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Estimation of Population Parameters and Stock Assessment of *Penaeus indicus* (H. Milne Edwards) in the Western Coastal Waters of Sri Lanka

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Abstract

Population parameters of *Penaeus indicus, Penaeidae* of the artisanal shrimp fishery in the Negombo lagoon and the associated coastal ecosystem on the west coast of Sri Lanka were derived from length frequency data, analyzed using the FiSAT computer program. The asymptotic length ($L\infty$) and growth rate constant (K) were estimated to be 19.2 cm and 1.5 year^{-1} for males and 19.9 cm and 1.9 year^{-1} for females. Based on these growth parameters, the estimated values for the fishing mortality coefficients were 1.67 and 2.49 year^{-1} for males and females respectively. The natural mortality coefficient was estimated at 1.73 year^{-1} for both sexes. Recruitment for the estuarine environment and the offshore areas was continuous with two peaks per year. The estimated values for length at 50% capture (Lc) for almost all the gear types in the system were less than the estimated sizes at 50% maturity of males and females of *P. indicus*. The maximum sustainable yield (MSY) and the optimum effort level were estimated at 128.07 MT and 40% of the present effort respectively. The estimated values for the maximum sustainable economic yield (MSE) and the respective effort level were 125.51 MT and 30% of the present effort.

Introduction

Shrimps form an important component in the fauna of estuarine and coastal waters, varying in size from microscopic to about 35 cm long. Although nearly 2,500 species are known, only slightly less than 300 are of economic interest (Fischer and Bianchi 1984). The genus *Penaeus* occurs in tropical and subtropical waters, between 40^0N to 40^0S and is the most important commercial group (Anon 1983).

Coastal penaeid shrimp stocks have become more intensely studied during the last three decades as their importance in tropical fisheries increased. Much progress in biological research has been accomplished since the landmark FAO World Science Conference on biology and culture of shrimps and prawns held in Mexico in 1967 (Garcia 1985). Three key features that characterize the genus *penaeus* have been identified. Firstly, growth rates are rapid as a result of high ambient temperatures. Secondly, they are short-lived and finally, the juveniles are found in inshore waters, where they are frequently subjected to strong environmentally driven variability in recruitment and stock size (Garcia 1984).

Penaeus indicus (H. Milne Edwards) is one of the most abundant species in Sri Lankan waters and its juveniles contribute to a productive fishery in estuarine waters (De Bruin 1965, 1970, 1971; Siddeek 1978). It constitutes almost 50 to 70% of the total annual shrimp landings of the island (Jayawickrema and Jayakody 1992). In backwaters it is mainly caught by trammel nets, drag nets, cast nets, traps and stake-seine nets (De Bruin 1970; Siddeek 1978). In the Negombo lagoon and the associated coastal ecosystem on the west coast of Sri Lanka where the present study was conducted, *P. indicus* makes a substantial contribution to the catches of the traditional shrimp fishery throughout the year.

Though *P. indicus* is one of the most abundant shrimps in the penaeid fauna of Sri Lanka, except for the studies conducted by Jayakody and Costa (1988) and Jayawickrema and Jayakody (1991,1992) which were based on the length frequency data only from the seas off Negombo, a comprehensive study on the population dynamics of this species utilizing the length frequency data from the entire system (both from estuarine environment and offshore areas) has not been attempted so far. In the present study, population parameters and mortality rates of *P. indicus* were estimated for evaluation and management of the *P. indicus* fishery resources from the artisanal shrimp fishery in the Negombo lagoon and the coastal ecosystem on the west coast of Sri Lanka.

Materials and Methods

Collection of data

The sampling programme commenced in September 1998 and continued for 24 consecutive months. Length frequency data of *P. indicus* were collected from the different gears employed to exploit shrimps in the Negombo Lagoon (trammel nets, cast nets, drag nets and stake-seine nets) and the associated coastal region (nonmechanized and mechanized trawls) at weekly intervals. On each sampling day, 2 to 3 representative shrimp samples (each between 10 to 20% of the total shrimp catch) from each gear were collected at the fish landing centers (Figs. 1a and 1b). These were then brought to the laboratory at the National Aquatic Resources Research and Development Agency (NARA), Colombo for analysis (sample size varied from 659 to 24,396 shrimps). In the laboratory, all the shrimps were sorted according to species and sex. The total length of each specimen was measured to the nearest 0.1 cm using a measuring board; the weight of the entire sample was also determined. These were then raised to the respective total catches. Finally, these information were pooled together and raised to the estimated total effort of respective gear types for each month to estimate the entire length frequency distribution exploited by different gear types on a monthly basis.

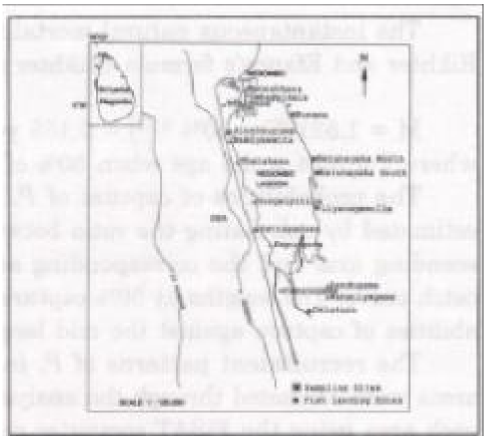

Fig. 1a. Map showing fish landing sites and the sampling sites in the Negombo lagoon.

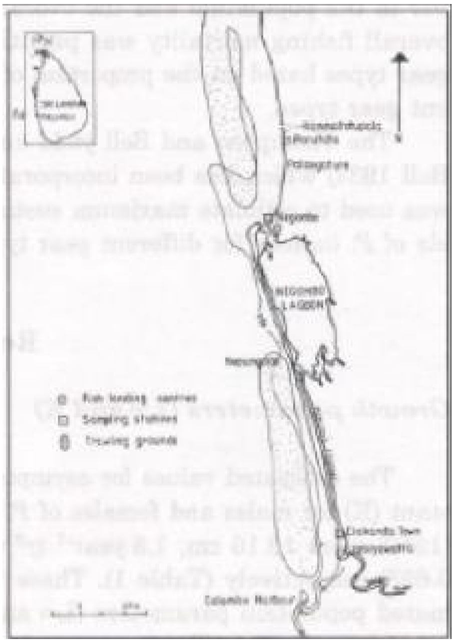

Fig. 1b. Map showing fish landing centers and the sampling stations in the coastal region.

Analysis of data

Monthly length frequency distributions of *P. indicus* were analyzed using the FiSAT computer programme (Gayanilo and Pauly 1997). The following step-wise procedure was adopted for correction of length frequency data for mesh selection:

1. Estimation of an initial value for asymptotic length (L_∞) using the Powell-Wetherall Method (Powell 1979, Wetherall et al. 1987).
2. Estimation of probabilities of capture using the value 1.0 for the curvature parameter, K and the preliminary estimation made on the asymptotic length, L_∞
3. Correction of the original length frequencies using probabilities of capture (Pauly 1986 a, b & c).

The parameters of the von Bertalanffy growth equation, asymptotic length (L_∞) and growth rate constant (K) were estimated using ELEFAN I routine and the Gulland and Holt plot [using growth increment data estimated by modal progression analysis – Bhattacharya (1967) method] incorporated into the FiSAT computer programme.

Growth performance index (ϕ) for *P. indicus* was computed using the following equation (Pauly and Munro 1984, Moreau et al. 1986):

$$\phi = \log_{10}K + 2\log_{10}L_\infty$$

The instantaneous natural mortality coefficient (M) was estimated using Rikhter and Efanov's formula (Rikhter and Efanov 1976):

$$M = 1.521/(Tm\ 50\%^{0.72}) - 0.155\ year^{-1}$$

where Tm 50% = the age when 50% of the population is mature.

The probabilities of capture of *P. indicus* for different gear types were estimated by calculating the ratio between the points of the extrapolated descending arm and the corresponding ascending arm of the length converted catch curve. The lengths at 50% capture (Lc) were estimated by plotting probabilities of capture against the mid lengths.

The recruitment patterns of *P. indicus* to both estuarine and offshore areas were estimated through the analysis of pooled length frequency data from each area using the FiSAT computer programme (Gayanilo and Pauly 1997).

The length-based Virtual Population Analysis (VPA) was performed on the pooled annual length frequencies from the system to estimate the mean number in the population and the overall fishing mortality by length group. The overall fishing mortality was partitioned into fishing mortality by different gear types based on the proportion of the number of shrimps caught by different gear types.

The Thompson and Bell yield and stock prediction model (Thompson and Bell 1934) which has been incorporated into the FiSAT computer programme was used to estimate maximum sustainable yields and the optimum effort levels of *P. indicus* for different gear types.

Results

Growth parameters (L¥ and K)

The estimated values for asymptotic length (L_∞) and the growth rate constant (K) for males and females of *P. indicus* using the Gulland and Holt plot (1959) were 19.16 cm, 1.5·year^{-1} (r^2 = 0.174) and 19.87 cm, 1.87·year^{-1} (r^2 = 0.698) respectively (Table 1). These values compare favorably with the estimated population parameters (L_∞ and K) by the ELEFAN I routine incorporated into the FiSAT software package (Gayanilo and Pauly 1997) (Table 1, Figs. 2a and 2b).

Table 1. Estimation of population parameters.

Method	L_{00} (cm)	K (year^{-1})	r^2/ Rn
Gulland and Holt plot			
Male	19.16	1.5	0.174
Female	19.87	1.87	0.698
ELEFAN I			
Male	19.2	1.51	0.124
Female	19.1	1.8	0.122

Growth performance index (f)

The estimated values for the growth performance index (ϕ) of *P. indicus* during the present investigation were 2.74 for males and 2.82 for females which were within the range of ϕ values recorded in the literature (Table 2) though few exceptionally high values were recorded from India.

Instantaneous rate of natural mortality coefficient (M)

The value for the instantaneous rate of natural mortality coefficient of males and females of *P. indicus* using Rikhter and Efanov's formula (Rikhter and Efanov 1976) was estimated to be $1.73 \cdot year^{-1}$.

Table 2. Growth performance indices of *P. indicus* in different localities.

Location	L00 (cm)	K ($year^{-1}$)	Growth performance index	Source
Seas off west	19.2	1.51	2.74*	Present investigation
coast of Sri	19.1	1.8	2.82**	
Lanka	21.96	1.58	2.88***	Jayawickrema and Jayakody (1991)
Kakinada/	22.72	1.8	2.97*	
India	21.84	2	2.98**	Devi (1986)
Manila Bay/	20.5	1.2	2.7*	
Philippines	21	1	2.64**	
Punnaikkayal/	22	1.2	2.76*	
India	22.6	1	2.71**	
Manappad/	20.6	1.2	2.71*	Agasen and Mundo (1988)
India				
East coast of	20	2	2.9*	
India	23	2	3.02**	Rao et al. (1993)

*male
**female
***sex is not considered

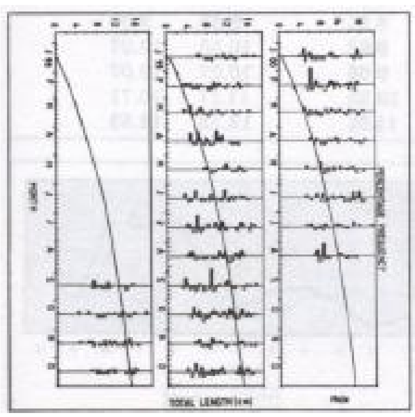

Fig. 2a. Restructured length-frequency distributions and the estimated growth curves for male *P. indicus*.

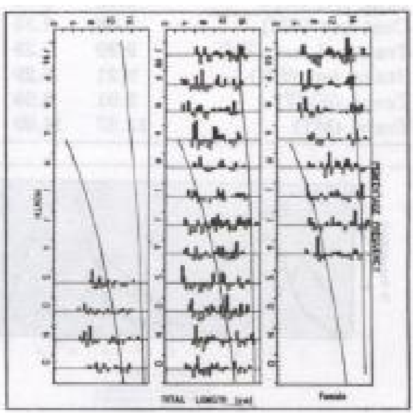

Fig. 2b. Restructured length-frequency distributions and the estimated growth curves for female *P. indicus*.

Probabilities of capture

The estimated sizes at 25, 50 and 75% probabilities of capture of males and females of *P. indicus* for different gear types are given in table 3. The values for *P. indicus* were highest for both sexes for mechanized trawls. In contrast, the lowest values were recorded for drag nets. In addition, it was also noted that the values for length at 50% capture (Lc) of almost all the gear types were less than the estimated sizes at 50% maturity of males and females of *P. indicus* (12.83 and 14.86 cm respectively) (Jayawardane et al. in preparation).

Recruitment pattern

Results of the analyses of recruitment pattern to the lagoon and offshore environment show two pulses of different magnitude (Figs. 3 and 4). In the lagoon the two pulses of recruitment amount to 60 and 40% of the total male recruits and 29 and 71% for females. The means of the two pulses are separated by an interval of 4 months in males and 6 months in females. On the other hand, for offshore areas the two pulses of recruitment produced 30 and 70% and 29 and 71% of recruits and the means of the recruitment pulses are separated by the intervals of 4 and 6 months in males and females respectively.

Virtual population analysis (VPA)

The present study has revealed that *P. indicus* resources in the study area are exploited using six different gear types *viz.* drag nets, cast nets, trammel nets, stake-seine nets, nonmechanized trawls and mechanized trawls. Results of the length-based VPA performed on males and females indicate that

Table 3. Estimated sizes at probabilities of capture of *P. indicus* (cm) for different gear types.

Fishing gear	L 25%		L 50%		L 75%	
	Male	Female	Male	Female	Male	Female
Drag net (DN)	6.35	5.72	7	6.1	7.42	6.46
Cast net (CN)	8.06	8.35	8.48	8.94	8.86	9.39
Trammel net (TN)	9.89	9.29	10.21	9.68	10.55	10.07
Stake net (SN)	9.21	9.29	9.67	9.68	10.07	10.07
Trawl (NMT)	9.91	9.59	10.66	10.25	11.17	10.71
Trawl (MT)	12.27	11.09	13.26	11.95	13.73	12.53

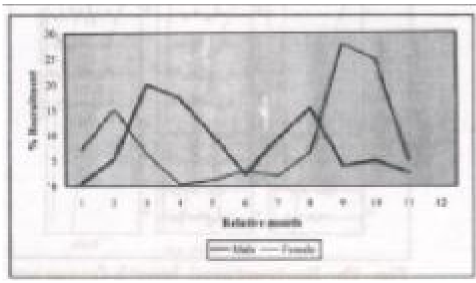

Fig. 3. Recruitment pattern of *P. indicus* to the Negombo lagoon.

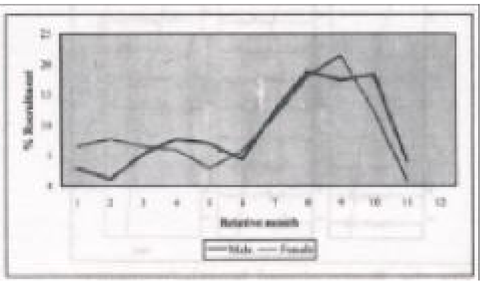

Fig. 4. Recruitment pattern of *P. indicus* towards offshore areas.

(Figs. 5 and 6) the minimum and maximum fishing mortalities for males were experienced by the size groups with mid lengths of 3.0 and 12.2 cm respectively. Generally, fishing mortality was comparatively high over the mid lengths from 10.2 to 13.0 cm. On the other hand the minimum and maximum fishing mortalities for females were recorded for the mid lengths, 3.0 and 12.6 cm respectively. As for males the fishing mortality was comparatively high in the middle of the size range, over the mid lengths from 9.8 to 13.4 cm. When the fishing mortality of males and females was divided among the different gear components (Table 4), the highest values were recorded for trammel nets for both sexes. The lowest values on the other hand were recorded for drag nets. A summary of the results of the analysis is given in table 4.

Thompson and Bell long term yield and stock prediction

The maximum sustainable yield (MSY) and the optimum effort level (respective effort level) for overall fishery (i.e. for all gears) were estimated to be 128.07 MT (worth SLRS Million 37.29) and 0.4 times the present effort respectively (Fig. 7). Thus according to the analysis to obtain MSY, the present effort has to be reduced by 60%. Similarly the maximum sustainable economic yield (MSE) was estimated at 125.51 MT (worth SLRS Million 39.34) (Fig. 8) and the respective effort level was 0.3 times the present effort.

The estimated MSY, MSE, optimum effort levels and the respective values for different gear types are summarized in table 5 (assuming the current effort level is equal to 1, the optimum effort levels are presented with respect to the current effort level). The present study shows that except for drag nets, cast

Table 4. Summary of the length based virtual population analysis.

Parameter			Fishing gear	Fishing mortality	
	Male	Female		Male	Female
Recruitment number	15,987,648	15,250,419	Drag net	0.04	0.07
Mean fishing mortality	1.67	2.49	Cast net	0.12	0.19
Mean exploitation rate	0.52	0.59	Trammel net	1.5	2.23
			Stake-seine net	0.62	0.89
			Nonmechanized trawls	0.4	0.43
			Mechanized trawls	1.24	1.18

Table 5. Summary of Thompson and Bell long term yield and stock prediction of *P. indicus*.

Gear type	MSY (MT)	Optimum effort level	Value (SLRS Millions)	Current yield (MT)	MSE (MT)	Optimum effort level	Value (SLRS Millions)
Drag net	4.14 <	4 <	0.43	1.4	4.14 <	4 <	0.43
Cast net	8.4 <	4 <	1.05	6.25	6.92	1.5	1.16
Trammel net	63.72	0.7	15.35	61.61	63.72	0.7	15.35
Stake-seine net	30.23	2.6	5	28.8	28.8	1	5.91
Nonmechanized trawl	8.46	0.3	2.77	3.68	8.24	0.2	2.88
Mechanized trawl	46.5	0.2	21.74	7.85	46.5	0.2	21.74
Total	148.91	3.8	46.34	109.59	154.18	3.6	47.47

nets and stake-seine nets, all the other gears employed in the shrimp fishery in the Negombo lagoon and the associated coastal waters have exceeded their respective optimum effort levels. Therefore, the fishing effort of the offending gears should be substantially reduced to optimize the shrimp fishery.

Discussion

During the present study, estimates of growth parameters of *P. indicus* were based on the von Bertalanffy Growth Function (VBGF) which considers the asymptotic size of shrimp. Various authors have observed that asymptotic length ($L\infty$) is an imprecisely defined parameter (Knight 1968; Roff 1980; Moreau and Moreau 1987). The definition of $L\infty$ is the mean size of a cohort of shrimp population which they would reach if they lived and grew indefinitely (Ricker 1975). However, despite criticisms on the VBGF, it can be expected that the continued use of this equation will occur as a convenient way of modelling many of the growth series observed (Moreau and Moreau 1987).

Although the physiology of crustaceans is different from that of fishes, their average body growth appear to conform to the von Bertalanffy growth model (Garcia and Le Reste 1981). An individual crustacean (a shrimp, a lobster or a crab) does not conform to the von Bertalanffy model, but some stepwise curve with each step account for a moult. Members of a cohort moult at different times therefore, the average growth curve of a cohort of crustaceans becomes a smooth curve (Sparre and Venema 1992).

In general, ELEFAN I and similar methods in concept are most effective when one of the parameters of the growth equation, generally $L\infty$ can be estimated or approximated to a narrow range (Basson et al. 1988). The estimates

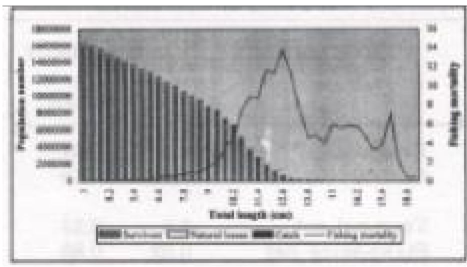
Fig. 5. Length based Virtual Population Analysis - *P. indicus* (male).

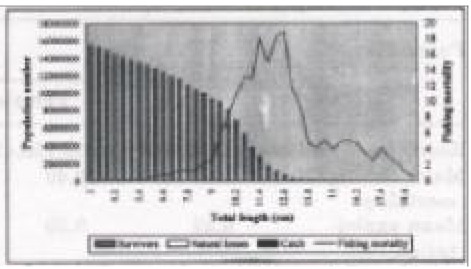
Fig. 6. Length based Virtual Population Analysis - *P. indicus* (female).

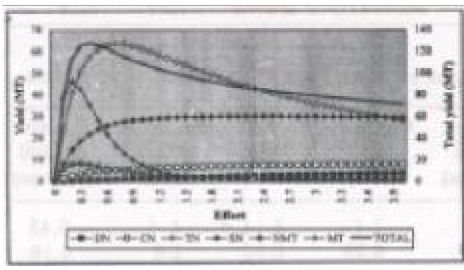
Fig. 7. Projected annual yields of *P. indicus* when the fishing effort of all gears is increased.

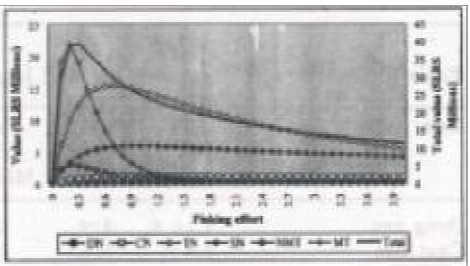
Fig. 8. Projected annual values of *P. indicus* when the fishing effort of all gears is increased.

of growth parameters in the present investigation were based on the approximation of L_∞ values, which were determined using the Powell-Wetherall method (Powell 1979, Wetherall 1986, Wetherall et. al. 1987). According to Pauly (1986c), estimation of population parameters using ELEFAN technique with inadequate length frequency data or length frequency data where modal progression is not apparent might lead to an unreliable result. During the present investigation however, randomly selected large samples representing almost all the major gear types employed to exploit shrimps (over a wide range of sizes) in the system were used in estimating population parameters and the effect of gear selection on the catch samples was reduced by correcting these prior to the process. The growth parameters estimated therefore, during the present study are likely to be accurate.

The estimated growth parameters of *P. indicus* are biologically reasonable as the growth performance index (ϕ) estimated for shrimp populations in the seas off west coast of Sri Lanka are within the range of ϕ values recorded in the literature (Table 2).

The present study has also revealed that the estimated values for the sizes at first maturity of males and females of *P. indicus* (12.83 and 14.86 cm respectively) were greater than the estimated sizes at first capture for almost all the gears during the present investigation (Table 3). Although exploitation of undersized shrimps is an inevitable consequence of lagoon fisheries, the fact that both trawl types operating in the offshore areas also take away prospective spawners should be considered as a serious condition, and increased effort in such a situation could result in the collapse of the fishery due to recruitment over fishing.

The analysis of recruitment patterns indicate that there is a discrepancy between the time of recruitment of males and females of *P. indicus* to both estuarine and marine environments. However, the absence of synchronization between recruitment time of different sexes could presumably be due to the difference between the estimated growth rates of males and females of *P. indicus* which were 1.5 and $1.8 \cdot year^{-1}$ respectively.

The analysis performed on the different gear types employed to exploit *P. indicus* in the system revealed that, except in the case of drag nets, cast nets and stake-seine nets, the present effort of individual gears should be considerably reduced to obtain optimum yields with respect to each gear.

Of the six different fishing gears employed to exploit *P. indicus* in the system, the economy of the trammel net and the cast net fishermen depends upon the juveniles and pre-adults of *P. indicus* in the Negombo lagoon to a great extent. The results of the present study reveal that the current effort level of trammel nets was slightly higher than the estimated optimum effort level. The study also revealed that, the present effort of trammel nets should be reduced by 30% to obtain optimum yield. It was also revealed during the present investigation that some trammel net fishermen have enhanced their share by increasing the number of nets used. This act reduces the catches of the other fishermen, unless they also use more nets. In order to avoid an unnecessary spiralling of gear usage and hence the cost, it is advisable to limit the quantity of trammel nets to be used in a fishing unit. This would also be an effective measure to bring down the existing fishing effort.

Although the present study indicated that there is room for the cast net effort to be increased to obtain optimum yields, as the cast nets exploit under sized shrimps of *P. indicus* in varying proportions, it is advisable to conduct further investigations prior to making initiatives in terms of alteration of the cast net effort. Aside from this, cast net is a part time gear employed only during peak abundance of juveniles and pre-adults of *P. indicus* exploiting considerable proportions of undersized shrimps in the Negombo lagoon. It is advisable therefore, at this stage to introduce an appropriate mesh regulation for cast nets with a view of increasing the mean size of the shrimps exploited, which would also be favorable from an economic point of view.

The findings also provided evidence that would justify a reduction in the effort of nonmechanized trawls at least by 70% in order to obtain optimum yields of *P. indicus*. On the other hand the economy of the traditional trawl fishermen largely depends upon the small shrimp component to which *Metapenaeus dobsoni* and *Parapenaeopsis coromandelica* together make a substantial contribution, and the trawl catch of *P. indicus* is relatively small. Once all these aspects are taken into consideration, it is recommended that the effort of nonmechanized trawls be maintained at the present level.

The present study provided sufficient evidence to justify a substantial reduction in the effort of mechanized trawls with a view of obtaining optimum yields. Although this seems to be a justifiable conclusion from a biological point of view this may lead to a series of social problems as a reduction in the effort would leave a substantial portion of the fishing community unemployed. It was also noted that owing to the declaration of a security zone based in Colombo harbor, trawl fishermen have already lost access to a substantial portion of the fishing ground. Under the present circumstances, reduction in the fishing effort is therefore unlikely unless suitable sources of alternate employment are provided to this segment of the fishing community, who are likely to be left unemployed. The scale of the lagoon fisheries targeting juveniles also justifies much closer regulation and management.

As the different gear types employed to exploit shrimps in the system take away undersized shrimps in varying proportions, it is advisable to make necessary arrangements to bring about suitable mesh regulations to the above gear types in terms of existence of the *P. indicus* resources in the Negombo lagoon and the associated coastal ecosystem. The shrimp fishery in the Negombo lagoon and the associated coastal waters is a multispecies fishery targeting different shrimp species and sizes as well. Therefore, prior to the introduction of mesh regulations to the fishery, a comprehensive study should be conducted to determine the optimum mesh sizes for different fishing gears operating in the system. In addition, this exercise should be an integrated approach as such an initiative may have an adverse impact on the existence of finfish and crustacean resources in the system.

The results of the present study suggest that substantial reductions in the fishing effort of certain fishing gears exploiting shrimps are needed to obtain optimum yields of *P. indicus*. Though reduced numbers of fishing units would result in improved shrimp catches for those remaining in the fishery, there would be a serious negative impact on those who were displaced, due to the present severe shortage of alternative employment opportunities. On the other hand as the shrimp fishery in the Negombo lagoon and the associated coastal ecosystem is a multispecies one, any alteration to the fishing effort should be made cautiously as it might affect the existence of a number of other finfish and crustaceans. Therefore, any initiative towards the management of the shrimp fishery in the system should be an integrated approach.

The results also suggest that the catch rates of shrimps would be further reduced with the influx of additional fishing units into the fishery; implying that opportunities for employment appear to be almost maximized.

Acknowledgments

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