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Population dynamics and the management of the Indian mackerel *Rastrelliger kanagurta* from the Bay of Bengal

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Abstract
FiSAT program was used to estimate population parameters of *Rastrelliger kanagurta* from length frequency data. L∝ and K were found to be 27.4 cm and 0.90 $year^1$ respectively. The Wetherall plot provided an estimate of L∝ and Z/K were 26.7 cm and 4.683 respectively. The annual rate of natural and fishing mortality were estimated as 1.71 and 3.21 respectively. The exploitation rate was 0.652. The selection pattern L_{50} was 18.09 cm. Recruitment pattern suggests two seasonal pulses one in March-May and another in September-October. Peak recruitment appeared in March-May. Maximum yield could be achieved by decreasing length at first capture to 13.0 cm. The relationship between total length and body weight was found to be $W = 0.01583 L^{2.8952}$. Yield and Stock prediction analysis suggested that highest yield and price could be achieved by decreasing the fishing mortality to 2.0 coefficient rate.

Key words : Population dynamics, Indian mackerel, Bay of Bengal

Introduction

The Indian Mackerel (*Rastrelliger kanagurta*) is seasonal, appearing in the fishery and the spawning concentrations have been taken in large quantities on the Middling fishing ground (West 1973). The actual sizes of these resources is not known, but indications suggest the presence of these in commercial quantities. Mackerel, *Rastrelliger kanagurta* forms 0.67% of the total catch in the Bay of Bengal during 1989-90 (Mustafa and Khan 1993). However, the fishery is concentrated in the deeper water at the depth range of 40-75m. According to the results of pelagic trawl survey with the FAO/Norwegian Research vessel Dr. Fridof Nansen, the higher concentration was observed in approximate position 20° 15′ N and 91° 20′ E in the Bay of Bengal (Chowdhury *et al.* 1979). According to the bottom trawl survey results of R/V Anusandhani, the standing biomass of *R.kanagurta* accounted 1836 ±42 tons of which 10.5% was distributed in 10 - 20 m, 10.8% in 20-50 m, 21.6% in 50-80 m and 57.2% in 80-100 m (Lamboeuf 1987). The importance of this fishery is also indicated by Hossain (1970), Khan *et al.* (1983 & 1989), Lamboeuf (1987), Mustafa and Khan (1993), Mustafa *et al.* (1996) and Shafi and Quddus (1982). The mackerel (*Rastrelliger kanagurta*) are the most abundantly caught species in the fisheries of India, are not very important in the Bay of Bengal area under consideration.

Management issues such as determination of the state of fishing and the optimum number of trawlers is related to the question of how the abundance of the various fin fish species fluctuates in the time and how they are distributed within the shelf area. Knowledge of life cycle pattern and population dynamics of the commercial important fish species is essential when determining a management strategy and subsequent recruitment of the offspring to the fishery 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. Recruitment to the fishery expresses itself by an increase in the catch per unit of effort and a decrease in the average size of the fin fishes.

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. The gear used was a fish trawl. The mesh size of cod end was 32 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 3244 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 Table 1. Samplings were done monthly and all length-frequency data for each month were pooled and pooled data were entered in computer through FiSAT program.

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_∞ and K values were estimated by ELEFAN I (Pauly and David 1981, Saeger and Gayanilo 1986). Additional estimate of L_∞ and Z/K value was obtained by plotting L - L' on L (Wetherall 1986 as modified by Pauly 1986).

The growth performance of *Rastrelliger kanagurta* population in terms of length growth was performed based on the ϕ' index of Pauly and Munro (1984).

$$\phi' = \text{Log}_{10}K + 2\log_{10}L_\infty \quad (1)$$

where K and L_∞ (von Bertalanffy growth parameters) were used.

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

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

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,;

$\ln (Ni/(-e^{-zj\,dti})) = a - zj + 1 * ti$ -- (3)

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.

$Log10M = 0.0066 - 0.279 Log10L\infty + 0.6543 Log10 + 0.463 Log10T$ -------------- (4)

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 ELEFAN II (Jones and van Zalinge 1981). The exploitation ratio E was then computed from 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 was 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 ($Lc/L\infty$) 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 weight = log a + b log length, $W = a \cdot L^b$.

Virtual population analysis (VPA)

The total landing were 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 *R. kanagurta* was carried out.

Yield and stock prediction

Thompson and Bell (1934) routine were used to analyzed yield and stock prediction for *R. kanagurta.* 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.

Table 1. Length-frequency data used for estimating population parameters in Indian mackerel (*Rastrelliger kanagurta*) 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
11					1							
21					10							1
13				1	5	2						18
14	4			1	2	1			1			20
15	3	8		2	1	6		8	24			10
16	14	6		11	1	7		1	163	4	3	4
17	20	5	1	20	8	44	6	4	179	13	55	15
18	22	23	4	8	10	69	58	34	39	5	60	13
19	29	57	3	2	4	57	167	115	61	26	10	2
20	13	27	6		3	21	41	73	131	7	12	1
21	10	6	2		0	6	4	12	21		49	1
22	5	22	1		1	2	1	0			41	
23	1	11			1	3		1			4	
24		2				4						
25						1						
26						1						
Length (cm)	Apr' 96	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan' 97	Feb	Mar
11					1							
21					15	5						
13					13	54						
14	3	4			13	10						
15	1	6			2	3		3				
16	2	7	1		1	1		10	1		1	
17	13	12	2	3	3		2	13	1		5	1
18	20	17	2	1	6		48	18	7	1	15	2
19	27	14	5	1	5		98	15	17	3	25	4
20	10	2	15	2	7		42	4	12	6	50	6
21	3	10	7	6	2		7	2	2	2	60	12

22	1	7	2	2			0	1	1	1	22	8
23		2		1			1		1		11	5
24		1									2	7
25												2
26												

Results and discussion

Growth parameters

Extreme value theory was applied to predict L∝ from extreme values. Predicted extreme length was found 27.55 cm. At 95% confidence interval predicted extreme length lies between 25.72 cm and 29.37 cm. Scan of K values was performed to predict growth constant K ($year^{-1}$). Predicted growth constant K ($year^{-1}$) was found to be 0.90. The growth parameters, L∝ and K of the *R. kanagurta* have been estimated for 1995-97. L∝ and K were found to be 27.4 cm and 0.90 per year respectively. For these estimates through FiSAT the response surface (ESP/ASP) was 0.280 for main line (solid line) and 0.165 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.

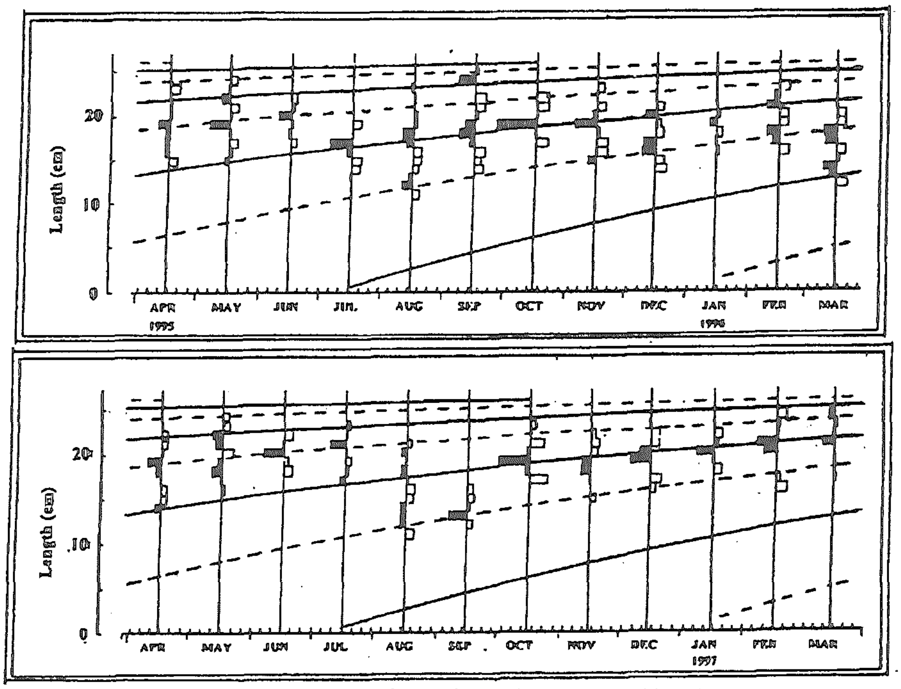

Fig. 1. Growth curve superimposed over the restructured length-frequency data of *Rastrelliger kanagurta* from the Bay of Bengal.

Estimation of L∝ and Z/K

The modified Wetherall plot (1986) analysis incorporated in the FiSAT yielded the regression line Y = 4.70 + (- 0.176)*X and r = 0.99. Based on these points from 18.5 cm show a good linear relationship and that points of lengths below 24.5cm smoothly approach the extended line from which L∝=26.7cm & Z/K=4.68 were obtained.

Growth performance

Growth performance for *R. kanagurta* was 2.83. Growth performance index value for *R. kanagurta* (ϕ'=2.83) is well within the range 2.71-3.11 observed in this species (Guanco 1991, Bay of Bengal Programme 1985). Growth parameters from studies in Indian waters cover a very wide range of values. The results show K values between 0.6 and 1.90 and L∝ between 25.0 and 38.0 cm. The values obtained in this study of L∝ = 27.4 cm and K= 0.90 are well within the range of values in this area. The mean ϕ' value of L∝ and K for studies in this region is 2.89, and this agree with a value of 2.83 for this study.

Mortality

The mortality rates M, F and Z were found to be 1.71, 3.21 and 4.92 respectively. Fig. 2 presents the catch curve utilized in the estimation of Z. The darkened quadrilateral represent the points used in calculation Z via least squares linear regression. The correlation co-efficient for the regression was 0.999 (a=15.18 and b= - 4.92). The Jones and van Zalinge plot (1981) yielded the regression line Y=-1.95+ (4.943) * X and r=0.996. Based on these points from 19.25 cm show a good linear relationship and that points of lengths below 26.25 cm smoothing approach the extended line from which Z=4.943 was obtained.

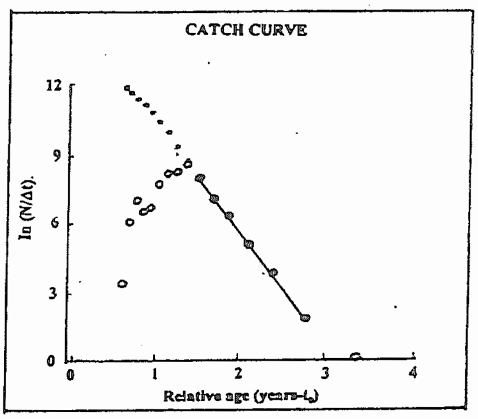

Fig. 2. Length-converted catch curve of *Rastrelliger kanagurta*

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 0.652. From these value, the stock of *R. kanagurta* of Bangladesh coast appears to be over fishing.

Selection pattern

The length at first capture (Lc) from "Selection curve" were found to be 17.384, 18.346 and 19.308 for escapment factor L_{25}, L_{50} and L_{75} respectively.

Recruitment pattern

Recruitment pattern suggestive of two uneven seasonal pulses in March-May and September-October. Peaks appeared in March-May. It appears from original pattern of recruitment with superimposed normal distribution that this species is recruited in the fishery mainly during March-May.

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 $Lc/L\infty = 0.66$ and $M/K = 1.90$. Fig. 3 shows the yield-per-recruit isopleths diagrams of the various length at entry for *R. kanagurta* species into the fishery based on different values of E and a, constant value of M=1.71. 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=0.654 and Lc=13.0 cm in the yield-per-recruit diagram was so called potential yield-per-recruit. Hence, the value of Lc=13.0 cm for 0.9 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 Lc and F. However this might cause a significant depletion of spawning stock. Hence, about 1.08% of the species entered in to the fishery less then sustainable length (TL<13.0 cm). Present length at first entry was 11.0 cm. It is therefore recommended that maximum yield could be attended by simultaneously increasing the length at first capture to length at MSY 13.0.0 cm.

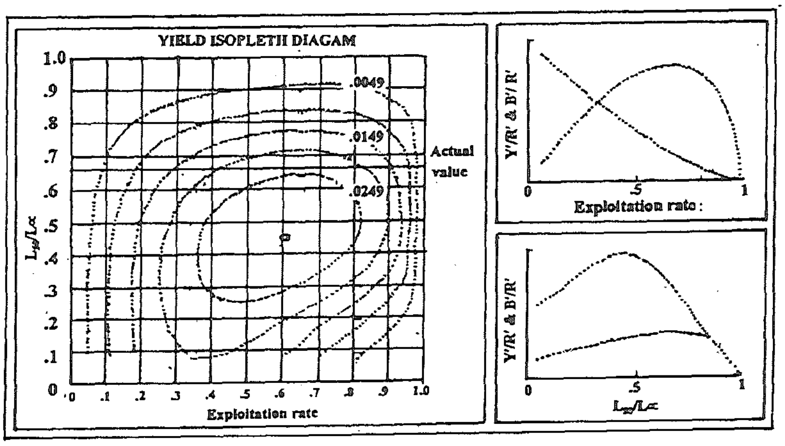

Fig. 3. Yield per recruit isopleths diagram of *Rastrelliger kanagurta*

Length-weight relationship

From the regression analysis of the length and weight the relationship was found to be $W=0.01583.\ L^{2.8952}$. The power function for length-weight relationship estimated in this study seems to be in good agreement with other findings, i.e., Bay of Bengal Programme (1985), Gomal (1988) and Luther (1973).

Virtual population analysis

An average value of F (L>11.0 cm) and E were obtained 0.579 and 0.253 respectively. $L\infty$ = 27.4 cm, K = 0.90, M = 1.71, F = 3.21, a = 0.01583 and b = 2.8952 were used as inputs to a VPA. The t_0 value was taken as 0. The virtual population analysis produced for *R. kanagurta* with those parameters are shown in Fig. 4. Highest exploitation was observed between 16.0 cm and 22.0 cm length class.

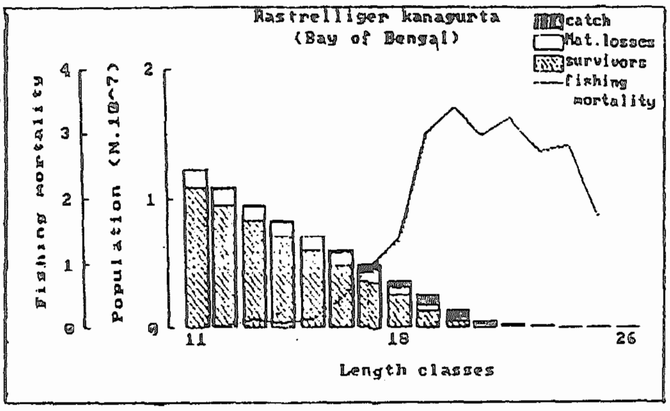

Fig. 4. Length-cohort analysis of polled data of *Rastrelliger kanagurta.*

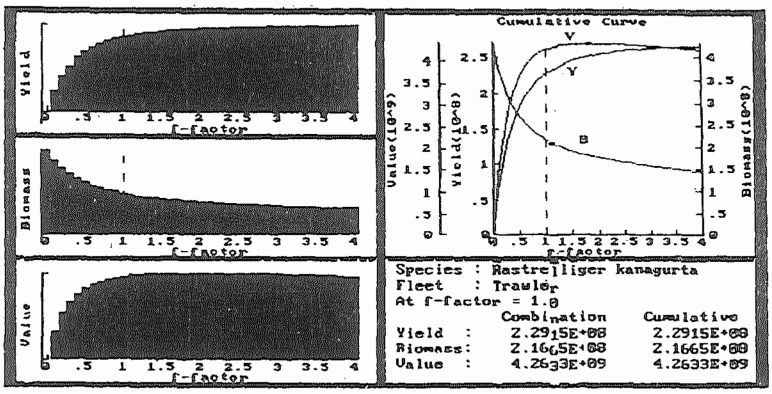

Fig. 5. Thompson and Bell yield stock prediction analysis of *Rastrelliger kanagurta.*

Yield and 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 highest yield and price could be attended by simultaneously decreasing the fishing mortality to 2.0 coefficient rate (Fig. 5).

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