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RESEARCH ARTICLE

Using length data to derive biological reference points for kiddi shrimp *Parapenaeopsis stylifera* (Milne Edwards, 1837) from the south-eastern Arabian Sea, India

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Abstract – *Parapenaeopsis stylifera*, a major commercial penaeid shrimp fishery resource in the Indian Ocean, has lacked adequate information on life history parameters for nearly two decades. In this study, growth and mortality parameters of *P. stylifera* from the southwest coast of India were estimated using length data and used to derive biological reference points for the species. The asymptotic length for females was $L_\infty = 131$ mm; $k = 1.1$ y^{-1} and for males $L_\infty = 117$ mm; $k = 1.25$ y^{-1}. Mortality parameter estimates were $Z = 4.42$, $M = 1.24$, $F = 3.18$ y^{-1} and exploitation rate $E = 0.72$ for females; $Z = 5.76$, $M = 1.39$, $F = 4.37$ y^{-1} and $E = 0.76$ for males. Thomson and Bell yield biomass, Beverton and Holt yield per recruit, and relative yield per recruit models were applied to predict the stock status and length cohort analysis for estimating the stock size. The Beverton and Holt analysis gave $E_{max} = 0.69$ in females and 0.75 for males, which is below the $E_{current}$ values obtained for the sexes. The Thomson and Bell analysis indicated that if $F_{current}$ at which the yield is 121 460 t in females and in males 128 064 t is further increased, rise in yield will be modest. B/B_0 and SB/SB_0 at $F_{current}$ were 24% and 18% for females and 21% and 16% for males, respectively. Target reference point $F_{0.1}$ and $F_{0.5}$ at different levels of age at capture t_c (0.5, 0.6, 0.7 and 0.8 yrs) was estimated by Beverton and Holt yield per recruit model. The outcome from these models forms integral inputs for multispecies/multigear tropical fisheries management. *Parapenaeopsis stylifera* is one of the inshore penaeid shrimp identified by the Marine Stewardship Council for certification from the region and, moreover, biological reference points are a prerequisite to assessment and management of tropical multispecies fisheries for ecosystem-based fisheries management.

Keywords: Arabian Sea / growth / *Parapenaeopsis stylifera* / reference points / size at first maturity / shrimp / size frequency

1 Introduction

Shrimps from India, as frozen products, contribute substantially to the international export market. Indian waters are habitat to a plethora of marine decapod crustaceans, with more than 70 species of penaeid shrimps recorded from the region (Radhakrishnan et al., 2012). Major commercial shrimp landings are composed of species belonging to the genera *Metapenaeus*, *Parapenaeopsis* and *Penaeus*. *Parapenaeosis stylifera* is a major fishery resource on the southwest coast of the Indian subcontinent. The European Union, Japan and southeast Asian countries are the major export markets for the resource. The species is distributed in the Indian Ocean from Kuwait and Pakistan to Bangladesh (Farfante and Kensley, 1997). Fishable quantity has been reported from Malaysia (Hall, 1962), Sri Lanka (De Bruin, 1965) and Pakistan (Ahmad, 1957). Introduction of trawlers by the erstwhile Indo-Norwegian project during the 1950's lead to an organised fishery for shrimps in Kerala, although prior to this period *P. stylifera* was a common species in the markets (Menon, 1953). The estimated annual production of *P. stylifera* during 1982–1987 varied from 10 344 t to 17 675 t with an annual average of 13 963 t (Suseelan, 1989). In the present study, the annual catches fluctuated between 5 269 t (2011) to 14 106 t (2019) (Figure given in Supplementary file). The resource is caught in single day trawlers (44%), voyaging daily (starting early morning and returning noon), and on multiday trips (55%) ranging from 3 to 4 days of voyage.

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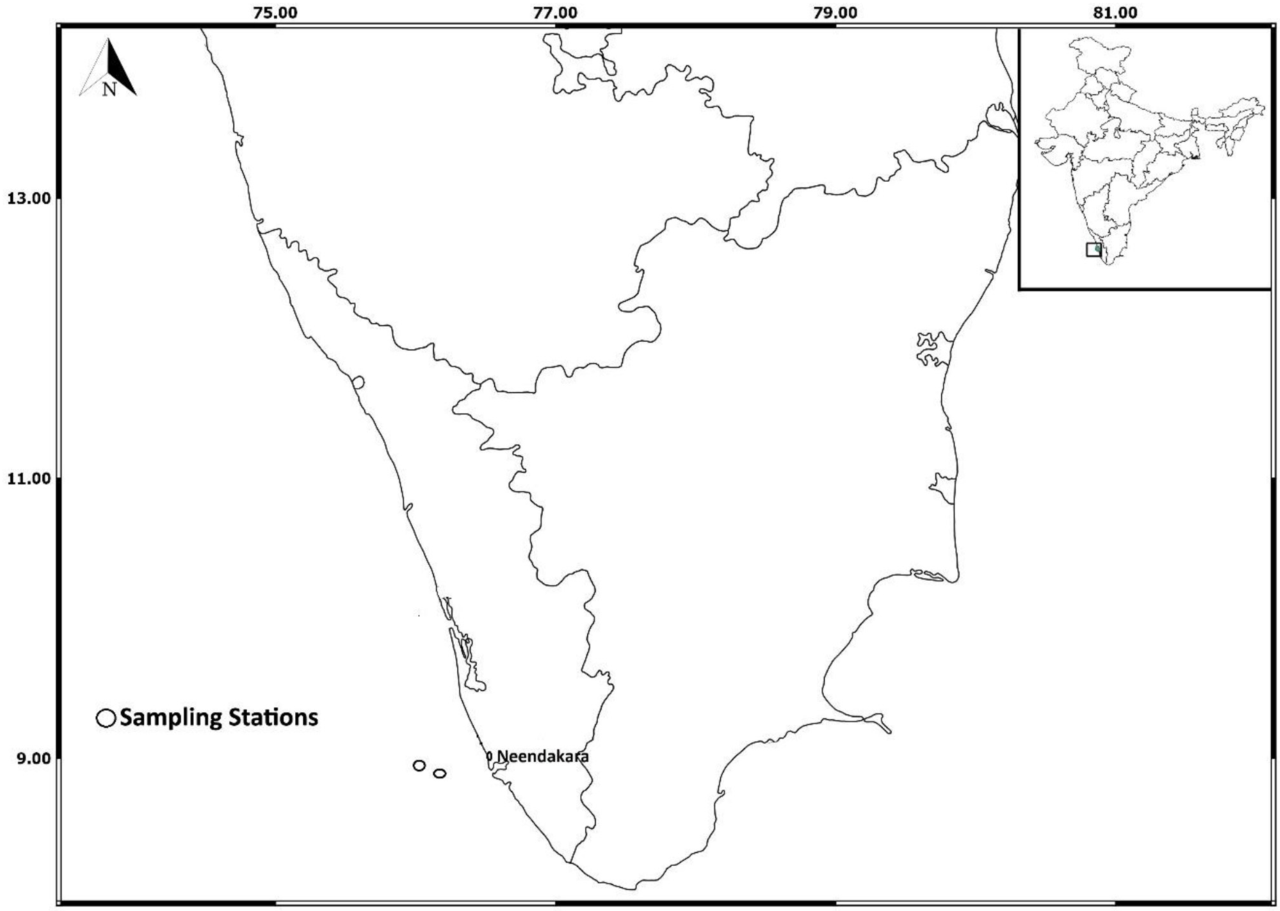

Fig. 1. Map showing study area.

Since penaeid shrimps are short-lived resources with high fishery/ecosystem importance, they need more frequent assessments to understand their stock status and to keep the probability of overfishing at acceptable levels. There are two recent studies, one from the north-eastern Arabian Sea by Mohsin et al. (2017) who worked out the stock status of the species in Pakistan waters using surplus production models, and the other by Mohsen (2017) on the population dynamics from the north-west of Qeshm Island, Iran but it has been almost two decades (Suseelan and Rajan, 1989; Suseelan et al. 1989; Geeta and Nair, 1992; Alagaraja et al., 1986; Sarada, 2002, Dineshbabu, 2005) since any information on its life history parameters were published from Indian waters. Derivation of biological reference points (BRP) at regular intervals and ascertaining the stock status of the resource is also a prerequisite to assessment and management of tropical multispecies fisheries for ecosystem-based fisheries management (EBFM). This fishery resource from Kerala is also a candidate for the Marine Stewardship Council (MSC) certification. The main objectives of this study were i) to estimate growth and mortality parameters of *P. stylifera* from Kerala, south-west coast of India, and ii) to derive biological reference points, using multiple statistical methods, based on the length frequency data collected from January 2011 to December 2019, for the efficient management of the stock of *P. stylifera* along the south-west coast of India. Different stock assessment methods are used and it is recommended to use several of them (Lleonart, 2002) "if possible" as a fishery is a complex system.

2 Materials and methods

2.1 Study area and sampling

A total of 13 530 *P. stylifera* individuals (6954 females and 6576 males) were obtained by random sampling between January 2011 and December 2019 at fortnightly intervals for length frequency studies from single-day trawlers (3–4 h voyage) operating from Neendakara fisheries harbour (8°.93′7″N 76°.53′8″E) in Kerala, south-west coast of India (Fig. 1). Samples were transported to the laboratory on ice. Since the vessels targeting the species bring the entire catch to the landing centre, the samples used in the analysis can be considered representative of the population.

2.2 Data analysis

Shrimps were individually sexed, measured for total length from tip of the rostrum to the tip of the telson (to the nearest mm) and weighed in 'g', and size frequency distributions were constructed using size classes of 5 mm TL for 13 530 shrimps (51.39% females and 48.60% males) sampled. We measured the total length and weight only of those specimens with intact rostrum and telson. Specimens with broken rostrum/telson were discarded from the analysis. Given the biological differences between the sexes (growth and mortality rates), all the analyses were performed separately for males and females. Sex was determined by visual examination of the secondary sexual characters, namely thelycum in females and petasma in males. Length at age was established using von Bertalanffy growth equation (1938):

$$L_t = L_\infty(1 - e\hat{}(-k(t - t_0)))$$

L_∞, k and t_0 were estimated from the length-frequency data using ELEFAN I with the FiSAT II program (FAO-ICLARM Fish Stock Assessment Tools, Version 1.2.2). L_∞ is the asymptotic length, k is the von Bertalanffy growth constant and L_t is the expected length at age t years. t_0 is the age at which the total length of the shrimp is zero and here in this study is considered zero as in most penaeid shrimps (Silva et al., 2019). Life span or the approximate maximum age t_{max} that a population would reach was calculated by the equation $t_{max} = 3/k + t_0$ (Pauly and Munro, 1984).

Length/weight relationships were derived by applying the exponential equation: $W = aL^b$, where W is the body weight (W, g), L is the length (L, cm), and ‘a’ and ‘b’ are constants. Size at 50% maturity in females was estimated using the King (1995) equation: $P = 1/(1 + \exp(-r(L - Lm))$, where P is the predicted mature proportion, r = slope of the curve, and L = the total length. Proportion of sexually mature females were used in the analysis. Gonadosomatic index was determined using the equation: GSI = Weight of ovary/weight of shrimp × 100. Relative condition factor (Kn) was calculated as $Kn = W_0/W_c$ where W_0 is the observed weight and W_c the calculated weight of shrimp, determined by inputting ‘a’ and ‘b’ values from the length/weight relationship (Le Cren, 1951).

Sex ratio was estimated each month and a Chi square (χ^2) test (Snedecor and Cochran, 1967) on the sex ratio was performed, as is standard procedure to determine the significant variation in the frequency of each sex from the 1:1 ratio.

Total instantaneous mortality Z (Z, yr^{-1}) was calculated from length converted catch curve analysis (Pauly, 1983), and natural mortality (M, yr^{-1}) from Pauly’s empirical formula (1980). Fishing mortality (F, yr^{-1}) was calculated from the equation $F = Z - M$. The exploitation rate E was obtained from Gulland (1971): $E = F/Z = F/(M + F)$.

Length cohort analysis (LCA) was used separately for the sexes to estimate the stock status, as LCA is used widely in tropical crustacean assessments (Sparre and Venema, 1998). Male L_{m50} or length at which 50% of the individuals are mature was applied as 65 mm from Rao (1968) in LCA for males.

Thomson and Bell yield analysis (1934) was done to estimate the maximum sustainable yield (MSY), maximum economic yield, and the spawning stock biomass SSB, by inputting results obtained from LCA. The relative yield per recruit (Y’/R) and relative biomass per recruit (B’/R) of Beverton and Holt (1966), as modified by Pauly and Soriano (1986), was used to estimate the reference points – $E_{0.1}$ (the exploitation level at which the marginal increase in yield per recruit reaches 1/10 of the marginal increase computed at a very low value of E), $E_{0.5}$ (the exploitation level which will result in a reduction of the unexploited biomass by 50%) and E_{max} (the exploitation level that produces the maximum yield per recruit). L_c/L_α and M/K derived from ELEFAN I were used as input parameters. The yield per recruit (Y/R) at different age at capture (tc) by Beverton and Holt (1957) analysis was also conducted.

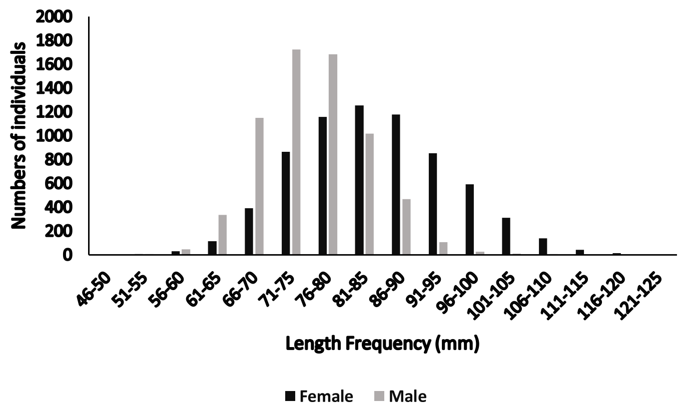

Fig. 2. Size frequency distribution of females and males of *P. stylifera*.

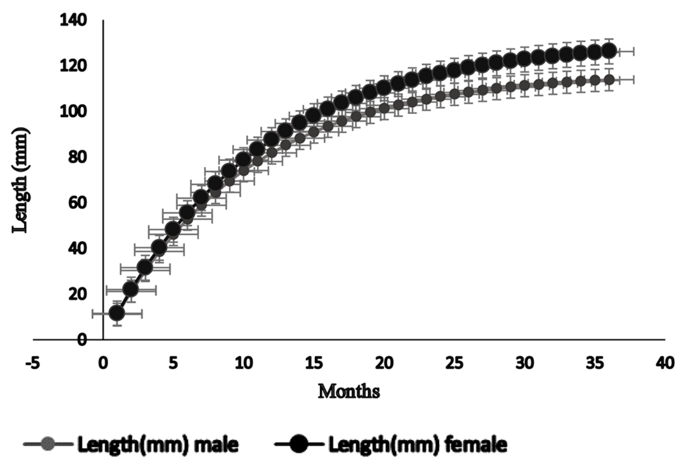

Fig. 3. Length at age for females and males of *P. stylifera*.

3 Results

3.1 Population structure, t_{max}, L_m and length at age

We collected 13 530 individuals of *P. stylifera* ranging in total length from 46 to 125 mm in females and 51 to 115 mm in males. In general, females were larger than males and dominated ($p < 0.05$) in the larger length classes (>80 mm TL). In the length classes up to 80 mm, males were dominant (Fig. 2). Length at age of females was 87 mm in the first year and 116 mm in the second year; 81 mm in the first year and 106 mm in the second year for males (Fig. 3).

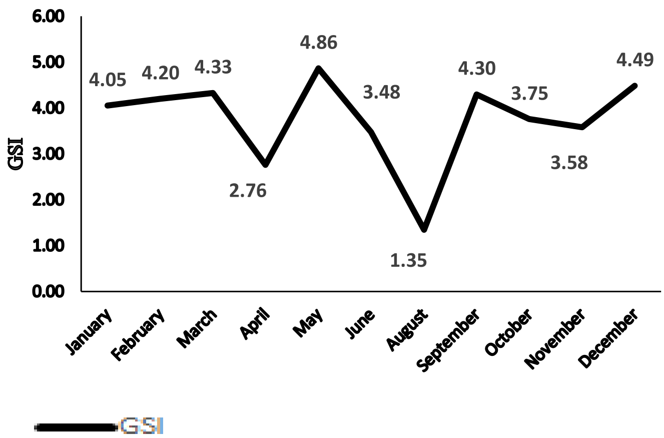

Fig. 4. Gonadosomatic index of *P. stylifera* females.

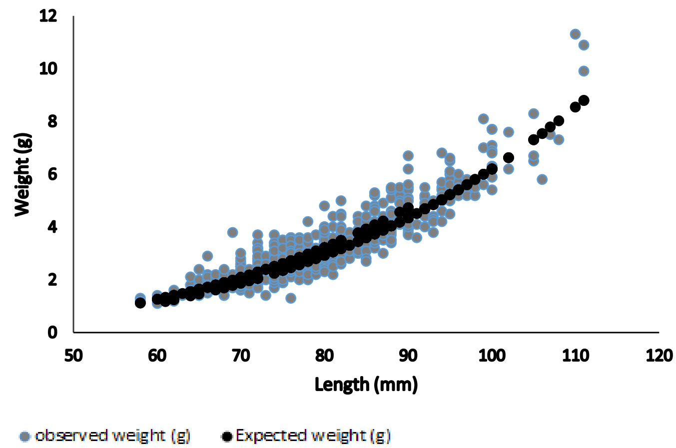

Fig. 5. Length/Weight relationship in pooled *P. stylifera*.

Estimated size at 50% maturity was 71 mm TL in females ($n = 580$, $R^2 = 0.97$). Minimum size at maturity (MSM) which is the smallest size at which the shrimps were mature was observed at 65–68 mm TL. Maximum life span was 2.7 in females and 2.3 in males.

3.2 Sex ratio, GSI and spawning period

Male to female ratio was 1:1.13. Chi square test (χ^2) revealed dominance of females in the fishery during February ($\chi^2 = 30.95$, $p < 0.05$), March ($\chi^2 = 5.45$, $p < 0.05$), September ($\chi^2 = 2.23$, $p < 0.05$), October ($\chi^2 = 7.42$, $p < 0.05$) and November ($\chi^2 = 3.57$, $p < 0.05$), and in the remaining months followed 1:1 sex ratio. Spawning was continuous with peaks during April and September to December as maximum numbers of mature females were recorded during these months. Gonadosomatic index (GSI) revealed May (4.86) and December (4.49) as the peak spawning months in females (Fig. 4). Kn was observed to be above 1 during January to March, May, and August to December, with the highest value recorded in December for both females (1.18) and males (1.08).

3.3 Length/weight relationship

The length/weight regression was $W = 0.00000118L^{3.3}$ ($R^2 = 0.77$, $n = 582$) for females and $W = 0.00000201L^{3.2}$ ($R^2 = 0.86$, $n = 580$) for males. The difference between the slopes was not significantly different ($p > 0.01$) at 1%, hence the relationship for the pooled data was derived as $W = 0.00000526L^3$ ($R^2 = 0.83$, $n = 1162$) (Fig. 5).

3.4 Growth, mortality and recruitment

von Bertalanffy parameters L_∞ and k obtained were 131 mm; $K = 1.1\ y^{-1}$ in females; 117 mm and $1.25\ y^{-1}$ for males. Probability of capture was $L_{25} = 67.58$, $L_{50} = 71.04$ and $L_{75} = 74.49$ mm for females, and $L_{25} = 64.57$, $L_{50} = 66.23$ and $L_{75} = 67.89$ mm for males. Mortality parameters Z, M and F were 4.42, $M = 1.24$, $F = 3.18\ y^{-1}$ and $E = 0.72$ for females; $Z = 5.76$, $M = 1.39$, $F = 4.37\ y^{-1}$ and $E = 0.76$ for males (Figs. 6a and 6b). The data points on the initial ascending limb were excluded in the estimation of Z as these are length groups subject to lower fishing mortality because they are considered less vulnerable to the gear and thus might not have been fully recruited to the fishery or might have escaped the gear. The two length classes in females and one in males in the descending limb are comparatively less represented in the catch data. Hence these length groups were ignored.

3.5 Length cohort analysis

Length cohort analysis (LCA) was performed with inputs L_∞, k, M and L_{m50} values for females and males independently (Figure given in Supplementary file). Constants ‘a’ and ‘b’ values from the length/weight relationship were also included in the analysis. Highest fishing mortality was observed in the length range 101–105 mm TL in females and in males in the length range 86–90 mm.

3.6 Biological reference points

3.6.1 Thomson and Bell analysis

Results from LCA were input into the analysis. Figures 7a and 7b shows MSY, MSE and SSB of females and males, respectively at different F-factor. Yield at $F_{current}$ for females was 121 460 and males 128 064 t, which is close to the MSY level. Further increment in fishing pressure will not concede higher yield or financial returns. In contrast, a decrease in current fishing effort leads to maximum economic yield (MSE) at $F = 0.8$ and $F = 0.6$ in females and males, respectively. At these levels of fishing B/B_0 and SSB/SSB_0 are 27% and 22% in females, respectively and 30% and 25% in males, respectively. At $F_{current}$, B/B_0 and SB/SB_0 are 24% and 18% for females, respectively and 21% and 16% for males, respectively.

3.6.2 Beverton and Holt yield per recruit analysis

$F_{0.1}$ and $F_{0.5}$ were estimated from yield F curve at different age at capture tc (0.5, 0.6, 0.7 and 0.8 yrs) at current natural mortality $M = 1.24$ and 1.39 for females and males,

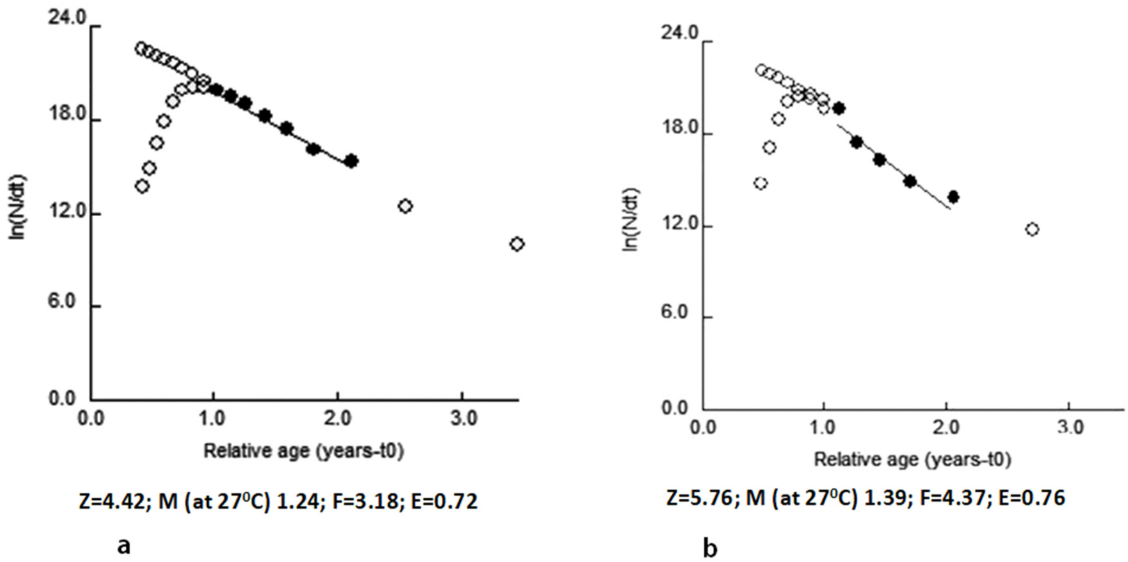

Fig. 6. Mortality in (a) female, and (b) male *P. stylifera.*

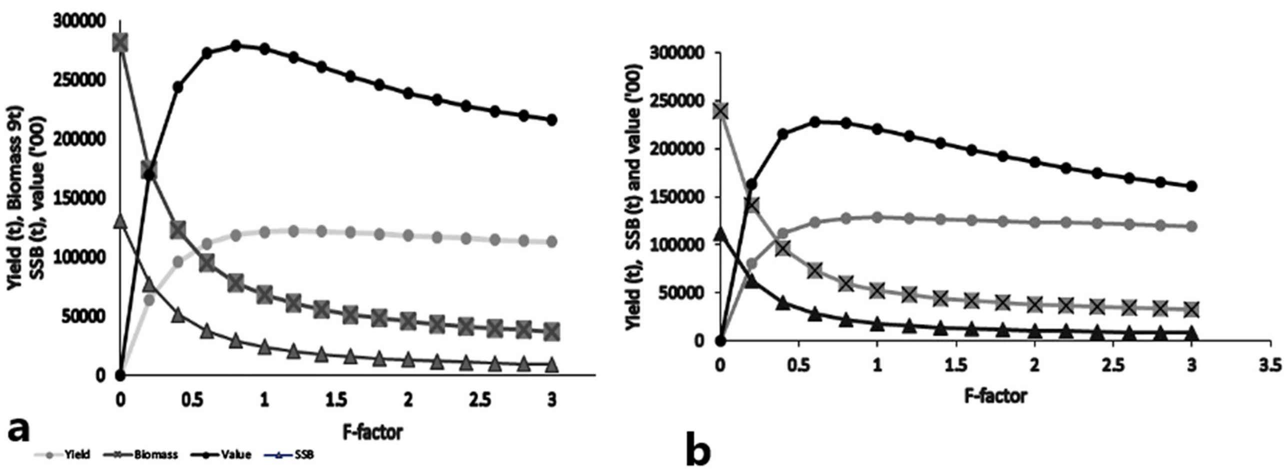

Fig. 7. Thomson and Bell analysis of yield/recruit for (a) female, and (b) male *P. stylifera*.

respectively (Figs. 8a and 8b). $F_{0.1}$is the fishing mortality where the slope of the yield per recruit curve is 10% of that at the origin and $F_{0.5}$ is the fishing mortality that will reduce the equilibrium spawning potential per recruit to 50% to what it would be without fishing. Parameters used for the analysis were $k = 1.1$, $W_{\infty} = 11.8$, $t_0 = 0$, $tr = 0.4$, $tc = \{0.5, 0.6, 0.7, 0.8\}$, $M = 1.24$ for females, and $k = 1.3$, $W_{\infty} = 8.4$, $t_0 = 0$, $tr = 0.4$, $tc = \{0.5, 0.6, 0.7, 0.8\}$ and $M = 1.39$ for males. Yield per recruit at $F_{current}$ ranged from 1.24–1.28 in females, and 1.33–1.43 in males. $F_{current} > F_{0.1}$ and $F_{0.5}$ the conservative level of fishing for both the sexes.

3.6.3 Beverton and Holt relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R)

Beverton and Holt relative yield per recruit analysis revealed E_{max} as 0.69, $E_{50} = 0.37$ and $E_{10} = 0.60$ for females and $E_{max} = 0.75$, $E_{0.5}$ as 0.39 and $E_{0.1}$ as 0.66 for males (Figs. 9a and 9b). The input parameters for the analysis, M/K ratio was 1 for both the sexes and $Lc/L_{\infty} = 0.53$ for females and 0.59 for males, respectively. The reference points $E_{0.1}$ is the level of exploitation at which the marginal increase in yield per recruit reaches 1/10 of the marginal increase computed at a very low value of E, $E_{0.5}$ is the exploitation level which will result in exploitation of the unexploited biomass by 50% and E_{max} is the exploitation level that produces the maximum yield per recruit. $E_{current}$ for females and males ($E = 0.72$; $E = 0.76$) are higher than E_{max}, which indicates limiting exploitation rate to the conservative levels $E_{0.1}$ or E_{50}.

4 Discussion

The study estimated spawning period, length/weight relationship, growth, mortality and biological reference points

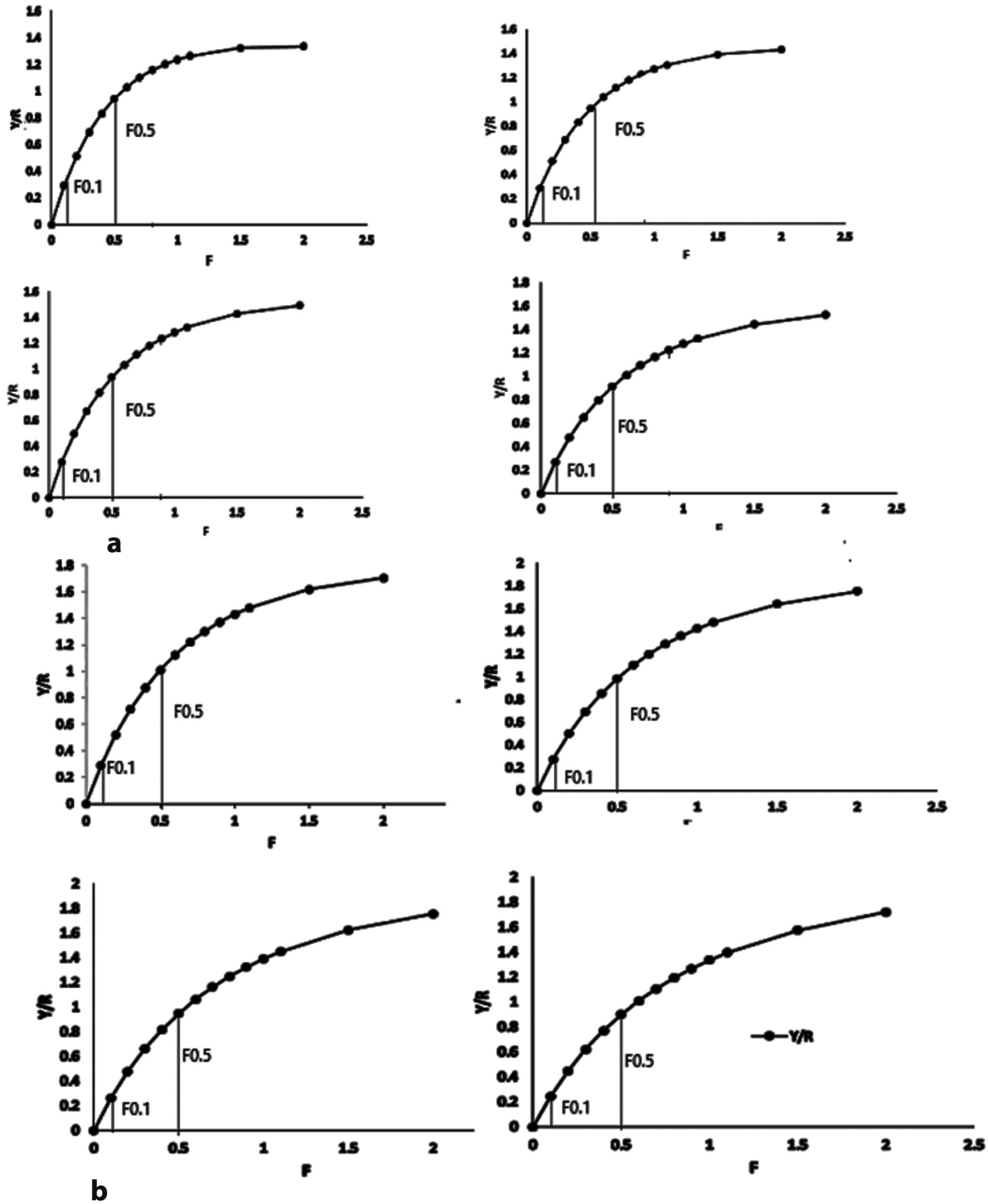

Fig. 8. Curves of yield per recruit on fishing mortality (F) for females (a) and males (b) estimated for age at capturet c = 0.5, 0.6, 0.7 and 0.8.

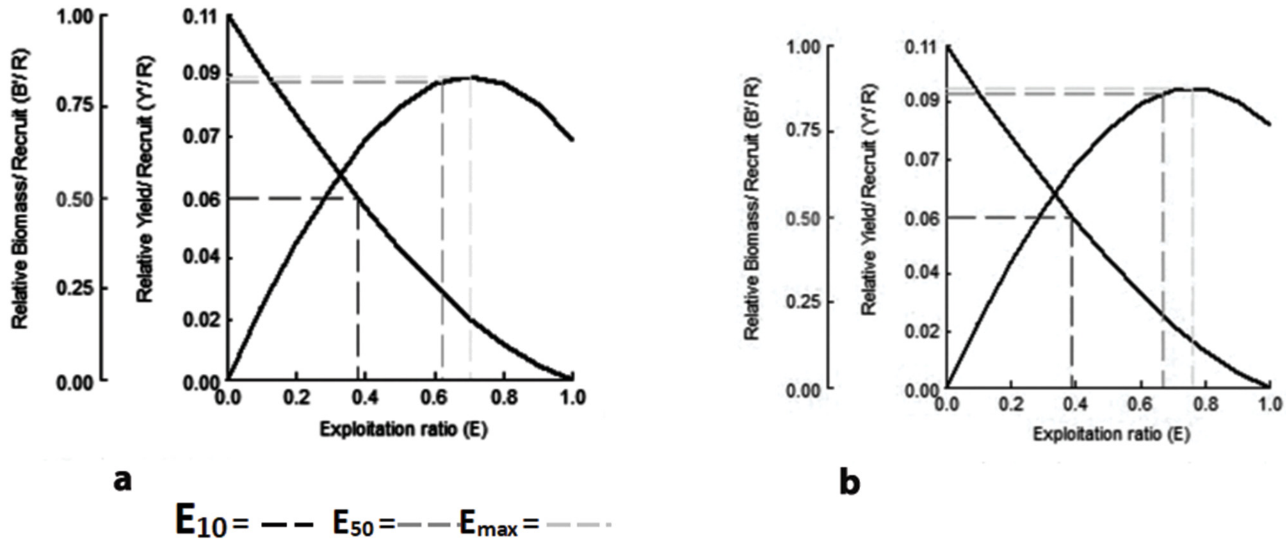

Fig. 9. Beverton and Holt yield/recruit for (a) female and (b) male *P. stylifera*.

Table 1. Comparison of growth parameters of *P. stylifera* between previous and present studies.

Study area	Sex	L∞ mm	K (yr^{-1})	Authors
Cochin, Central Kerala	Male Female	130 134	0.19 (monthly) 0.20 (monthly)	Alagaraja et al. (1986)
Cochin, Central Kerala	Male Female	108 135	1.05 1.19	Suseelan and Rajan (1989)
Calicut, North Kerala	Male Female	111.8 132.03	0.2065 (monthly) 0.1912 (monthly)	Sarada (2002)
Neendakara, South Kerala	Male Female	121 133	1.2 1.51	Present study

leading to the stock status of *P. stylifera* using length data collected over a nine-year period at fortnightly intervals from trawler landings. The analysis is based on the data from single-day trawlers, mainly targeting the species and bringing the entire catch to the landing centre. Hence our data can be considered representative of the population of *P. stylifera*. Our observation on size range for the sexes were slightly more divergent than Suseelan (1989); Suseelan (1989) reported 35–100 mm size range for males and 35–115 mm for females. Again, in another study, Suseelan (1998) observed 46–100 mm in males and 46–125 in females, which is less than that reported in this paper. In penaeid shrimps, females generally reach larger sizes than males (Boschi, 1989), and the males have higher growth coefficients with lower asymptotic length, which is consistent with the findings in our study. *Parapenaeopsis stylifera* followed the reported trends of other tropical penaeid shrimps: faster growth, short life span completing its life cycle in 2.0–3 yrs (Garcia, 1988). Estimated L_m in this study is in accordance with Ramamurthy (1980), reported as 71 mm total length. Menon (1953) and Sarada (2002) recorded size at first maturity at 75 mm and 74.6 mmTL, respectively and Ayub (1998) from Pakistan observed size at maturity as 54 mm in males and 76 mm in females. Size at maturity is widely used as an indicator of minimum permissible capture size (Lucofora et al., 1999).

Previous investigations showed that the species spawn mainly in October-December in northern Kerala and in south Kerala during November, January and April (George et al., 1968; Rao, 1968). In Pakistani waters, spawning peak was during November to February (Ayub and Ahmed, 2002). Spawning periods may vary depending on the availability of food and other environmental fluctuations. Two spawning peaks were reported in other species of shrimps (Rao, 1968; Penn, 1980). In our study, two spawning peaks were also noticed (May and December) based on the highest values of the gonado-somatic index in females and during April and September to December, the percentage of mature females was at a maximum.

Length/weight relationship exhibited ‘b’ values as 3.2 and 3.3 for females and males, respectively and 3 for pooled data which agrees with the observation of Froese (2006) that the ‘b’ value in the length/weight relationship ranges between 2.5 and 3.5. The results of Kn, which were around one during most months, indicate a favourable environment for the growth of the species.

L_∞ for the sexes concurred with previous studies on *P. stylifera* from Kerala (Suseelan, 1989; Sarada, 2002) (Tab. 1). The von Bertalanffy model (1938) is the most useful for the study of rapidly growing animals like penaeid and sergestid shrimps (Petriella and Boschi, 1997) as their growth is discontinuous. Z in our study was 4.42 for females and 5.76 for males. Most of the penaeid shrimp fisheries around the world have high fishing mortalities (Jones and Zalinge, 1981; Mehanna, 2000).

Yield per recruit models are very useful for single species approach to shrimp management and the models of Thomson and Bell and Beverton and Holt are widely used (Garcia, 1988) for stock assessment. Fishing at the MSY level does not necessarily maximise profits, but reduction of effort often leads to higher economic yield and higher spawning stock biomass. Reducing biomass to 25–30% of unexploited levels typically maximises their yields, while values beyond this level can result in losses of diversity and other ecological processes (McClanahan et al., 2011). Reducing present F to $F_{0.1}$ or $F_{0.5}$ which are target reference points would likely result in higher spawner biomass per recruit compared to current F. The conclusions of these Y/R models are very sensitive to seasonal patterns of recruitment, catchability, fishing effort etc. and more elaborate models are needed to fine tune management measures. This is especially the case when the problem of stock and recruitment relationship and uncertainty generated by non-fishery variables must be taken into account (Garcia, 1988). These models need to be applied in combination with stock recruit relationship (SRR) models to recognise the consequence of distinct management plans or strategies on egg production and yield. Understanding the relation between spawner abundance and subsequent recruitment is the most important issue in fisheries biology and management (Myers, 2007). Biological reference points, derived in this study by different models, can serve as an important supplement in fishery management plans. The BSM – Bayesian Schaefer Model, CMSY – Catch Maximum Sustainable Yield (Froese et al., 2017) are a step further in determining the stock status of the species. These methods can provide preliminary or prior reference points with reliable long time series of catch data, and also quantify the uncertainty of the parameter estimates. However, they do not consider the environment or stock interactions, factors for which models need to be developed. The best assessment is one that uses all the models that can be applied depending on available data and compares the results of all models, and the different results are used critically to gauge conclusions (Bonfil, 2005). In multi-species and multi-gear tropical fisheries, such inputs on major commercial resources form an integral part of holistic fishery assessments.

Supplementary Material

The Supplementary Material is available at https://www.alr-journal.org/10.1051/alr/2021003/olm.

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