CHAPTER -4

POPULATION DYNAMICS AND STOCK ASSESSMENT

4.1. INTRODUCTION:

Age and growth are the important characteristics of a population study. The growth parameters are numerical values in an equation by which it is possible to predict the body size of fish when they reach a certain age. In waters of temperate countries, on counting the year rings on otoliths and scales (hard parts), the age of individual fishes are easily determined. The extreme fluctuations in environmental conditions from summer to winter and vice versa leads to the formation of the year rings. Since crustaceans do not possess bony structures that record imprints of seasonal variations, direct estimation of growth in natural populations is difficult (Leena and Deshmukh, 2009). In shrimps, age and growth calculation is difficult in tropical and sub - tropical waters. Therefore, Von Bertalanffy Growth Model is used which converts length frequency data into age composition for age determination in tropical systems (Sparre and Venema, 1998). The important von Bertallanfy growth parameters are asymptotic length, growth coefficient and age at zero length. The mean length reached by a fish of a given stock if it would have been allowed to grow for an infinitely long period is termed as asymptotic length. Growth co-efficient or curvature parameter determines how fast the fish approaches asymptotic length. Age at zero length determines the point in time when the fish has zero length. Biologically, this has no meaning, because the growth begins at hatching when the larva already has a certain length. *P. monodon* is one of the most important species both for culture and capture in West Bengal having good market demand and earning foreign money by exporting them, if the production is achieved continuously year round.

The stock assessment is closely related to the growth and mortality characteristics displayed by the group of fish. The mortality parameters reflect the rate at which the fish die, i.e. the number of deaths per unit time. Mortality is of two types; natural mortality and fishing mortality. Natural mortality is the removal of fish from the stock due to causes not associated with fishing, which includes disease, competition, cannibalism, old age, predation, pollution or any other natural factor that causes the death of fish. Natural mortality is denoted by (M) in fisheries models. Fishing mortality is the removal of fish from the stock due to fishing activities using any fishing gear. Fishing mortality is denoted by (F) in fisheries models. Natural mortality and fishing mortality are additive instantaneous rates that sum up to the instantaneous total mortality coefficient. Total mortality is denoted by (Z) in fisheries models and Z=M+F. All mortality rates are calculated annually. In mathematical yield models, mortality rate estimates are included to predict yield levels obtained under various exploitation scenarios.

The exploitation ratio is defined as the fraction of a year class recruits that is caught during all the year of existence. Exploitation rate, applied on a fish stock, is the proportion of the numbers or biomass removed by fishing. Exploitation ratio and rate are two indicators used to assess the status of the fishery. Shrimp fishery is one of the most important earning sources for foreign exchange from capture based fishery production. It possesses high demand especially in developing countries due to its nutritional value and taste. Studies on the stock assessment, the mathematical models are useful for predicting future yields and stock biomass at different levels of mortalities. Maximum size and growth rate, the probability of capture relative to size for a fishing gear and natural and fishing mortality are all estimated from length frequency data and this have the advantage of assessing data collected very quickly from landing sites and markets (Pilling et al., 2008). However, with a word of caution, as landed catch is always not an indicative of the stock biomass as higher catches are obtained even when the stock crashes, length frequency should be sampled extensively over a period of time to neutralize this limitation. The present study assesses the population parameters and the stock of *P. monodon* (Fabricius, 1798) landed at Digha coast, West Bengal, India.

4.2. RIVEW OF LITERATURE

4.2.1. Age and growth:

The age and growth of *P. monodon* during the juvenile phase from the Chilka lake and Godavari estuary was studied by Rao (1967) and Subramanyam and Ganapathi (1975). From the study conducted on the age and growth from the trawl landings at Kakinada, Rao (2003) opined that in *P. monodon*, females grew faster than the males from the age of three months onwards. According to him, males reached 139 mm, 217 mm and 250 mm total length and females reached 167 mm, 257 mm and 294 mm total length at the end of 6, 12 and 18 months respectively. *P. monodon* life span was calculated to be about two years. The average growth observed by Delmendo and Rabanal (1956) in the nursery ponds in Philippines was 230 mm TL in one year. Lalithadevi (1987) estimated the von Bertalanffy growth parameters asymptotic length ($L\infty$), growth coefficient (k) and age at zero length (t_0) in *P. monodon* as 357 mm and 296.9 mm, 1.200 and 2.316 and -0.041 and -0.138 in females and males. Villaluz et al. (1969) estimated that the lifespan of *P. monodon* is one or two years while Motoh (1981) estimated it to be about 1.5 years for males and 2 years for females. Sriraman et al. (1989) observed four broods in a year and that females grew up to 185 mm and 265 mm and males up to 155 mm and 237 mm in 1 and 2 years, respectively. Growth assessed by probability plot was 120 mm, 199 mm, 273 mm and 296 mm for females and 120 mm, 176 mm, 224 mm and 253 mm for males in 0, 1, 2 and 3 year respectively. From Von Bertalanffy growth equation it was found that females can grow up to 48.79 mm, 198.42 mm, 262.13 mm and 287.56 mm and males 43.37 mm, 173.04 mm, 217.35 mm and 250.15 mm respectively in 0, 1, 2 and 3 year. The asymptotic length calculated by Ford – Walford method was 360 mm in females and 338 mm in males. Komi et al. (2013) estimated the asymptotic length (L∞) and growth rate (k) to be 31.50 cm and 0.870 yr^{-1} respectively.

Srivatsa (1953) stated that the life span of *P. monodon* in the Gulf of Kutch was 12 to 14 months. However, wild and captive giant tiger prawns from the Gulf of Mexico were estimated to have a lifespan of about 2 years and individuals introduced into the Gulf were having a lifespan closer to 3 years (Dall et al., 1991)

4.2.2. Mortality:

Rao et al. (1993), from the east coast, has made a detailed study on the population parameters and mortality rates of *P. monodon*. Komi et al., (2013) reported that the asymptotic length (L∞) and growth rate (k) were 31.5 cm and 0.870 yr^{-1}respectively. Natural mortality was 1.64302 yr^{-1}, fishing mortality was 0.38698 yr^{-1} and total mortality was 2.03 yr^{-1}. Exploitation rate was 0.1906 and the maximum allowable level of exploitation (E_{max}) was 0.421. Present exploitation ratio was 0.1906, which was lower than that associated with the maximum relative yield per recruit. This indicated under fishing of *P. monodon*. There was a scope of increasing the fishing effort on the stock by 100 – 120% of the present value to achieve the maximum yield per recruit.

Khan et al. (2003) observed between 1984 – 1987 in Bangladesh waters, that males of *P. monodon* recorded natural mortality (M) of 2.13 yr^{-1}, fishing mortality (F) of 5.93 yr^{-1}, total mortality (Z) of 8.06 yr^{-1} and exploitation rate (E) of 0.74. Females of *P. monodon* recorded natural mortality (M) of 1.97 yr^{-1}, fishing mortality (F) of 2.68 yr^{-1}, total mortality (Z) of 4.65 yr^{-1} and exploitation rate (E) of 0.58.

Lalitadevi (987) surveyed the penaeid shrimp mortalities between 1979 and 1983 and reported on an average total mortality (Z) of female *P. monodon* to be 5.12 yr^{-1}, natural mortality (M) to be 2.02 yr^{-1} and fishing mortality (F) to be 3.11; while in male *P. monodon*, total mortality (Z) was 10.58 yr^{-1}, natural morality rate (M) was 2.89 yr^{-1} and fishing mortality (F) was 7.69 yr-1. *P. monodon* males had exploitation rate (E) of 0.7262, and females were exploited rate (E) of 0.5897.

4.3. MATERIALS AND METHODS:

The monthly and annual estimates of catch and effort were made following the Multistage Stratified Random Sampling Technique devised by Fishery Resource Assessment Division of Central Marine Fisheries Research Institute, India (Srinath et al., 2005). In this, the stratification is over space and time. A sampling unit is considered to be a boat-net combination. Based on the information on the number of units that have gone for fishing, the number of units to be sampled is determined. One calendar month is recognized as the stratification over time. Landing centre days are the primary stage sampling units and the space-time stratum is a zone and a calendar month. If in a zone, there are 20 landing centers, there will be 20 x 30 = 600 landing centre days in that zone for that month (of 30 days). A month is divided into 3 groups each of 10 days for observation purpose. A day is selected at random from the first five days of a month after which the next 5 consecutive days are automatically selected. Two consecutive days are formed from these three clusters. For example, in a given month, for a given zone, from the five days if 4 is the date (day) selected at random then the clusters formed are 4, 5; 6, 7 and 8, 9 in the first ten day group. The clusters are systematically selected with an interval of 10 days for the remaining ten day groups. Therefore in the above situation, in the remaining groups, the clusters of observation days are 14, 15; 16, 17; 18, 19; 24, 25; 26, 27 and 28, 29. There will be 9 clusters of two days each in a month normally. Nine centers are selected with replacement and allotted to the 9 cluster days as described earlier based on the total number of landing centers in the given zone. Therefore 9 landing centre days are observed in a month. In a centre, the observation is made from 1200 hrs to 1800 hrs on the first day and from 0600 hrs to 1200 hrs on the second day. For the intervening period of these two days, from 1800 hrs of the first day of observation to 0600 hrs of the 2nd day of observation of a landing centre-day, the data are collected by enquiry and the landing is termed as ‘night landing’. The landings for one (landing centre day) day (24 hours) is calculated by adding the ‘night landing’ obtained by enquiry on the second day covering the period of 1800 hrs of the first day to 0600 hrs of the next day to the day landings. When the number of boats/craft landings is large during an observation period, it is not practicable to record the catches of all boats landed. Then it becomes essential to sample the boats/craft. All the boats are enumerated for catch and other particulars when the total number of boats landed is 15 or less. However, if the total number of boats exceeds 15, the following procedure is followed to sample the number of boats:

Number of units landed	Fraction to be examined
Less than or equal to 15	100 %
Between 16 and 19	First 10 and the balance 50 %
Between 20 and 29	1 in 2
Between 30 and 39	1 in 3
Between 40 and 49	1 in 4
Between 50 and 59	1 in 5

The arrival of the multiday trawlers at the fishing harbour in a 12 hour period is taken as one unit effort. For arriving at the days’ catch, the average by catch and species composition by weight for the observed units were multiplied by the number of units landed on that day. For raising to the month, the total species wise catch and effort were multiplied with a factor obtained by dividing the actual fishing days by the total number of days in the month.

Multistage stratified random sampling technique is superior to other sampling techniques in that greater precision is achieved with a relatively smaller sampling size. However, care should be taken that landing centres are properly classified or stratified for it to be accurate.

Around 633 individuals of *P. monodon* in the length range of 12.5 to 27.7 cm and body weight of 47 to 261 g were measured during the investigation period. Monthly length-frequency data of *P. monodon* were pooled and grouped with 0.6 cm class intervals. For examining the retrospective development of the stock and for making quantitative predictions, mathematical and statistical models of stock assessment are widely used by fishery managers. Stock assessment is defined as the process of collecting and analysing demographic information about fish populations to describe the conditions or status of a fish stock. A wide array of life history characteristics for a given species are described by stock assessment, which includes information on age, growth, natural mortality, sexual maturity and reproduction, stock boundaries, diet preferences, habitat characteristics, species interactions and environmental factors.Several numerical methods have been developed which allow the conversion of length-frequency data into age composition. The month-wise length composition data for three years (2011-2013) were pooled and grouped with 0.6 cm class interval and analyzed using the ELEFAN I (Electronic Length Frequency Analysis – I)module of FiSAT (FAO ICLARM Stock Assessment Tools)software version 1.2.2 (Gayanilo et al., 2005) for estimating Von Bertalanffy growth parameters, $L\infty$(asymptotic length) and k (growth coefficient). Age at zero length (t_0) was calculated as $\log(-t_0) = -0.392 - 0.275 \log L\infty - 1.038k$ (Pauly, 1979); where $L\infty$ is asymptotic length and k is growth coefficient. ELEFAN I is a routine in FiSAT that can be used to identify the (seasonally oscillating) growth curve that "best" fits a set of length-frequency data, using the value of Rn as a criterion (Gayanilo and Pauly, 1997). In ELEFAN I, data are reconstructed to generate "peaks" and "troughs", and the goodness of fit index (Rn) is defined by Rn = 10ESP/ASP/10; where the ASP ("Available Sum of Peaks") is computed by adding the 'best' values of the available 'peaks' and the ESP ("Explained Sum of Peaks") is computed by summing all the peaks and troughs "hit" by a growth curve. Growth and age were determined using the von

Bertalanffy growth equation(Von Bertalanffy, 1938).Growth model, $Lt = L\infty (1 - e^{-k (t- t_0)})$, uses body length as a function of age; where Lt is length at time t, L∞ is asymptotic length, k is growth co-efficient and t_0 is age at zero length. Growth performance index (φ) reflects the growth rate of a fish of unit length. However for a species, the value is more or less constant but the higher value is better for growth performance. As the value is more or less similar for a species, it helps us to evaluate the nature and accuracy of the growth curve. Growth performance index (φ) was estimated as $(\varphi) = 2 \log L\infty + \log k$ (Pauly and Munro, 1984); where L∞ is asymptotic length and k is growth coefficient. Lifespan (t_{max}) was estimated at $3/k + t_0$ (Pauly, 1983a).

The probability of fish being retained in a fishing gear as a function of its length is termed as probability at first capture (Lc). Trawl-type selection curve (i.e. the probability of capture of an individual in trawl net plotted against the size of the fish) is mostly sigmoid or S-shaped. The length of the fish at which 50% of the fish has the probability of being retained by the gear on encounter is defined as size at first capture or $Lc_{50}$and is estimated using standard equations (Pauly, 1984) using the logistic curve assuming selection to be symmetrical. The equation is:

$\ln ((1/P_L)-1) = S1 - S2 \cdot L$; where P_L is the probability of capture for length L, and $L_{50}= S1/S2$

Variability in recruitment is the driving force causing changes in fish populations. The number of fishes surviving to enter the fishery or to some life history stages such as settlement or maturity is termed as recruitment. The midpoint of the smallest length group in the catch was taken as the length at recruitment (Lr). Recruitment patterns were computed from FiSAT software. The number of pulses per year and the relative strength of each pulse was reconstructed using time series length-frequency data. The unit of time in the time series is one month. The growth parameters are required inputs for computing the recruitment pulses. In case where there are two recruitment pulses, the composite data can be decomposed. Recruitment results are approximations because, while allowing statements on the number of annual pulses and on their relative strength, this model is based on two assumptions that are rarely met in reality: (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.

The loss of fish in a fish stock through death is termed as mortality and is a very important parameter used in fisheries population dynamics. Natural mortality (M) was calculated by Pauly's empirical formula In (M) = -0.0152 - 0.279 ln ($L\infty$) + 0.6543 ln (K) + 0.463 ln (T) (Pauly, 1980); where $L\infty$ is asymptotic length, k is growth co-efficient and T is mean annual habitat temperature. Total mortality (Z) was calculated from length converted catch curve (Pauly, 1983b) using FiSAT software. A "*linearized catch curve*" is a graphical representation of the logarithms of numbers caught plotted against age. Fishing mortality (F) was estimated as Z - M. From the total catch data by age or size, the entire population is reconstructed using Virtual population analyses (VPA). From the real total catch data and estimates of natural mortality and terminal fisheries mortality, the virtual population is created. In this method, the catch is used to calculate the population that was present in the water to produce this catch. VPA looks from a historical perspective on a population. The most important tasks for fishery scientists is to predict the future catches and the benefit of VPA is that once the history is known it becomes easier to predict the future catches. Length structured virtual population analysis (VPA) of FiSAT was used to obtain fishing mortalities per length class. The equations used in VPA are as follows:

The initial step is to estimate the terminal population (N_t) given the inputs, from

$N_t = C_t \cdot (M + F_t)/F_t$; where C_t is 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,

$C_i = N_{i+Dt} \cdot (F_i/Z_i) \cdot (\exp(Z_i \cdot Dt_i)-1)$; where $Dt_i = (t_{i+1} - t_i)$, and $t_i = t_o - (1/K) \cdot \ln(1-(L_i/L_¥))$ and where population sizes (N_i) are computed from $N_i = N_{i+Dt} \cdot \exp(Z_i)$

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

The proportion of a population that is caught during a certain period, usually a year is termed as exploitation. The fraction of deaths caused by fishing is called exploitation ratio (E) and exploitation rate (U) is the proportion of the population that is caught during a certain period. Exploitation ratio (E) and exploitation rate (U) were calculated as F/Z and F/Z $(1-e^{-z})$. Standing stock (P) and biomass (B) were calculated from the ratios of Y/U and Y/F respectively; where Y is the annual average yield in tonnes. Standing stock is a concentration of fish population for a given area. The total weight of the fish in a stock left after fishing is termed as biomass. The largest average catch that can be captured from a stock under existing environmental conditions is defined as Maximum sustainable yield (MSY). The population is maintained at some intermediate abundance with a maximum replacement rate by a balance between too much and too little harvest using the estimates of MSY. Maximum Sustainable Yield (MSY) was calculated as MSY = Z*0.5*B (Gulland, 1979) for exploited fish stocks.

The yield per recruit model (Beverton and Holt, 1957) is a "*steady state model*". It is a model which assumes that all fish alive have been exposed to fishing pressure since they were recruited and thereby, describes the state of the stock and the yield in a situation when the fishing pattern has been the same for a long time. Beverton and Holt approach has several assumptions, which are:

1. Recruitment is constant, yet not specified.

2. All fish of a cohort are hatched on the same date.

3. Recruitment and selection is "*knife-edge*".

4. The fishing and natural mortalities are constant from the moment of entry to the exploited phase.

5. There is a complete mixing within the stock.

6. The length-weight relationship has the exponent 3.

The model allows us to calculate Y/R with varying inputs of F. It helps us to assess the impact of various input values on the yield per recruit of the species under investigation. As F is proportional to effort, F can directly be controlled by fishery managers. Hence Y/R is a function of F. The annual average biomass of survivors as a function of fishing mortality (or effort) is expressed by the Beverton and Holt's biomass per recruit model. It is of utmost importance to fisheries managers to determine changes in Y/R for different values of F. Therefore, a "*relative yield per recruit model*" was developed by Beverton and Holt (1966) which provides this kind of information needed for management. Using Beverton and Holt Yield per Recruit model in Excel worksheet (Sparre, 1987), the relative yield per recruit (Y/R) and biomass per recruit (B/R) at different levels of F was estimated.

4.4. RESULTS

4.4.1. Growth

The growth parameters $L\propto$ and k estimated for male and females were 24.89 cm and 29.3 cm and 1.24 year^{-1}and 0.94 year^{-1} respectively using the ELEFAN I programme (Figures 4.1 and 4.2; Tables 4.1 and 4.2). The asymptotic weight was 170.48 g for males and 294.85 g for females and size at first capture (Lc) was 16.91 cm at an age (t_c) of 0.72 year for male and 19.36 cm at an age of 1.05 year for female. The growth performance index (φ) was 2.94 and 2.91 for male and female and t_0 was –0.097 years for both sexes. The von Bertalanffy growth equation derived was $L_t = 24.89\ [1 - e^{-1.4(t + 0.097)}]$ for male and $L_t = 29.3\ [1 - e^{-0.94(t + 0.097)}]$ for female. The longevity was 2.05 years for male and 3.09 years for female. Length attained by the female at the end of 1st, 2nd and 3rd year was 18.85 cm, 25.22 cm and 27.71 cm. For male, length attained after 1st and 2nd year was 19.5 cm and 23.57 cm. The length at first capture was 16.86 cm for male and 19.36 cm for female.

4.4.2. Mortality, exploitation and virtual population analysis (VPA)

Natural Mortality, Fishing Mortality and Total Mortality calculated were 2.35, 3.94 and 6.28 for male and 1.73, 3.12 and 4.85 for female, respectively. Length converted catch curve used in the estimation of Z are presented for males and females in Figures 4.3 and 4.4. The exploitation rate (U) was 0.46and exploitation ratio (E) was 0.63 for male and the exploitation rate (U) was 0.42and exploitation ratio (E) was 0.64 for female (Table 4.3)

VPA indicated that the main loss in the stock up to15.9 cm and 17.1 cm size was due to natural causes for males and females (Figure 4.5 and 4.6). Fishing mortality exceeded natural mortality from 17.7 cm for male and 20.7 cm for female. The maximum fishing mortality for male of 6.004 was at size of 18.3 cm and for female of 4.58 was at size of21.3 cm (Tables 4.4 and 4.5).

4.4.3. Probabilities of capture

Probability of capture was estimated from the results obtained from the length-converted catch curve method (Fig. 4.3). Using probability of capture, different values obtained were L_{25} = 18.60 cm, L_{50} = 19.36 cm and L_{75}= 20.01 cm for females (Figure 4.9) and L_{25} = 16.46 cm, L_{50} = 16.91 cm and L_{75}= 17.22 cm for males (Figure 4.10).

4.4.4. Stock and maximum sustainable yield (MSY)

The average annual standing stock (P), biomass (B) and MSY were 308 t, 36 t and 112 t for males and 331 t, 45 t and 109 t for females during the study period.

4.4.5. Recruitment pattern

The recruitment pattern revealed that for most months of the year, young ones were recruited into the fishery. Major peak in recruitment was during April –August for males and this pulse produced on an average 75.06% of the recruits (Figure 4.7) and for females, the major peak in recruitment was from May - August and this pulse produced on an average 68.54% of the recruits (Figure 4.8). Smallest length at recruitment was 12.25 cm for male and 15.25 cm for female. Annually, 10.78 million were recruited into the fishery.

4.4.6. Yield / recruit

From the yield and biomass curves for males and females, it was evident that maximum yield and yield/recruit was obtained by tripling the present fishing level. The maximum yield and yield per recruit obtained by increasing the present fishing effort by 200% for males was 164.18 t and 23.441g, whereas it is 140.63 t and 20.078 g at the present fishing effort. At the increased effort, the increase in relative yield would be 16.7% (Figures 4.11, 4.12 and 4.13 and Table 4.6). In the case of females, the maximum yield and yield per recruit obtained was 161.82 t and 42.894 g at thrice the present fishing effort, whereas it is 140.65 t and 37.283 g at the present fishing effort. The increase in relative yield at the increased effort would be 15.05% (Figures 4.14, 4.15 and 4.16 and Table 4.7).

4.5. DISCUSSIONS

In the present study, the population parameters estimated using the ELEFAN-I programme, $L\infty$ was 24.89 cm and 29.3 cm for males and females, respectively and k was 1.4 yr^{-1} for males and 0.94 yr^{-1} for females, respectively. Total mortality coefficient (Z) for males and females was 6.3 yr^{-1} and 4.85 yr^{-1}, natural mortality (M) for males and females was 2.35 yr^{-1} and 1.73 yr^{-1}, fishing mortality (F) for males and females was 3.94 yr^{-1} and 3.12 yr^{-1} and exploitation ratio (E) was 0.63 and 0.64 for males and females obtained using the length converted catch curve. Rao et al. (1993) estimated the mortality rate and other population parameters of *P. monodon*. The natural mortality (M) was 2.005 yr^{-1} for males and 1.840 yr^{-1} for females while fishing mortality (F) yr^{-1} was 2.277 for male and 2.255 for females and total mortality (Z) yr^{-1} 4.327 for males and 4.098 for females. Exploitation rate (E) was 0.526

for males and 0.551 for females. According to Komi et al. (2013) the asymptotic length ($L\infty$) and growth rate (K) were 31.5 cm and 0.870 yr^{-1} respectively. Natural mortality (M) yr^{-1} was 1.64302 while fishing mortality (F) yr^{-1} was 0.38698 and total mortality (Z) yr^{-1} was 2.03. The exploitation rate was 0.1906 and the maximum allowable exploitation limit was 0.421. Khan et al. (2003) observed the natural mortality (M) to be 2.13, fishing mortality (F) to be 5.93, total mortality (Z) to be 8.06 yr^{-1} and exploitation rate (E) to be 0.74 for males while for females the natural mortality (M) was 1.97, fishing mortality (F) was 2.68, total mortality (Z) was 4.65 yr^{-1} and exploitation rate (E) was 0.58 of *P. monodon*. Lalithadevi (1987) estimated the total mortality (Z) to be 10.58 yr^{-1}, fishing mortality (F) to be 7.69 yr^{-1}, natural mortality (Z) to be 2.89 yr^{-1} and exploitation rate (E) to be 0.7262 for males while for females the natural mortality (M) was 2.02 yr^{-1}, fishing mortality (F) was 3.11 yr^{-1}, total mortality (Z) was 5.12yr^{-1} and exploitation rate (E) was 0.5897 of *P. monodon*. The differences in the growth and mortality parameters observed between the present study and earlier workers are due to environmental variations, food availability, predation, exploitation and type of fishing gears used natural mortality due to disease etc. Again, this substantiates the fact, that the stock landed at Digha is from one unit stock which is biologically isolated from similar other stocks. Each unit stock would have its own set of growth and mortality parameters.

In the present study the length at first capture (Lc_{50}) for females of *P. monodon* was 19.36 cm, whereas length at first maturity was 16.35 cm, indicating that the shrimps are able to mature and spawn at least once in their lifetime before they are caught and this indicated no stress on spawning stock. Therefore, it can be surmised that the spawning stock biomass is in a healthy state to sustain the population.

The longevity of *P. monodon* at Digha coast in the present study was 2 years and 3 years for males and females respectively, which differs from Motoh (1981), who observed the longevity to be about 1.5 years for males and 2 years for females and Srivasta (1953), who stated that life span of *P. monodon* from the Gulf of Kutch was 12 to 14 months. The differences are attributed to the pollution free environment existing along the coasts of Odisha and West Bengal in the northern Bay of Bengal, where they do not suffer stress and due to high nutritional value of feeds available potentially extending their life.

MSY calculated was 221 t; 112 t for males and 109 t for females. For both males and females, maximum yield and yield/recruit was obtained by tripling the present fishing level. The increase in relative yield at the increased effort for males and females was 16.7% and 15.05%. The shrimp trawl fishery at Digha targets a wide variety of penaeid prawns, and not *P*. *monodon* alone. Therefore, recommending an increase in effort to the tune of 200% may not be advisable as other penaeid resources could easily be overexploited as a result. Moreover, the average increase in yield is only close to 16% by tripling the effort and this could make fisheries economics unprofitable and unsustainable. Therefore, it is recommended that the present fishing effort to be maintained for sustainably and optimally exploiting the shrimp resources, particularly *P*. *monodon* along the coast of Digha in northern Bay of Bengal.

Table 4.1. Length frequency data of females' *P. monodon* collected during January 2011 to December 2013 from Digha coast.

Mid-Length (cm)	Jan	Feb	Mar	April	June	July	Aug	Sept	Oct	Nov	Dec
12.3											4
12.9								2			
13.5								1			
14.1											3
14.7										1	1
15.3					1					4	2
15.9			1				1				
16.5	1		1								
17.1			1				2				1
17.7	1		2		2	2	6	2			1
18.3	2		1		4	6	10	5		1	5
18.9	2	2	2	1	4	3	8	8	6	3	3
19.5	1				3	4	7	6	3	7	3
20.1	1	3	2		4	2	3	3	7	6	3
20.7	2	1	2		2		6	4	8	2	6
21.3	7	7	4	2	12	3	8	9	9	9	10
21.9	1	5		1	3	2	2	3	5		
22.5	4	5	3		4	1	1	1	1		6
23.1		4	1		2	1			1	1	1
23.7		7	1	1	2	1					1
24.3		1	1		3	3		1		3	
24.9		1			1	1					
25.5						1		1			
26.1					1						
26.7											
27.3											
27.9											1

Note: Data for three years are pooled and presented month wise.

Table 4.2.Length frequency data of males' *P.monodon* collected during January 2011 to December 2013 from Digha coast.

Mid-Length (cm)	Jan	Feb	Mar	Apr	June	July	Aug	Sept	Oct	Nov	Dec
15.3							3				
15.9							1	1			
16.5					1	8	2	3	1	2	
17.1		2	1		3	6	4	7	4	3	3
17.7		1			8	5	3	6	8	7	9
18.3	13	13	3	1	3	3	2	4	9	10	8
18.9	5	5	3	1	1	2		1	2	6	4
19.5		3	1	2	1	1				2	5
20.1		7	1	1	2	2			3		
20.7		2	1		1				1		
21.3		1			1						
21.9											
22.5						1					
23.1											
23.7			2								

Note: Data for three years are pooled and presented month wise.

Table 4.3.Stock estimates of *P. Monodon* collected during January 2011 to December 2013 from Digha coast.

Sex	L∞ (cm)	k (yr^{-1})	Z (yr^{-1})	M (yr^{-1})	F (yr^{-1})	U	Y (t)	P (t)	B (t)	T_{max}(yr)	Wt∞ (g)
Male	24.9	1.4	6.28	2.35	3.94	0.46	140.7	308	36	2.05	170.5
Female	29.3	0.94	4.85	1.73	3.12	0.42	140.7	331	45	3.09	294.9

Note: Data for three years are pooled and presented.

Table 4.4. Virtual Population Analysis of females' *P. monodon* collected during January 2011 to December 2013 from Digha coast.

Mid-length (cm)	Fishing mortality (F)
12.3	0.0665
12.9	0.0343
13.5	0.0177
14.1	0.055
14.7	0.038
15.3	0.1384
15.9	0.0412
16.5	0.0429
17.1	0.0896
17.7	0.3788
18.3	0.8719
18.9	1.2011
19.5	1.0992
20.1	1.2544
20.7	1.4181
21.3	4.5865
21.9	1.7568
22.5	2.7237
23.1	1.5361
23.7	2.4506
24.3	3.5601
24.9	1.3918
25.5	1.293
26.1	0.9131
26.7	0
27.3	0
27.9	3.12

Note: Data for three years are pooled and presented.

Table 4.5. Virtual Population Analysis of males' *P. monodon* collected during January 2011 to December 2013 from Digha coast.

Mid-length (cm)	Fishing mortality (F)
15.3	0.1228
15.9	0.086
16.5	0.7824
17.1	1.7062
17.7	2.929
18.3	6.0044
18.9	3.9116
19.5	2.6958
20.1	4.1472
20.7	1.8962
21.3	0.9869
21.9	0
22.5	0.7359
23.1	0
23.7	3.94

Note: Data for three years are pooled and presented.

Table 4.6.Yield per recruit of males *P monodon* collected during January 2011 to December 2013 from Digha coast.

F multiplier					
X	Y/R (g)	Yield (t)	B/R (g)	Biomass (t)	Rel Y%
0	0	0			0
0.2	9.570	67.03	12.14	85.06	47.66
0.4	14.391	100.79	9.13	63.96	71.67
0.6	17.163	120.21	7.26	50.85	85.48
0.8	18.907	132.43	6.00	42.01	94.17
1	20.078	140.63	5.10	35.69	100.00
1.2	20.905	146.42	4.42	30.97	104.12
1.4	21.512	150.68	3.90	27.32	107.14
1.6	21.972	153.90	3.49	24.41	109.44
1.8	22.330	156.41	3.15	22.05	111.22
2	22.615	158.40	2.87	20.10	112.64
2.2	22.845	160.01	2.64	18.46	113.78
2.4	23.035	161.34	2.44	17.06	114.73
2.6	23.193	162.45	2.26	15.86	115.51
2.8	23.327	163.38	2.11	14.81	116.18
3	23.441	164.18	1.98	13.89	116.75

Note: Data for three years are pooled and presented.

Table 4.7.Yield per recruit of females *P monodon* collected during January 2011 to December 2013 from Digha coast.

F multiplier					
X	Y/R (g)	Yield (t)	B/R (g)	Biomass (t)	Rel Y%
0	0	0			0
0.2	18.475	69.70	29.61	111.69	49.55
0.4	27.321	103.07	21.89	82.59	73.28
0.6	32.246	121.65	17.23	64.98	86.49
0.8	35.278	133.09	14.13	53.32	94.62
1	37.283	140.65	11.95	45.08	100.00
1.2	38.682	145.93	10.33	38.98	103.75
1.4	39.702	149.78	9.09	34.29	106.49
1.6	40.469	152.67	8.11	30.58	108.55
1.8	41.064	154.91	7.31	27.58	110.14
2	41.534	156.69	6.66	25.11	111.40
2.2	41.915	158.12	6.11	23.04	112.42
2.4	42.227	159.30	5.64	21.27	113.26
2.6	42.487	160.28	5.24	19.76	113.96
2.8	42.707	161.11	4.89	18.44	114.55
3	42.894	161.82	4.58	17.29	115.05

Note: Data for three years are pooled and presented.

Figure 4.1.Restructured length-frequency distribution and the estimated growth curve of females' *P. monodon* collected during January2011 to December 2013 from Digha coast.

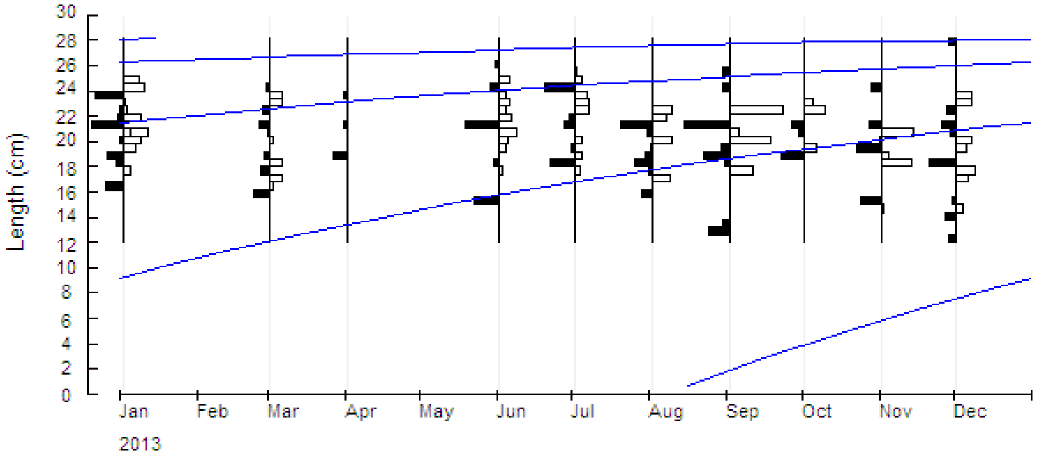


Figure 4.2.Restructured length-frequency distribution and the estimated growth curve of males '*P. monodon* collected during January2011 to December 2013 from Digha coast.

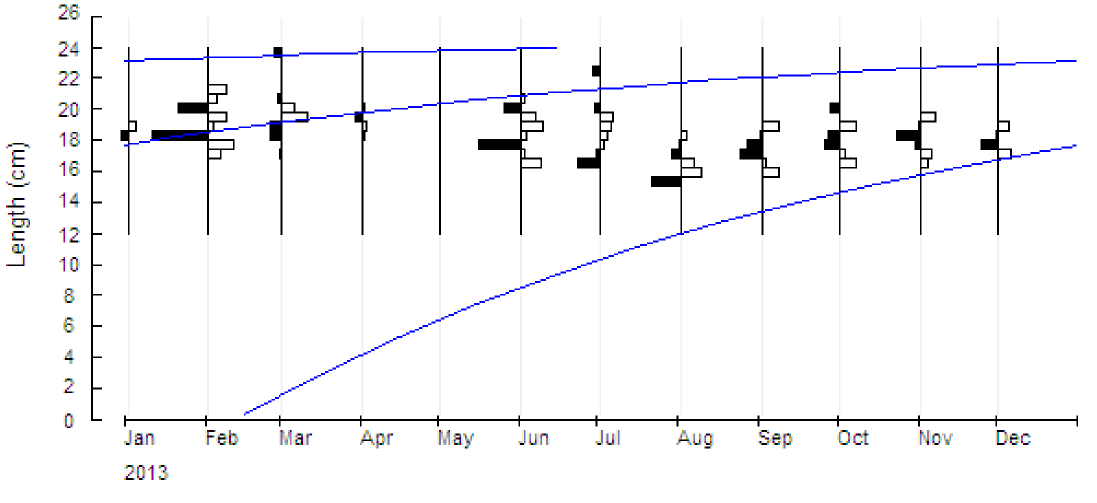
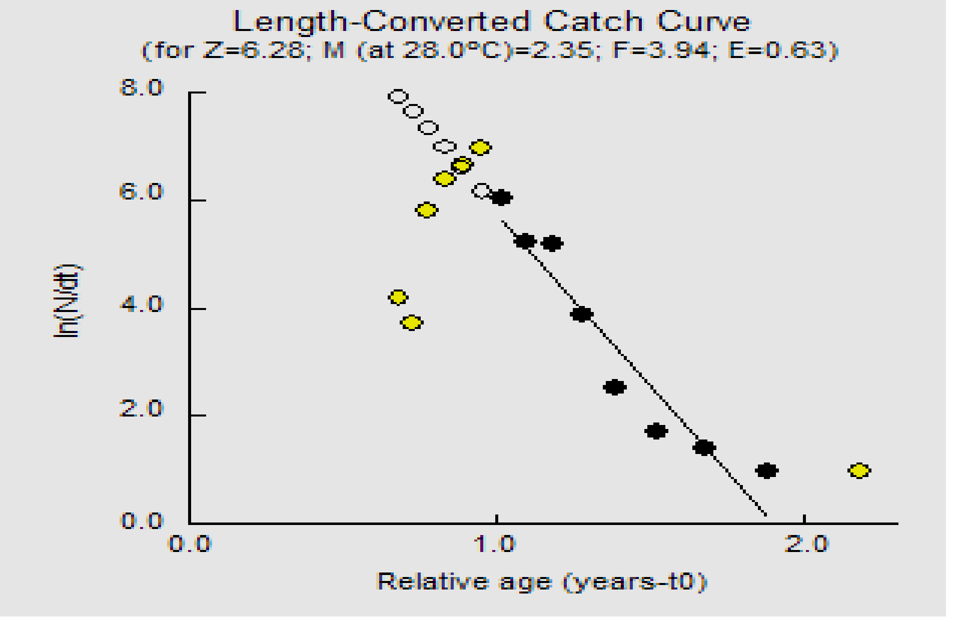
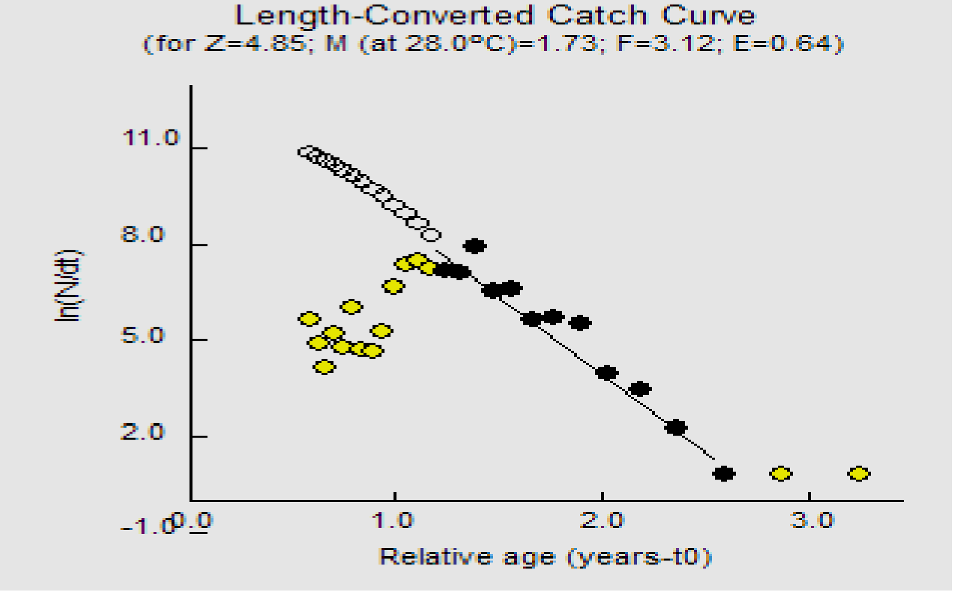


Figure 4.3. Length converted catch curve of males *P. monodon* collected during January2011 to December 2013 from Digha coast.



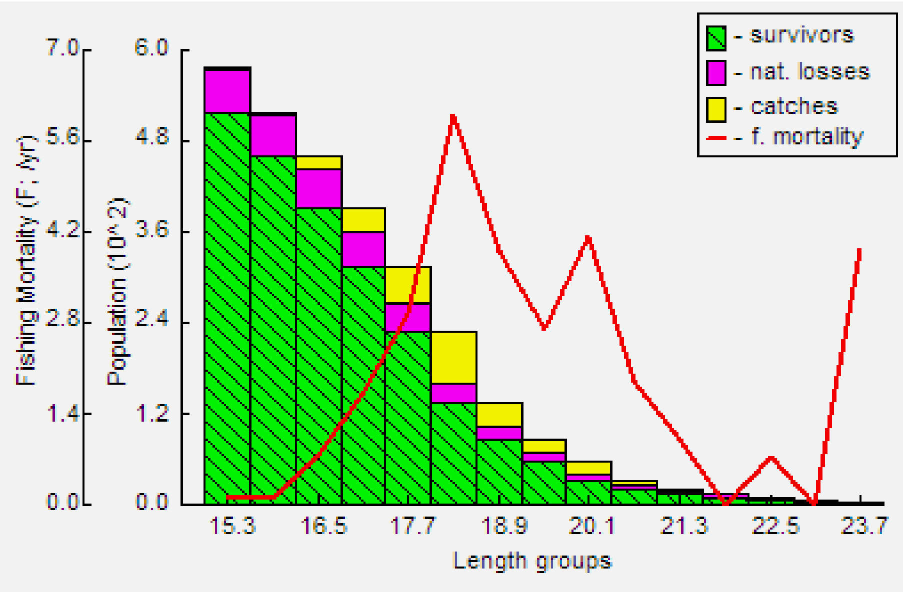
Note: Data for three years are pooled and presented.

Figure 4.4. Length converted catch curve of females *P .monodon* collected during January 2011 to December 2013 from Digha coast.



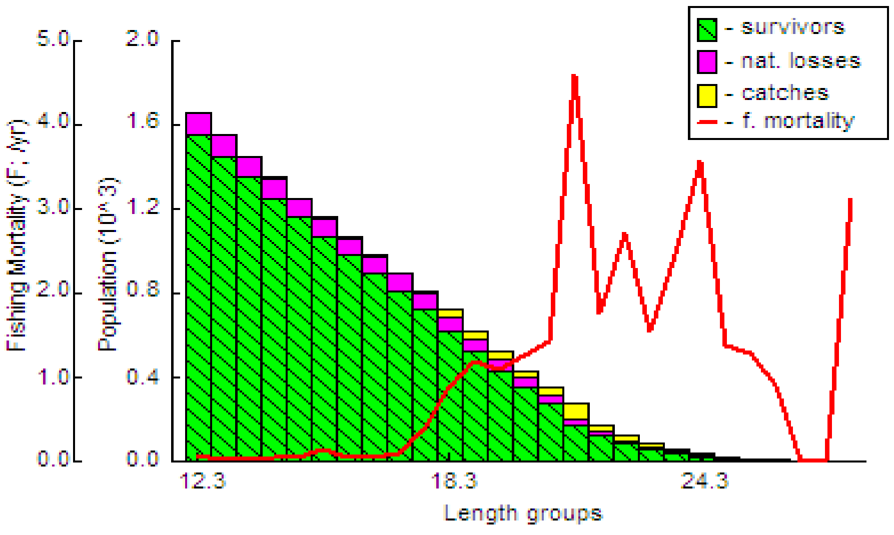
Note: Data for three years are pooled and presented.

Figure 4.5.Length structured virtual population analysis of males *P .monodon* collected during January2011 to December 2013 from Digha coast.



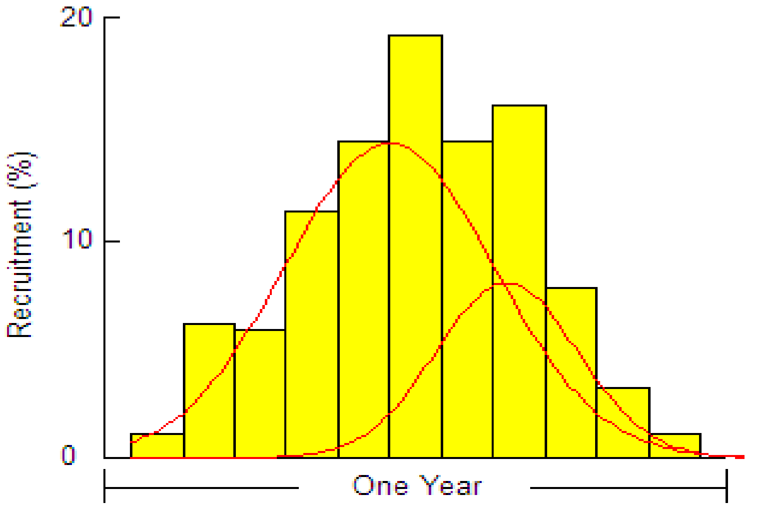
Note: Data for three years are pooled and presented.

Figure 4.6.Length structured virtual population analysis of females *P. monodon* collected during January 2011 to December 2013 from Digha coast.



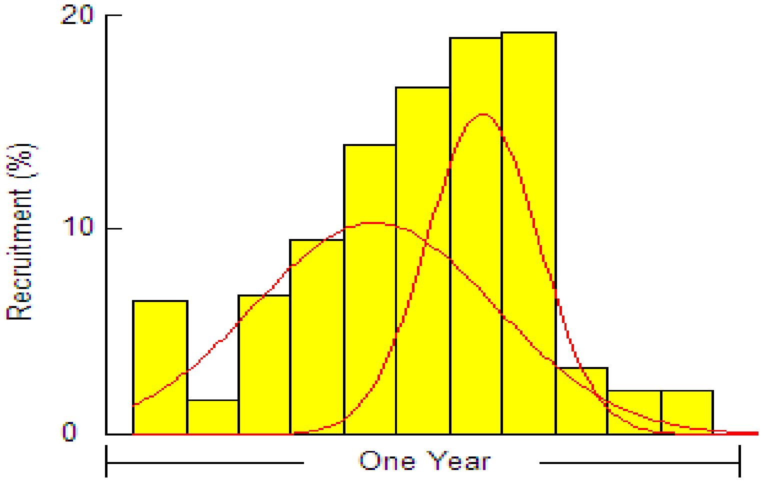
Note: Data for three years are pooled and presented.

Figure 4.7. Recruitment patterns of males' *P.monodon* collected during January2011 to December 2013 from Digha coast.



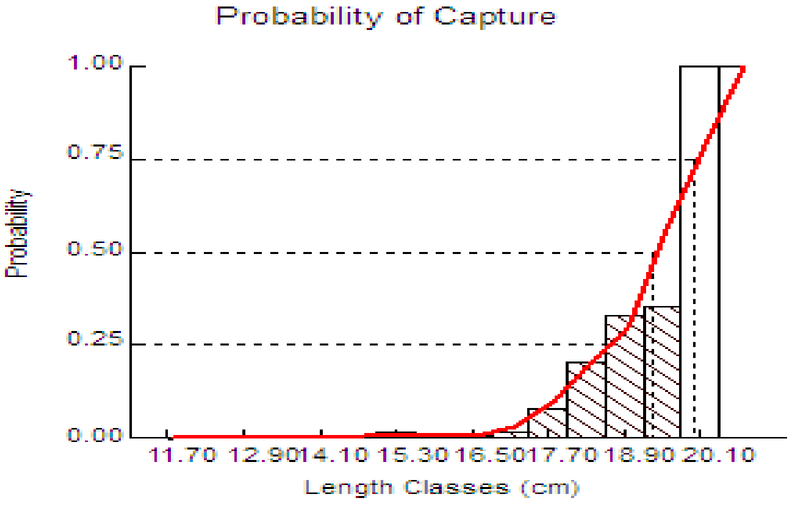
Note: Data for three years are pooled and presented.

Figure 4.8. Recruitment patterns of females of *P. monodon* collected during January 2011 to December 2013 from Digha coast.



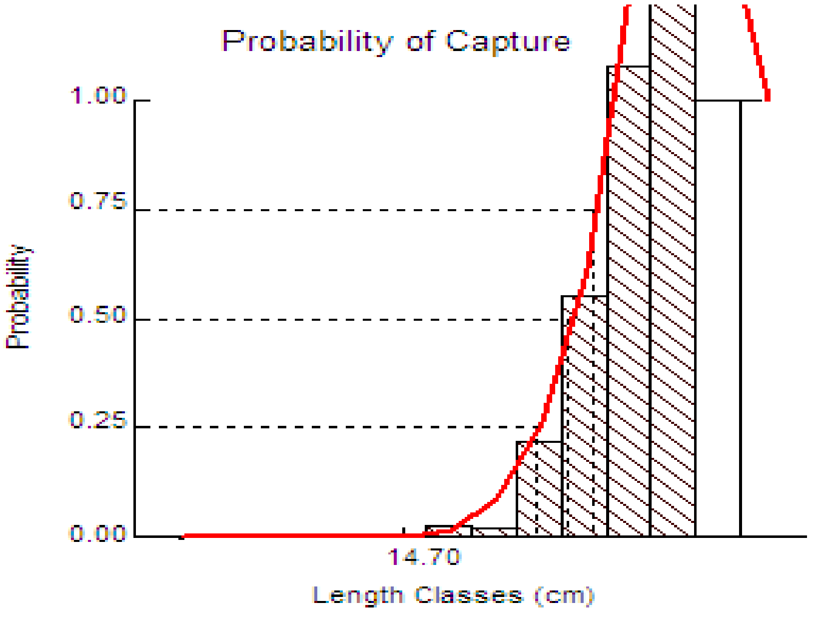
Note: Data for three years are pooled and presented.

Figure 4.9. Probability of capture of females' *P. monodon* collected during January 2011 to December 2013 from Digha coast.



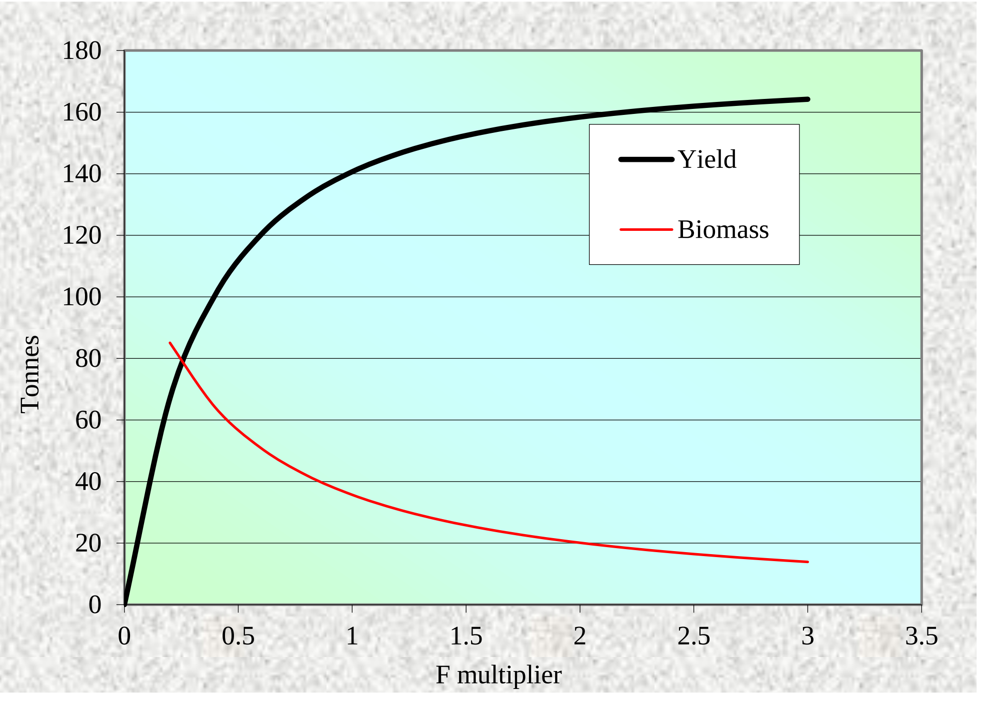
Note: Data for three years are pooled and presented.

Figure 4.10.Probability of capture of females' *P. monodon* collected during January 2011 to December 2013 from Digha coast.



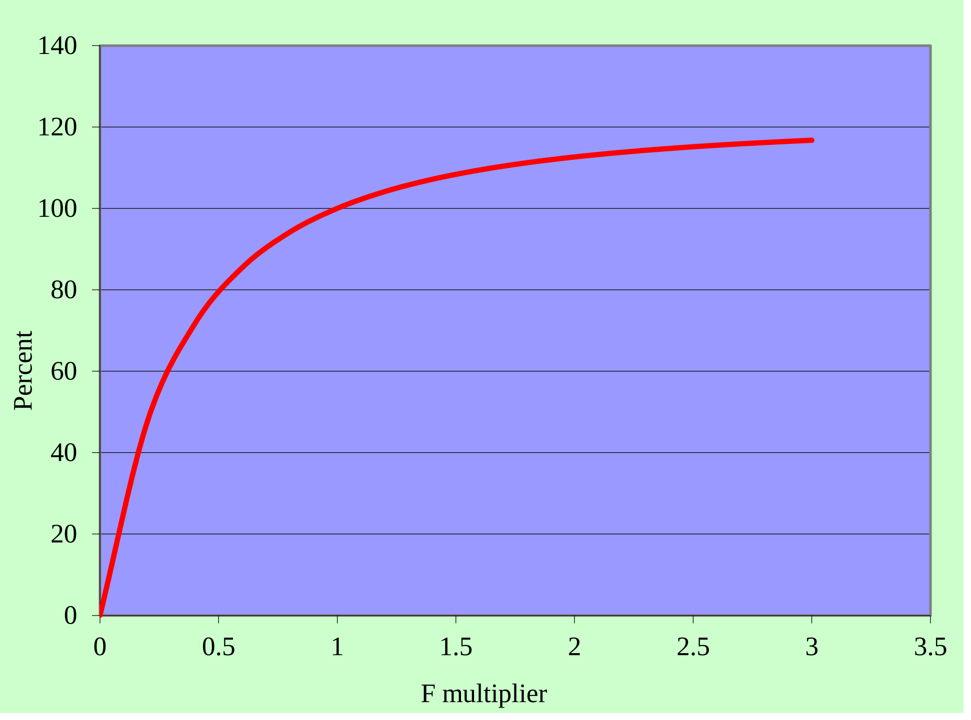
Note: Data for three years are pooled and presented.

Figure 4.11. Yield and biomass curves of males' *P. monodon* collected during January2011 to December 2013 from Digha coast.



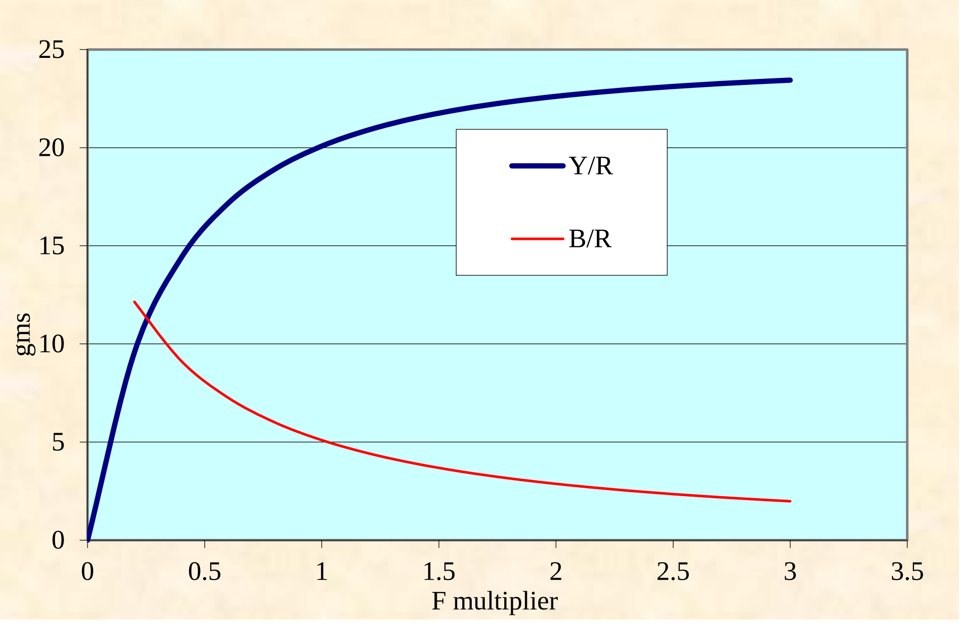
Note: Data for three years are pooled and presented.

Figure 4.12. Relative yield to present yield of males *P. monodon* collected during January2011 to December 2013 from Digha coast.



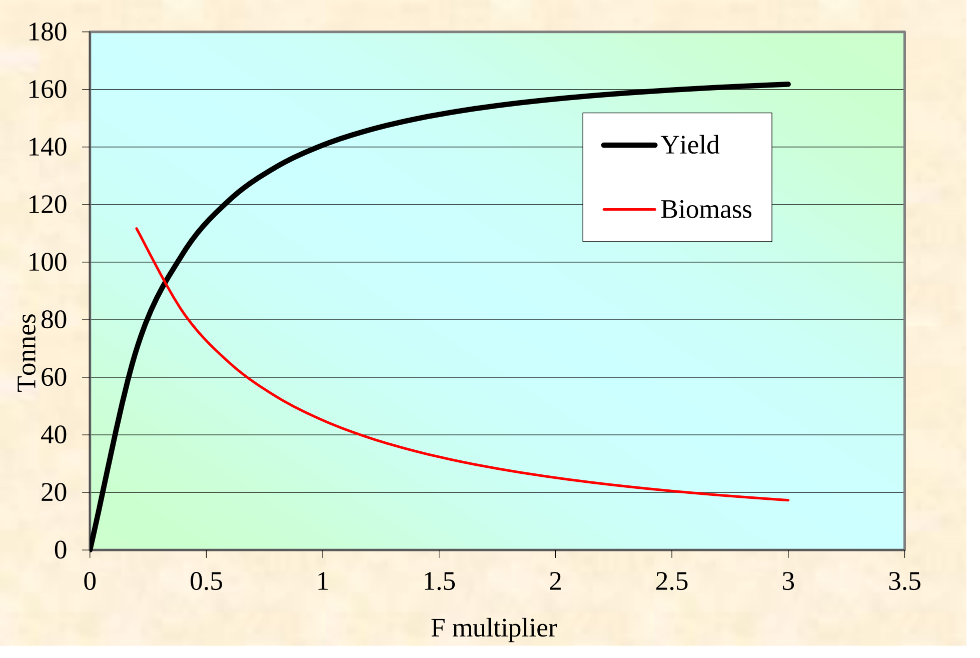
Note: Data for three years are pooled and presented.

Figure 4.13. Yield per recruit and biomass per recruit of males *P. monodon* collected during January2011 to December 2013 from Digha coast.



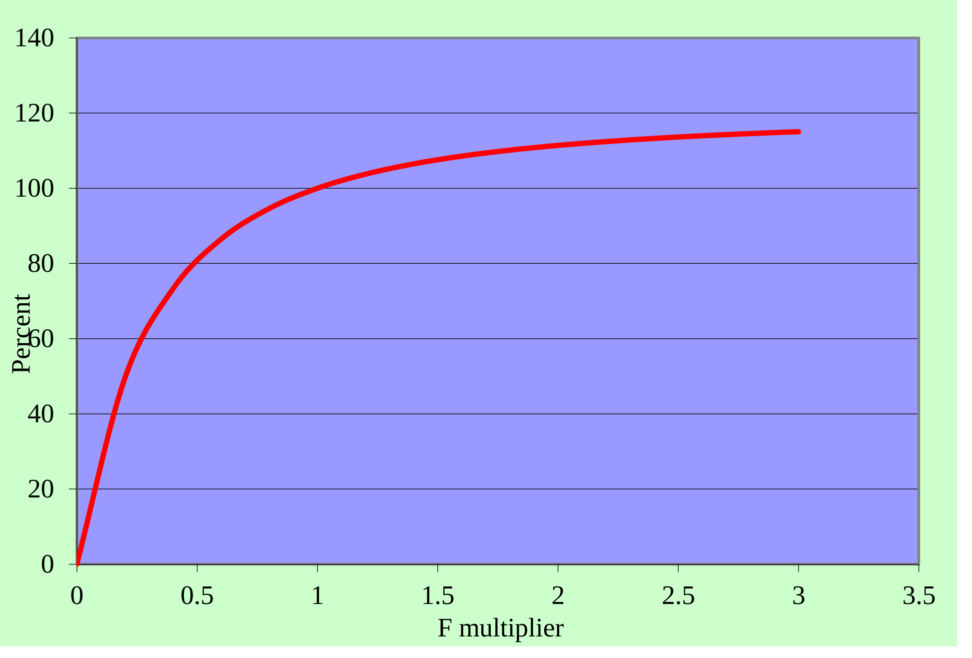
Note: Data for three years are pooled and presented.

Figure 4.14. Yield and biomass curves of females' *P. monodon* collected during January 2011 to December 2013 from Digha coast.



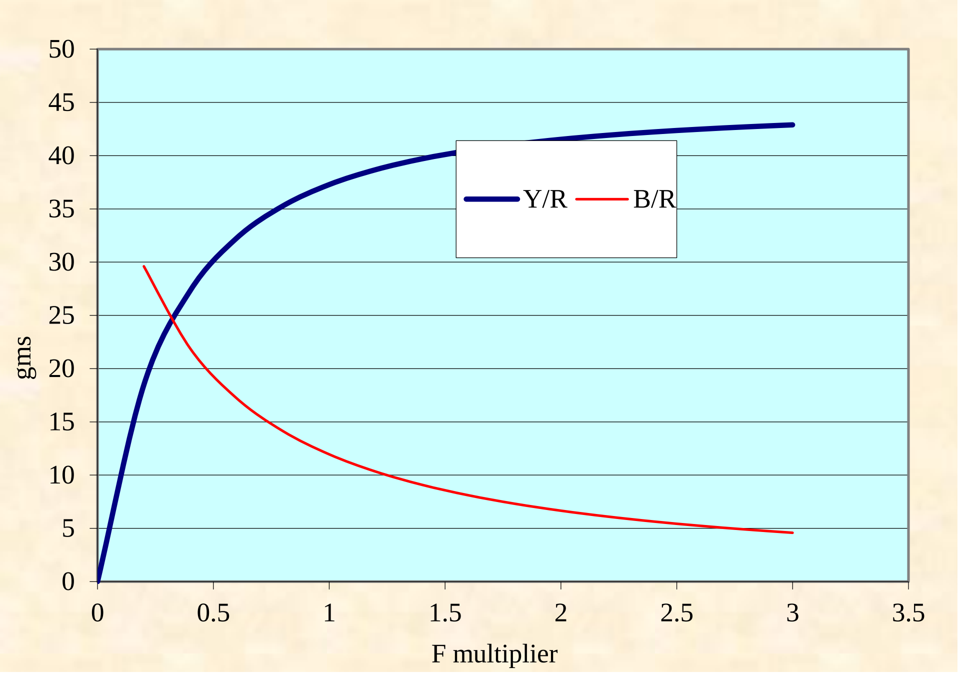
Note: Data for three years are pooled and presented.

Figure 4.15. Relative yield to present yield of females' *P. monodon* collected during January 2011 to December 2013 from Digha coast.



Note: Data for three years are pooled and presented.

Figure 4.16. Yield per recruit and biomass per recruit of females *P.monodon* collected during January2011 to December 2013 from Digha coast.



Note: Data for three years are pooled and presented.