E values were estimated to be 0.6747 and 0.6950 respectively during the study period.

11.3.3. Recruitment patterns

By pooling the annual length frequency for the two years, the recruitment patterns were determined in males and females of *H.woodmasoni* separately as depicted in Fig. 11.1 and 11.2. The recruitment pattern in male *H.woodmasoni* showed the entry of two
distinct modes to the usable stock, one major mode added to the stock during March to April, contributed 33.29% of the recruitment to the fishery while the second minor mode was observed in September (16.57%). Similarly, in females also, recruitment of two modes to fishery was evident, a major one in March and a minor one in July, contributed up to 11.25 and 20.03% respectively. It is noteworthy to mention that though the species is characterized by a continuous reproductive activity, it exhibited a prolonged breeding peak starting from October to April when 60% of the females belonged to both mature and ripe stages (refer Chapter 8). In *H. gibbosus*, a major mode was discernible during July and August followed by a smaller one in February in male while in female a minor mode was observed during December to February followed by a major mode in July (20.39%) (Fig. 11.3 & 11.4).

11.3.4. The relative Yield /Recruitment Model (Y'/R)

The LC/Lc and M/K used for the Y'/R analysis of *H. woodmasoni* were 0.56 and 1.69 in males and 0.51 and 1.93 in females respectively. The yield per recruitment reached a maximum at an exploitation rate of 0.839 (E_{max}) and with the further increase of exploitation rate the Y'/R decreases. Fig. 11.5 showed that the present level of exploitation has exceeded the optimum exploitation rate (0.5) in male *H. woodmasoni*. The E_{-0.1} was estimated as 0.761 while E_{-0.5} was 0.382.
In females of *H. woodmasoni*, $E_{\text{max}}$ was observed as 0.791. From Fig. 11.6, it appears that the present exploitation rate (0.74) has significantly exceeded the optimum exploitation rate (0.5). The females are subjected to overexploitation when compared to their male counterparts in the population. The $E_{-0.1}$ in females was estimated as 0.713 and $E_{-0.5}$ as 0.367.

Results of the length converted cohort analysis revealed that in males and females, specimens in the length groups 50-60mm and above were vulnerable to exploitation, however, heavy exploitation of the length class 80-90 mm was quite discernible. The fishing mortality there after showed a steep increase in males. In females also, the exploitation started from the length group 50-60 mm onwards which attained peak at 70-100 mm length class. The fishing mortality showed a gradual increase up to 90-100 mm, however, it become steady henceforth (Fig. 11.7 & 11.8).

The $L_c/L_x$ and $M/K$ used for the $Y'/R$ analysis of *H. gibbosus* were 0.57 and 1.73 in males and 0.57 and 2.05 in females respectively. In males and females, $E_{\text{max}}$ was observed at 0.791 and 0.933 respectively. In the males, the present exploitation rate (0.748) has significantly exceeded the optimum exploitation rate (0.5) (Fig 11.9). Thus, it can be concluded that the males of *H. gibbosus* are subjected to overexploitation in the
population. The \( E_{-0.1} \) in males was estimated as 0.812 and \( E_{-0.5} \) as 0.386.

Fig. 11. 10 shows the exploitation level of females, which indicates that the present exploitation rate, \( U \) (0.675) was higher than optimum exploitation level, 0.5. The \( E_{-0.1} \) was estimated as 0.852 and \( E_{-0.5} \) as 0.388.

Results of the length converted cohort analysis are depicted in Fig. 11. 11 & 11.12. In male population of \textit{H. gibbosus}, specimens below 50mm are not vulnerable to exploitation, however, the exploitation above 60 mm showed a gradual increase attaining peak exploitation between 90 and 120 mm. The fishing mortality was invariably high in the size groups 90-130mm.

Among females, the specimens in the length group 70-80mm and above were vulnerable to exploitation; however, heavy exploitation was discernible at 90-110mm size groups. The fishing mortality was found to be increasing from 90mm onwards with peak in 100-110mm size groups.

11.4. DISCUSSION

Even though very few studies on the stock assessment of pandalid shrimps had been attempted at temperate waters, the same with
reference to Indian Ocean region are totally lacking. Furthermore, no attempt has so far been made from any part of the world to estimate the stock assessment of *H. gibbosus* and *H. woodmasoni*. In India, the studies on population dynamics were done only on coastal water penaeid prawns, however, the recently started deep sea prawn fishery off Kerala enabled in carrying out a maiden study on the dynamics of the deep water pandalids of Indian waters.

In the present study, analytical models working with concepts such as mortality rates and individual growth rates have been used to get reliable assessment of *H. gibbosus* and *H. woodmasoni* stocks. The total instantaneous rate of mortality, \( Z \) was estimated with the help of four methods viz., Beverton and Holt method, Ssentongo and Larkin method, Length converted catch curve method and Pauly's pile up method using the length frequency data of two years (2000-02). In *H. woodmasoni*, the \( Z \) value was estimated to be 3.12 and 4.58 respectively for males and females while in *H. gibbosus*, it was high in males (5.18), in contrast, the value was low in female with 3.56.

For estimating natural mortality coefficient, Rickter and Effanov method, Sekharans' method and Pauly's empirical method were employed in the present study, however, the regression of \( Z \) against effort (Sparre and Venema, 1992) has not been attempted for mortality
estimation due to the practical difficulty in apportioning the fishing effort for a single species alone in the context of multi species complexity of deep sea prawns harvested off Kerala. Moreover, as natural mortality is influenced by several biological and environmental parameters, it is difficult to get an accurate estimate (Pauly, 1982; Cushing, 1981). Further, it is also related to other growth parameters like $L_\alpha$ (Sparre and Venema, 1992) and maturity (Rikhtor and Effanov, 1976).

The natural mortality ($M$) in $H.$ woodmasoni and $H.$ gibbosus can be explained following Gulland (1969) who related natural mortality to age and size, as larger fishes generally would have less rate of predation. Since $M$ is linked to longevity and the latter to growth coefficient $K$, $M/K$ ratio is found constant among closely related species and sometimes within the similar taxonomic groups (Beverton and Holt, 1959). $M/K$ ratio usually ranges from 1 to 2.5 (Beverton and Holt, 1959). In males and females of $H.$ woodmasoni, the $M/K$ ratio arrived at by all the three methods were found to be within the known limits. It may, therefore, be inferred that the estimation of $M$ following all the three methods in both the sexes were appeared to be reasonable in $H.$ woodmasoni.

In the present study, the $M/K$ ratio obtained for males $H.$ gibbosus by the three methods were found to be within known limits of 1-2.5 while in female also similar results could be apparent barring the method of
Pauly's empirical formula. It may, therefore, be inferred that the estimates of \( M \) following all the methods were appeared to be reasonable and acceptable in *H. gibbosus* with an exception as mentioned above.

The fishing mortality rate (\( F \)) in the females of *H. woodmasoni* was found to be very high (3.42) when compared to males (1.73). The exploitation rate and exploitation ratio were also found to be far higher in females when compared to their male counterparts. The sex ratio analysis of the exploited stock of *H. woodmasoni* indicated that the females were represented far in excess of males during 2000-01 and 2001-02 with a male to female ratio 1:1.62 and 1:2.04 for the first and second years respectively. In addition, the peak occurrence of berried females could also be encountered coinciding with the peak fishing season during when the percentage of ovigerous females in the total female population ranged from 74.11 % in March to 86.01 % in January. As the exploitation ratio of both males and females are found to be more than the optimum levels in the present study, it is evident that the stock of *H. woodmasoni* is grossly over exploited beyond the sustainable limit and this is all the more pertinent in case of female population. The modal size group in the fishery revealed the dominance of size group 90-100mm in both the sexes of *H. woodmasoni* and the size at first maturity of male and female were worked out at 96.75mm and 100mm respectively. The length cohort analysis also showed the very high fishing mortality in 100-130mm
length groups. This finding clearly shows that, the entire population does not get a chance to reproduce even once during their lifetime.

In the case of *H.gibbosus*, the fishing mortality of males was found to be higher than their female counterparts in the population, thus suggesting that the males are subjected to more fishing pressure than their female counterparts. However, the exploitation ratio is more than 0.5 in both the sexes, there is every necessity to reduce the fishing effort to maintain the stock at optimal levels and also to avoid the stock from over exploitation.

In *H.gibbosus*, males dominated in the exploited stock during most of the months during the study period showing a male female ratio 1:0.85. The modal length group in both the sexes were observed to be 80-90mm while the size at first maturity calculated for males and females were 97mm and 98.5mm respectively. The fishing mortality was observed to be high in 90-110 mm size groups. Also the modal size group of ovigerous females in both the species were 90-110mm. Therefore, the results of the present study are indicative of the existence of gross over exploitation of spawning stock of *H. gibbosus* which can cause very serious impact on the sustainability of the stock. The percentage of ovigerous females was also found to be high during December to March (refer chapter 5 for details). It would thus appear that the stock of both *H.woodmasoni* and
*H.gibbosus* are prone to the threat of both growth and recruitment over fishing as defined by Pauly (1982) and may collapse in near future unless otherwise the fishing effort is judiciously regulated at optimal levels giving due emphasis to maximum sustainable yield. The exploitation of these new deeper water resources must be carefully developed, taking into consideration that deep water species can generally withstand only low levels of exploitation in terms of long term sustainable fishery (Colloca, 2002). In this context, it is found imperative to do appropriate enactments as a conservation measure to protect the stock from the risk of over exploitation. In view of the fact that the smaller size classes were prone to intensive exploitation, a closed season during the recruitment period together with the enforcement of statutory mesh size of 35mm for bottom trawling shall be done as the immediate measure of conservation for the sustenance of the stock of deep sea prawns off Kerala Coast. However, the fishing grounds of deep sea prawns are located beyond the territorial waters of Kerala and therefore the Government of Kerala have no executive powers to enforce the above conservation measures in EEZ of Kerala. Therefore, it is recommended that Government of Kerala may initiate appropriate steps to get the above conservation measures implemented through Government of India at the earliest.
### Instantaneous rate of total mortality ($Z$) for males and females of *Heterocarpus woodmasoni* during 2000-02

<table>
<thead>
<tr>
<th>Sex</th>
<th>Pauly's pile up</th>
<th>Beverton &amp; Holt</th>
<th>Ssentongo&amp; Larkins</th>
<th>Length Catch curve</th>
<th>Jons Zalinge plot</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>4.2245</td>
<td>2.7658</td>
<td>2.8038</td>
<td>4.80</td>
<td>8.30</td>
<td>4.5828</td>
</tr>
<tr>
<td>Male</td>
<td>2.84</td>
<td>3.04</td>
<td>2.98</td>
<td>3.82</td>
<td>4.38</td>
<td>3.1165</td>
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</tbody>
</table>

### Instantaneous rate of natural mortality (M) and fishing mortality (F) for males and females of *Heterocarpus woodmasoni* during 2000-02

<table>
<thead>
<tr>
<th>Sex</th>
<th>Rickter Effanov</th>
<th>Sekharan's Method</th>
<th>Pauly's Empirical</th>
<th>Average natural mortality</th>
<th>Average Fishing mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>1.37</td>
<td>0.921</td>
<td>1.19</td>
<td>1.1603</td>
<td>3.4225</td>
</tr>
<tr>
<td>Male</td>
<td>1.37</td>
<td>1.26</td>
<td>1.52</td>
<td>1.3829</td>
<td>1.7338</td>
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</tbody>
</table>

### Instantaneous rate of total mortality ($Z$) for males and females of *Heterocarpus gibbosus* during 2000-02

<table>
<thead>
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<th>Sex</th>
<th>Pauly's pile up</th>
<th>Beverton &amp; Holt</th>
<th>Ssentongo&amp; Larkins</th>
<th>Length Catch curve</th>
<th>Jons Zalinge plot</th>
<th>Average</th>
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<tr>
<td>Female</td>
<td>2.0675</td>
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<td>2.6541</td>
<td>6.8818</td>
<td>6.015</td>
<td>3.76</td>
<td>4.386</td>
<td>5.1837</td>
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</tbody>
</table>

### Instantaneous rate of natural mortality (M) and fishing mortality (F) for males and females of *Heterocarpus gibbosus* during 2000-02

<table>
<thead>
<tr>
<th>Sex</th>
<th>Rickter Effanov</th>
<th>Sekharan's Method</th>
<th>Pauly's Empirical</th>
<th>Average natural mortality</th>
<th>Average Fishing mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>1.37</td>
<td>1.07</td>
<td>0.81</td>
<td>1.0845</td>
<td>2.4712</td>
</tr>
<tr>
<td>Male</td>
<td>1.37</td>
<td>1.34</td>
<td>1.14</td>
<td>1.2819</td>
<td>3.9017</td>
</tr>
</tbody>
</table>
**Fig. 11.1**

RECRUITMENT PATTERN

*Heterocarpus woodmasoni*

(male)

- Group parameters:
  - Mean (1) : 4.04
  - Mean (2) : 9.03
  - S.D. : 0.87
  - N (%) (1) : 58.28
  - N (%) (2) : 41.74

- Absolute Time:
  - Dec : 1.68
  - Feb : 3.59
  - Mar : 6.09
  - Apr : 17.20
  - May : 11.88
  - Jun : 1.49
  - Jul : 5.78
  - Aug : 14.89
  - Sep : 16.57
  - Oct : 5.37
  - Nov : 0.00

- Species name: *Heterocarpus woodmasoni*

**Fig. 11.2**

RECRUITMENT PATTERN

*Heterocarpus woodmasoni*

(female)

- Group parameters:
  - Mean (1) : 4.04
  - Mean (2) : 8.50
  - S.D. : 0.80
  - N (%) (1) : 56.85
  - N (%) (2) : 43.15

- Absolute Time:
  - Dec : 5.37
  - Jan : 5.72
  - Feb : 8.61
  - Mar : 7.42
  - Apr : 11.25
  - May : 8.42
  - Jun : 6.86
  - Jul : 13.34
  - Aug : 20.03
  - Sep : 12.75
  - Oct : 0.13
  - Nov : 0.00

- Species name: *Heterocarpus woodmasoni*
### Fig. 11.3.
**RECRUITMENT PATTERN**

*Heterocarpus gibbosus* (male)

<table>
<thead>
<tr>
<th>Time</th>
<th>Recruitment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec</td>
<td>2.18</td>
</tr>
<tr>
<td>Jan</td>
<td>1.50</td>
</tr>
<tr>
<td>Feb</td>
<td>9.31</td>
</tr>
<tr>
<td>Mar</td>
<td>10.38</td>
</tr>
<tr>
<td>Apr</td>
<td>2.32</td>
</tr>
<tr>
<td>May</td>
<td>7.76</td>
</tr>
<tr>
<td>Jun</td>
<td>13.33</td>
</tr>
<tr>
<td>Jul</td>
<td>20.39</td>
</tr>
<tr>
<td>Aug</td>
<td>19.85</td>
</tr>
<tr>
<td>Sep</td>
<td>11.15</td>
</tr>
<tr>
<td>Oct</td>
<td>1.82</td>
</tr>
<tr>
<td>Nov</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Group parameters:
- Mean (1): 2.91
- S.D. (1): 1.10
- N (%): 25.84

Species name:
- Heterocarpus gibbosus

**La = 200, K = .74, C = 0, wp = 0, t_{e} = .98**

### Fig. 11.4
**RECRUITMENT PATTERN**

*Heterocarpus gibbosus* (female)

<table>
<thead>
<tr>
<th>Time</th>
<th>Recruitment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug</td>
<td>1.82</td>
</tr>
<tr>
<td>Nov</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Group parameters:
- Mean (1): 3.45
- S.D. (1): 1.68
- N (%): 51.01

Species name:
- Heterocarpus gibbosus

**La = 203, K = .53, C = 0, wp = 0, t_{e} = .86**
Fig. 11.5. Relative yield per recruit curve for the females of Heterocarpus woodmasoni.

Optima

Examp : $L_c / L_\alpha = 0.51$

$M.K = 1.93$

R搪 yield perf recruit
Knife-edge option

Relative yield (10%)
Fig 11.8. Relative yield per recruit curve for the males of Heterocarpus woodmasoni.

Exploitation rate

Knife-edge option

Optima

Exam

M.K

E-1

E-5

Exploitation rate

0.8390

0.7613

0.3820

0.56

1.69

0.8390

0.7613

0.3820

0.56

1.69
Fig. 11.7  Length cohort analysis of males of *Heterocarpus woodmasoni*

Fig. 11.8  Length cohort analysis of females of *Heterocarpus woodmasoni*
Relative yield per recruit curve for the males of *Heterocarpus gibbosus*

<table>
<thead>
<tr>
<th>Exploitation Rate</th>
<th>Rel. yield/recruit</th>
<th>Rel. biomass/recruit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0.25</td>
<td>0.5</td>
<td>0.75</td>
</tr>
<tr>
<td>0.5</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>0.75</td>
<td>4.5</td>
<td>0.25</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

Optima
- Exam : 0.8760
- $E_{-0.5}$ : 0.8127
- $E_{-0.5}$ : 0.3869

$Lc/L\alpha = 0.57$

$M.K = 1.73$

Knife-edge option

Rel. yield/recruit
Fig 11.10. Relative yield per recruit curve for the females of Heterocarpus gibbosus.

![Diagram showing relative yield per recruit curve for Heterocarpus gibbosus.]

Optima:
- Exam = 0.9330
- E = 1.0857
- E = 0.3875

Knife-edge option:
- $L_c / \alpha = 0.57$
- $M.K = 2.05$
Fig. 11.11 Length cohort analysis of males of *Heterocarpus gibbosus*

![Graph showing length cohort analysis of males of *Heterocarpus gibbosus*](image)

Fig. 11.12 Length cohort analysis of females of *Heterocarpus gibbosus*

![Graph showing length cohort analysis of females of *Heterocarpus gibbosus*](image)