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Population Dynamics of Indian Shrimp (*Penaeus indicus*, Milne Edwards) on the West Coast of Sri Lanka

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Abstract

Monthly length-frequency data of *Penaeus indicus* collected at Negombo and Chilaw during 1979-1981 were analyzed to trace von Bertalanffy growth curves. The asymptotic length and the growth constant were estimated to be 5.65 cm (carapace length) and 1.8 $year^{-1}$, respectively. Based on these growth parameters, the total mortality rate during the study period was determined to be 4.41 $year^{-1}$. Natural mortality rate was calculated as 3.04 and hence fishing mortality rate (F) was 1.37. Recruitment was continuous with two peaks per year. From the study, the maximum lifespan of *P. indicus* is about two years. The yield-per-recruit analysis shows that high yield-per-recruit values are obtained at high fishing mortalities which may not be biologically and/or commercially appropriate.

Introduction

Thirty-one species of penaeid shrimp have been recorded so far from Sri Lankan waters (De Bruin 1970). Of these, commercially the most important is *Penaeus indicus* Milne Edwards. Several studies have been carried out on various aspects of its taxonomy, biology, population dynamics, etc., in the Indo-Pacific region (Menon 1957; Subramaniam 1965; Mohamed et al. 1981).

P. indicus is a valuable fishery resource in the west coast of Sri Lanka but it shows erratic fluctuations from year to year. De Bruin (1965, 1970, 1971) described the fluctuating pattern of the fishery for this shrimp in the estuarine systems of Panadura and Negombo. In the late 1970s, the standing stocks of certain species of penaeid shrimp were estimated using the De Lury method (Siddeek 1978). In the present study, an attempt is made to estimate the population dynamics of *P. indicus* in order to devise a system of management for its fishery in Sri Lankan waters.

Materials and Methods

Length-frequency data of *P. indicus* were collected from commercial catches during the period February 1979 to February 1981 from Negombo and Chilaw shrimp landing centers (Fig. 1). Each trawler was assigned a number in accordance with its landing time.

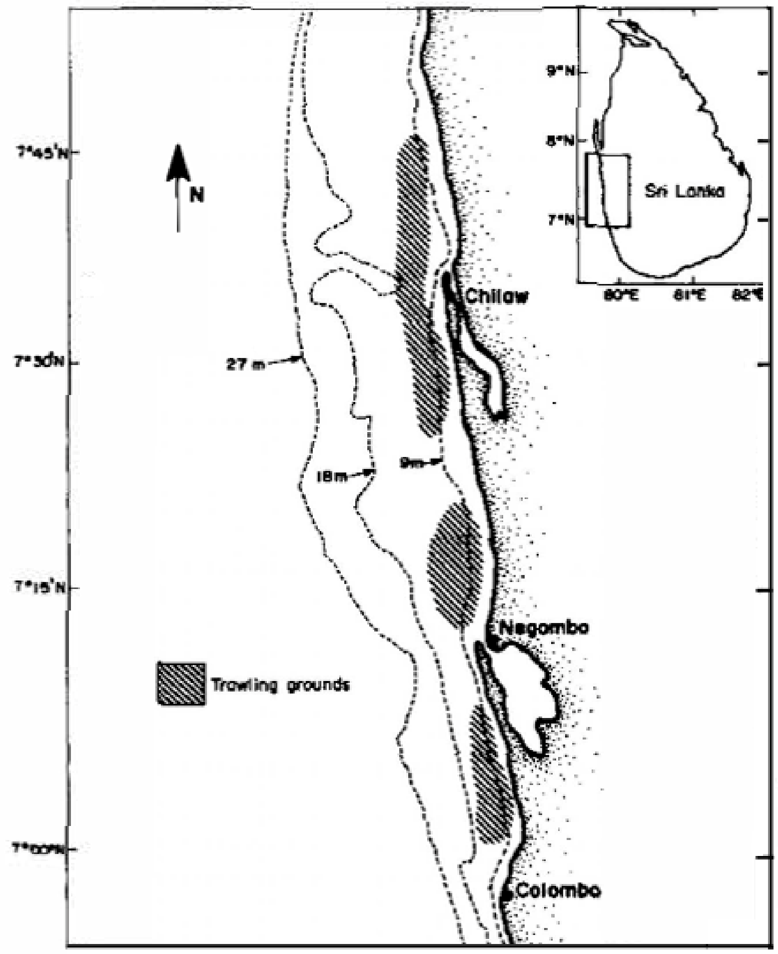

Fig. 1. Shrimp trawling areas along the west coast of Sri Lanka from Colombo to Chilaw.

According to a random number chart, fishermen of the selected trawlers were interviewed. The number of trips made to the trawling grounds was taken as the fishing effort. Carapace lengths were measured to the nearest mm. The von Bertalanffy growth parameters (growth constant (K) and asymptotic length (L_∞)) were estimated using the ELEFAN I computer program (Pauly and David 1981). The data used were pooled data of 1979-1980 as there was no statistically significant difference between similar months of each year. The asymptotic length was also estimated through a Ford-Walford plot. Total mortality (Z) was estimated using the length-converted catch curve method which has been incorporated into the ELEFAN II computer program (Pauly et al. 1984) and using Beverton and Holt's (1956) formula. The length-converted catch curve method involves plotting natural logarithms of numbers in a certain size class per time interval needed to grow through the size class ($N/\Delta t$) against the corresponding relative age assuming the age at size zero ($t_0 = 0$). Natural mortality (M) was estimated using Pauly's (1980) equation and the Beverton and Holt (1959) method. A yield-per-recruit analysis was performed based on Beverton and Holt (1957). Exploitation rate was determined following Gulland (1971).

Results

Growth Parameters (L_∞, K)

Table 1 shows the length distributions of *P. indicus* from February 1979 to February 1981. The data from corresponding months of the two years were pooled and analyzed using ELEFAN I and the resulting growth pattern is given in Fig. 2. L_∞ was calculated to be 5.6 cm carapace length, with $K = 1.8$ year^{-1}.

Recruitment Pattern

By projecting the length-frequency data backward into the time axis down to zero length, a frequency distribution reflecting the pattern of recruitment was worked out from the ELEFAN II program. Results are shown in Fig. 3. Full recruitment, that is the smallest size at which all shrimps are caught by the gear, was estimated to be at 2.1 cm carapace length.

Table 1. Percentage length frequencies of *P. indicus* during the study period (carapace length).

Length group (cm)	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
1.00 — 1.20	—	1.242	—	—	—	—	—	—	—	—	—	—
1.25 — 1.45	—	0.311	—	—	—	—	—	—	—	—	—	—
1.50 — 1.70	—	1.242	—	—	—	—	—	—	—	—	—	—
1.75 — 1.95	1.653	6.832	1.075	—	—	0.968	—	0.275	0.575	—	—	—
2.00 — 2.20	6.198	7.453	6.452	0.971	5.741	7.419	8.642	9.066	8.046	1.403	—	—
2.25 — 2.45	23.554	2.950	11.290	7.767	16.429	8.387	23.148	19.505	24.138	8.617	—	—
2.50 — 2.70	26.860	9.938	17.204	11.974	18.571	5.161	26.852	23.901	26.437	16.232	—	1.875
2.75 — 2.95	8.678	18.944	22.043	22.330	19.286	10.605	17.593	17.857	10.920	20.441	—	7.500
3.00 — 3.20	9.901	27.640	25.806	29.450	21.429	15.161	10.494	12.637	6.322	15.631	—	20.625
3.25 — 3.45	8.264	9.627	9.677	14.563	10.714	20.000	3.395	6.319	6.322	17.234	—	11.250
3.50 — 3.70	4.545	7.764	3.226	4.531	5.714	9.032	4.012	5.769	5.172	10.621	—	25.625
3.75 — 3.95	1.240	2.484	1.613	5.502	1.429	6.452	2.469	2.747	5.172	4.208	—	18.750
4.00 — 4.20	4.132	1.242	0.538	1.618	—	10.328	1.543	0.549	1.149	2.605	—	10.000
4.25 — 4.45	1.653	0.621	1.075	0.971	—	4.194	1.235	1.099	4.023	2.204	—	1.250
4.50 — 4.70	2.279	0.311	—	—	0.714	1.290	0.617	0.275	1.149	0.802	—	0.625
4.75 — 4.95	0.413	—	—	—	—	—	—	—	—	—	—	1.250
5.00 — 5.20	0.826	0.932	—	—	—	—	—	—	—	—	—	1.250
5.25 — 5.45	0.418	0.621	—	—	—	—	—	—	0.575	—	—	—
5.50 — 5.70	—	—	—	—	—	—	—	—	—	—	—	—
5.75 — 5.95	—	—	—	—	—	—	—	—	—	—	—	—

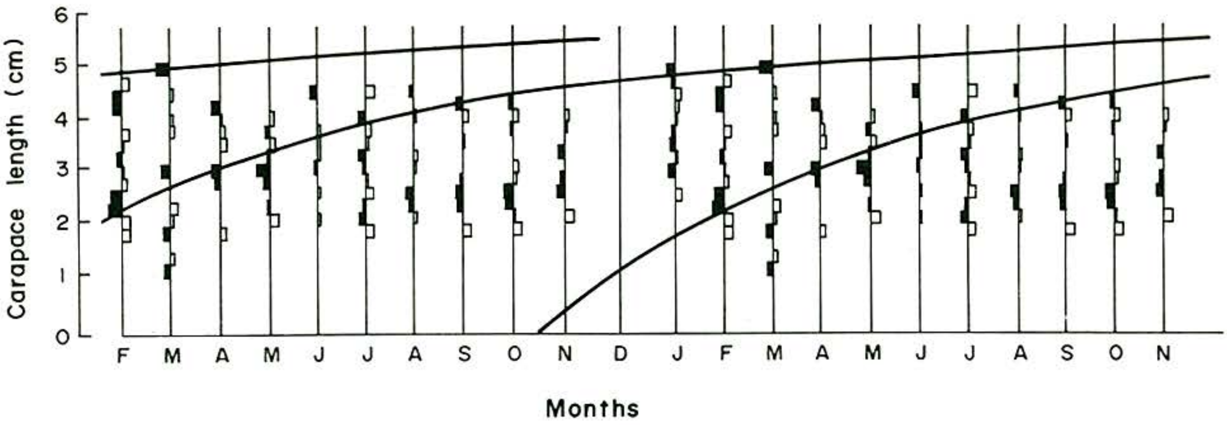

Fig. 2. Growth curve constructed on the size-frequency composition of *Penaeus indicus* given in Table 1.

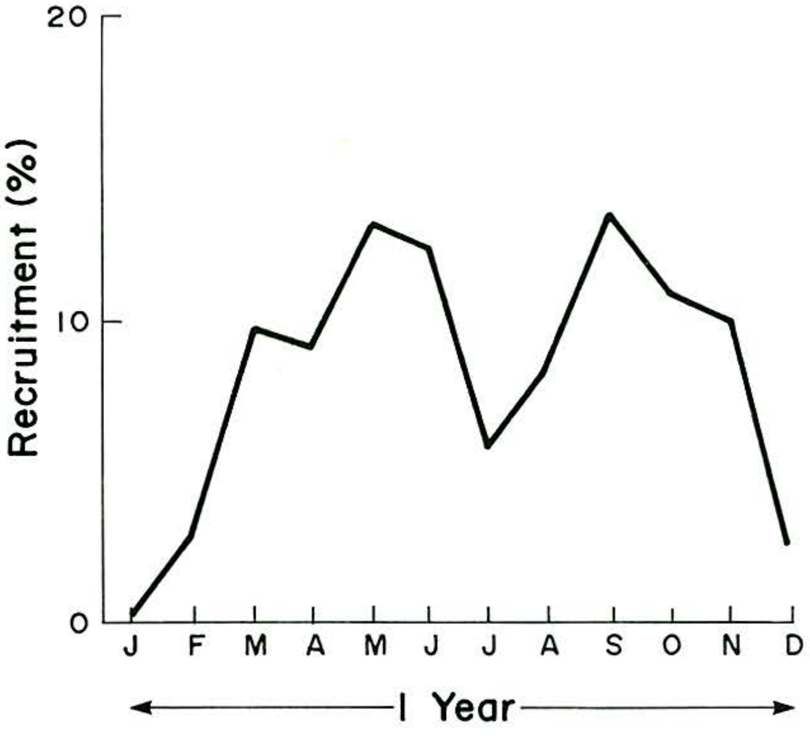

Fig. 3. Recruitment pattern for *Penaeus indicus* constructed using the ELEFAN II program.

This analysis was performed by ELEFAN II and the results are shown in Fig. 4; from the slope of the curve, Z was estimated to be 4.41.

According to the Beverton and Holt (1956) method:

$$Z = K \cdot (\overline{L}_{\infty} - L) \cdot (L - \overline{L}')^{-1} \qquad ...1)$$

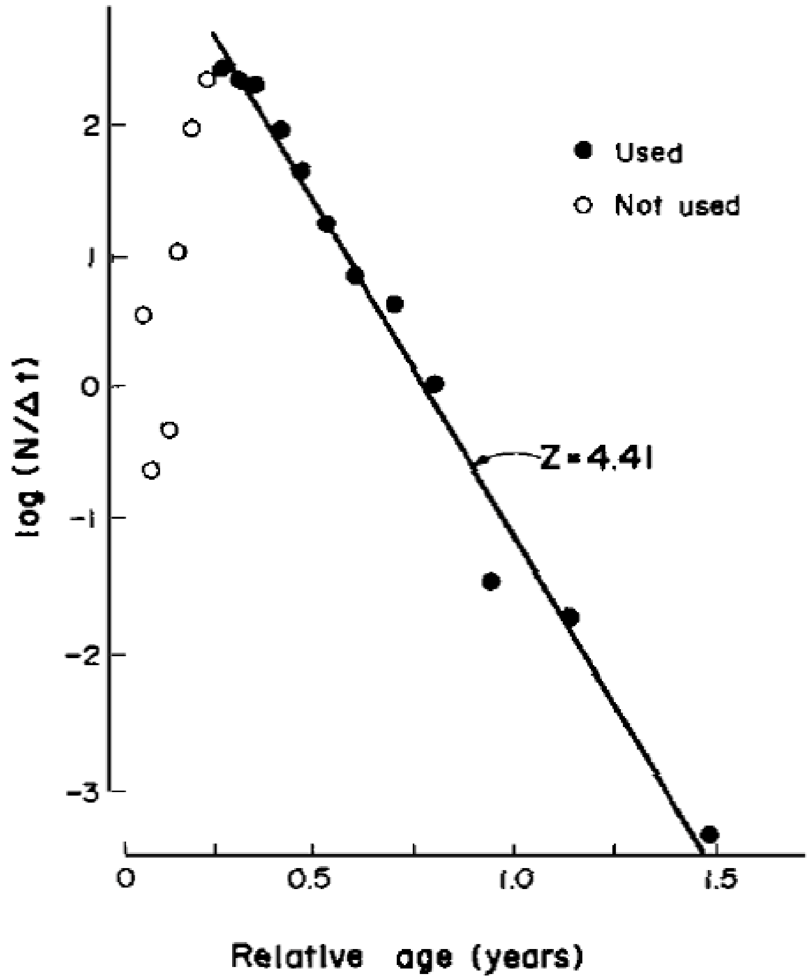

Fig. 4. Length-converted catch curve and mortality estimate for *Penaeus indicus* based on the data on Table 1.

where L_∞ = asymptotic length; $\overline{L}$ = mean length of all shrimp which are fully recruited to the fishery; L' = length at which full recruitment is attained (the first point of the descending limb of the length-converted catch curve was considered as L'); and K = growth constant. All lengths are carapace lengths.

Substituting the values of the parameters estimated above gave:

$$Z = 1.8\,(5.625 - 3.15) \cdot (3.5 - 2.10)^{-1}$$

from which Z = 4.25.

Natural Mortality (M)

According to the Pauly (1980) method, the relationship is:

$$\log_{10}M = -0.0066 - 0.279 \log_{10} TL_\infty + 0.6543 \log_{10}K + 0.4634 \log_{10} T \qquad ...2)$$

where TL_∞ is the asymptotic *total* length; K is the growth constant; and T is the annual mean temperature (°C) of the water in which the stock lives, about 28.5°C. L_∞ was derived from the relationship between total length (X) and carapace length (Y) in the equation:

$$Y = -1.0063 + 0.363\,X \qquad ...3)$$

and was determined to be 18.2 cm. Substituting these values in equation (2) gave M = 3.04.

According to the second method the assumption is that the M/K values should mostly lie in the range 1.5 to 2.5. Thus, for *P. indicus* the values of M should be within the range 2.7 to 4.5, in agreement with the first method.

Fishing Mortality (F)

Using the relationship, Z = F + M, the value of F is 1.37 (= 4.41 - 3.04).

Exploitation Rate (E)

Gulland (1971) suggested that the optimum fishing mortality in an exploited stock should approximate natural mortality. This corresponds to an exploitation rate (E = F/F + M) of approximately 0.5. Using F = 1.37 and M = 3.04 leads to E = 0.31.

This figure suggests that the *P. indicus* stock is not overexploited.

Theoretical Age at Length Zero (t_0)

Using Pauly's empirical equation for t_0 (Pauly 1979), a very approximate estimate of theoretical age at zero length was obtained

$$\log(-t_0) = -0.392 - 0.275 \log L_\infty - 1.038\, K \qquad \ldots 4)$$

from which $t_0 = -0.1$ years.

Yield per Recruit

A yield isopleth diagram was constructed for *P. indicus.* The parameter values used for the derivation of the yield isopleth diagram are given in Table 2. Based on these parameters, yield per

Table 2. Parameter values for the yield isopleth.

Parameter	Definition	Value
L_∞	Asymptotic carapace length	5.65 cm
K	Growth constant	1.8 $year^{-1}$
W_∞	Asymptotic weight	68 g
M	Natural mortality coefficient	3.04
F	Fishing mortality coefficient	variable
t_r	Mean age at recruitment	0.25 year
t_c	Mean age at first capture	variable
t_0	Theoretical age at length zero	−0.1 year

recruit (Y/R) as a function of age at first capture (t_c) and fishing mortality (F) was estimated from equation (5) below. Age at recruitment (t_r) was taken as 0.25 years, corresponding to the age of the smallest shrimp caught. The mean age at first capture (t_c) was taken as 0.46 years, corresponding to the age of all shrimp which are fully recruited to the fishery. The yield isopleth is given in Fig. 5.

$$Y/R = F \cdot \exp(-Mr_2) \cdot W_\infty [Z^{-1} - 3 \cdot \exp(-Kr_1) \cdot (Z + K)^{-1} + 3 \cdot \exp(-2Kr_1) \cdot (Z + 2K)^{-1} - \exp(-3Kr_1) \cdot (Z + 3K)^{-1}] \quad \text{... 5)}$$

where $r_1 = t_c - t_o$, $r_2 = t_c - t_r$, and $Z = F + M$ (Beverton and Holt 1957).

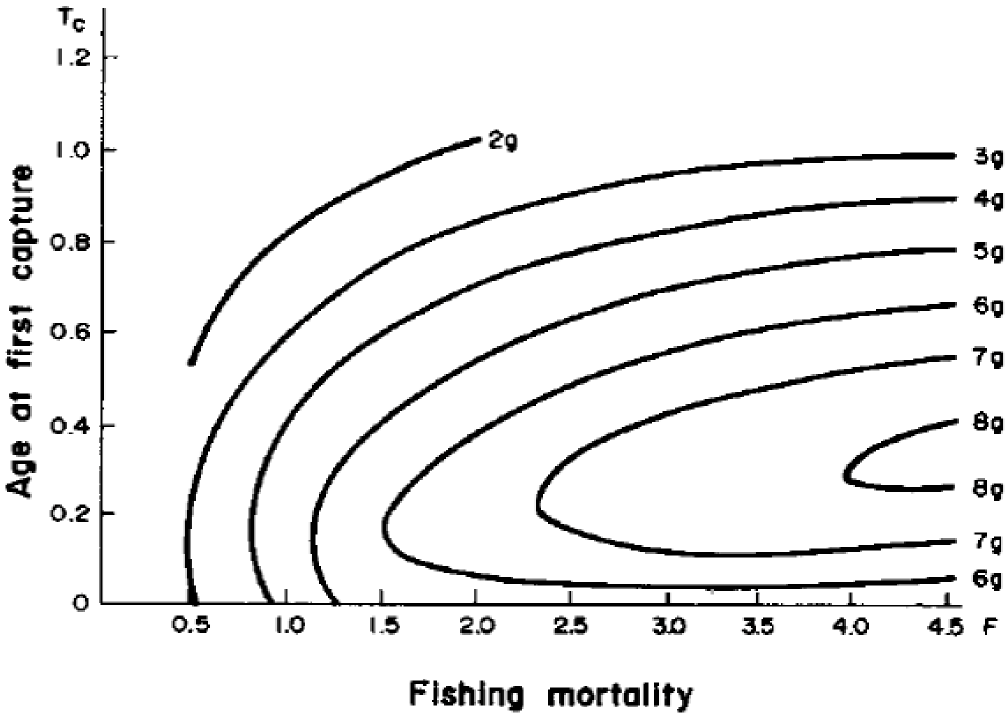

Fig. 5. Yield (in grams) for *Penaeus indicus* as a function of fishing mortality and mean age at first capture.

Discussion

The estimation of different population parameters and yield per recruit of *P. indicus* made in this paper is tentative. The estimation of shrimp growth in nature by any of the presently known methods is difficult. Both immigration and emigration occur; growth estimations based on modal size, length-frequency distribution and mean size are questionable because continuous recruitment of juveniles depresses mean and modal sizes.

The rapid growth implied by $K = 1.8$ and $L_\infty = 5.6$ cm agrees with the results obtained by other workers, e.g., $L_\infty = 4.25$ cm carapace length and $K = 2.34$ for *P. semisulcatus* (Jones and van Zalinge 1981). Shrimp populations with rapid growth have a shorter lifespan than slow growing shrimp populations (FAO 1976). The growth curve suggests that *P. indicus* has a maximum lifespan of slightly above two years.

As shown in Fig. 3, recruitment takes place during most of the year except December to February and July-August. This can be interpreted as a recruitment pattern with two peaks almost equal in magnitude, one around May and the other around October. The southwest monsoon prevails from May to August and heavy rains during this period would lower the salinity in the lagoons. The drop in salinity may cause osmotic stress which may be the cause for offshore migration, which takes place around May.

The estimated values of $Z = 4.24$ using Beverton and Holt equation (1) and catch curve ($Z = 4.41$) fit closely and also appear to lie in an acceptable range. In most parts of the world, shrimp stocks have been subjected to high fishing mortalities and show high Z values, e.g., $Z = 3.56$ for *Metapenaeus dobsoni* (George and Banerji 1965), $Z = 8\text{-}9$ for *Penaeus semisulcatus* (Jones and van Zalinge 1981). The rough estimate of $M = 3.04$ is acceptable, using the approximate method suggested by Beverton and Holt (1959) in which M should lie between 2.7 and 4.5 for $K = 1.8$. However, according to Garcia and Le Reste (1981) M values of penaeid shrimps should be in the range of 2 to 3.

Higher natural mortality values may sometimes be due to predation, as observed in various shrimp populations. A relationship between high growth rate and high natural mortality has been observed for many fish (Beverton and Holt 1959) and such a relationship probably holds for shrimp populations.

The yield isopleth diagram shows that the present F value (1.37) and t_c of 0.46 years give a yield of 4.5 g per recruit and increasing F to a value of 2.5 would give a higher yield of 6 g. It further shows that decreasing the present t_c (0.46 years) to 0.3 years gives a still higher yield of 7 g per recruit. There are no published data regarding age of spawning of *P. indicus* in Sri Lankan waters, but unpublished data (Jayasinghe, pers. comm.) show that spawning begins at around nine months of age. Generally fishermen start exploiting shrimp as soon as they migrate out of the estuarine environment. The mean length, when shrimp are fully recruited to the fishery is 3.15 cm (carapace length) and at this time age is about 5.5 months ($t_c = 0.46$ years). This suggests that increasing F would cause adverse effects on the spawning population because spawning starts at an age of around nine months. Although decreasing t_c leads to a higher yield-per-recruit value, it is not advisable to do so unless we know the real interactions of the shrimp with bycatch species. The estimated values of yield per recruit for different values of F and t_c (Fig. 5) show that high yield can be obtained at high F values, but increasing F to such high values is not biologically appropriate.

The limiting factor is the estimated value of M. In *P. indicus,* M values cannot be estimated by the classical methods due to the unavailability of time-series data on the changes in yearly effort and total mortality. However, if M were 2 instead of the present value of 3 (Fig. 6), a higher yield of 8.5 g per recruit would be possible for the

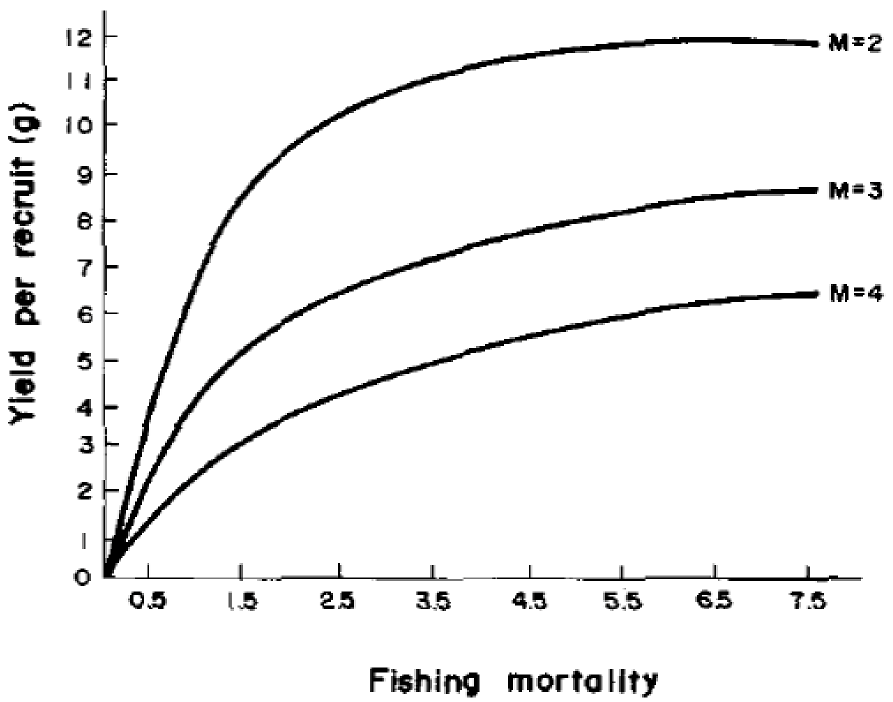

Fig. 6. Yield per recruit as a function of fishing mortality for *Penaeus indicus* for three values of natural mortality.

present F value (F = 1.37); if M were 4 there would be a lower yield of 2.8 g per recruit. Without a clear picture of the stock-recruitment relationship of *P. indicus* over several years, it is difficult to decide conclusively an appropriate value for t_c.

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