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Population Dynamics of *Coilia ramcarati* from the Estuarine Set Bagnet Fishery of Bangladesh

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Abstract

Population parameters of *Coilia ramcarati* were estimated from length-frequency data collected from Estuarine Set Bag Net (ESBN) Fishery of Chittagong and Cox's Bazar region in Bangladesh from January to December, 2010. For the purpose of estimating the parameters FAO-ICLARM Stock Assessment Tool (FiSAT II) software was used. The asymptotic Length (L_∞) and growth constant (K) were estimated to be 22.58 cm for male, 19.43 cm for female and 0.49 y^{-1} for male, 2.10 y^{-1} for female, respectively. The male *C. ramcarati* found to attain larger body size compared to female. A slightly fluctuating positive trend was observed for mean weight. The value of exploitation rate depicts overfishing condition for this species in the ESBN fishery with high catching probability of the juveniles. The recruitment pattern of this species was found continuous throughout the year characterized by 2 peaks both for male and female.

Keywords: Asymptotic length, growth coefficient, Mortality, VPA, recruitment

Introduction

The estimation of population dynamics leads fisheries scientists and managers towards a better prediction of a stock that helps to assess the present status of certain fishery and to determine sustainable yields [1,2]. Linkage of population dynamics with life history traits provides powerful tools for predicting how reproductive investment will influence future abundances of a stock [3].Without the information of these parameters, it is not possible to undertake a sound and effective management program for a fish population [4]. The small fish *Coilia ramcarati* (Hamilton, 1822) is a member of the family Engraulidae (Anchovies), commonly known as "Tapper tail anchovy" or "Frill-tailed golden anchovy" locally called "Olua mach" in Bangladesh. Anchovies of the family Engraulidae occupy a very important place in the world fisheries [5]. In Bangladesh, *C. ramcarati* has a high market value compared to other species of the genus [6] and is one of the targeted fish species of Estuarine Set Bagnet fishery (ESBN) that contributes a notable share, about 0.12 to 2.25 % of the total artisanal fishery [7]. This species also supports an appreciable fishery in West Bengal [8] and Orissa together with *C. dussumieri* [9]. The ESBN is a traditional fishing gear which has been in operation since very long by small-scale fishers in the Bay of Bengal region with some regional variations in the design and mode of operation [10]. The ESBN fishery is the most significant fishery in terms of the number used, the catch size and species composition as well as due to its destructive impacts on the coastal resource base [10-12]. Therefore, the present study aims to determine the population parameters of *C. ramcarati* using length-frequency based analysis from the ESBN Fishery of Bangladesh.

Materials and methods

Fish samples were collected from the landing centre and local markets of Chittagong from January to December, 2010 of which 755 were male and 892 were female. The lengths were measured using a graduated board with a block at one end, against which the snout of the fish was placed. Lengths were measured to the nearest 0.01 cm. After blotting the excess water, the weight of each specimen was taken by an electric balance to ±0.01 g.

Estimation of asymptotic length (L_∞) and growth coefficient (K)

Monthly Length frequency distribution data were used to estimate the total asymptotic length (L_∞ cm) and growth coefficient (K^{-year}) of the Von Bertalanffy growth equation [12,13]. The Electronic Length Frequency Analysis (ELEFAN I and II) routines incorporated in FiSAT II software [14] were used to determine L_∞ and K value following the Powell-Wetherall method [15]. This method was used to provide an initial estimate of L_∞. This initial estimate of L_∞ was then used as a seed value to determine the value of K [16]. Minor adjustments to L_∞ and K were made to maximize the "goodness of fit" criterion built into ELEFAN I [17]. This led to a preliminary estimate of L_∞ and K that were used to obtain the "probabilities of capture" by length class using the routine in FiSAT II. These "probabilities of capture" were used to correct the length frequency distribution data to account for incomplete selection and recruitment. The final estimates of L_∞ and K were obtained using these corrected length distribution data through ELEFAN I [16].

Length weight relationship

Length and weight observations were transformed using natural logarithms, and were plotted for visual inspection of outliers and only extreme outliers attributed to data error were eliminated [18-20]. The formula used for the expression of the length-weight relationship for the present analysis was;

$$W = aL^{b} \text{ [21-24].} \tag{1}$$

where 'a' is a constant, 'b' is an exponent, W is the weight and L is the corresponding total length of the weight. The value of 'a' and 'b' was calculated by using the formula;

$$Ln(a) = \frac{\sum \ln W \sum (\ln L)^2 - \sum \ln L \sum (\ln L \ln W)}{N \sum (\ln L)^2 - (\sum (\ln L)^2} \text{ [21]} \tag{2}$$

and

$$b = \frac{\sum \ln W - N \ln(a)}{\sum \ln L} \text{ [21].} \tag{3}$$

where, N = number of classes used in the calculation. In determining the regression line of body weight on total length least square methods were followed. The coefficient of correlation (r) was calculated using the following formula;

$$r = \frac{N * \Sigma LW - \Sigma L * \Sigma W}{\sqrt{[\{N * \Sigma L^2 - (\Sigma L)^2\}\{N * \Sigma W^2 - (\Sigma W)^2\}]}} \text{ [25]} \tag{4}$$

where, n = number of length classes. The significance of 'r' was tested by t-test using the following formula, with ($N - 2$) degrees of freedom.

$$t = \frac{r\sqrt{(N-2)}}{\sqrt{(1-r^2)}} \text{ [25]} \tag{5}$$

The coefficient of determination (R^2) was calculated using the following formula;

$$R^2 = 1 - \frac{\Sigma(W - \hat{W})^2}{\Sigma(W - \overline{W})^2} \text{ [25]} \tag{6}$$

where, w = observed weight, $\hat{W}$ = calculated weight and $\overline{W}$ = mean weight.

Mortality estimation (total mortality coefficient, rate of natural and fishing mortality)

Following the ELEFAN II routines in FiSAT II [14], the total mortality coefficient, Z (y *-1*) was estimated using the length-converted catch curve by means of the final estimates of L_∞ and K and the length frequency distribution data [13]; [26] for the species *C. ramcarati*. The rate of natural mortality, M (y *-1*) was estimated using Pauly's empirical equation,

$$Log_{10} M = -0.0066 - 0.279 Log_{10} L_\infty + 0.06543 Log_{10} K + .04634 Log_{10} T \tag{7}$$

Here, T was taken as 27 °C. Fishing mortality rate F (y^{-1}), was obtained by subtracting M from Z, i.e.;

$$F = Z - M \text{ [16].} \tag{8}$$

The exploitation ratio, E, was calculated by the formula;

$$E = F/(F + M) \text{ [27,28].} \tag{9}$$

Probability of capture

Probability of capture, calculated from the length-converted catch curve routine, was used to estimate the final values of L_{25}, L_{50} and L_{75} i.e. lengths at which 25, 50 and 75 % of the fish to be considered as vulnerable to the gear [26].

Recruitment pattern

ELEFAN II routine of FiSAT was used to obtain recruitment pattern by the backward projection of the frequencies onto the time axis of a time-series of samples along a trajectory defined by the Von Bertalanffy growth equation [29-31]. This routine reconstructs the recruitment pulses from a time series of length-frequency data to determine the number of pulses per year and the relative strength of each pulse [32].

Virtual population analysis

The terminal population (N_t) was estimated from;

$$N_t = C_t(M + F_t)/F_t \tag{10}$$

where, C_t is the terminal catches and F_t is the terminal Fishing Mortality and M is the Natural Mortality. Starting from N_t, successive values of F were estimated, by iteratively solving;

$$C_i = N_i + \Delta t(F_i / Z_i)(exp(Z_i \Delta t_i) - 1) \text{ [30].} \tag{11}$$

Where, C_i = catch (in numbers) for a population during a unit time period *i*. $\Delta t_i = (t_{i+1} - t_i)$, and;

$$t_i = [t_0 - (1/K)\ln(1-(L_i / L_\infty))]. \tag{12}$$

The population sizes (N_i) were computed from;

$$N_i = N_{i+\Delta t_i} \exp(Z_i). \tag{13}$$

The last 2 equations were used alternatively, until the population sizes and fishing mortality for all length groups have been computed [30,32].

Yield per recruit and biomass per recruit

Relative yield-per-recruit (Y'/R) was computed using the following formula [14,27];

$$Y'/R = EU^m\left(1 - \frac{3U}{(1+m)}\right) + \frac{3U^2}{(1+2m)} - \frac{U^3}{(1+3m)} \tag{14}$$

where, $U = 1 - (L_c / L_\infty)$, $m = (1-E)/(M/K) = K/Z$. L_c is the length of fish at first capture *i.e.* length at which 50 percent of the fish are retained by the gear (L_{50}) and $E = F/Z$. The relative biomass-per-recruit (B'/R) was estimated from the relationship;

$$B'/R = (Y'/R)/F \text{ [33].} \tag{15}$$

The value of E_{max}, $E_{0.1}$ and $E_{0.5}$ were estimated by using the first derivative of this function, where, E_{max} = maximum sustainable exploitation rate, $E_{0.1}$ = exploitation rate at which the marginal increase of relative yield-per-recruit is $1/10^{th}$ and $E_{0.5}$ = value of E under which the stock has been reduced to 50 % of its unexploited biomass.

Results and discussion

Asymptotic length (L_∞) and growth coefficient (K)

The maximum total length of the male *C. ramcarati* (**Figure 1a**) was found to be higher (22.40 cm) compared to the total length (18.50 cm) of female (**Figure 1b**) fish. Similarly the body weight of male *C. ramcarati* was found to be higher (46.59 g) than that of females (17.89 g). This indicates that the male *C. ramcarati* attains larger body size compared to the female. The value of asymptotic length ($L\infty$) estimated in the present study both for males (22.58 cm) and females (19.43 cm) of *C. ramcarati* were lower than the value (26.5 cm) found by [34], this difference may be due to the dissimilarity in fishing gear used.

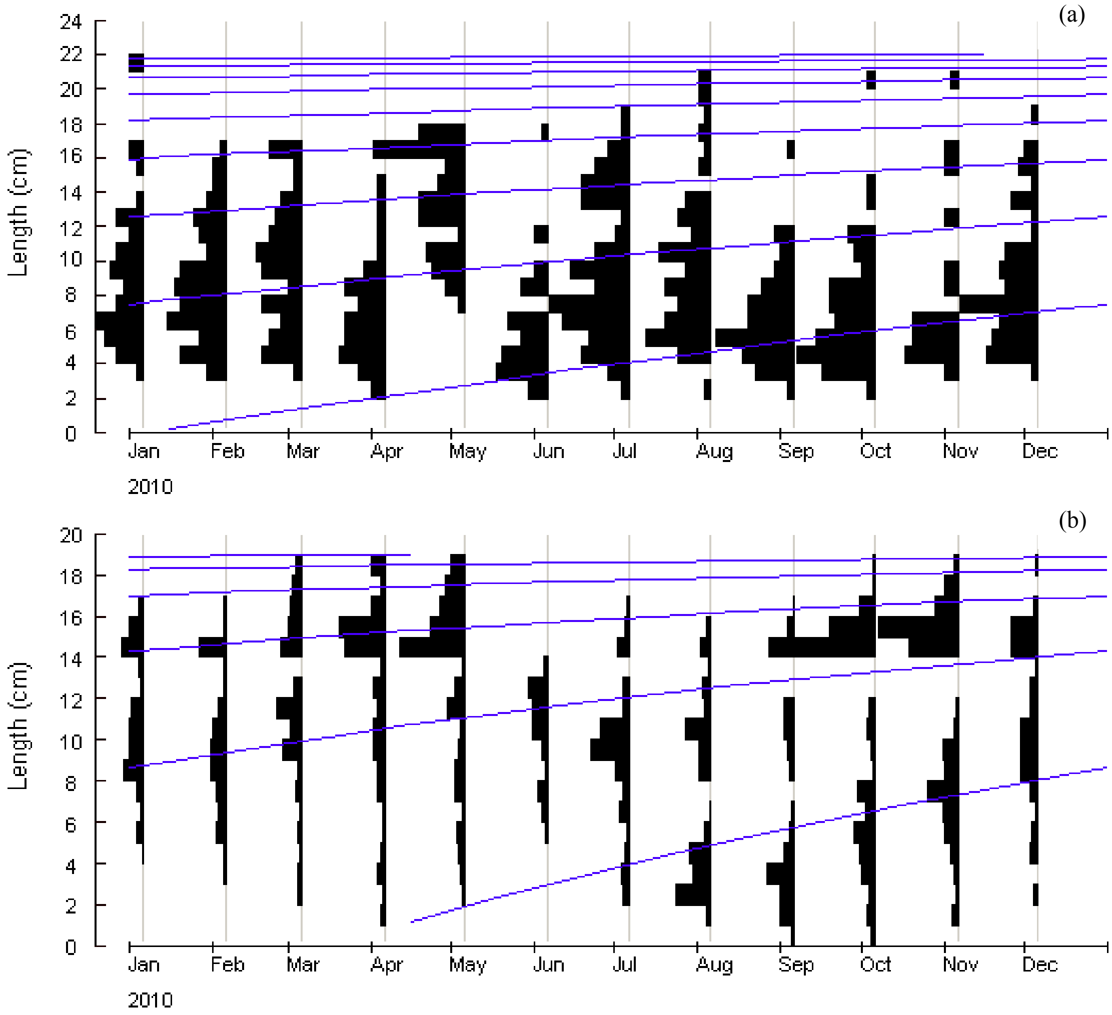


Figure 1 Length-frequency distribution of *C. ramcarati* male (a) and female (b), in different months with superimposed growth curves as obtained from K-scan of FiSAT.

The smaller body size of the investigated samples might be due to the collection of the samples only from the ESBN. In ESBN fishery, juveniles are predominantly susceptible or the fish cannot attain higher length due to thinning of the population caused by early fishing or growth overfishing [35]. The value of growth Coefficient (*K*) obtained during the present study for both males (0.49 $^{y-1}$) and females (2.10^{y-1}) was found to be higher compared to the report of [34]. However, the growth parameters of *C. dussumieri* estimated by [7] were higher than that of the result obtained from the present study and the report of [34]. Herein, it may be concluded that the fish *C. ramcarati* is a slow growing fish compared to other *coilia* species.

Length weight relationship

The minimum and maximum total lengths of male varied between 2.70 and 22.40 cm and those of weight between 0.18 and 46.59 g (**Figure 2a**). For females, the minimum and maximum total lengths fluctuated between 3.00 and 21.00 cm and those of weight between 0.39 and 48.00 g. The exponential form of the Length weight relationship equation was found to be $W = -0.045663TL^{2.2415}$ for males and $W = -3.6014TL^{2.5285}$ for females. The value of '*b*' for an ideal fish ranges between 2.50 and 4.00 [20] and is equal to 3 in the case of isometric growth when fish increases in all dimensions at the same rate as they grow [28, 35]. This "Cube Law" was not followed by male *C. ramcarati* (*b* = 2.2415) as the present study shows an allometric growth pattern with weight increasing at a relatively slow rate ($b < 3.0$) that agrees with the conclusion of [36]. In contrast, female *C. ramcarati* followed this "Cube Law" (b = 2.5285). Hence it may be concluded that isometric growth is expected for female *C. ramcarati* but not for the males. The result of the present investigation agrees with [19] as the value of '*b*' ranges from 2.50 to 4.00 for females. The coefficient of the correlation between the measurements-lengths and weights both for the males and females were highly significant at 5 % level of significance.

Mortality (total, natural and fishing) coefficient and exploitation rate

Higher total mortality was observed both for males (8.89^{y-1}), **Figure 2a** and females (10.20^{y-1}), **Figure 2b**, of which fishing mortality was found to dominate. High fishing mortality both for the males (7.70^{y-1}) and females (6.98^{y-1}) indicate that high fishing pressure is prevailing for the species *C. ramcarati* in ESBN.

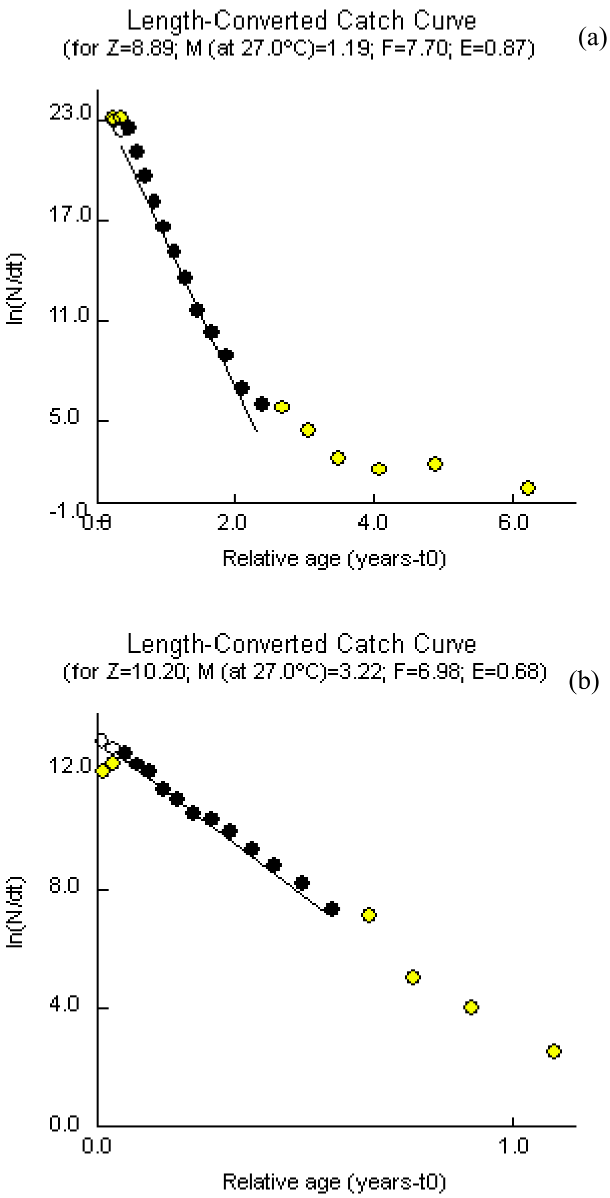


Figure 2 Length-converted catch curve for (a) male and (b) female *C. ramcarati* used for estimating different mortalities and exploitation rate.

This argument justified the higher values of exploitation rate both for males (0.87) and females (0.68). A suitable yield is optimized when F = M, and when E > 0.5 the stock is generally supposed to be over fished [29]. Therefore, the higher exploitation rate than the optimum fishing level (0.5) again confirmed that high fishing pressure prevails in the ESBN fishery for this species. This agrees with the result of [4,37].

Probability of capture

The estimated lengths for 25 % (L_{25}), 50 % (L_{50}) and 75 % (L_{75}) probabilities of capture would be 0.73, 1.37 and 2.00 cm respectively for male *C. ramcarati* (**Figure 3a**) and −0.04, 1.08 and 2.21 cm respectively for female *C. ramcarati* (**Figure 3b**) indicating high catching probability of the juveniles.

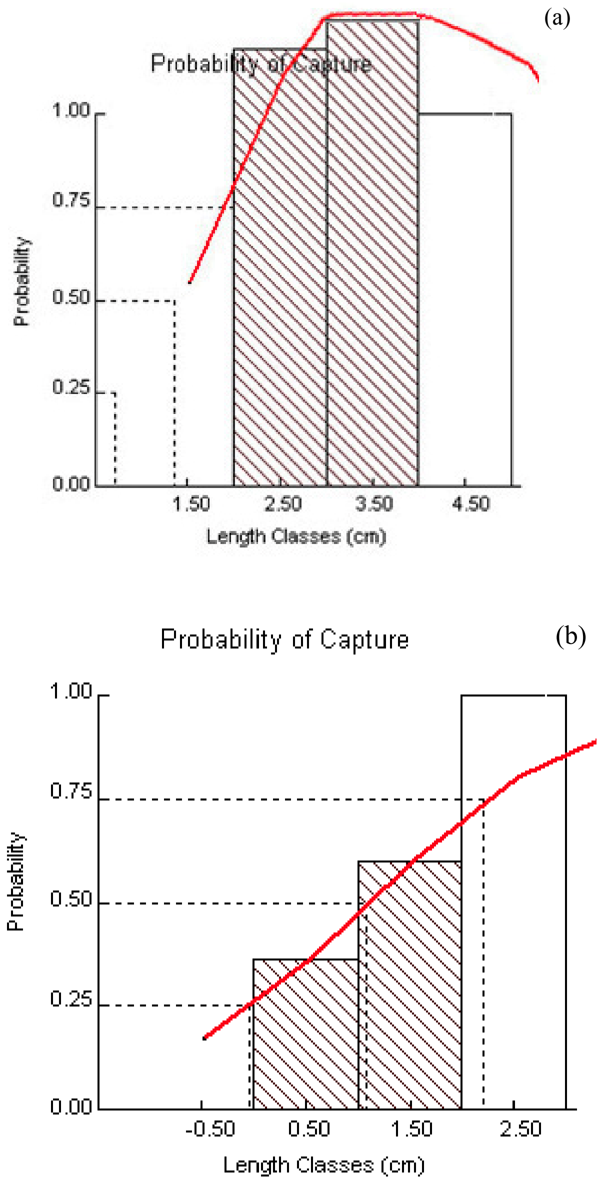


Figure 3 Probability of capture of male (a) and female (b) *C. ramcarati*.

From the probability of capture analysis it was found that about 75 % fish are caught between the length at 2.00 to 2.21 cm for males and females, respectively. These indicated a higher catching probability of the juveniles in the ESBN catches that agrees with [11,37] who reported the catches of the

ESBN are mainly juveniles, young fishes and other aquatic animals. The estimated length for 25 % (L_{25}), 50 % (L_{50}) of female fish is lower than that of males. It discloses that the female is more selective than the male and is more likely to be caught in the ESBN.

Recruitment pattern

Two recruitment peaks were observed for male *C. ramcarati*, the first one during April to June and the second one during July to October (**Figure 4a**) and with continuous recruitment in almost every month. The female recruits in the fishery almost every month with continuous recruitment (**Figure 4b**). However, two peaks were observed for *C. ramcarati* female, one during February and the other in the month of August.

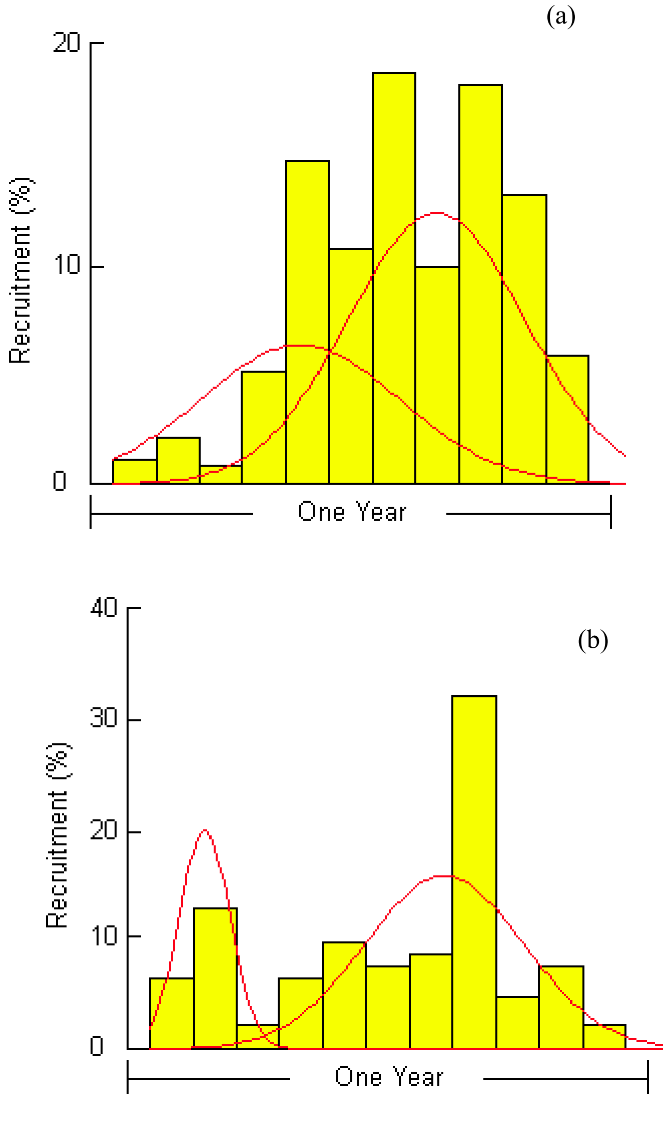


Figure 4 Recruitment patterns of (a) male and (b) female *C. ramcarati* for the investigated period.

The present study showed that both male and female *C. ramcarati* recruits in the fishery continuously almost every month with 2 peaks. The same was reported by [3,37] for ESBN fishes and for other coastal fishes of Bangladesh [1,38,39] and also for *C. dussumieri* stock in India [4].

Virtual population analysis (VPA)

The F-at-length array shows that the maximum fishing mortality occurs at the mid-length ranging between 4.00 to 12.00 cm with a maximum at the length of 5.00 cm for males (**Figure 5a**) and between 3.5 to 10.5 cm with a maximum value at the length of 8.5 cm for female *C. ramcarati* (**Figure 5b**).

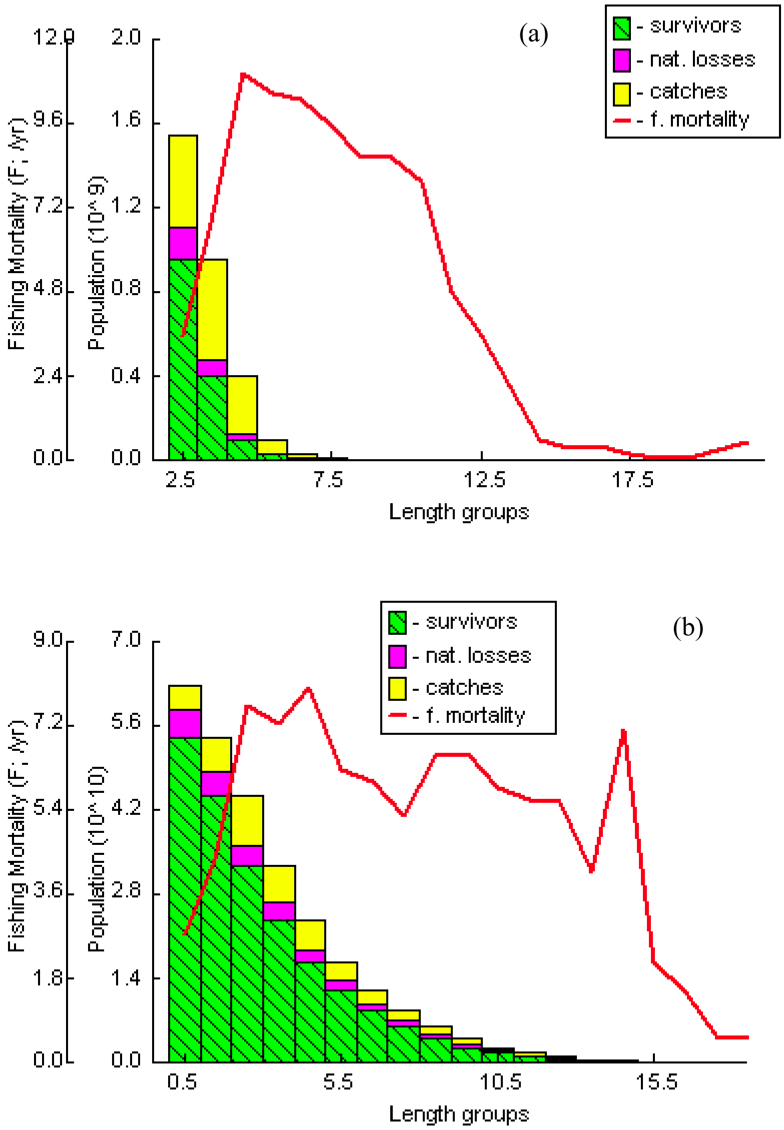
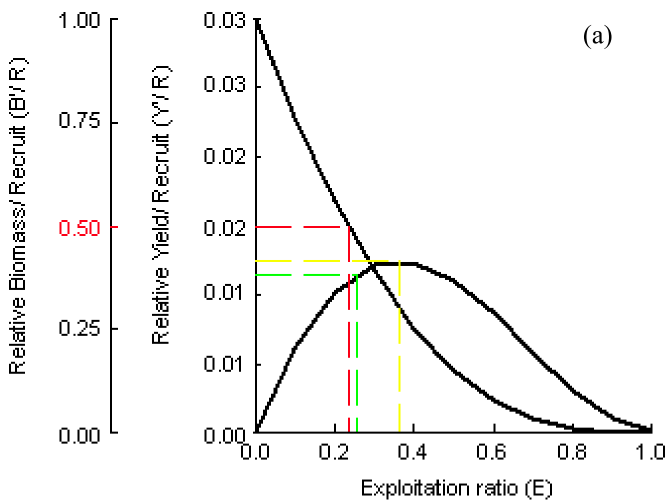


Figure 5 Virtual population analyses of (a) male and (b) female *C. ramcarati*.

The F-at-length array showed that the maximum fishing mortality occurs at a length ranging between 4.00 and 12.00 cm with a maximum at 5.00 cm, for males. In the case of females it varied from 3.5 to 10.5 cm with a maximum value at 8.5 cm, indicating higher fishing mortality at the juvenile stages of *C. ramcarati* in the ESBN fishery. The total steady state biomass was found to be 211,019 tones for males and 111,966.69 tones for females. Fishing mortality significantly decreases with increasing body length after a gradual increase at the lower length classes and especially there is no catch at the upper classes. This trend of fishing mortality indicated a decline of the larger fish of older age classes in the catch that agrees with [28], who stated that when a fish stock is more heavily exploited; larger fish are removed from the stock.

Yield per recruit and biomass per recruit

The Y'/R and B'/R curve for different exploitation Rates (E_i) produced a E_{max} value from which F_{max} was calculated and found to be 3.2092 $^{y-1}$ for males (**Figure 6a**) whereas 3.9474 $^{y-1}$ for females (**Figure 6b**). The E_{10} and E_{50} values were found to be 0.26 and 0.23, respectively in the case of males and 0.31 and 0.253 for females.



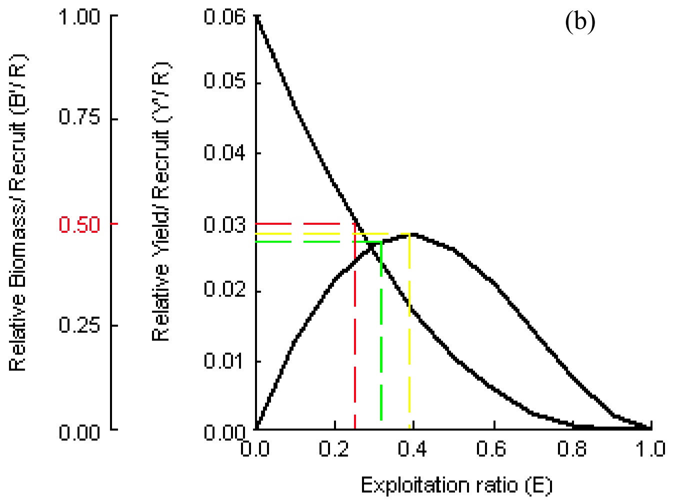


Figure 6 Relative yield-per-recruit and biomass-per-recruit for (a) male and (b) female *C. ramcarati*.

The E_{max} value for male and female were found to be 0.36 and 0.38 respectively. From the average of E_{max} value (0.37), an average F_{max} value (3.57) were obtained which suggests that present fishing mortality should be reduced to 48.64 for sustainable management of the ESBN fisheries of *C. ramcarati.*

Conclusions

The ESBN is an efficient gear capturing species of wide size-range including the juveniles of *C. ramcarati.* The stock of this species is now at an over-exploitation level. The strategies applied by the fishers for fishing have a significant impact on the stock of the exploited species. When a stock reduces to below its natural abundance, effects of exploitation may influence populations of other interacting species. Imposition of single or a combination of several regulations may reduce the threat and protect the fishery. A minimum mesh size of the net can be set and applied for allowing small individuals to escape and grow to reach a size at which they can reproduce at least once before being caught. Selection of species with regular or smooth body by net occurs on a narrow mesh size range as selectivity is affected by species' shape. This strategy might be very efficient and practicable for the studied fishery because of the regular or smooth spindle body shape of the fish. Size limit as well as rejection of females or spawning individuals after sorting out from a large catch without interference is often difficult and unreasonable and may not be very effective especially in the case of a multi species artisanal fishery of the *C. ramcarati* species. Therefore, to minimize the impacts of the ESBN fishery, the choice of an appropriate fishing strategy and increased mesh size, complete or partial withdrawal of this gear particularly during the spawning season of the studied species are recommended, which in turn will help to manage this fishery in a more sustainable way.

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