Population Dynamics of *Penaeus indicus* on the West Coast of Sri Lanka

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Abstract

Growth and mortality parameters of *Penaeus indicus* at Negombo and Chilaw (Sri Lanka) caught between September 1982 and June 1986 are analyzed on an annual basis using length-frequency data.

The asymptotic lengths for different periods and areas varied from 20.5 to 24.0 cm (total length) and the von Bertalanffy growth constant was between 1.5 and 1.8 per year. Total mortality varied from 2.89 to 4.49 per year. The mean natural mortalities for the whole period of study were 2.7 and 2.6 per year for Negombo and Chilaw, respectively. Fishing mortality was 0.39 to 0.97 per year in Negombo and 0.39 to 1.86 per year in Chilaw.

From the relative yield isopleths drawn, an increase of fishing effort to a value of fishing mortality of 2.6 per year can be made with an increase of minimum mesh size. As this is a multispecies fishery, the optimum mesh size should be determined after finding a balance with the other commercially important shrimp species.

Introduction

The penaeid shrimp (Family Penaeidae) are an important fisheries resource in Sri Lanka. According to the Ministry of Fisheries, Sri Lanka, shrimp contribute 3% by weight of the total marine landings. Frozen shrimp provide 70-80% of the total foreign exchange from marine products. The total annual shrimp catch is around 4,000 tonnes. Thirty-one species of penaeid shrimp have been recorded off Sri Lanka (de Bruin 1970). Four species are of commercial importance, *Penaeus indicus, P. monodon, P. semisulcatus* and *P. merguiensis. P. indicus* catches constitute 50-70% of the total annual shrimp catch.

De Bruin (1965, 1970, 1971) has described the distribution and fluctuations in abundance of penaeid shrimp off Sri Lanka. He also

presented some probable recruitment patterns of penaeid shrimp from the west coast of Sri Lanka. Studies on the distribution of spawning populations of *P. indicus* from south Indian waters (Pannikkar and Menon 1956) showed that females prefer deeper waters for spawning.

Subrahmanyam (1965) recorded eggs and larval stages from sub-surface and surface waters. According to Manisseri and Manimaran (1981), this species spends the juvenile stages in estuaries and moves out to sea during its sub-adult stage.

Jayakody and Costa (1985) examined growth, mortality and yield per recruit for *P. indicus* from the west coast of Sri Lanka from February 1979 to February 1981. Their studies show that the species has an asymptotic length (L_∞) of about 5.6 cm (carapace length) and a growth constant (K) of 1.8 per year. Yield-per-recruit analysis suggested that *P. indicus* can withstand heavy fishing mortalities, assuming no effect of fishing on recruitment.

The present study examines sex ratio, growth parameters $(L_\infty$ and K), total mortality (Z), natural mortality (M) and yield per recruit (Y/R) of *P. indicus* from the west coast (Negombo and Chilaw areas) of Sri Lanka based on data collected between September 1982 and June 1986 with the aim of finding a management strategy for this species.

Materials and Methods

In the Negombo area, shrimp trawling is done by sail-driven outrigger canoes; whereas in Chilaw, it is done by 8.6-m mechanized boats. The trawling speed of the sail-driven canoes is highly variable, but on average probably lower than the mechanized boats. The average trawling speed of mechanized boats in Chilaw is 1.2 knots. The dimensions and construction of the trawl nets were similar, having a cod-end mesh size of 10 mm (Siddeek 1978).

Each landing site was visited four days each month, two days during the first fortnight, and two days during the latter fortnight. Each trawler was given a number according to the landing time and every fifth boat was selected for sampling. Fishermen of the selected trawlers were asked for the number of trawl hauls, place of trawling and the time spent in the trawling grounds. The catch by weight of different species of shrimp was recorded. Total length of shrimp was measured to the nearest millimeter and the sex was recorded.

A null hypothesis, that the sexes were equally distributed, was tested by the log-likelihood ratio test (Zar 1974). The test statistics are given by equation (1) below:

$$G = 2 \ f_i \ln \frac{f_i}{F_i} \qquad \qquad ...1)$$

f_i = Observed value
F_i = Expected value

Growth parameters of the von Bertalanffy growth formula, L_∞ (asymptotic length), K (growth constant) and t_o were estimated, and growth curves drawn using the ELEFAN 1 program (Pauly and David 1981).

As all the data available in this study were for total length, a linear regression was made with 100 specimens to find the relationship between total length and carapace length.

Total mortality (Z) was calculated according to the Beverton and Holt (1956) formula.

$$Z = \frac{K \ (L - \overline{L})}{\overline{L} - L'} \qquad \qquad ...2)$$

$\overline{L}$ = Mean length in catch
L' = Smallest length of animals fully represented in catch samples

The smallest length which was represented by more than 10 individuals for each study period of 12 months, was taken as L' in this investigation.

Natural mortality (M) was obtained using the formula derived by Pauly (1980) taking 28.5°C as the mean annual environmental temperature (T). The relationship of M with L_∞, K and T is as follows:

$$\text{Log}_{10} M = -0.0066 - 0.279\log_{10} L_\infty + 0.6543\log_{10} K + 0.4634\log_{10} T \qquad ...3)$$

Fishing mortality (F) was obtained by the relationship:

$$Z = F + M \qquad \qquad ...4)$$

The relative yield per recruit (Y/R) which is proportional to the yield per recruit in units of weight was calculated using a modified version of the yield equation (Beverton and Holt 1964).

$$Y/R = E\,(1 - C)^{M/K}\,[1 - \frac{3\,(1 - c)}{1 + \frac{(1 - E)}{M/K}} + \frac{3\,(1 - a)^{2}}{1 + \frac{2\,(1 - E)}{M/K}} - \frac{(1 - c)^{3}}{1 + \frac{3\,(1 - E)}{M/K}}\,] \qquad ...5)$$

where

Y/R = Relative yield per recruit
C   = L_c/L, E = F/Z
L_c = Length at first capture

The yield isopleth diagrams were drawn varying L_c from 8.5 to 18.5 cm; and F from 0.5 to 5.0 for both the Negombo and Chilaw areas.

Results

Analyzing the two areas separately on a monthly basis by using the log-likelihood ratio test, indicates that the null hypothesis, that the sexes are equally distributed, cannot be rejected (Table 1).

Growth Parameters

Table 2 shows the results obtained from the ELEFAN 1 program for different periods from the two areas.

Using these growth parameters, growth curves were drawn for the period July 1985-June 1986 to represent the whole period of investigation (Fig. 1).

The relationship obtained by the regression of carapace length (CL) and total length (TL) has the form:

CL = 0.29 (TL) - 1.15

(N = 100, r = 0.963)

Table 3 shows the values of total mortality (Z) obtained by the Beverton and Holt (1956) method, natural mortality (M) calculated by Pauly's formula, and the calculated annual fishing mortalities (F) using equation (4).

Table 1. Distribution of males and females of *Penaeus indicus* from Negombo/Chilaw (d.f. = 1, critical value = 3.841 (P=0.05)).

Year	Number of months analyzed	Number of months with		No significant difference at 5% level
		More males	More females	
1982	4/4	1/-	-/1	3/3
1983	10/12	-/1	2/1	8/10
1984	12/10	2/1	3/4	7/5
1985	12/12	3/-	3/7	6/5
1986	6/6	-/-	1/3	5/3
Total	44/44	6/2	9/16	29/26

Table 2. Von Bertalanffy growth parameters for *Penaeus indicus* for different periods from Negombo/Chilaw.

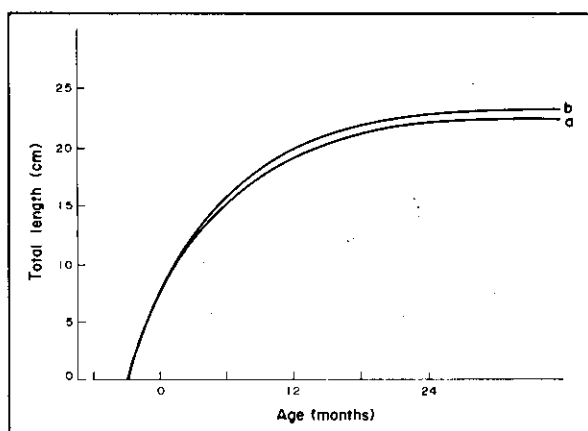| Period	L_∞ TL (cm)	K (annual)	t_o (years)
September 1982 - June 1983	21.5/24.0	1.60/1.50	-0.23/-0.23
July 1983 - June 1984	21.5/22.5	1.80/1.60	-0.19/-0.45
July 1984 - June 1985	20.5/20.0	1.50/1.50	-0.33/-0.20
July 1985 - June 1986	22.5/23.2	1.55/1.60	-0.23/-0.22

Fig. 1 Growth curve of *Penaeus indicus* from Negombo (a) and Chilaw (b) for July 1985 – June 1986.

Table 3. Total (Z), natural (M) and fishing (F) mortalities (annual) of *Penaeus indicus* from Negombo and Chilaw.

	Negombo			Chilaw		
Period	Z	M	F	Z	M	F
September 1982 - June 1983	2.89	2.69	0.39	3.17	2.49	0.48
July 1983 - June 1984	3.57	2.90	0.67	3.04	2.65	0.39
July 1984 - June 1985	3.16	2.61	0.56	2.90	2.60	0.30
July 1985 - June 1986	3.57	2.60	0.97	4.49	2.63	1.86

Relative Yield Per Recruit

The relative yield-per-recruit values calculated, according to equation (5) for different periods, show very similar values. Therefore yield isopleth diagrams for the last year of investigation, July 1985 - June 1986, from both areas were drawn (Fig. 2).
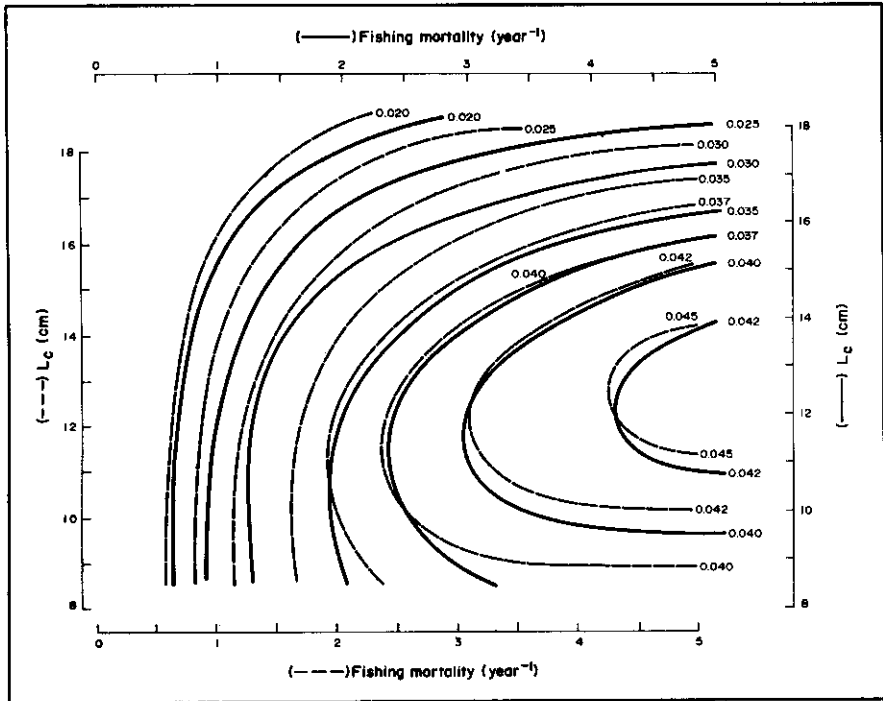

Fig. 2. Yield isopleth diagrams for *Penaeus indicus* from Negombo (——) and Chilaw (– – –) for July 1985 – June 1986. (L_c = mean length at first capture).

Discussion

In this study, all the population dynamics parameters have been calculated using formulae derived mainly for fish and later applied to shrimp by several authors including Jones and van Zalinge (1981). The growth pattern of penaeids in general may be more complex than the pattern described by the von Bertalanffy growth equation (Nair et al. 1983b) on which this study is mainly based. Shrimp show a stepwise growth due to moulting. The discrete recruitment pattern (Jayakody and Costa 1985) and a part of the life cycle spent in estuaries (Manisseri and Manimaran 1981) make it difficult to estimate growth parameters accurately.

The asymptotic lengths found in this study (Table 2) are very close to the previous values recorded for this species (Jayakody and Costa 1985). Specimens with total lengths very close to the L_∞ values obtained in this study have been recorded from the Indian Ocean (Manisseri and Manimaran 1981). Few specimens of the length group of 20-20.9 cm were recorded. Therefore the values of L_∞ of this study (20.5-24.0 cm) seem acceptable.

The annual K values (Table 2) agree with the K estimate obtained by Jayakody and Costa (1985) for the same species and by Jones and van Zalinge (1981) for *P. semisulcatus*. The high growth constant is acceptable in this shrimp species which has a very short lifespan (Fig. 1).

Yearly variations of growth parameters can result because food availability varies in the lagoon where this species spends part of its life. The abundance of food plays a major role in controlling the growth of penaeids (Nair et al. 1983a). The runoff and the river inflow resulting from the monsoon, which bring nutrients to the lagoon, vary year to year and influence the recruitment strength by affecting the number or size of recruits or both (Da Silva 1986).

The values of total mortality (Z) differ from each other without any systematic trend. These also differ from the value calculated previously for the same species by the same method (Jayakody and Costa 1985).

The natural mortality (M) values (Table 3) agree with the mean annual M value of 2.76 per year for *P. indicus* from Sofala Bank, Mozambique (Ulltang et al. 1985). Jayakody and Costa (1985) report a higher value from Sri Lankan waters. According to Garcia and Le Reste (1981), the M value of penaied shrimp should lie in the range of 2-3 per year.

For many fish, a high M is associated with high growth rates (Pauly 1980), which may be the case in shrimp too. Cannibalism is not observed in *P. indicus* and penaeids are preyed upon by demersal fish in the area (Mohammed 1970). Pauly (1980) suggested that "chance mortality" is the main component of M of fish which are low in the food chain and have a high number of predators. Therefore, the high M observed may be mainly due to predation.

In Chilaw there is a drastic increase of F from July 1984–June 1985 to July 1985–June 1986 (Table 3). During the latter period the traditional trawling method was being replaced by otter doors to spread the wings of the trawl nets. This probably increased catching efficiency.

The smallest total length of *P. indicus* caught in these two areas was around 8 cm. In the case of Negombo, L_t of 8.5 cm and the present F value of 0.97 per year give a relative yield of 0.026. In Chilaw, an L_t of 8.5 cm and the present F value of 1.86 per year; give a relative yield of 0.035. In this fishery, exploitation ratios (E) of 0.27 and 0.4 for Negombo and Chilaw, respectively, have been observed. If the E value is larger than 0.5, small changes of E correspond to large changes in F (Gulland 1983). The optimum level of fishing mortality necessary to produce MSY is roughly around the value of the natural mortality (Gulland 1971).

Considering the above factors, if the fishing mortality (F) is increased to 2.6 per year (M = 2.6 per year), and minimum mesh size is increased to give an L_t around 11 cm, the yield can be increased by 46% in Negombo (Fig. 2). In Chilaw, increasing the F value to 2.6 per year and L_t to around 12 cm gives the optimum yield and increases the present yield by 14% (Fig. 2). But these are not economically feasible in both areas. According to yield isopleths, increasing the minimum mesh size without increasing the fishing effort will not increase the relative yield considerably.

In the case of *P. indicus* in Sri Lankan waters, according to unpublished studies, spawning begins from 9 months of age onwards, when it is around 18 cm in total length. The fishermen start exploitation of this species as soon as they migrate to the sea, at a size well below this length. Therefore fishing at higher intensities could lead to a decrease of spawning stock to a level where recruitment is adversely affected.

The yield isopleths indicate that there should be a regulation for minimum mesh size. This is a multispecies fishery where shrimps smaller than *P. indicus* are caught which are also of commercial importance for local consumption. A single optimum mesh size should

be determined as an average according to the weight and economical value of each species (Pauly 1979).

Acknowledgements

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