*J. mar. biol. Ass. India*, 1992, 34 (1 & 2) : 94-102

# POPULATION DYNAMICS OF *PENAEUS INDICUS* (H. MILNE EDWARDS) IN THE WEST COAST OF SRI LANKA*

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## Abstract

Growth and mortality parameters of *Penaeus indicus* from Sri Lanka (Negombo and Chilaw) caught between September 1982 and June 1986 are analysed on annual basis, based on length frequency data. The yield isopleths were then drawn.

The asymptotic length for different periods and areas varied from 20.5 - 24.0 cm total length and growth constant of the von Bertalanffy growth formula was found to be between 1.5-1.8. The total mortality varied from 2.89-4.49. The mean natural mortalities for the whole period of study were 2.7 and 2.6 for Negombo and Chilaw respectively, whereas fishing mortality varied between 0.39-0.97 in Negombo and 0.30-1.86 in Chilaw.

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

## Introduction

The Penaeid Prawns are an important commercial fishery resource in Sri Lanka. According to the Ministry of Fisheries, Sri Lanka, of the total marine landings, prawns contribute to 3% by weight. Among marine products exported from the country, frozen prawns is a major item. Valuewise the earning from prawn exports is around 70—80% of the total foreign exchange from marine products. The total annual shrimp catch is around 4,000 tonnes. Thirtyone species of penaeid prawns have been recorded off Sri Lanka (de Bruin, 1970). Of those, four species *Penaeus indicus*, *P. monodon*, *P. semisulcatus* and *P. merguiensis* are of commercial importance. Out of these species *P. indicus* catch constitutes about 50—70 % of the total annual shrimp catch. The catches also comprise of smaller prawns such as *Parapenaeopsis stylifera*, *P. cornuta*, *P. coromandelica* and *Metapenaeus dobsoni*.

De Bruin (1965, 1970, 1971) has described the distribution and fluctuations in abundance of penaeid shrimps off Sri Lanka. He also presented some probable recruitment patterns of penaeid shrimps from the west coast of Sri Lanka. Studies on the distribution of spawning populations of *P. indicus* from South Indian waters, Panikkar and Menon (1956) showed that females prefer deeper waters for spawning.

* Presented at the 'Symposium on Tropical Marine Living Resources' held by the Marine Biological Association of India at Cochin from January 12 to 16, 1988.

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

Population size has been investigated by Siddeek (1978) for *Parapenaeopsis stylifera*, *P. cornuta*, *P. coromandelica* and *Metapenaeus dobsoni* from Sri Lankan waters.

Jayakody (1985) examined growth, mortality and yield per recruit for *P. indicus* from the west coast of Sri Lanka during the period February 1979 to February 1981. His studies show that the species has an asymptotic length ($L\infty$) of about 5.6 cm carapace length and a growth constant (K) of 1.8. Yield per recruit analysis suggested that *P. indicus* can withstand heavy fishing mortalities.

The present study examines population dynamics parameters such as 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 the data collected between September 1982 and June 1986 with the aim of finding a management strategy for this species.

The authors would like to express their sincere thanks to the Chairman of the National Aquatic Resources Agency (NARA) for providing facilities to carryout this nvestigations. They are also grateful to the technical staff of NARA for their assistance in collecting data.

## MATERIALS AND METHODS

Materials for this study were collected from commercial shrimp bottom trawlers operating in Negombo and Chilaw areas of the west coast of Sri Lanka. Samples were taken during September 1982 to June 1986.

In the Negombo area shrimp trawling is done by sail driven outrigger canoes whereas in Chilaw it is done by mechanized boats ($3\frac{1}{2}$ tonnes, 8.6 m). The trawling speed of the sail driven canoes are highly variable. But on an average probably lower than the mechanised boats. The average trawling speed of mechanised boats in Chilaw were 1.2 knots. Dimension of the trawl nets and the manner in which they were constructed were similar, having a cod-end mesh size of 10 mm (Siddeek, 1978).

Each landing site was visited four days a month, two days during the first fortnight and two days during the later 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 prawns were recorded. Total length of prawns were measured to the nearest millimetre and the sex was recorded.

## SEX RATIO

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

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

$f_i$ = Observed value and $F_i$ = Expected value.

## GROWTH PARAMETERS

Growth parameters of the von Bertalanffy growth equation, $L\infty$ (asymptotic length), K (growth constant) and $t_o$ relative to 1st of January (theoretical age of fish when length is zero), were estimated and growth curves were drawn using the ELEFAN 1 program (Pauly and David, 1981). The von Bertalanffy growth equation (von Bertalanffy, 1938) for length has the form :

$$l_t = L_\infty \left(1 - e^{-K(t-t_0)}\right) \quad (2)$$

As all the data available in this study are for total length, a linear regression was done with 100 specimens to find the relationship between total length and carapace length (Pauly, 1980 a).

### Total Mortality

Total mortality (z) was calculated according to the Beverton and Holt (1956) formula :

$$Z = \frac{K(L_\infty - \bar{L})}{\bar{L} - L'} \quad (3)$$

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

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

### Natural Mortality

Natural mortality (M) was obtained using the formula derived by Pauly (1980 b) taking 28.5°C as the mean annual environmental temperature (T) because according to Pauly (1980 b) the tropical temperature is around 28.0°C. The relationship of M with $L_\infty$, K and T is as follows :

$$\log_{10} M = -0.0066 - 0.2791 \log_{10} L_\infty + 0.6543 \log_{10} K + 0.4634 \log_{10} T \quad (4)$$

The upper and lower limits of natural mortality was estimated by Beverton and Holt (1959) approximation, which says that $M/K$ values lie in the range of 1.5 - 2.5.

### Fishing Mortality

Fishing mortality ($F$) was obtained by the relationship :

$$Z = F + M$$

### Relative Yield per Recruit

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).

$$Y'/R = E(1-C)^{M/K}\left[1 - \frac{3(1-c)}{1+\frac{(1-E)}{M/K}} + \frac{3(1-c)^2}{1+\frac{2(1-E)}{M/K}} - \frac{(1-c)^3}{1+\frac{3(1-E)}{M/K}}\right] \quad (6)$$

Where,

$Y'/R$ = Relative yield per recruit, $C = L_c/L_\infty$, $E = F/Z$, $L_c$ = Length at first capture.

The yield isopleth diagram were drawn varying $L_c$ from 8.5 cm to 18.5 cm and varying $F$ from 0.5 to 5.0 for both Negombo and Chilaw areas (Fig. 2, 3).

## Results

Analysing the two areas separately on 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 (Fig. 1), for the period from July 1985 to June 1986 as representative for the whole period of investigation.

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

$$CL = 0.2975 \times TL - 1.1498 \quad (7)$$

($N = 100$, $r = 0.9634$)

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

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

*Total mortality*

Values of total mortality ($Z$) obtained by the Beverton and Holt (1956) method is shown in Table 3.

*Natural mortality*

Natural mortality ($M$) calculated by Pauly's formula (Pauly, 1980 b) and the lower and upper limits of natural mortality (Beverton and Holt, 1959) are given in Table 4.

*Fishing mortality*

The calculated fishing mortalities using eq. 5 are given in Table 5.

*Relative yield per recruit*

The relative yield per recruit values calculated, according to equation (6) for different periods, show very closely related values. Therefore yield isopleth diagrams for the last year of investigation, July 1985—June 1986 from both areas were drawn (Fig. 2, 3).

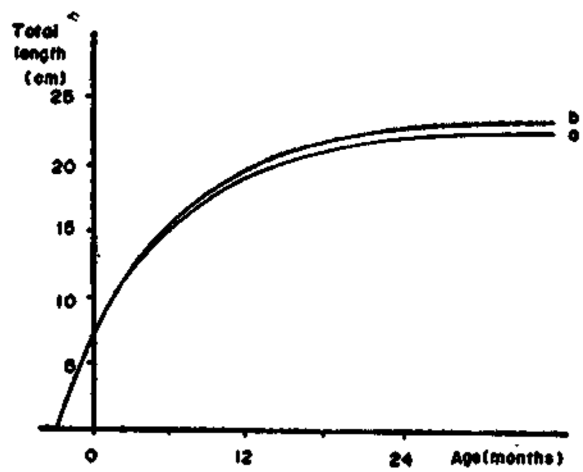


Fig. 1. Growth curve of *P. indicus*: a. from Negomba and b. Chilaw from July 1985 to June 1986.

## DISCUSSION

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

The asymptotic lengths resulted in this study (Table 2) are very close to the value

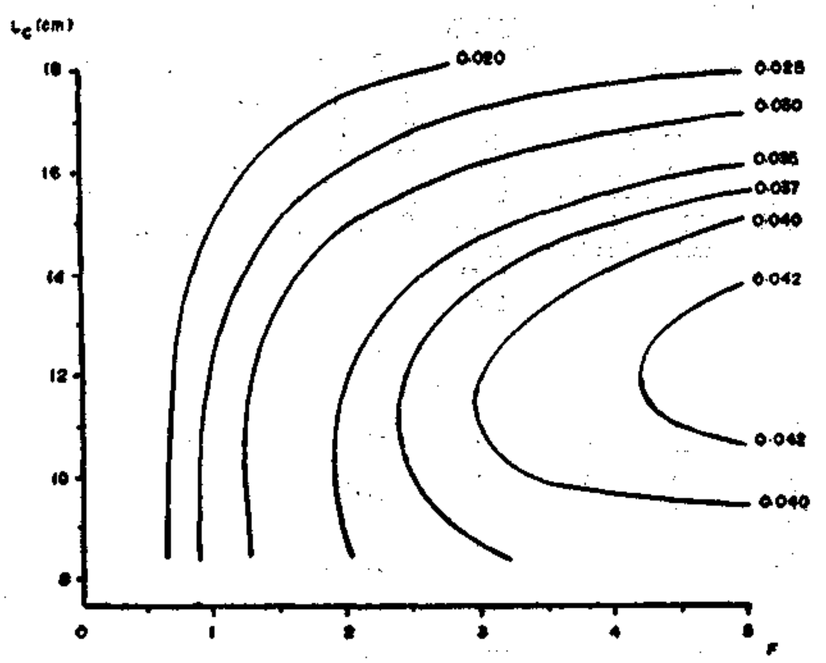


FIG. 2. Yield isopleth diagram for *P. indicus* from Negombo from July 1985 to June 1986. ($L_c$ = Mean length at first capture and F = Fishing mortality).

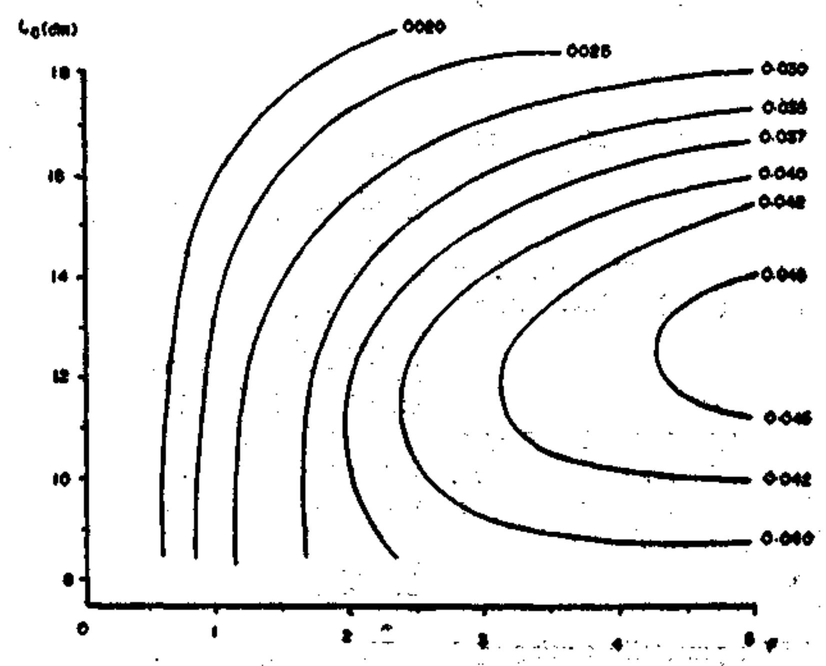


FIG. 3. Yield isopleth diagram for *P. indicus* from Chilaw from July 1985 to June 1986. ($L_c$=Mean length at first capture and F = Fishing mortality).

recorded for this species (Jayakody, 1985). Specimens with values of total length very close to the $L_\infty$ values obtained in this study have been recorded from the Indian Ocean (Manisseri and Manimaran, 1981). During the present investigation few specimens of the length group of 20.0 - 20.9 cm have been recorded. Therefore the values of $L_\infty$ of this study seem acceptable.

TABLE 2. *von Bertalanffy growth parameters for* P. indicus *for different periods from Negombo and Chilaw*

| Period | $L_\infty$ T.L.(cm) | K (annual) | $t_0$ (years) |
|---|---|---|---|
| *Negombo* | | | |
| September 1982-June 1983 | 21.5 | 1.60 | —0.27 |
| August 1983-June 1984 | 21.5 | 1.80 | —0.19 |
| July 1984-June 1985 .. | 20.5 | 1.50 | —0.33 |
| July 1985-June 1986 .. | 22.5 | 1.55 | —0.23 |
| *Chilaw* | | | |
| September 1982-June 1983 | 24.0 | 1.50 | —0.23 |
| August 1983-June 1984 | 22.5 | 1.60 | —0.45 |
| July 1984-June 1985 .. | 20.0 | 1.50 | —0.20 |
| July 1985-June 1986 ... | 23.2 | 1.60 | —0.22 |

The annual $K$ values (Table 2) agree with the $K$ estimate obtained by Jayakody (1985) for the same species and by Jones and van Zalinge (1981) for *P. semisulcatus*. The high growth constant is acceptable to this shrimp species which has a very short life span (Fig. 1) and a high growth potential, because prawns are voracious feeders (Balasubramanian *et* al., 1979). Pauly (1989 b) suggested that factors causing stress such as predation increase $K$.

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

TABLE 3. *Total mortalities (annual) for* P. indicus *from Negombo and Chilaw*

| Period | Negombo | Chilaw |
|---|---|---|
| September 1982-June 1983 .. | 2.89 | 3.17 |
| *July 1983-June 1984 .. | 3.57 | 3.04 |
| July 1984-June 1985 .. | 3.16 | 2.90 |
| July 1985-June 1986 .. | 3.57 | 4.49 |

* For Negombo from August 1983-June 1984.

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, 1985). This method of calculation of $Z$ (eq. 3) has its own limitations, because it depends on the smallest length of animals represented in catch samples which is very subjective depending on the person collecting the data.

The natural mortality ($M$) values (Table 4) agree with the mean annual ($M$) value of 2.76 for *P. indicus* from Sofala Bank, Mozambique (Ulltang *et al.*, 1985). Jayakody (1985) reports a higher value from Sri Lankan waters. $M$ value of penaeid shrimps should lie in the range of 2-3 (Garcia and Reste, 1981). The $M$ values of this study lie in the range of lower and upper limits calculated by Beverton and Holt's (1959) approximation.

For many fish a high $M$ is associated with high growth rates (Pauly, 1980 b), which may be the case in shrimps too. Cannibalism is not observed in *P. indicus* and penaeids are preyed upon by demersal fish in the area (Mohamed, 1970). Pauly (1980 b) says 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.

TABLE 4. *Natural mortalities (annual) for* P. indicus *from Negombo and Chilaw obtained by different methods*

| Period | Pauly's Method M | Beverton and Holt Method lower limit of M | Beverton and Holt Method upper limit of M |
|---|---|---|---|
| *Negombo* | | | |
| September 1982-June 1983 | 2.69 | 2.40 | 4.00 |
| August 1983-June 1984 .. | 2.90 | 2.70 | 4.50 |
| July 1984-June 1985 .. | 2.61 | 2.25 | 3.75 |
| July 1985-June 1986 .. | 2.60 | 2.33 | 3.88 |
| *Chilaw* | | | |
| September 1982-June 1983 | 2.49 | 2.25 | 3.75 |
| July 1983-June 1984 .. | 2.65 | 2.40 | 4.00 |
| July 1984-June 1985 .. | 2.60 | 2.25 | 3.75 |
| July 1985-June 1986 .. | 2.63 | 2.40 | 4.00 |

In Chilaw there is a drastic increase of $F$ from the period July 1984 - June 1985 to July 1985 - June 1986 (Table 5). During the latter period traditional trawling method was replaced by otter doors to spread the wings which has probably increased the catching efficiency.

The smallest total length of *P. indicus* caught in these two areas is around 8 cm. In the case of Negombo $L_c$ of 8.5 and the present $F$ value of 0.97 gives a relative yield of 0.026. In Chilaw $L_c$ of 8.5 and the present $F$ value of 1.86 gives a relative yield of 0.035. In this fishery exploitation ratios of 0.27 and 0.4 or 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 should equal the natural mortality (Gulland, 1971).

TABLE 5. *Fishing mortalities (annual) for* P. indicus *from Negombo and Chilaw*

| Period | Negombo | Chilaw |
|---|---|---|
| September 1982-June 1983 .. | 0.39 | 0.48 |
| July 1983-June 1984 .. | 0.67 | 0.39 |
| July 1984-June 1985 .. | 0.56 | 0.30 |
| July 1985-June 1986 .. | 0.97 | 1.86 |

*Relative Yield per recruit*

The relative yield per recruit values calculated, according to equation (6) for different periods, show very closely related values. Therefore yield isopleth diagrams or the last year of investigation, July 1985-June 1986 from both areas were drawn (Fig. 2 and 4).

Considering the above factors, if fishing mortality ($F$) is increased to 2.6 ($M = 2.6$) and increase the minimum mesh size so as to give a $L_c$ around 11 cm, the yield can be increased by 46% in Negombo (Fig. 2). In Chilaw increasing the $F$ value to 2.6 and $L_c$ around 12 cm given the optimum yield and increase the present yield by 14% (Fig. 3). 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 unpublished data says that spawning is from 9th month onwards, which is around 18 cm in total length. The fishermen start exploitation of this species as soon as they migrate to the sea, which are well below this length. Therefore fishing at higher intensities could lead to a decrease of spawning stock below the level where recruitment is affected adversely. This species breeds in deeper areas in the sea (Panikkar and Menon, 1956). Therefore the fishing should be restricted in areas where they breed.

The abundance of shrimps in the fishing areas increases when they migrate from estuaries mainly during the flooding season (de Silva, 1986 ; Jayakody, 1985). Therefore, if the fishing intensity can be increased moderately during this season, the surplus can be harvested, most of which would otherwise be lost due to predation.

The yield isopleths indicate that there should be a regulation in the minimum mesh size. This fishery is multispecies, fishery where shrimps smaller in size than *P. indicus* are caught which are also of commercial importance for local consumption. The calculation of a single optimum mesh size should be determined as an average weighted according to the weight and economical value of each species (Pauly, 1979).

The above assessment has its own limitations regarding the estimation of growth parameters. The probable major error is that in the case of penaeid shrimps the stocks are never in equilibrium (Pauly, 1984). According to Gulland (1983) in the case of short lived penaeid shrimps, provided recruitment is not affected by the reduction in adult stock, whatever happens to the shrimps presently in the fishery and however badly they are fished, all will be well in the following year where the next brood comes in. If this fails, it will have serious consequences for the fishery and the stock itself.

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