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POPULATION DYNAMICS AND THE MANAGEMENT OF THE COMMERCIAL SHRIMP *PENAEUS SEMISULCATUS* FROM THE BAY OF BENGAL

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FiSAT programme was used to estimate population parameters of *Penaeus semisulcatus* from length frequency data-based computer programme. L∞ and K for male and female were found to be 23.5 cm and 27.0 cm; and 0.8 year^{-1} and 0.9 year^{-1} respectively. The estimate provided by Wetherall plot for L∞ was 23.224 cm and 27.258 cm for male and female respectively. An additional estimate of Z/K was 4.688 for male and 5.373 for female. The growth performance index was 2.654 and 2.817 for male and female respectively. The annual rate of natural and fishing mortality were estimated as 1.73, 3.47 for male and 1.72, 2.98 for female respectively. The exploitation rates were 0.67 and 0.63 for male and female respectively. The selection pattern Lc for male was 15.88 cm and for female 18.869 cm. Recruitment pattern suggestive was one even seasonal pulse during June, July and August. Peak recruitment appeared in July. Yield-per-recruit analysis suggested that the investigated stocks are overexploited. Yield-per-recruit isopleths suggested that length at first capture was 12.0 cm (male) and 13.52 cm (female) without depletion of spawning stock. The relationship between total length and body weight were found to be $W = 0.01167\ TL^{2.8956}$ for male and $W = 0.011028\ TL^{2.9218}$ for female. Highest exploitation was observed between length class 15.0 to 19.0 cm for male and between 18.0 to 23.0 cm for female. Yield and Stock Prediction analysis suggested that the highest yield and price could be achieved by simultaneously decreasing the fishing mortality to 1.5 coefficient rate.

Key words: Asymptotic, Isopleths, *Penaeus semisulcatus*.

Introduction

Penaeid shrimp fishery is one of the most important among Bangladesh marine fisheries. *Penaeus semisulcatus*, the black tiger shrimp is a commercially important species in Bangladesh offshore waters, where it comprises around 2.93% among the shrimp species (Mustafa *et al* 1987). They have a wide range of distribution between 20 and 80m depth contour (Khan *et al* 1989; Lamboeuf 1987; Mustafa *et al* 1987; Mustafa and Khan 1993). In the offshore fishery of Bangladesh, this species plays a significant role (Chowdhury *et al* 1979; Khan *et al* 1989; Lamboeuf 1987; Mohiuddin *et al* 1980; Mustafa *et al* 1987; Mustafa and Khan 1993; Saetre 1981). It is evident that catch per unit effort of *P.semisulcatus* has declined from year to year for both sexes (Mustafa and Khan 1993). Exploitation level of *P.semisulcatus* in the Bay of Bengal are also found to be high (Zalinge 1986) indicating the necessity to manage the fishery. Length frequency data for male and female are given in tables 5 and 6 respectively. This study deals with the growth parameters (L∞, K) of the von Bertalanffy equation, instantaneous mortality rates (Z, M and F), selection patterns (Lc), recruitment patterns and the application of the yield-per-recruit, biomass-per-recruit, yield-per-recruit isopleths, length cohort analysis and yield-stock prediction with a view to identify appropriate management policy.

Knowledge of life cycle pattern and population dynamics of the commercial shrimp species are essential when determining a management strategy and subsequent recruitment of the offspring to the fishery which are linked in time and space in order to propose those measures which would be most beneficial to the fishery as well as to the conservation of the stock.

Materials and Methods

The study was conducted from April 1995 to March 1997. Length frequency and length weight data were collected for present study from commercial shrimp trawlers immediately after return from trips and research vessels R/V Anusandhani within the continental shelf of Bangladesh. The gear used was a pair of shrimp trawl of the same size and was operated from the outriggers. The mesh size of cod end was 45mm. Trawling depth varied from 20m to 90m. Total length from the tip of the rostrum to the tip of the telson at one centimeter intervals for a total of 764 male and 637 female specimen were measured on board immediately after the catch as well as in

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the landing center (Tables 1a and 1b). Sampling were done monthly and all length-frequency data for each month were pooled and pooled data were entered in the computer through FiSAT programme.

FiSAT (FAO-ICLARM Stock Assessment Tools) as explained in detail by Gayanilo *et al* (1994), the software which resulted from the merging of its predecessors (the complete ELEFAN package developed at ICLARM and LFSA developed by FAO) was used to analyse the length frequency data. FiSAT was developed mainly for the detailed analysis of length frequency data.

As explained in detail by Pauly and David (1981) and Saeger and Gayanilo (1986) the growth parameters $L\infty$ (asymptotic length) and K (growth constant) of the von Bertalanffy equation for growth in length are estimated by the Electronic Length Frequency Analysis (ELEFAN I) computed using a microcomputer programme through an objective method. Fish growth is conventionally described in fisheries work by the von Bertalanffy growth equation and in the notation of Beverton and Holt (1956) which is expressed as:

$$Lt = L\infty\ (1 - e^{-k(t-t_0)}) \quad \ldots\ldots(1)$$

Where, Lt is the length at age t; $L\infty$ is the asymptotic length; e is the base of Napierian logarithm; K the growth coefficient and t the theoretical age at 0 length. Estimation of $L\infty$ and Z/K were obtained using the method of Wetherall (1986), modified by Pauly (1986).

Growth performance of *P. semisulcatus* (male and female) was performed, based on the ϕ' index of Pauly and Munro (1984), viz:

$$\phi' = \log10\ K + 2\ \log10\ L\infty$$

where K and $L\infty$ (von Bertalanffy growth parameters) were used.

The ELEFAN II estimate Z from catch curve based on equation as :

$$Z = \frac{K\ (L\infty - L)}{L - L'} \quad \ldots\ldots(2)$$

where L is the mean length in the sample, computed from L' (upper) and L' (lower) limit of the smallest length class used in the computation of $L\infty$ (Beverton and Holt 1956). The decrease in number through time of a cohort/population is described as an exponential decay process (Beverton and Holt 1957) viz:

$$N_t = N_0 * e\text{-}z*t \quad \ldots\ldots(3)$$

Where N_t is the number surviving at time t; N is initial number and ; Z is the total instantaneous mortality of which F and M are its fishing and natural mortality components. The parameter Z of equation 2 estimated by using the routine ELEFAN II (Pauly 1983; Saeger and Gayanilo 1986) which was based on the methods of catch curve analysis and an extract solution found by using the recursive model, i.e.

$$\ln [Ni/(-e^{-zj\ dti})] = a - zj + 1 * ti \quad \ldots\ldots(4)$$

where dti is the time needed to grow through class i, ti the relative age corresponding to the lower limit of class i, zj is an initial value of z and Ni is the number of fishes (Pauly 1984). The parameter M was estimated using the empirical relationship derived by Pauly (1980) i.e.

$$\text{Log10M} = 0.0066 - 0.2790\ \text{Log 10L}\infty + 0.6543\ \text{Log 10} + 0.4630\ \text{Log10T} \quad \ldots\ldots(5)$$

Where $L\infty$ is expressed in cm, T(°C) is the mean annual environment temperature (here it was taken as 28°C). The estimate of F was taken by subtraction of M from Z. An additional estimate of Z value was obtained by Jones and van Zalinge (1981), i.e.

$$\ln(CLi, \infty) = a + b\ \ln\ (L\infty - Li) \quad \ldots\ldots(6)$$

Where CLi, ∞ is the cumulative catch (computed from the highest length class with non-zero catch) corresponding to length class i, an Li is the lower limit of length class i. The slope b, is an estimate of Z or Z/K.

Table 1a

Length-frequency data used estimating population parameters in black tiger shrimp (*P.semisulcatus* male) caught in the Bangladesh EEZ (April 95-March 97)

Length (cm)	Apr'95	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan'96	Feb	Mar
12	--	--	--	--	1	1	--	--	--	--	--	--
13	--	--	3	2	2	2	--	--	--	--	--	--
14	1	1	2	3	12	4	--	--	1	--	--	--
15	2	1	1	1	14	26	23	5	6	4	3	--
16	0	2	0	0	7	25	44	15	24	16	20	1
17	4	4	0	1	2	12	9	14	8	9	22	7
18	3	3	4	1	2	4	1	2	1	4	9	1
19	--	--	2	3	1	1	2	--	--	--	--	--
Length (cm)	Apr'95	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan'96	Feb	Mar
12	--	3	1	--	--	--	--	--	--	--	--	--
13	--	2	2	3	--	--	--	1	--	--	--	--
14	--	2	3	2	2	--	--	2	--	--	--	--
15	--	4	0	2	3	4	6	3	3	1	1	--
16	1	2	1	1	1	14	7	13	15	26	7	2
17	1	4	2	0	0	13	2	20	9	49	12	3
18	8	3	3	2	1	2	2	8	4	24	5	7
19	2	--	--	1	1	2	--	5	--	4	2	1
20	--	--	--	2	--	--	--	2	--	0	--	--
21	--	--	--	--	--	--	--	1	--	0	--	--
22	--	--	--	--	--	--	--	3	--	1	--	--

The exploitation ratio E was then computed from the expression:

$$E = F/Z = F/(F+M)$$

"Selection pattern" was determined using the routine ELEFAN II i.e. plots of probability of capture by length (Pauly 1984) by extrapolating the catch curve and calculating the number of fish that would have been caught. Recruitment pattern is obtained by backward projection of the length axis of a set of length frequency data (seasonally growth curve) according to the routine ELEFAN II.

The asymptotic length ($L\infty$), growth coefficient (K), natural mortality (M) and gear selection factor (Lc) were used for the estimation of yield-per-recruit and relative-biomass-per-recruit as defined by Beverton and Holt (1956, 1957), as modified by Pauly and Sorino (1986). The FiSAT software package of Gayanilo *et al* (1994) was then used to analyse yield-per-recruit and biomass-per-recruit. Herein, biomass (B) per recruit (R) calculated as relative biomass per recruit (R′/R′).

Table 1b

Length-frequency data used for estimating population parameters in black tiger shrimp (*P.semisulcatus* female) caught in the Bangladesh EEZ (April'95-March'97)

Length (cm)	Apr'95	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan'96	Feb	Mar
12	--	--	--	--	--	--	--	--	--	--	--	--
13	--	--	--	--	--	--	--	--	--	--	--	--
14	--	--	--	--	--	--	--	--	--	--	--	--
15	--	--	--	--	--	1	--	--	--	--	--	--
16	--	1	1		1	2	--	--	--	--	--	--
17	--	0	3	1	3	5	8	1	--	--	--	--
18	--	0	2	2	12	16	30	1	1	--	--	--
19	--	1	1	3	12	18	22	24	3	5	10	3
20	1	3	0	2	6	5	12	13	7	11	18	6
21	1	6	0	1	2	2	1	3	3	8	13	1
22	3	9	3	1	1	3	1	3	1	2	1	
23	2	--	--	1	2	--	--	--	--	2	--	--
24	--	--	--	3	--	--	--	--	--	--	--	--
Length (cm)	Apr'95	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan'96	Feb	Mar
12	--	--	--	--	--	--	--	2	--	--	--	--
13	--	1	--	--	--	--	--	3	--	--	--	--
14	--	1	--	--	--	--	--	3	--	--	--	--
152	2	--	--	--	--	2	2	--	--	--	--	--
16	1	3	2	1	--	1	1	1	--	--	--	--
17	1	1	2	1	--	2	1	1	--	--	--	--
18	2	--	1	2	--	24	2	4	--	--	--	--
19	3	--		2	--	13	5	14	5	2	4	--
20	5	--	--	--	--	3	4	15	10	10	11	2
21	7	--	--	--	1	3	--	8	7	22	9	7
22	--	--	--	--	2	1	--	8	2	7	5	1
23	--	--	--	--	2	--	--	2	1	1	0	--
24	--	--	--	--	1	--	--	1	--	--	0	--
25	--	--	--	--	--	--	--	--	--	--	1	--

The analysis provides estimates of Y′/R′ and B′/R′ for specified values of the exploitation ratio (E=F/Z) and size at entry to the fishery (Lc) in percentage of B′/R′ in the unfished population; thus a value of (B′/R′) = 100% implies that the population is unfished. Values of B′/R′ < 100% imply that the biomass-per-recruit has decreased because of fishing.

FiSAT software (Gayanilo *et al* 1994) incorporates yield-per-recruit isopleths analysis, which shows how yield-per-recruit isopleths were studied using this biomass-per-recruit of same value against exploitation rate and selectivity ($Lc/L\infty$) to get isopleths line of maximum yield-per-recruit.

Length-weight relationship The total length (TL) in cm and total weight (W) in g were recorded. The relationship between length and weight was calculated by a computer programme followed by Sparre (1985). The intercept (a) and

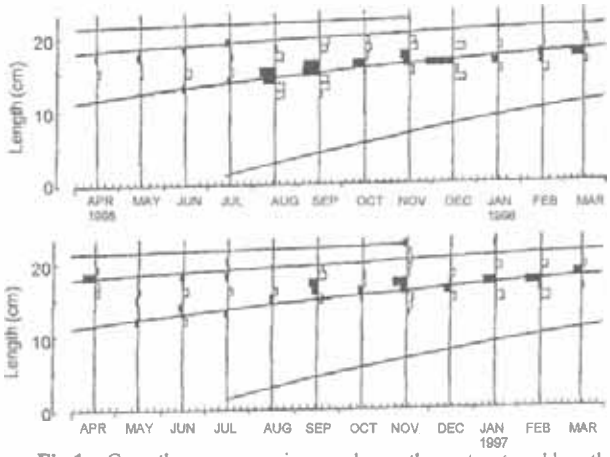


Fig 1a. Growth curve superimposed over the restructured length frequency data of *P.semisulcatus* male from the Bay of Bengal Bangladesh

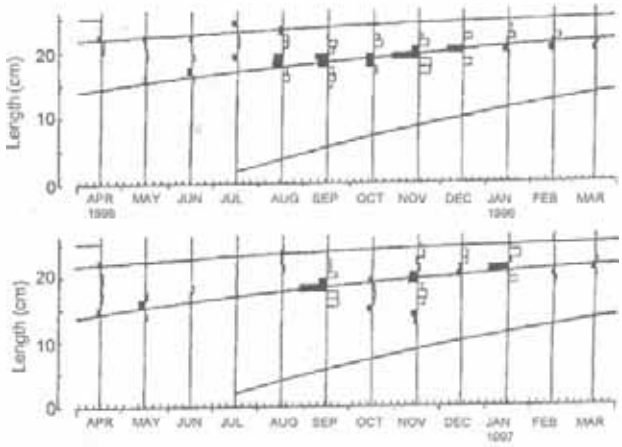


Fig 1b. Growth curve superimposed over the restructured length fequency data of *P. semisulcatus* female from the Bay of Bengal, Bangladesh.

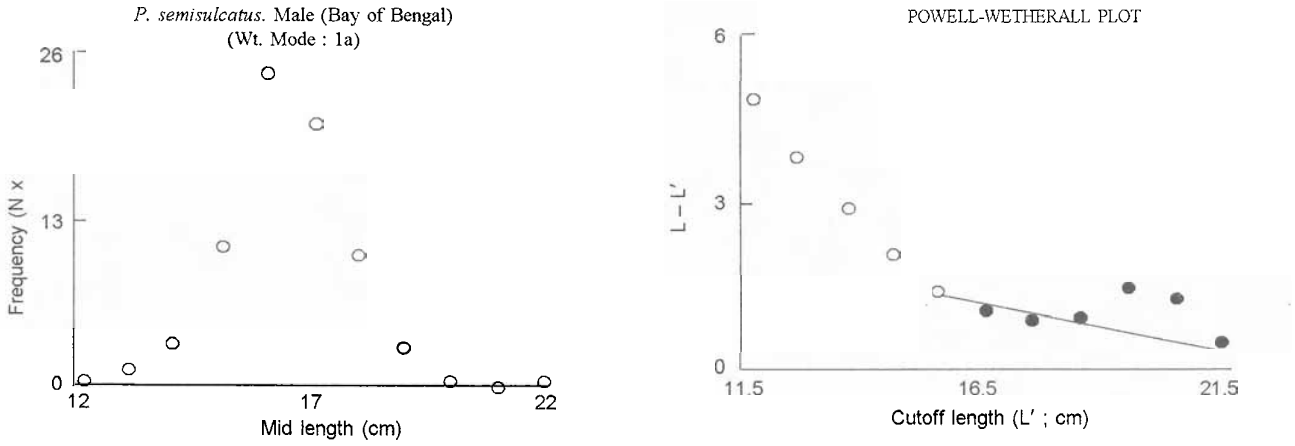


Fig 2a. Estimation of L∞ and Z/K using the methods of Wetherall for *P. semisulcatus* male; the estimated L ∞ = 23.22 cm and Z/K=4.68.

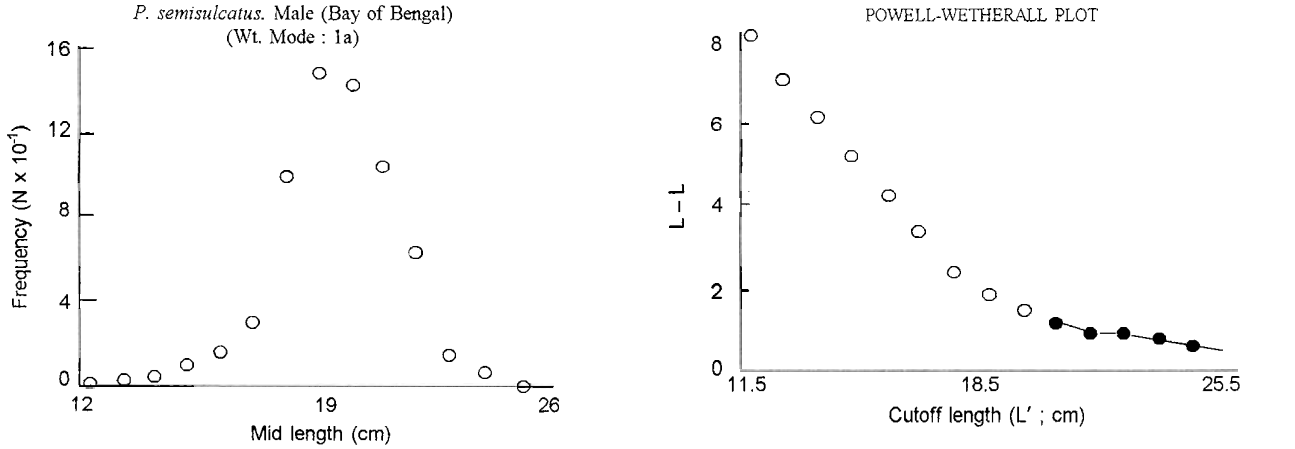


Fig 2b. Estimation of L∞ and Z/K using the methods of Wetherall for *P. semisulcatus* male; the estimated L ∞ = 23.22 cm and Z/K=4.68.

slope (b) of regression line were calculated by using following formula: Log weight = log a + b log length; $W = a \cdot L^b$.

Virtual population analysis. The total landing was distributed over length groups. The predictive counterpart of VPA and cohort analysis is published by Thompson and Bell (1934) and applied by Gulland (1965). It is reviewed by Jones (1984) and Pauly (1984). An estimated length structured Virtual Population Analysis of *P.semisulcatus* was carried out. L∞, K, M, F, a, and b for male and female were used as input to a VPA. The t_0 value was taken as 0 for both male and female.

Yield and stock prediction. Thompson and Bell (1934) routine were used to analyse yield and stock prediction for *P.semisulcatus*. This model combines features of Beverton and Holt's Y/R model with those of VPA and used to analyse single or several species for single or several fleet.

Results and Discussion

Growth parameters. Predicted extreme length for male and female were found to be 22.02cm and 26.90cm respectively. Predicted extreme length lies between 21.03 and 23.01cm for male and between 25.21cm and 28.59cm for female at 95% confidence interval. Scan of K values was performed to predict growth constant K (year^{-1}). Predicted growth constant K (year^{-1}) for male and female were found to be 0.83 and 0.90.

The growth parameters, L∞ and K of the *P. semisulcatus,* have been estimated separately for male and female for 1995-97. There is considerable difference between the length of male and female of the same age. L∞ for male and female were found to be 23.5 and 27.0 cm and K for male and female were found to be 0.8 and 0.9 per year respectively. For these estimates through FiSAT the response surface (ESP/ASP) was

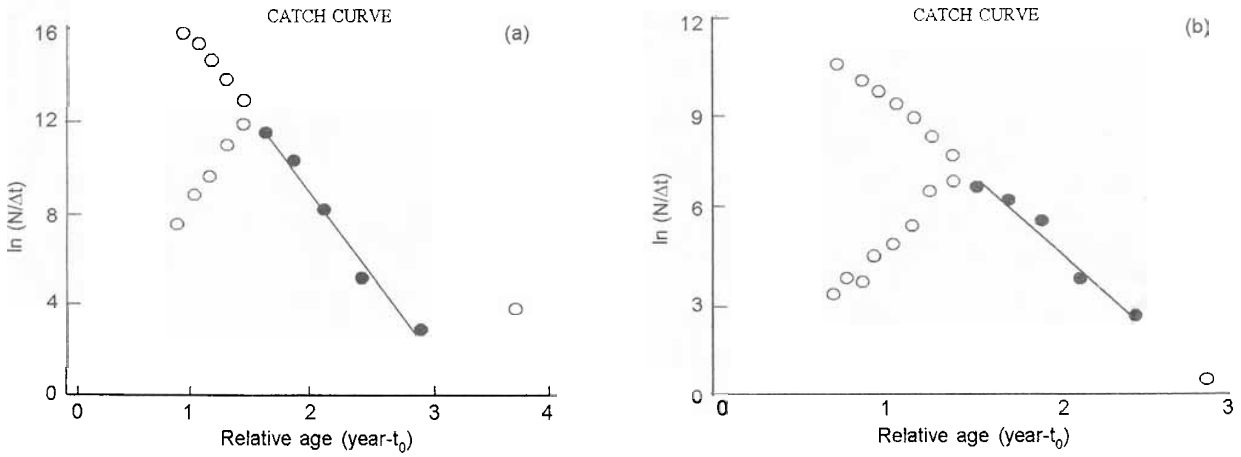


Fig 3a. Length-converted catch curve of *P. semisulcatus* male from the Bay of Bengal, Bangladesh.

Fig 3b. Length-converted catch curve of *P. semisulcatus* female from the Bay of Bengal, Bangladesh

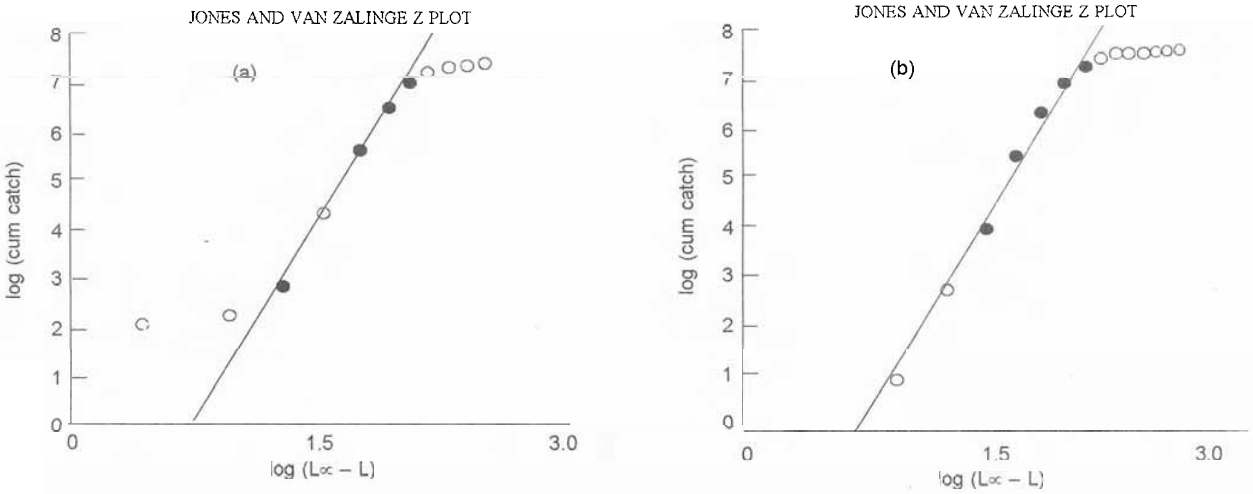


Fig 4. Jones and van Zalinge Plot of *P. semisulcatus* male (a) and female (b)

0.344 for male and 0.471 for female. The growth curves produced for male and female with those parameters are shown over its restructured length distribution in Figs.1a and 1b. The t_0 value was taken as 0 for both male and female.

Estimation of L∝ and Z/K. The modified Wetherall (1986) plot analysis incorporated in the FiSAT yielded the regression line Y = 4.08 + (-0.176)× X (male), 4.28 + (-0.157)× X (female) and correlation coefficient (r) = 0.889 and 0.903 for male and female respectively. Based on these points from 17.5cm (male), 20.5cm (female) and above showed a good linear relationship and those points of lengths below 17.5cm (male), 20.5cm (female) smoothly approach the extended line from which L∝ = 23.224cm (male), 27.258cm (female) and Z/K = 4.688 (male), 5.373 (female) were obtained (Figs. 2a and 2b).

Growth performance. Growth performance for *P. semisulcatus* male and female were found to be 2.654 and 2.817 respectively.

Mortality. The mortality rates M, F and Z computed for the male were 1.73, 3.47 and 5.20 and for the female 1.72, 2.98 and 4.70 respectively. Figs. 3a and 3b present the catch curve, utilized in the estimation of Z for male and female. The darkened circle represented the points used in the calculation of Z via least squares linear regression. The correlation co-efficient for the regression was 0.995 (a = 15.22 and b = - 5.20) and 0.99 (a = 14.06 and b = - 4.70) for male and female respectively. The

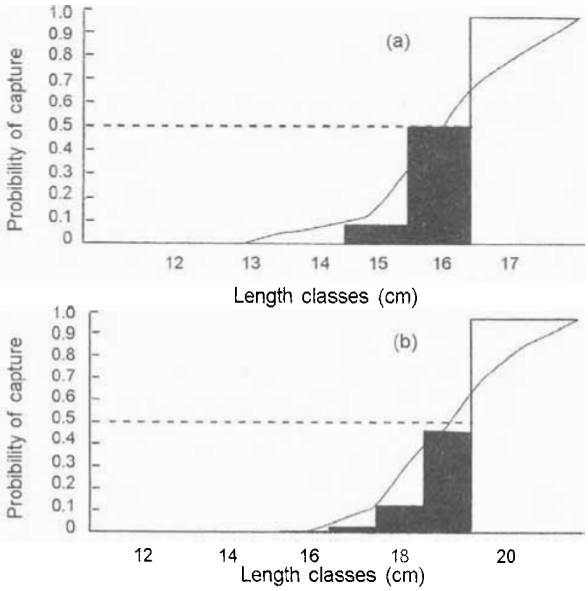
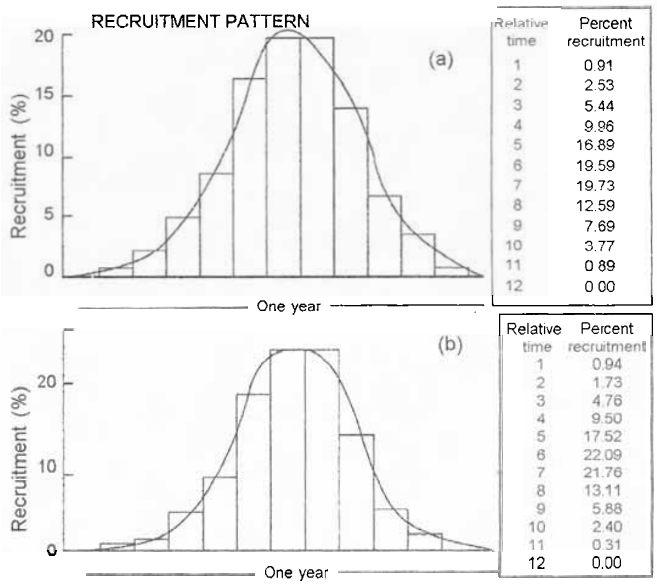


Fig 5. Selection pattern of *P. semisulcatus* male (a) & female (b)



Relative time	Percent recruitment
1	0.91
2	2.53
3	5.44
4	9.96
5	16.89
6	19.59
7	19.73
8	12.59
9	7.69
10	3.77
11	0.89
12	0.00

Relative time	Percent recruitment
1	0.94
2	1.73
3	4.76
4	9.50
5	17.52
6	22.09
7	21.76
8	13.11
9	5.88
10	2.40
11	0.31
12	0.00

Fig 6. Recruitment pattern showing reeruitment season for *p.semisulcatus* male (a) and female (b)

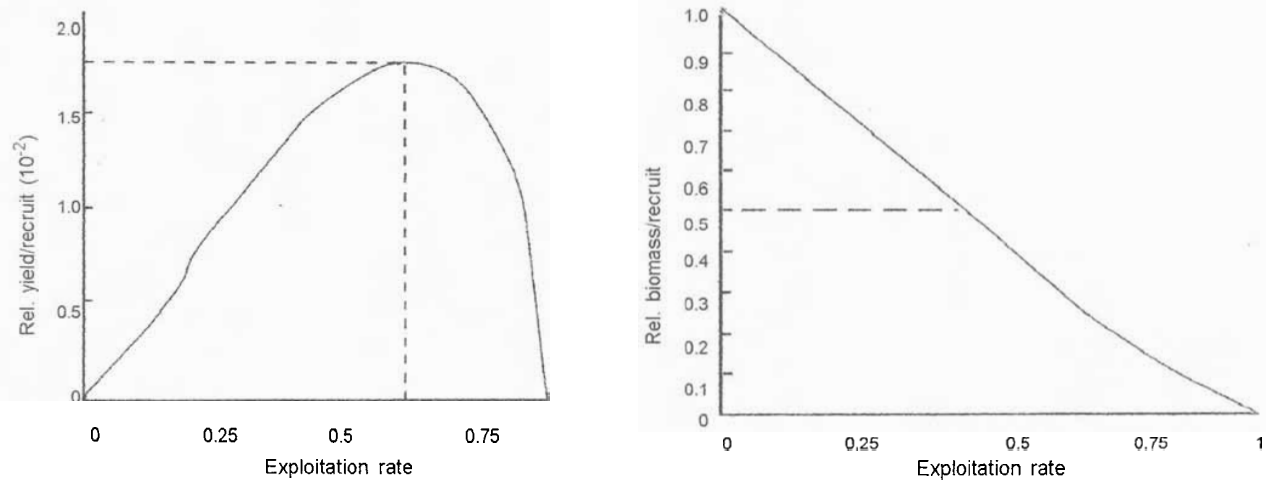


Fig 7a. Relative yield per recruit and relative biomass per recruit of *P.semisulcatus* male (Lc/L∞ = 0.69 and M/K = 2.04)

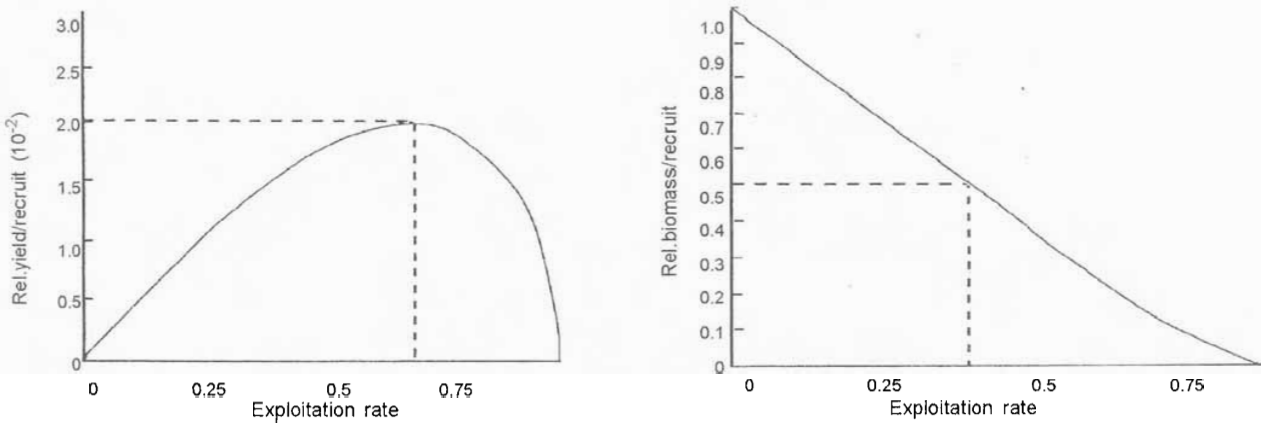


Fig 7b. Relative yield per recruit and relative biomass per recruit of *P.semisulcatus* female (Lc/L ∞ =0.70 and M/K = 1.91)

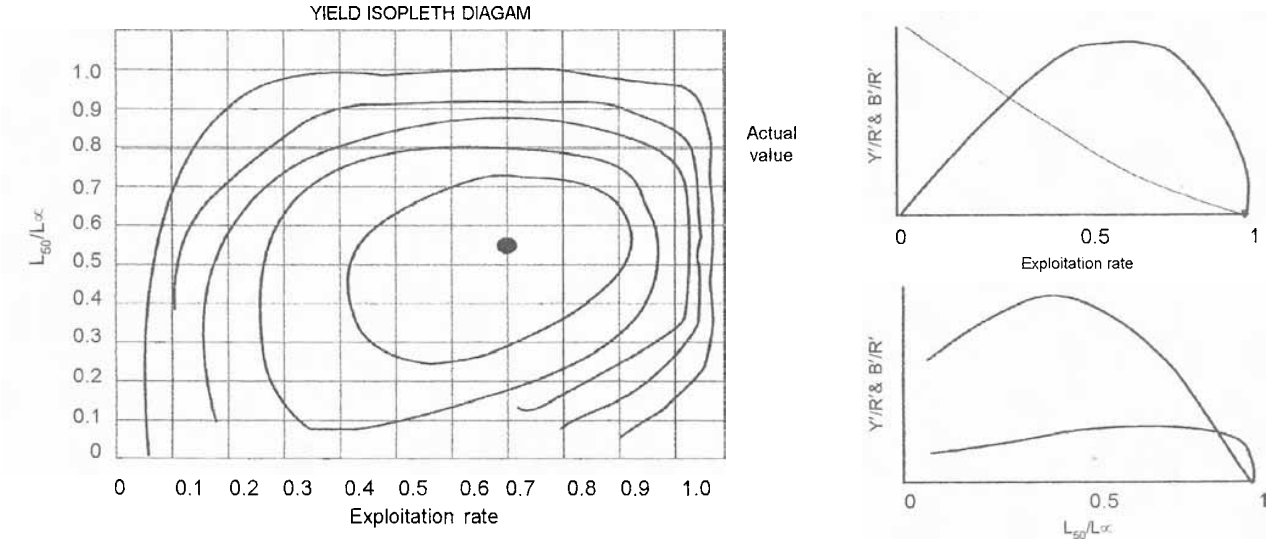


Fig 8 a. Yield per recruit isopleths diagram of *P.semisulcatus male.*

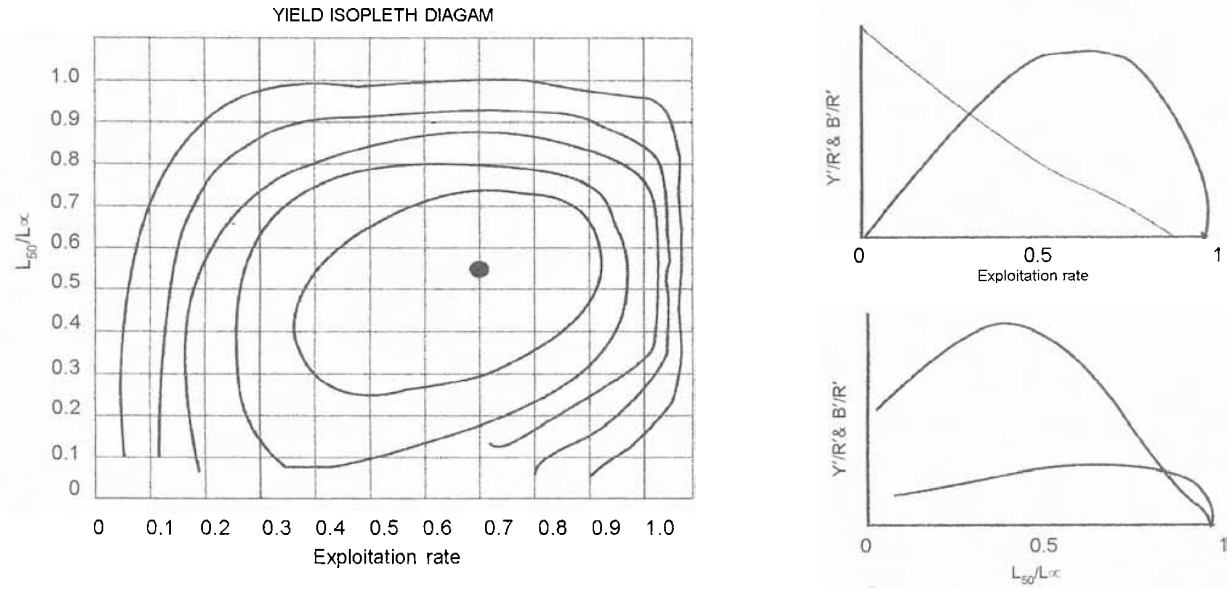


Fig 8b. Yield per recruit isopleths diagram of *P.semisulcatus* female.

Jones and van Zalinge plot (1981) yielded the regression line Y = - 4.11 + (5.637) ×X (male), -3.29 + (5.029) ×X (female) and correlation coefficient (r) = 0.997 and 0.987 for male and female respectively. Based on these points from 16.25cm (male), 19.25cm (female) show a good linear relationship and those points of lengths below 16.25cm (male), 19.25cm (female) approach the extended line from which Z = 5.637(male) and 5.029 (female) were obtained (Figs. 4a and 4b).

Exploitation rate. The exploitation rate E has been estimated from the Gulland's (1971) equation E=F/F+M. Thus, from the range of values F and F+M it can be shown that the rate of exploitation, E is 0.67 and 0.63 for male and female respectively. From these values, the stock of *P. semisulcatus* of Bangladesh coast appears to be over fishing.

Selection pattern. The length at first capture (Lc) from "Selection pattern" was found to be 15.881cm and 18.869cm for male and female respectively (Figs.5a and 5b).

Recruitment pattern. The recruitment pattern (Figs. 6a and 6b) found through the ELEFAN II shows that, annual recruit-

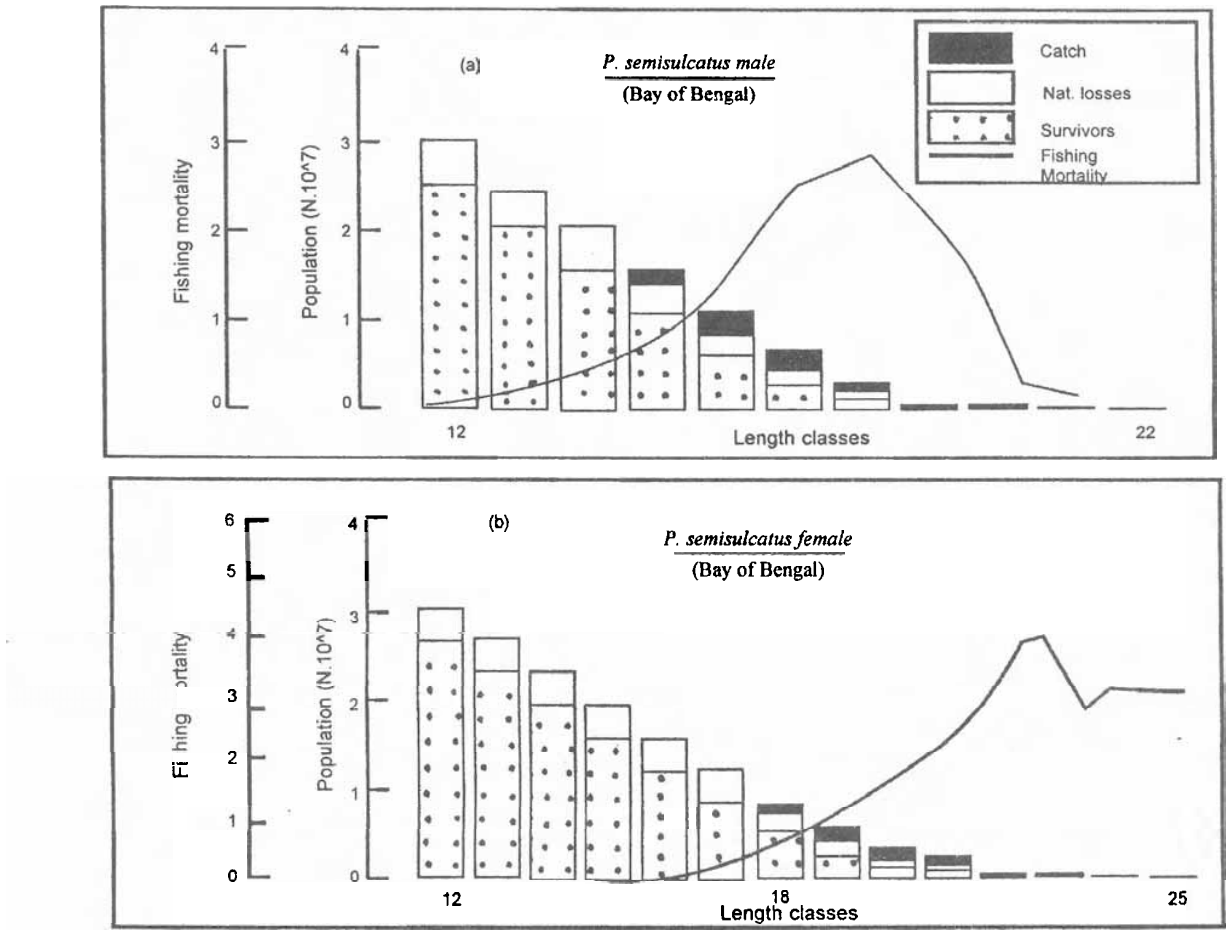


Fig 9. Length-cohort analysis of *P. semisulcatus* male (a) and female (b) in the Bay of Bengal (April'95-March'97)

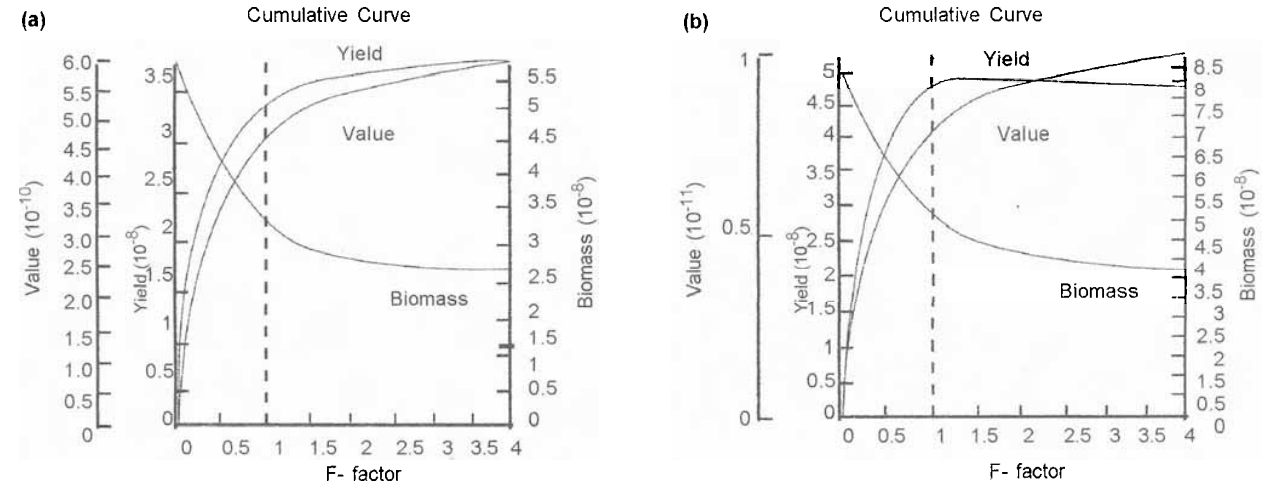


Fig 10. Estimation of yield and biomass by length based Thompson and Bell methods for *P.semisulcatus* male (a) and female (b) off Bangladesh (small vertical line on curves show the F_{MSY} level and the vertical line of f-factor the present effort level).

ment consists of one even seasonal pulse during June, July and August. Peak appeared in July. Females appear to have higher growth coefficient than male. So females reached length at first capture (Lc) earlier than male. As may be derived from growth curve, one spawning appears to take place in July. It appears from original pattern of recruitment with superimposed normal distribution that this specie is recruited in the fishery mainly during June, July and August.

Yield per recruit and biomass per recruit. The yield-per recruit and biomass-per-recruit were determined as function of the exploitation rate assuming Lc/L∞ =0.675 (male), 0.590 (female) and M/K=2.04 (male), 1.91 (female) respectively. Figs. 7a and 7b shows the present exploitation rate 0.67 (male), 0.63 (female) which were not exceeding the optimum exploitation (E_{max}) 0.662 and 0.670 for male and female respectively.

Figs. 8a and 8b show the yield-per-recruit isopleths diagrams of the various length at entry for *P. semisulcatus* male and female into the fishery based on different values of E and a, constant value of M= 1.73 and 1.72 for male and female respectively. The discontinued curves indicated the range, which produced the maximum yield-per-recruit. The maximum value of relative-yield-per-recruit at the meeting point of the eumetric yield curve with the maximum sustainable yield (MSY) curve at E = 0.60 (male and female) and Lc = 12.00 cm (male), 13.52 cm (female) in the yield-per-recruit diagram was so called potential yield-per-recruit. Hence, the value of Lc = 12.00 cm (male), 13.52 cm (female) for around 0.76 year (male and female) should be considered as the optimum age of exploitation at which the biomass (standing stock) attains its maximum size. The curve suggests that the maximum yield-per-recruit could be achieved simultaneously decreasing both Lc and F. Present length at first entry was 12.00 cm for both male and female. All the males which entered into the fishery were matured.

Length-weight relationship. The length-weight relationship for male and female were found to be $W = 0.01167L^{2.8956}$ and $W = 0.011028\ L^{2.9218}$ respectively.

Carapace length total length relationship. The values of a and b were found to be -0.3093846 and 0.2326593 for male and - 2.311236 and 0.3496471 for female respectively. So, the equation for the carapace length and total length stand as:

$$CL = -0.3093846 + 0.2326593TL \quad \text{(male)}$$
$$CL = -2.311236 + 0.3496471TL \quad \text{(female)}$$

The coefficient of correlation were found to be 0.996 and 0.995 for male and female respectively.

Virtual population analysis. An estimated length structured virtual population analysis of *Penaeus semisulcatus* was carried out. L∞ = 23.5 cm, K = 0.8, M = 1.73, F = 3.47, a = 0.01167, b = 2.8956 for male and L∞ = 27.0 cm, K = 0.9, M = 1.72, F = 2.98, a = 0.011028, b = 2.9218 were used as inputs to a VAP. The t_0 value was taken as 0 for both male and female. An average value of F(L) > 12.00 cm for both male and female) and E was obtained for male were 0.61 and 0.261 and for female 0.455 and 0.200 respectively. The virtual population analysis produced for male and female with those parameters are shown in Figs. 9a and 9b. Highest exploitation was observed between length class 15.00 cm and 19.00 cm for male and between length class 18.00 cm and 23.00 cm for female.

Yield stock prediction. Yield, biomass and value were determined as a function of the growth parameters (L∞ and K), mortality rates (M and F), recruited size, length-weight relationship (intercept and slope) and price (class length) respectively. Yield and Stock Prediction analysis showed that the highest yield and price could be attained by simultaneously decreasing the fishing mortality to 1.5 coefficient rate (Figs. 10a and 10b).

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