Population dynamics and the management of the goat fish
*U*penaeus sulphureus* from the Bay of Bengal

M.G. Mustafa* and M. Shahadat Ali
Department of Zoology, University of Dhaka, Dhaka 1000, Bangladesh
*Corresponding author present address : WorldFish Center, House # 22/B, Road 7, Block F, Banani,
Dhaka 1213, Bangladesh

Abstract
FiSAT program was used to estimate population parameters of *U*penaeus sulphureus* from length frequency data. L∞ and K were found to be 22.7 cm and 0.98 year\(^{-1}\) respectively. The Wetherall plot provided an estimate of L∞ and Z/K were 21.585 cm and 4.759 respectively. The annual rate of natural and fishing mortality were estimated as 1.91 and 3.86 respectively. The exploitation rate was 0.668. The selection pattern Lc was 10.824 cm. Recruitment pattern suggest of two uneveNES seasonal pulses in March-April and August-October. Peaks appeared in August-October. Maximum yield could be achieved simultaneously increasing length at first capture to 10.0 cm. The length weight relationship was found to be \(W=0.03065 \times L^{2.8326}\). Highest yield and price could be achieved by decreasing the fishing mortality to 0.9 coefficient rate.

Key words : Population dynamics, *U*penaeus sulphureus*, Bay of Bengal

Introduction
*U*penaeus sulphureus* is the most abundant among the goat fish species available in the northern Bay of Bengal of Bangladesh. This species usually moves in school. It forms a considerable part of the demersal fishery and accounts for 3% of the total biomass. Significance of this fish in the fishery of Bangladesh coast has been indicated by several authors (Chowdhury et al. 1979, Khan et al. 1989, Lamboeuf 1987, Mohiuddin et al. 1980, Mustafa et al. 1987, Mustafa and Khan 1993, Quddus and Shafi 1983, Saetre 1981). They contributed 2.4% in 10-20m, 47.8% in 20-50m, 35.7% in 50-80m and 14.2% in 80-100m depth zone (Lamboeuf 1987). This study deals with the growth parameters (L∞, K) of the von Bertalanffy equation, instantaneous mortality rates (Z, M and F), selection pattern (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 identifying appropriate management policy.

Materials and methods
The study was conducted from April'95 to March'97. Length-frequency and length-weight data were collected for present study from commercial fishing trawlers
immediately after return from trips and research vessels R/V Anusandhani within the continental shelf of Bangladesh. Sampling were done monthly and all length-frequency data for each month were pooled and pooled data were entered in computer through FiSAT program. The gear used was a fish trawl. The mesh size of cod end was 32.0 mm. Trawling depth varying from 20m to 90m. Total length from the tip of the notch to the tip of the tail at two centimeter intervals for a total of 16,888 specimen were measured on board immediately after the catch as well as in the landing center. Length frequency data used for population dynamics analysis are given in Table1.

FiSAT (FAO-ICLARM Stock Assessment Tools) as explained in detail by Gayanilo et al. (1994) is the software resulted from the merging of its predecessors, the complete ELEFAN package developed at ICLARM and LFSA developed by FAO were used to analyzed the length frequency data. FiSAT was developed mainly for the detailed analysis of length frequency data. Length-frequency based computer programs ELEFAN I and ELEFAN II were used to estimate population parameters. \( L_\infty \) and \( K \) values were estimated by ELEFAN I (Pauly and David 1981, Saeger and Gayanilo 1986). Additional estimate of \( L_\infty \) and \( Z/K \) value was obtained by plotting \( L - L' \) on \( L \) (Wetherall 1986 as modified by Pauly 1986).

The growth performance of \( U. \) sulphureus population in terms of length growth was performed based on the \( \phi' \) index of Paul and Munro (1984).

\[
\phi' = \log_{10} K + 2\log_{10} L_\infty \quad \text{---------------------------------------- (1)}
\]

where \( K \) and \( L_\infty \) (von Bertalanffy growth parameters) were used.
The ELEFAN II estimate \( Z \) from catch curve based on equation as :

\[
Z = \frac{K (L_{\infty} - L)}{L - L'} \quad \text{---------------------------------------- (2)}
\]

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 \( L \) (Beverton and Holt 1956). The parameter \( Z \) of equation 2 estimated using the routine ELEFAN II (Pauly 1983, Saeger and Gayanilo 1986) which based on the methods of catch curve analysis (Robson and Chapman 1961) and an extract solution found using the recursive model, i.e.

\[
\ln (N_i/(e^{-z_i d_i})) = a - z_i + 1 * t_i \quad \text{---------------------------------------- (3)}
\]

where \( d_i \) is the time needed to grow through class i, \( t_i \) the relative age corresponding to the lower limit of class i, \( z_i \) is an initial value of \( Z \) and \( N_i \) is the number of fishes (Pauly 1984). The parameter \( M \) was estimated using the empirical relationship derived by Pauly (1980), i.e.

\[
\log_{10} M = 0.0066-0.279 \log_{10} L_\infty + 0.6543 \log_{10} T + 0.463 \log_{10} T \quad \text{---------------------------------------- (4)}
\]

where \( L_\infty \) is expressed in cm, \( T(\degree \text{C}) \) is the mean annual environment temperature (here it was taken as 28\(^\degree \text{C} \)). The estimate of \( F \) was taken by subtraction of \( M \) from \( Z \). An additional estimate of \( Z \) value was obtained by ELEFAN II (Jones and van Zalinge 1981). The exploitation ratio \( E \) was then computed from expression:

\[
E = F/Z = F/(F+M).
\]
Population dynamics of *Upenaeus sulphureus*

"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 separation of normal distribution (NORMSEP) program for the separation of mixture of normal distributions into their components have been accessed within ELEFAN II.

Relative yield-per-recruit (Y'/R') and relative biomass-per-recruit (B'/R') was obtained from the estimated growth parameter and probabilities of capture by length (Pauly and Soriano 1986). Here, yield (Y) per recruit (R) was calculated as relative yield-per-recruit (Y'/R') and relative biomass-per-recruit (B'/R').

The analysis provide 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 % 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.

Yield-per-recruit analysis provide a series of biomass-per-recruit for specified values of the natural mortality (M). Yield-per-recruit isopleths were studied using this biomass-per-recruit of same value against exploitation rate and selectivity (Lc/L∞) to get isopleths line of maximum yield-per-recruit.

**Length-weight relationship**

Total length in centimeter and total weight in gram were recorded. The relationship between length-weight was calculated by a computer program followed after Sparre (1985). The intercept (a) and slope (b) of regression line were calculated by using the following formula:

\[
\log W = \log a + b \log L,
\]

\[
W = a \cdot L^b.
\]

**Virtual population analysis (VPA)**

The total landing were distributed over length groups. The predictive counter part of VPA and cohort analysis published by Thompson and Bell (1934) and Gulland (1965). It is reviewed by Jones (1984) and Pauly (1984). An estimated length structured Virtual Population Analysis of *U. sulphureus* was carried out.

**Yield and stock prediction**

Thompson and Bell (1934) routine were used to analyzed yield and stock prediction for *U. sulphureus*. This model combines features of Beverton and Holt's (1957) Y/R model with those of VPA, and used to analyzed single or several species for single or several fleet.
Results and discussion

Growth parameters

Extreme value theory was applied to predict $L_{\infty}$ from extreme values. Predicted extreme length was found 22.64 cm. At 95% confidence interval predicted extreme length lies between 20.74 cm and 24.53 cm. Scan of $K$ value was performed to predict growth constant $K$ (year$^{-1}$). Predicted growth constant $K$ (year$^{-1}$) was found to be 0.98.

The growth parameters, $L_{\infty}$ and $K$ of the *U. sulphureus* have been estimated for 1995-97. $L_{\infty}$ and $K$ were found to be 22.7 cm and 0.98 per year respectively. For these estimates through FiSAT the response surface (ESP/ASP) was 0.199 for main line (solid line) and 0.14 for secondary line (dotted line). The growth curves with those parameters are shown over its restructured length distribution in Fig.1. The $t_0$ value was taken as 0. $L_{\infty}$ and $K$ (year$^{-1}$) has been reported for *U. sulphureus* were 22.0 cm and 1.1 (year$^{-1}$) respectively by Mustafa (1993).

![Growth curves](image_url)

Fig 1. Growth curve superimposed over the restructured length-frequency data of *Upenaeus sulphureus* from the Bay of Bengal

Estimation of $L_{\infty}$ and $Z/K$

The modified Wetherall plot (1986) analysis yielded the regression line $Y = 3.75 + (-0.174)X$ and $r = 0.975$. Based on these points from 11.5 cm show a good linear relationship and that points of lengths below 20.5 cm smoothly approach the extended line from which $L_{\infty} = 21.585$ cm and $Z/K = 4.759$ were obtained (Fig. 2).
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**Growth performance**

Growth performance index obtained here are $L_\infty = 22.7$ cm and $K = 0.98$ year$^{-1}$ giving $\phi' = \log_{10} 0.98 + 2 \log_{10} 22.7 = 2.70$. The nine other pairs of growth parameters in Table-2 give a mean $\phi'$ value of 2.571 is well within a 95% confidence interval of $\phi'$ based on literature data. The results obtained here are therefore not in disagreement with other growth studies of *U. sulphureus*.

**Mortality**

The mortality rates $M$, $F$ and $Z$ computed for the *U. sulphureus* were 1.91, 3.86 and 5.77 respectively. Fig. 3 presents the catch curve utilized in the estimation of $Z$. The darkened circle represent the points used in calculation $Z$ via least squares linear regression. The correlation co-efficient for the regression was 0.999 ($a = 15.63$ and $b = -5.72$). Right hand limb of the catch curve was considered. The fishing mortality rates taken by subtraction of $M$ from $Z$ and was found to be 3.86. These estimates generally agree with what little information is available in the literature (*Kh vittatus* (Zeiglar 1979). The Jones and van Zalinge plot (1981) yielded the regression line $Y = -4.13 + (5.741) \times X$ and $r = 0.999$. Based on these points from 12.25 cm show a good linear relationship and that points of lengths below 18.25 cm smoothing approach the extended line from which $Z = 5.741$ was obtained.
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. Mustafa (1993) have stated that the rate of exploitation for the stock of $U. sulphureus$ in Bangladesh marine water was found to be 0.82 on the basis of length frequency data. From these value, the stock of $U. sulphureus$ of Bangladesh coast appears to be over fishing.

Selection pattern

The length at first capture ($L_c$) from "Selection curve" were found to be 9.85, 10.824 and 11.798 for escapement factor $L_{25}$, $L_{50}$ and $L_{75}$ respectively. Mustafa (1993) reported that the selection ($L_{50}$) was 11.073 cm on the basis of the net used by the research vessel (Anusandhan) from the Bay of Bengal, Bangladesh.

Recruitment pattern

Recruitment pattern suggestive of two uneven seasonal pulses in March-April and August-October. Peaks appeared in August-October. It appears from original pattern of recruitment with superimposed normal distribution that 47.01% this species is recruited during March-April and 52.99% recruited during August-September.

Yield-per-recruit and biomass-per-recruit

The yield-per-recruit and biomass-per-recruit were determined as a function of the exploitation rate assuming $L_c/L_\infty = 0.4768$ and $M/K = 1.9489$. The present exploitation rate 0.67 which was exceeded the optimum exploitation ($E_{\text{max}}$) 0.57. Fig. 4 shows the yield-per-recruit isopleths diagrams of the various length at entry for $U. sulphureus$ species into the fishery based on different values of $E$ and a constant value of $M = 1.91$. The discontinued curves indicate 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 $E = 0.56$ and $L_c = 10.0$ cm in the yield-per-recruit diagram was so called potential yield-per-recruit. Hence, the value of $L_c = 10.0$ cm for 0.75 year 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 $L_c$ and $F$. However this might cause a significant depletion of spawning stock. Hence, about 17.37% of the species entered in to the fishery less then sustainable length ($TL<10.0$ cm). Present length at first entry was 5.0 cm. It is therefore recommended that maximum yield could be attended by simultaneously increasing the length at first capture to length at MSY 10.0 cm.
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Length-weight relationship

From the regression analysis of the length and weight the relationship was found to be $W = 0.03065 L^{2.8328}$.

Virtual population analysis

An average value of $F(L > 5.0 \text{ cm})$ and $E$ was obtained 0.969 and 0.337 respectively. $L_{\infty} = 22.7$, $K = 0.98$, $M = 1.91$, $F = 3.86$, $a = 0.03065$ and $b = 2.8328$ were used as inputs to a VPA. The $t_0$ value was taken a 0. The virtual population analysis produced for *U. sulphureus* with those parameters are shown in Fig. 5. Highest exploitation was observed between 10.0 and 19.0 cm length class.

Yield and stock prediction

Yield, Biomass and Value were determined as a function of the growth parameters ($L_{\infty}$ 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 highest yield and price could be attended by simultaneously decreasing the fishing mortality to 0.9 coefficient rate (Fig. 6).
Fig. 5. Length-cohort analysis of pooled data of *U. sulphureus*.

![Fig. 5](image)

Fig. 6. Thompson and Beil yield stock prediction analysis of *U. sulphureus*.

![Fig. 6](image)

Table 1. Length-frequency data used for estimating population parameters in goat fish (*Upenaeus sulphureus*) caught in the Bangladesh EEZ (April’95 - March’97)

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<th>Sep</th>
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Population dynamics of *Upenaeus sulphureus*

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Table 2. Growth parameters of *Upenaeus sulphureus* in various areas of the Indo Pacific region

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<th>K</th>
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References

M.G. Mustafa and M. Shahadat Ali


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