9. MORTALITY AND EXPLOITATION

9.1. INTRODUCTION

Stock size of a fish depends on recruitment, growth and mortality. The biomass of fish in the usable stock is getting increased by the reproduction and growth. Concurrently, due to loss of individuals from the population, the stock will be reduced in numbers and weight. The losses of individual in a population through death are due to various reasons, which are independent of each other.

Many factors in the marine environment contribute to the death of fish. To list a few are adverse conditions, lack of food, competition, predation, etc. Death of individuals in a population due to above said natural reasons are called as natural mortality (M). In an exploited stock, stock size further reduces due to human interference notably by fishing and hunting. Removal of individual fishes from the stock due to fishing and hunting is called as fishing mortality (F). The instantaneous rate of total mortality rate (Z) is the sum of the instantaneous rate of fishing mortality and the instantaneous rate of natural mortality.

Information on mortality rate is essential for formulation of exploitation strategy and thereby exploit and mange the fishery resources at optimal levels. Mortality estimates have been done in almost all major exploited fish stocks with a view to arrive at optimum levels of exploitation. Mortality estimates of Cobia inhabiting Chesapeake Bay, Gulf of Mexico and Australia were carried out by Richards (1967), Williams (2001) and Fry and Griffiths (2010) which provided
basic information on the dynamics of the Cobia stock. However, no information is available on mortality and exploitation of Cobia occurring in Indian waters.

Cobia is exploited world wide both by commercial and recreational fishery. In the commercial fishery they are generally caught as incidental catch in various fishery. Pakistan, Taiwan, Philippense, Viatnam, United State of America, Gulf of Mexico, Australia and India are major Cobia fishing nations. Cobia are mainly exploited by handlines, bottom trawls, driftnets, floating gillnets, drift gill nets, troll lines, pound nets, purse-seine and trawl nets (Freeman and Walford, 1976; Aprieto and Villoso, 1979; Pillai 1982; Manooch, 1984; Bianchi, 1985; Aprieto, 1985; Rountree, 1990). In India, Cobia is caught as incidental catch by hand lines, bottom trawls, drift gill nets, troll lines, purse-seine and trawl nets both along west and east coast of India.

Compared to major fishery resources that support marine fishing industry in India, landings of Cobia is very less, but their unit price and increased attention due to culture prospective make them an important fishery resource. In the present study, mortality rates of Cobia were estimated and the dynamics of recruitment and exploitation pattern exist in India have been examined with an aim to propose sustainable management measures to ensure rational exploitation and improve sustainability of the stock.

9.2. MATERIALS AND METHODS

1261 specimens having total length ranging from 22.6 cm to 181cm of Cobia collected during the period January 2008 to December 2009 were grouped
in to length class of 10 cm interval and analysed using FAO-ICLARM Stock Assessment Tools (FISAT) (Gayanilo et al., 2005).

9.2.1. Natural mortality estimation

The instantaneous rate of natural mortality (M), was estimated following Pauly’ empirical formula (Pauly, 1980 b, 1984) and Cushing formula (Cushing, 1980).

9.2.1. A. Pauly’s empirical formula

Pauly (1980 b) established relationship of growth parameters ($L_\infty$ (in cm) or $W_\infty$ (in g) and K (year$^{-1}$), mean annual habitat temperature (T in °C) and natural mortality. The relationship was derived by utilizing 175 sets of independent sets of mortality estimates and predictor value for the tropical fishes. The equation used was:

$$\ln(M) = -0.0152 - 0.279 \ln(L_\infty) + 0.6543 \ln(K) + 0.463 \ln(T) \ldots (39)$$

Where,

$L_\infty$ and K are von Bertalanffy growth parameters

T = the mean annual habitat temperature in °C.

von Bertalanffy growth parameters estimated by ELEFAN method/ Ford – Walford plot was used for the estimation. The mean annual habitat temperature recorded during the study was 28 °C.
9.2.1. B. Cushing formula

Cushing (1968) proposed a method by which M can be calculated based on longevity of the fish by applying equation:

$$M = (\ln .100)/t_{\text{max}}$$

(40)

Where,

$$t_{\text{max}} = \text{the age at } L_{\text{max}}$$

Here natural mortality estimated based on the assumption that 99% of the animals in a population die before attaining $L_{\text{max}}$. Maximum length of fish ($L_{\text{max}}$) in a population was estimated following Foramacion et al. (1991). This method is based on the assumption that the observed maximum length of a time series of samples does not refer to a fixed quantity but, rather represent a random variable which follows a probabilistic law.

$L'_{\text{max}}$ was estimated from a set of n extreme values ($L^*$, the largest specimen in each sample of a file) using the (Type I) regression:

$$L^* = a + 1/\alpha \cdot P$$

(41)

Where,

$$P = \text{the probability associated with the occurrence of an extreme value}$$

$$1/\alpha = \text{a measure of dispersion}$$

$$L'_{\text{max}} = \text{the intercept of the regression line with the probability associated with the } n^{\text{th}} \text{ observation (note that the scale used for } P \text{ is non-linear, i.e., corresponds to that used for extreme value probability paper).}$$
P is computed for any extreme value following Gumbel (1954) probability P obtained from the formula:

\[ P = \frac{m}{n+1} \] 

Where,

- \( m \) = the position of the value, ranked in ascending order
- \( n \) = the number of \( L^* \) values.

### 9.2.2. Total mortality estimation

The instantaneous rate of total mortality (\( Z \)) estimated following the Beverton and Holt model (Beverton and Holt, 1956) and length converted catch curve method (Pauly, 1984, 1990).

#### 9.2.2. A. Beverton and Holt model

Beverton and Holt (1956) assumed that growth follows the VBGF and mortality can be represented by negative exponential decay. Here instantaneous rate of total mortality (\( Z \)) was obtained from the formula:

\[ Z = K \cdot \frac{(L_\infty - L)'}{(L_\infty - L')} \] 

Where,

- \( Z \) = instantaneous rate of total mortality.
- \( L' \) = Mean total length in cm, \( L' = \) cut of length

#### 9.2.2. B. Length converted catch curve method

The method essentially consists of a plot of the natural logarithm of the number of fish in various age groups (\( N_t \)) against their corresponding age (\( t \)), which gives the linear relation.
\begin{equation}
\ln(N_i/D_{ti}) = a + b \times t_i \tag{44}
\end{equation}

Where,
- \(N_i\) = the number of fish in length class \(i\),
- \(D_{ti}\) = the time needed for the fish to grow through length class \(i\),
- \(t_i\) = the age (or the relative age, computed with \(t_0 = 0\)) corresponding to the mid length of class \(i\),
- \(b = \text{with sign changed is an estimate of } Z\).

Following estimation of \(Z\), the routine used to estimate \(M\) using Pauly's \(M\) equation and \(F\), from the equation:
\begin{equation}
F = Z - M \tag{45}
\end{equation}

Where,
- \(F = \text{instantaneous rate of fishing mortality}\)

And the exploitation ratio (E) from formula
\begin{equation}
E = F/Z \tag{46}
\end{equation}

9.2.3. Probability of capture

Probability of capture of fishes \(L_{25}\) (length at which 25 % of fishes caught), \(L_{50}\) (length at which 50 % of fishes caught) \(L_{75}\) (length at which 75 % of fishes caught) were estimated from length-converted catch curves by backward extrapolation of the catch curve and comparison of the numbers actually caught with those that "ought" to have been caught. Catch curve analysis extended to an estimation of probabilities of capture by backward projection of the number that would be expected if no selectivity had taken place (\(N'\)), using the formula
\[ N_{i+1}' = N_1 \times \exp (Z D_t) \]  
\[ \text{Where,} \]
\[ D_t \] as defined above in equation 44
\[ Z = \frac{Z_i + Z_{i+1}}{2} \]  
\[ \text{Where,} \]
\[ Z_i = M + F_i; F_{i-1} = F_i - X, \text{ and } X = F / (\text{no. of classes below } P_1 + 1) \]  
\[ \text{Where,} \]
\[ P_1 = \text{the first length group with a probability of capture equal to 1.0, and} \]
\[ \text{whose lower limit is an estimate of } L'. \text{ From this, probabilities of capture} \]
\[ \text{by length were computed from the ratios of } N_i/N_1'. \]
\[ \text{Values obtained were again tested following trawl type selection (Pauly,} \]
\[ 1984). \text{ Three points of logistic plots were selected and subjected to regression} \]
\[ \text{analysis. Then } L_{25}, L_{50} \text{ and } L_{75} \text{ were estimated following the equation:} \]
\[ \ln \left( \frac{1}{P_L} \right) - 1 = S_1 - S_2 \times L \]  
\[ \text{Where,} \]
\[ P_L = \text{the probability of capture for length } L, \]
\[ S_1 \text{ and } S_2 = \text{variables used for estimating the probability of capture under} \]
\[ \text{the logistic model} \]
\[ L_{25} = \frac{\ln (3) - S_1}{S_2} \]  
\[ L_{50} = \frac{S_1}{S_2} \]  
\[ L_{75} = \frac{\ln (3) + S_1}{S_2} \]
9.2.4. Sample weight estimation, growth performance indices and life span

In order to understand the sample weight of the specimens used for study and to use as an input parameter for models, sample weight was estimated following Beyer (1987). Sample weight of length group and mean weight of sample were estimated by using the formula:

$$WS^- = \frac{\sum (W_i \times N_i)}{\sum N_i}$$  \(…………………(53)\)

Where,

- $$WS^-$$ = mean weight of the sample s computed
- $$N_i$$ = the frequency count,
- $$W_i$$ = the mean weight of the fish in class i computed from

$$W_i = \left( \frac{1}{L_i+1} - L_i \right) \times (a/b+1) \times \left( L_i + 1 \right)^{-1} \times \left( L_{i+1}^b \right)$$  \(…………………(54)\)

Where,

- a and b = the coefficients of the length-weight relationship
- $$L_i$$ = the lower limit of length class i
- $$L_{i+1}$$ = the upper limit of length class i

The growth performance index $$\phi'$$ (Pauly, 1979) estimated from asymptotic length from the formula:

$$\phi' = \log_{10}(K) + 2 \cdot \log_{10}(L_\infty)$$  \(………………………….(55)\)

Where,

- $$L_\infty$$ = asymptotic length in cm
- $$K$$ = VBGF curvature parameter - year \(^{-1}\)
The oldest individual in an unexploited stock are often about 95 percent of the species’ asymptotic length \( L_\infty \). It means that life span \( t_{\text{max}} \) is defined as the time required for fish to reach 95 per cent of the species asymptotic length (King, 1995). Life span is estimated following the equation:

\[
t_{\text{max}} = \frac{-1}{K} \ln \left( 1 - \frac{0.95 \ L_\infty}{L_\infty} \right) \tag{56}
\]

Following equation is also used for estimation of life span:

\[
t_{\text{max}} = \frac{3}{K} \tag{57}
\]

Where,

\( L_\infty \) and \( K \) are growth parameters explained above in equation 56

\( t_{\text{max}} = \) maximum age \( (\text{life span}) \)

### 9.2.5. Recruitment pattern and Virtual Population Analysis (VPA)

Seasonal pattern of recruitment is assessed by backward projection, along a trajectory defined by the VBGF of the frequencies in to the time axis of a time-series of samples (Pauly, 1983; Moreau and Cuende, 1991). Model is based on two assumptions and they are  (i) all fish in the sample grow as described by a single set of growth parameters and (ii) one month out of twelve always has zero recruitment. Here restructured data has been used so that the temporal spread reduces and thus probably better reflects the actual seasonality of recruitment.

Length structured virtual population analysis (Pauly, 1984) is a modified version of Jones and van Zalinge (1981). Here length frequency, \( L_\infty \) and \( K \) are used as input parameter. This routine provides information on survivors, natural
mortality and fishing mortality in each length group. The initial step is to estimate the terminal population \( N_t \) given the inputs, from equation:

\[
N_t = C_t \cdot \left( M + F_t \right) / F_t \tag{58}
\]

Where,

\( C_t \) = the terminal catch (i.e., the catch taken from the largest length class).

Then, starting from \( N_t \), successive values of \( F \) are estimated, by iteratively solving,

\[
C_i = N_{i+Dt} \cdot \left( F_i / Z_i \right) \cdot \left( \exp(Z_i \times D_{ti}) - 1 \right) \tag{59}
\]

Where,

\( D_{ti} = (t_{i+1} - t_i) \),

\( t_i = t_o - \left( 1 / K \right) \times \ln\left( 1 - \left( L_i / L_\infty \right) \right) \tag{60} \)

Population sizes \( N_i \) were computed from

\[
N_i = N_{i+Dt} \times \exp(Z_i) \tag{61}
\]

The last two equations are used alternatively, until the population sizes and fishing mortality for all length groups have been computed.

9.2.6. Relative Yield/Recruitment (Y/R) and Biomass/Recruitment (B/R) analysis

Using knife-edge selection, relative yield-per-recruit \( (Y'/R) \) was computed from:

\[
Y/R = EU^{M/K} (1 - (3U / 1+m) + (3U^2 / 1+2M) - (3U^3 / 1+3M)) \tag{62}
\]

Where,

\( U = 1-(L_c / L_\infty) \) \tag{63}
Relative biomass-per-recruit ($B'/R$) is estimated from the relationship

$$B'/R = (Y'/R)/F,$$  
\hspace{7cm} (66)

$E_{\text{max}}$, $E_{0.1}$ and $E_{0.5}$ are estimated by using the first derivative of this function.

Plots of $Y'/R$ vs $E = F/Z$ and of $B'/R$ vs $E$, from which $E_{\text{max}}$ (exploitation rate which produces maximum yield), $E_{0.1}$ (exploitation rate at which the marginal increase of relative yield-per-recruit is $1/10$th of its value at $E=0$) and $E_{0.5}$ (value of $E$ under which the stock has been reduced to 50% of its unexploited biomass) were also estimated.

Later using selection ogive Relative yield-per-recruit ($Y'/R$) is computed from:

$$Y'/R = SP_i((Y'/R)_i X G_{i-1})-((Y'/R)_{i+1}X G_i))$$  
\hspace{7cm} (67)

Where,

$$(Y'/R)_i = \text{relative yield-per-recruit computed from the lower limit of class } i$$

$$Y/R = EU^{M/K} (1- (3U/1+m) + (3U^2/1+2m) - (3U^3/1+3m)$$  
\hspace{7cm} (68)

Where,

$U$ and $m$ are defined as equation 63 and 64,

$$P_i = \text{probability of capture between } L_i \text{ and } L_{i+1},$$

$$G_i = P_i r_j,$$  
\hspace{7cm} (69)

Where

$$r_j = (1-c_j)^{S_j/(1-c_{i-1})^S_i}$$  
\hspace{7cm} (70)

$$S_i = (M/K) (E/(1-E))P_i,$$  
\hspace{7cm} (71)
Here, B'/R is estimated from

\[ \left( \frac{B'}{R} \right)_i = (1-E) \cdot \frac{A}{B} \] (72)

Where,

\[ A = (1 - \frac{3U}{1+m} + \frac{3U^2}{1+2m} - \frac{3U^3}{1+3m}) \] (73)

\[ B = (1 - \frac{3U}{1+m'} + \frac{3U^2}{1+2m'} - \frac{3U^3}{1+3m'}) \] (74)

Where

\[ m' = \frac{1}{(M/K)} = \frac{m}{1-E} \] (75)

\[ E_{\text{max}}, E_{0.1} \text{ and } E_{0.5} \] were estimated by using the first derivative of the function.

**9.2.7. Thomson and Bell Yield and Stock prediction model**

This model combines features of Beverton and Holt's \( Y'/R \) model with those of VPA, which it inverts (Thomson and Bell, 1934; Sparre and Willmann, 1993). Though Cobia is exploited by multi gear in this study the model was used by limiting to trawlers alone.

The sum of the yields (\( Y = SY_i \)) was computed from:

\[ Y_i = C_i \times W^i \] (76)

Where,

\[ W^i = \left( \frac{1}{L_i + 1 - L_i} \right) \times \left( \frac{a}{b+1} \right) \times (L_i + 1^{b+1} + L_i^{b+1}) \] (77)

Where,

\[ a \text{ and } b \] are the coefficients of the length-weight relationship

\[ L_i = \text{lower limit of the length class}, \]

\[ L_{i+1} = \text{upper limit of the length class}, \]

\[ C_i = (N_i-N_{i+1})(F_i/(M+F_i)) \] (78)
Where,

\[ N_{i+1} = N_i \cdot \exp(-(M+F) \cdot D_{ti}) \]  \hspace{1cm} \text{(79)}

\[ D_{ti} = \frac{1}{K} \cdot \ln\left(\frac{L_{\text{max}} - L_i}{L_{\text{max}} - L_{i+1}}\right) \]  \hspace{1cm} \text{(80)}

The biomass was computed from

\[ B_i = \frac{(N_i - N_{i+1})}{(M + F)} \cdot D_{ti} \cdot W_i \]  \hspace{1cm} \text{(81)}

The value \( V_i \) is computed by

\[ V_i = Y_i \cdot v_i \]  \hspace{1cm} \text{(82)}

Where \( v_i \) is the unit value for class \( i \).

9.3. RESULTS

9.3.1. Mortality estimation

Natural mortality coefficient estimated following Cushing formula was 0.354. The age of longest fish was calculated following VBGF equation of the fish and substituted in the formula. Natural mortality obtained as per Pauly’s empirical formula was 0.416. Values obtained by both the methods are found to be very close. However, value obtained by Pauly’s empirical formula was used for further calculation, as the same is considered as more reliable and are based on interrelationship between VBGF parameters and mean habitat temperature.

Total mortality value obtained following Beverton and Holt model was 0.77 while value computed by catch curve method was 0.76. Length converted catch curve of Cobia made by plotting relative age against \( \ln \left( \frac{N}{D_t} \right) \) is shown in Fig. 67. As shown in the Fig. 67 Fishing mortality (\( F \)) was estimated as 0.36 while
exploitation ratio (E) as 0.47. Mortality rates estimated by both the methods were almost similar. However, value estimated by catch curve method was used for further analysis as this provided the facility to proceed to the estimation of probability of capture and this method is based on more input parameters than Beverton and Holt model.

Fig. 67. Length converted catch curve of *Rachycentron canadum* inhabiting along north west coast of India

9.3.2. Probability of capture

The relationship between length class and probability of their capture is depicted in Fig. 68. As evident from the graph $L_{25}$, $L_{50}$ and $L_{75}$ values were estimated as 20.2 cm, 46.4 and 71.65 respectively. These values were further tested with the trawl type selection method and results were found matching with the earlier.
9.3.3. Sample weight estimation, growth performance indices and life span

Month wise mean weight of fishes and mean weight of each length class of fishes estimated are shown in Table 44 & 45. Mean weight of Cobia ranged between 91.21 gm to 42397.21 gm and mean weight of the sample was more during April-July and November. Growth rate was more during initial size groups, which got reduced towards larger sizes.

The growth performance index (φ') estimated following Pauly (1979) was 3.957. Life span of the species estimated based on asymptotic length and growth rate were 12.482 and 12.5 years respectively. Life span estimation based on growth rate will give only an approximate value (King, 1995); hence, value
estimated based on asymptotic length is relatively more accurate and therefore used in subsequent analysis.

Table 44. Month wise weight of sample of *Rachycentron canadum* inhabiting along north west coast of India

<table>
<thead>
<tr>
<th>Month</th>
<th>Sum of frequency</th>
<th>Weight of sample (in gm.)</th>
<th>Mean weight (in gm.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>62</td>
<td>53053.17</td>
<td>855.70</td>
</tr>
<tr>
<td>February</td>
<td>141</td>
<td>550089.80</td>
<td>3901.35</td>
</tr>
<tr>
<td>March</td>
<td>131</td>
<td>498477.60</td>
<td>3805.17</td>
</tr>
<tr>
<td>April</td>
<td>134</td>
<td>942573.10</td>
<td>7034.13</td>
</tr>
<tr>
<td>May</td>
<td>95</td>
<td>1014009.00</td>
<td>10673.78</td>
</tr>
<tr>
<td>June</td>
<td>101</td>
<td>848892.10</td>
<td>8404.87</td>
</tr>
<tr>
<td>July</td>
<td>81</td>
<td>581725.10</td>
<td>7181.79</td>
</tr>
<tr>
<td>August</td>
<td>54</td>
<td>177331.70</td>
<td>3283.92</td>
</tr>
<tr>
<td>September</td>
<td>105</td>
<td>581236.60</td>
<td>5535.59</td>
</tr>
<tr>
<td>October</td>
<td>125</td>
<td>782074.20</td>
<td>6256.59</td>
</tr>
<tr>
<td>November</td>
<td>98</td>
<td>696163.90</td>
<td>7103.71</td>
</tr>
<tr>
<td>December</td>
<td>122</td>
<td>315921.90</td>
<td>2589.52</td>
</tr>
<tr>
<td>Mean weight</td>
<td></td>
<td>5637.75</td>
<td></td>
</tr>
</tbody>
</table>

Table 45. Mean weight and growth rate of *Rachycentron canadum* inhabiting along north west coast of India on length group basis

<table>
<thead>
<tr>
<th>Mid length of size class in cm</th>
<th>Mean weight (in gm.)</th>
<th>Growth rate</th>
<th>Mid length of size class in cm</th>
<th>Mean weight (in gm.)</th>
<th>Growth rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>91.21</td>
<td>-</td>
<td>115</td>
<td>9733.26</td>
<td>0.32</td>
</tr>
<tr>
<td>35</td>
<td>252.72</td>
<td>1.77</td>
<td>125</td>
<td>12640.68</td>
<td>0.30</td>
</tr>
<tr>
<td>45</td>
<td>544.61</td>
<td>1.15</td>
<td>135</td>
<td>16029.38</td>
<td>0.27</td>
</tr>
<tr>
<td>55</td>
<td>1007.91</td>
<td>0.85</td>
<td>145</td>
<td>19984.92</td>
<td>0.25</td>
</tr>
<tr>
<td>65</td>
<td>1684.44</td>
<td>0.67</td>
<td>155</td>
<td>24553.19</td>
<td>0.23</td>
</tr>
<tr>
<td>75</td>
<td>2616.74</td>
<td>0.55</td>
<td>165</td>
<td>26780.33</td>
<td>0.09</td>
</tr>
<tr>
<td>85</td>
<td>3847.90</td>
<td>0.47</td>
<td>175</td>
<td>35712.78</td>
<td>0.33</td>
</tr>
<tr>
<td>95</td>
<td>5421.57</td>
<td>0.41</td>
<td>185</td>
<td>42397.21</td>
<td>0.19</td>
</tr>
<tr>
<td>105</td>
<td>7381.85</td>
<td>0.36</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
9.3.4. Recruitment pattern and Virtual Population Analysis (VPA)

Seasonal recruitment pattern of Cobia in percentage is depicted in Fig.69. As seen from the Fig.69, more than 70 percentage of recruitment took place during March to July, with a definite peak during May.

![Seasonal recruitment pattern of Rachycentron canadum inhabiting along north west coast of India](image)

Result of VPA is shown in Fig.70. The dynamics of the stock influenced by number of survivors and portion of population subjected to natural mortality and fishing mortality are very much reflected in Fig.70. Here, fishing mortality increases towards higher length group as it followed fishing down the size. ie. Larger size group in the population were subsequently removed from the stock by the fishing gears.
Initial terminal fishing mortality was kept as “one” for estimation and Fig. 70 shows that terminal fishing mortality “one” leads to removal of all adults from the population. Tabular form of catch in numbers, population, fishing mortality and study state biomass in different length group are furnished in Table 46. The number of individual in a population reduces towards the higher classes, but biomass values were more in higher length groups. This is mainly due to growth and resultant increase in weight of individuals.

Fig.70. Length structured virtual population analysis of *Rachycentron canadum* inhabiting along north west coast of India
Table 46. Length-structured virtual population analysis of *Rachycentron canadum* inhabiting the north west coast of India

<table>
<thead>
<tr>
<th>Mid length in cm</th>
<th>Catch in million numbers</th>
<th>Population(N) in million</th>
<th>Fishing mortality(F)</th>
<th>Study state Biomass in thousand tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>10.50</td>
<td>447.39</td>
<td>0.10</td>
<td>94.52</td>
</tr>
<tr>
<td>35</td>
<td>14.30</td>
<td>394.45</td>
<td>0.15</td>
<td>242.97</td>
</tr>
<tr>
<td>45</td>
<td>16.20</td>
<td>340.77</td>
<td>0.18</td>
<td>478.09</td>
</tr>
<tr>
<td>55</td>
<td>14.10</td>
<td>288.62</td>
<td>0.18</td>
<td>799.44</td>
</tr>
<tr>
<td>65</td>
<td>11.50</td>
<td>242.04</td>
<td>0.16</td>
<td>1202.43</td>
</tr>
<tr>
<td>75</td>
<td>10.10</td>
<td>201.31</td>
<td>0.16</td>
<td>1672.40</td>
</tr>
<tr>
<td>85</td>
<td>6.20</td>
<td>165.04</td>
<td>0.11</td>
<td>2201.87</td>
</tr>
<tr>
<td>95</td>
<td>6.50</td>
<td>135.41</td>
<td>0.13</td>
<td>2754.74</td>
</tr>
<tr>
<td>105</td>
<td>7.80</td>
<td>108.03</td>
<td>0.18</td>
<td>3264.12</td>
</tr>
<tr>
<td>115</td>
<td>4.00</td>
<td>82.12</td>
<td>0.11</td>
<td>3705.72</td>
</tr>
<tr>
<td>125</td>
<td>8.20</td>
<td>62.59</td>
<td>0.26</td>
<td>3924.62</td>
</tr>
<tr>
<td>135</td>
<td>4.80</td>
<td>41.68</td>
<td>0.20</td>
<td>3832.82</td>
</tr>
<tr>
<td>145</td>
<td>4.00</td>
<td>27.09</td>
<td>0.23</td>
<td>3559.37</td>
</tr>
<tr>
<td>155</td>
<td>1.90</td>
<td>15.81</td>
<td>0.15</td>
<td>3123.71</td>
</tr>
<tr>
<td>165</td>
<td>1.40</td>
<td>8.70</td>
<td>0.16</td>
<td>2540.10</td>
</tr>
<tr>
<td>175</td>
<td>2.70</td>
<td>3.81</td>
<td>1.00</td>
<td>3972.88</td>
</tr>
</tbody>
</table>

9.3.5. Relative Yield/Recruitment (Y/R) and Biomass/ Recruitment (B/R) analysis

Results of Relative yield per recruit analysis of *Rachycentron canadum* of north west coast of India - Y/R isopleths diagram with current M/K value is shown as Fig.71. Here, Lc/ L∞ plotted against exploitation rate. Relative yield and biomass per recruit analysis of *Rachycentron canadum* of north west coast of India with current Lc is shown as Fig.72. The values of Lc/ L∞ and M/K used for the estimation are 0.237 and 1.7336 respectively. Exploitation rate (E) at different levels as E 0.1, E 0.5 and E max estimated by the analysis are 0.402, 0.288 and 0.47 respectively.
Fig. 71. Relative yield per recruit analysis of *Rachycentron canadum* of north west coast of India - Y/R isopleths diagram with current M/K value.

Fig. 72. Relative yield and biomass per recruit analysis of *Rachycentron canadum* of north west coast of India with current Lc.
9.3.6. Thomson and Bell Yield and Stock prediction model

Plots of yields, values and biomass estimates for a range of F factors for Cobia cumulative curve and species specific gear specific (trawl net) graphs were illustrated in Fig. 73. Model predicts that, at F equal to 0.4 stock will provide maximum yield but when F equal to 0.3 biomass reach to 50%.

Fig. 73. Thomson and Bell yield prediction of *Rachycentron canadum* of north west coast of India
9.4. DISCUSSION

Natural mortality coefficient estimated following Cushing (1968) and Pauly (1980) were 0.354 and 0.416 respectively. Both the values are less than 0.5. According to King (1995) natural mortality below 0.5 is considered as low; hence, natural mortality of Cobia arrived in the present study can be considered as low. Total mortality value obtained following Beverton and Holt model was 0.77 against 0.76 obtained by catch curve method. Fishing mortality (F) and exploitation ratio (E) estimated were 0.36 and 0.47. Lower rate of natural mortality indicates that more fishing effort is needed to achieve maximum sustainable yield.

Mortality rates of Rachycentron canadum reported by various authors from different localities are furnished as Table 47. Natural mortality rate reported by different authors were below 0.5 which ranged from 0.2- 0.41. Mortality rate reported by Richards (1967) and Williams (2001) are comparable with the result of the present study. Somvanshi et al. (2000) reported a natural mortality of 0.36 for the Cobia occurring along north west coast of India. In the present study natural mortality estimated is 0.41 from the same area. Somvanshi et al. (2000) estimated natural mortality by keeping mean habitat temperature as 25° C, which is on a lower side. Present study recorded mean habitat temperature as 28° C; hence the same was used for estimation of natural mortality. Total mortality value estimated in the present study is comparable to the results of earlier studies (Franks et al., 1999; Williams, 2001; Fry and Griffiths, 2010).
Table 47. Mortality rates of *Rachycentron canadum* reported by various authors from different localities

<table>
<thead>
<tr>
<th>Natural mortality (M)</th>
<th>Fishing mortality (F)</th>
<th>Total mortality (Z)</th>
<th>Location</th>
<th>Author/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2-0.4</td>
<td>-</td>
<td>-</td>
<td>Chesapeake Bay</td>
<td>Richards (1967)</td>
</tr>
<tr>
<td>0.24</td>
<td>-</td>
<td>-</td>
<td>Gulf of Aden</td>
<td>Edword <em>et al.</em>(1985)</td>
</tr>
<tr>
<td>0.29</td>
<td>-</td>
<td>-</td>
<td>South Africa</td>
<td>Torres (1991)</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>0.75</td>
<td>Northeastern Gulf of Mexico</td>
<td>Franks <em>et al.</em>(1999)</td>
</tr>
<tr>
<td>0.36</td>
<td>-</td>
<td>-</td>
<td>North west coast of India</td>
<td>Somvanshi <em>et al.</em>(2000)</td>
</tr>
<tr>
<td>0.2-0.4</td>
<td>-</td>
<td>0.72</td>
<td>Gulf of Mexico</td>
<td>Williams (2001)</td>
</tr>
<tr>
<td>0.35</td>
<td>-</td>
<td>0.85</td>
<td>North and eastern Australia</td>
<td>Fry and Griffiths(2010)</td>
</tr>
<tr>
<td>0.41</td>
<td>0.36</td>
<td>0.76</td>
<td>North west coast of India</td>
<td>Present study</td>
</tr>
</tbody>
</table>

Probability of capture estimated by backward extrapolation of the catch curve (Fig. 68) showed that most of the Cobia juveniles were vulnerable to trawl net. *L*<sub>50</sub> value (46.4 cm) and *L*<sub>75</sub> value (71.65 cm) estimated by this method were below or at par with the size at maturity (63 cm in the case of male and 70 cm for female). This clearly indicates that exploitation of Cobia stock by trawlers is not at all advisable. In India, there is no targeted fishery for Cobia, but they are mostly caught as bycatch. In a multi species fishery, mesh size regulations aimed at bycatch is not at all feasible. However, ban on fishing of juveniles and voluntary releases of juveniles to sea are possible management measures for the conservation of the stock of Cobia.

Mean weight of the sample recorded during the study is 5637.75 gram. Month wise analysis of mean of sample weight indicated that during April to July
and September to November mean weight of sample were above the mean weight of the sample. During January to March and August samples were dominated by juveniles, which indicate that recruitment of smaller fishes to fishery is mainly during the above months. Occurrence of larger specimens during April to July and September to November support the increased spawning activity during these months identified by the present study.

Values of growth performance indices, $L_{\text{max}}$ and life span of species reported by different authors from different localities are presented in Table 48. As evident from the Table 48 $L_{\text{max}}$ ranged between 142 cm to 200 cm while present study estimated $L_{\text{max}}$ as 185 cm. Maximum length of the fish recorded and $L_\infty$ estimated by the present study were 181 cm and 194.25 cm respectively. Landing records showed that Cobia may reach up to 2 m (Cadenat, 1950 and IGFA, 1991).

Table 48. Growth performance indices ($\phi'$), $L_{\text{max}}$ and life span of *Rachycentron canadum* reported by various authors from different localities

<table>
<thead>
<tr>
<th>$L_{\text{max}}$ in cm</th>
<th>$\phi'$ (M/F)</th>
<th>Longevity in years (M/F)</th>
<th>Location</th>
<th>Author/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>3.61/3.78</td>
<td>10</td>
<td>Chesapeake Bay</td>
<td>Richards (1967)</td>
</tr>
<tr>
<td>145</td>
<td>3.8/3.97</td>
<td>10</td>
<td>Western Lousenia</td>
<td>Thompson <em>et al.</em> (1991)</td>
</tr>
<tr>
<td>200</td>
<td>3.6</td>
<td>-</td>
<td>South Africa</td>
<td>Torres (1991)</td>
</tr>
<tr>
<td>165</td>
<td>3.77/3.89</td>
<td>11</td>
<td>Northeastern Gulf of Mexico</td>
<td>Franks <em>et al.</em> (1999)</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>11</td>
<td>Gulf of Mexico</td>
<td>Williams (2001)</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>13</td>
<td>North and eastern Australia</td>
<td>Fry and Griffiths (2010)</td>
</tr>
<tr>
<td>185</td>
<td>3.96</td>
<td>12.48</td>
<td>North west coast of India</td>
<td>Present study</td>
</tr>
</tbody>
</table>
Growth performance indices ($\phi'$) worked out by different authors from different geographical locations ranged from 3.6 –3.97. These values pertain to various habitats of Cobia and therefore the values cannot be compared. However, $\phi'$ value (3.96) estimated by the present study is within the range of earlier estimates available for Cobia.

Life span of Cobia in terms of years reported from different geographical areas varied from place to place. Longevity values ranged between 10 years and 14 years. Present study estimated the value as 12.48 years. High life span and low mortality rates indicated that Cobia stock in north west coast of India is in good condition.

Fig.69 shows the seasonal recruitment pattern of Cobia in terms of percentage. As illustrated, recruitment pattern of Cobia showed two modes, one during May and other during October. This is indicative of the existence of multi-age group in the stock and their prolonged breeding season. Recruitment pattern thus obtained matches with the breeding season assessed by the present study. Both modes in recruitment pattern coincided with south west monsoon and northeast monsoon periods in India, where availability of food organisms in the habitat will be very high.

Results of VPA (Fig.70 & Table. 46) show that fishing mortality increases towards higher length group while natural mortality showed a reverse trend. As larger fishes are less susceptible to predation, natural mortality will reduces when fish grows. Most of the organisms follow this pattern of natural mortality.
Analysis showed that at terminal fishing mortality “one” almost all the fishes above 75 cm length will be vulnerable to fishing.

There was a sudden reduction of catch in numbers from the size group with 75 cm to 85 cm which appears to be very interesting. In general, adult Cobia moves faster, hence chances of escape from the trawl net is more for larger fishes and this may be the reason for reduction of adult fishes in the catches. A completely different picture can be seen if we consider biomass in tonnes, the biomass increases towards larger size group. Fast growth rate observed for this species may be the reason for this increase.

Results of Relative yield per recruit and biomass per recruit and isopleths, in which $L_c / L_\infty$ plotted against exploitation rate (Fig. 71 & Fig. 72) illustrates the dynamics of Cobia fishery. The values of $L_c / L_\infty$ and $M/K$ estimated and used for analysis were 0.237 and 1.7336 respectively. Exploitation rate (E) at different levels like $E_{0.1}$, $E_{0.5}$ and $E_{\text{max}}$ were 0.402, 0.288 and 0.47 respectively. As depicted in the Fig. 71 & 72, 50% of stock can be removed with an exploitation ratio of 0.288. By increasing the exploitation ratio to $E_{0.1}$ yield from the stock can be increased and maximum yield can be obtained at an exploitation ratio of 0.47. Present exploitation ratio is 0.47, which indicates that stock is exploited optimally or fully and any further increase of fishing effort wills leads to over exploitation and subsequently leads to the collapse of the fishery. Low mortality rate, fast growth rate and high longevity recorded by the present study also manifest the health of stock.
Results of Thompson and Bell yield prediction model (Fig. 73) support the findings of Relative yield per recruit and Biomass per recruit models. Though Cobia is exploited by various fishing gear, prediction made here was exclusively based on trawl gear. As illustrated in the Fig. 73, 50% of stock can be removed at F factor below 0.3 and maximum yield can be achieved by spending an effort of 0.4. Fishing mortality estimated during the present study is 0.36. This indicates that stock is optimally or fully exploited. Increasing the effort F to one will result in the removal of 90% of the biomass and reduction of yield by 25%.

Any increase of effort beyond optimum level of effort (0.4) mainly affects the biomass of larger sized group; hence, this results in a drastic reduction of biomass. As shown in the Fig.73, increase of effort mainly affects large sized fishes (marked red in colour) than the smaller fishes. Increased life span of the species makes the management of the species more difficult as recovery time needed for the rebuilding the stock may take minimum three to four years.

9.4.1. Conservation and management

Cobia is a pelagic fish whose vertical distribution extent throughout the water column. It is distributed all along the coast of India. There is no targeted Cobia fishery existing anywhere in India and they are mainly exploited as bycatch in the hook and line, troll line, drifts gill net and bottom trawl. Summary of the biological and population parameters of Cobia estimated by the present study are furnished in Table 49. As seen from the Table 49, Cobia matures early at one to two years at 63-70cm length. Length of probability of capture L_{50} of Cobia by
trawl net is less than the size at maturity. This clearly indicates that exploitation of Cobia by existing trawl net is not at all advisable.

In a multi species fishery, mesh size regulation for the targeted and non targeted fishes is extremely difficult. Use of a separate fishing gear for this species may not be economical due to lesser availability of the resource. As a conservation measure complete ban of fishing, keeping and sale of juvenile fishes (Cobia below 63 cm length) will definitely control growth over fishing. Enforcement of ban on keeping and sale of juvenile fish will result in voluntary release of incidentally caught juveniles, as most of the Cobia fishes caught by trawlers are found in live condition immediately after haul.

Peak breeding season, fishing season and recruitment of Cobia coincided with monsoon period. In India uniform ban on trawling exist during these periods. Hence, there is no need for declaration of any closed season for Cobia fishing. Present exploitation rate and maximum allowable exploitation are equal and this suggests that presently stock is either optimally or fully exploited. Higher demand and increased popularity during recent years may lead to targeted exploitation of the resource. The targeted exploitation may lead to increased fishing effort, removal of larger sized fishes, over exploitation and collapse of the fishery. Cobia being long-lived species, recovery of stock will take a minimum three to four years. Hence, at any cost increase of fishing effort should be controlled.

Agencies like Central Marine Fisheries Research Institute (CMFRI), Ministry of Agriculture (MOA) and Marine Product Export Development
Authority (MPEDA) are responsible for data collection from landing centers and publishing of marine fish landing data in India. However, the data banks do not reflect Cobia landings. Cobia is either included with the group other carangids or miscellaneous fishes. This defers fishery managers to assess the fishing trend of Cobia in commercial fishery and recommend fishery management measures for Cobia. Reporting of Cobia landings separately is the need of hour to be implemented immediately.

Present study showed that Cobia can be collected live and utilised for stocking. Popularisation of live collection method and well organized collection center facilities at landing centers and fishing harbors will solve the problem of non availability of fingerlings for stocking. Fishes of size 20 to 30 cm TL can be collected live. Specimens ranging from 30 to 63 cm TL can be released to sea and adult fishes can be stored in ice or in frozen condition. Present study estimated 447.39 million numbers of fishes in the size range of 20 –30 cm. Judicious exploitation of these size group fishes can definitely support Cobia culture till commercial hatchery production succeeds.
Table 49. Primary account on biological and population parameters of *Rachycentron canadum* inhabiting the north west coast of India

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Remarks/ method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length at maturity -Male</td>
<td>63 cm</td>
<td>Hodgkiss and Man (1978) method</td>
</tr>
<tr>
<td>Length at maturity -Female</td>
<td>70 cm</td>
<td></td>
</tr>
<tr>
<td>Peak Breeding season</td>
<td>July- Aug. and Nov. Jan.</td>
<td>Percentage of mature specimen and Gonadosomatic index</td>
</tr>
<tr>
<td>Fecundity</td>
<td>1,231,630–1,800,350</td>
<td>Absolute fecundity</td>
</tr>
<tr>
<td>Trophic value</td>
<td>4.386</td>
<td>Christensen and Pauly (1992) method</td>
</tr>
<tr>
<td>Age at maturity -Male</td>
<td>1.48 yrs</td>
<td>von Bertalanffy growth equation</td>
</tr>
<tr>
<td>Age at maturity -Female</td>
<td>1.71 years</td>
<td></td>
</tr>
<tr>
<td>Growth rate (K)</td>
<td>0.24</td>
<td>ELEFAN method and Ford Walford plot</td>
</tr>
<tr>
<td>Asymptotic length (L∞)</td>
<td>194.25</td>
<td></td>
</tr>
<tr>
<td>Minimum length of sample</td>
<td>22.6 cm</td>
<td>Measurement of sample</td>
</tr>
<tr>
<td>Maximum length of sample</td>
<td>183 cm</td>
<td></td>
</tr>
<tr>
<td>Length maximum (L max)</td>
<td>185 cm</td>
<td>Foramacion <em>et al.</em> (1991) method</td>
</tr>
<tr>
<td>Age at zero length (t0)</td>
<td>-0.615</td>
<td>ELEFAN method and Ford Walford plot</td>
</tr>
<tr>
<td>Life span</td>
<td>12.48 years</td>
<td>King (1995) method</td>
</tr>
<tr>
<td>Biomass</td>
<td>2209.514 metric tones</td>
<td>Swept area method</td>
</tr>
<tr>
<td>Potential yeild</td>
<td>839.6 metric tonnes</td>
<td>Cadimas formula</td>
</tr>
<tr>
<td>Natural mortality (M)</td>
<td>0.416</td>
<td>Pauly’s empirical formula</td>
</tr>
<tr>
<td>Total mortality(Z)</td>
<td>0.76</td>
<td>Catch curve method</td>
</tr>
<tr>
<td>Fishing mortality(F)</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td>Exploitation ratio</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>Probability of capture L25</td>
<td>20.2 cm</td>
<td>Pauly(1984) method</td>
</tr>
<tr>
<td>Probability of capture L50</td>
<td>46.4</td>
<td></td>
</tr>
<tr>
<td>Probability of capture L75</td>
<td>71.65</td>
<td></td>
</tr>
<tr>
<td>Length at capture (Lc)</td>
<td>46.04</td>
<td></td>
</tr>
<tr>
<td>(Lc)/ (L∞)</td>
<td>0.237</td>
<td>By division</td>
</tr>
<tr>
<td>M/K</td>
<td>1.733</td>
<td>By division</td>
</tr>
<tr>
<td>E 0.1</td>
<td>0.402</td>
<td>Relative yield per recruit and biomass per recruit model</td>
</tr>
<tr>
<td>E 0.5</td>
<td>0.288</td>
<td></td>
</tr>
<tr>
<td>E max</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>Exploitation ratio</td>
<td>0.47</td>
<td>Catch curve method</td>
</tr>
</tbody>
</table>