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Research Article

Population characteristics of green tiger shrimp (*Penaeus semisulcatus* De Haan, 1844), in Palk Bay, Southeast coast of India

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Green tiger shrimp (*Penaeus semisulcatus*), also known as flower shrimp, is one of Palk Bay's most economically productive fisheries. Despite the uniqueness of Palk Bay's fishery, there has been no assessment of the green tiger shrimp's population parameters in the past 3 decades. The current study aims to understand the population characteristics of *P. semisulcatus* in Palk Bay. For the study, a total of 14,844 individuals of *P. semisulcatus* were randomly sampled for length frequency analysis between January 2017 and December 2022. The growth parameters were L_∞ = 229.3 mm, k = 1.24 y^{-1} for males, and L_∞ = 270.4 mm, k = 1.14 y^{-1} for females. Mortality parameters and exploitation ratio estimates recorded were Z = 5.301, M = 2.214, F = 3.087 y^{-1}, E = 0.582 for males, and Z = 5.474, M = 2.002, F = 3.265 y^{-1}, E = 0.634 for females. For both males and females, the E_{curr} (current exploitation ratio) was higher than the optimum exploitation ratio (E = 0.5), and the Lm_{50} (length at maturity) was lower than the LC_{50} (length at capture). This study generates primary information that provides valuable inputs for developing suitable fishery management plans for the resource from the Palk Bay region, potentially leading to its sustainability certification for trade.

[**Keywords**: Exploitation, Fishery and Management Plans, Sustainability, Tamil Nadu]

Introduction

Palk Bay (9°55' to 10°45' N and 78°58' to 79°55' E) is (Fig. 1) located on India's southeast coast, stretching from Point Calimere in the north to Dhanushkodi in the south[1]. It is home to coral reefs, mangroves, lagoons, and seagrass ecosystems. The region's marine environment and physical features vary widely. This diverse and productive ecosystem, including estuaries, salt marshes, seagrass beds, and mangroves, is susceptible to human activity. Trawl fishing in Palk Bay began in the twentieth century[2] and its shrimp fishery has been growing since 1980. There is a well-established fishery for *Penaeus semisulcatus* de Haan, 1844 in Palk Bay and the Gulf of Mannar. This species is found on both the eastern and western coasts of India, although its abundance declines as one travels northward along the eastern coast. Only from October to November, it does constitute a fishery on the western shore, along the Gujarat coast[3]. Thomas[4,5] observed *P. semisulcatus* to be the most important species in the Mandapam shrimp fishery. During 1986 – 1993, penaeid shrimp contributed 16.7 % of total landings, with *P. semisulcatus* accounting for more than 50 %[(ref. 6)]. The variability of estimated monthly landings of *P. semisulcatus* by mini trawl, *thalluvalai*, was recorded with an average of 3.4 t and a maximum of 10.0 t in March 2007[(ref. 7)]. In 2012, the landing of penaeid shrimps from trawling along the northern Mandapam coast was 2347.61 tonnes[8].

Several attempts have been made worldwide to generate information on the stock status of the shrimp, especially from Kuwaiti waters[9], Bushehr coastal waters and the Persian Gulf[10], Yemeni Red Sea waters[11], Gulf of Suez, Egypt[12], Iskenderun Bay, north-eastern Mediterranean[13], Arabian Gulf[14,15], Bay of Bengal, Bangladesh[16], West Central Philippines, Northern Panay, Pilar and Capiz Bays[17], and the north-eastern Mediterranean coast of Turkey[18]. However, studies from India are few. Thomas[5] investigated the length-weight relationship, relative condition factor and age and growth of *P. semisulcatus* in Palk Bay's Mandapam waters. Maheswarudu *et al.*[19] made a preliminary observation on the biology and exploitation of *P. semisulcatus* in the 1990s, but recent information is not available on its population characteristics in the Palk Bay. Green tiger shrimp fisheries and biology have been

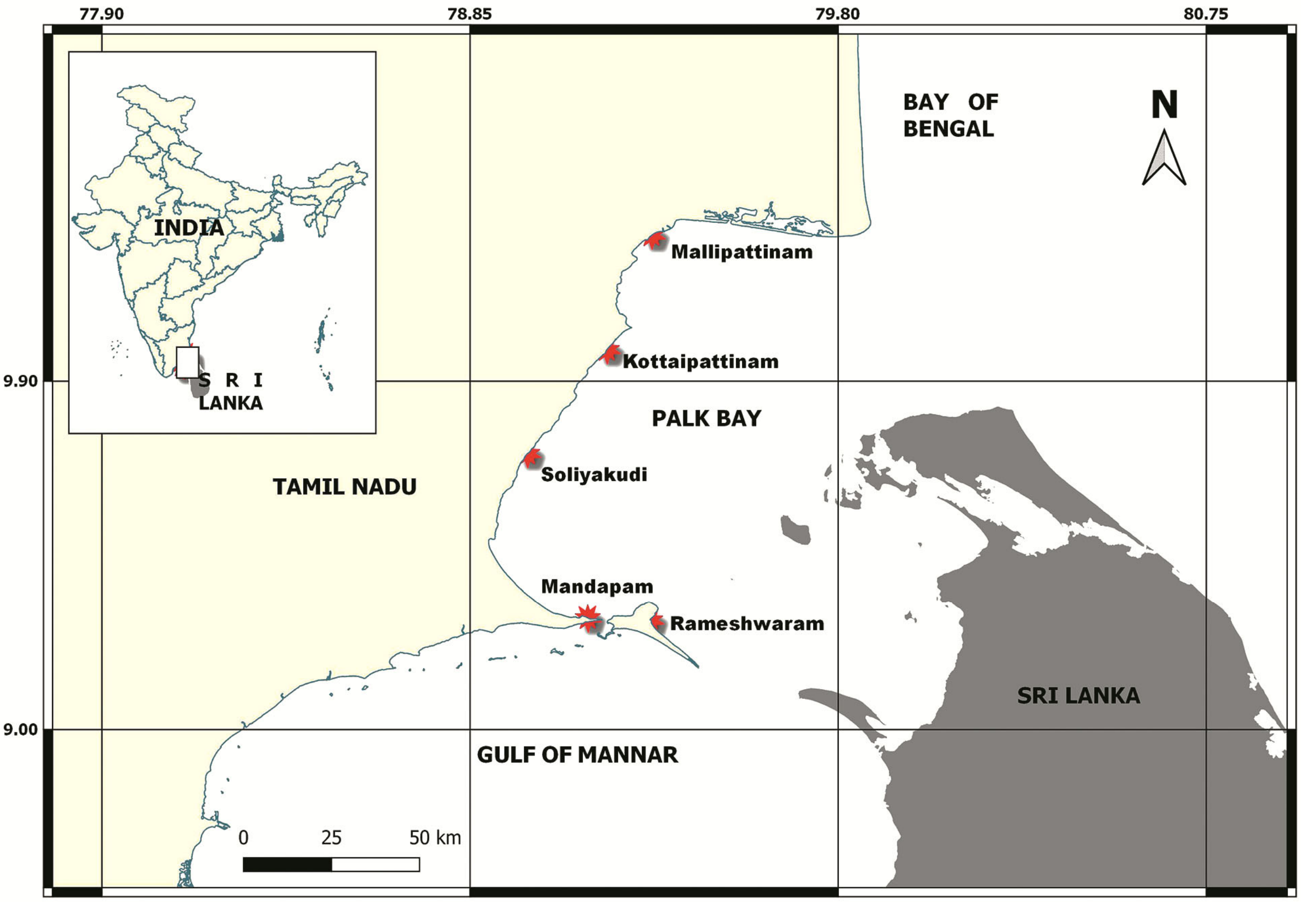

Fig. 1 — Location of the study area and sampling sites (red starred) for *P. semisulcatus* De Haan, 1844, in Palk Bay, Tamil Nadu

documented from Puthiyappa along the Kerala coast[20]. Growth parameters vary between species, but they can also vary from stock to stock within the same species, *i.e.*, a species' growth parameters might assume various values in various regions of its range[21]. Instantaneous mortality rates are extensively utilised as population parameters in shrimp stock assessment[22]. These mortality parameters provide information regarding population dynamics[23-25].

Knowledge of these factors is crucial in fishery management since it determines whether a region is intensively fished or under-exploited, allowing for suitable management strategies[26]. Considering the study efforts performed in recent years outside India, the works carried out in India appear to be primary as well as outmoded, and hence its economic value and for sustainable utilisation of the resource, efforts were made to update the current information on *P. semisulcatus* in the Palk Bay. This study aimed to investigate the population characteristics of green tiger shrimp in Palk Bay, on India's southeast coast, in order contribute to develop management approaches for this valued fishery resource.

Material and Methods

Study area and sampling

This study employs a descriptive quantitative research method. The sampling process was conducted through a survey. The site was identified through a purposive sampling approach, which entailed following fishermen utilising trawl fishing gear. The sampling method utilises either a purposive or random sampling approach. Data on length frequency from the unsorted shrimp samples obtained from the trawl landings at Mallipattinam, Kottaipattinam, Soliyakudi, Mandapam, and Rameshwaram (Fig. 1) was collected biweekly in the period from 2017 to 2022. The shrimp sample used in the study was considered representative of the population. The trawl landings and effort data for the Tamil Nadu coast from 2017 to 2022 were sourced from the NMFDC (National Marine Fishery Resources Data Centre) of the ICAR-Central Marine

Fisheries Research Institute in Kochi, India, for further analysis[27].

Population parameters estimation

The shrimps were segregated sex-wise. The weight in grammes and the Total Length (TL), measured to the closest millimetre from the tip of the rostrum to the tip of the telson, were noted. Using 5 mm TL size classes, the size-frequency distributions were created for 14,844 shrimps (42.63 % males; 57.37 % females) collected. The TL and weight of only intact individuals were measured. Excluded from the analysis were specimens with damaged telson or rostrum. Because of biological differences, separate analyses were carried out for males and females (growth and mortality rates). The secondary sexual characteristics of female thelycum (Fig. 2a) and male petasma (Fig. 2b) were visually examined to determine sex.

Length-at-age was established using growth equation developed by the von Bertalanffy[28].

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

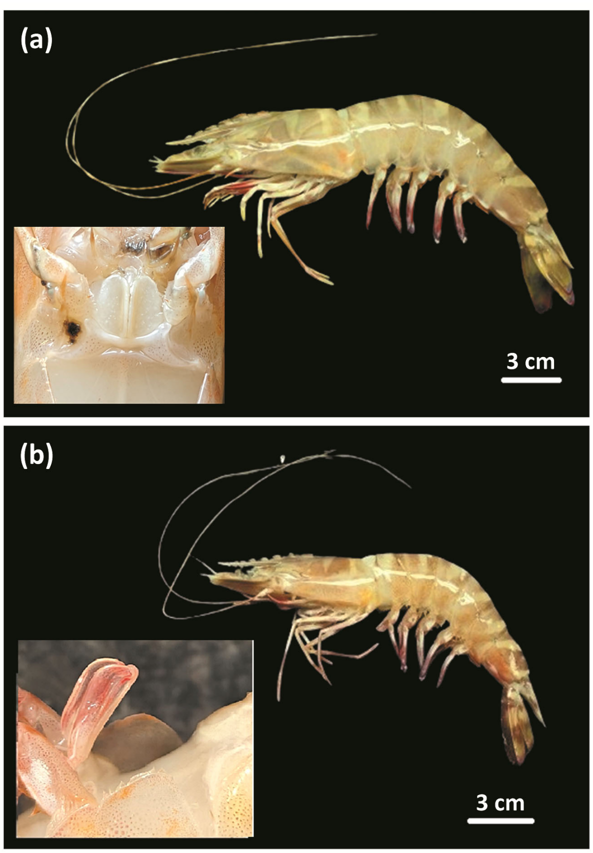

Fig. 2 — Sex differentiation of *P. semisulcatus*: a) female, and b) male with zoomed images of the thelycum in females and petasma in males. Size bar is for full shrimp photos

Where, L_t - Length at a given age, L_∞ - asymptotic length, k - growth coefficient, t - age, and t_0 - Arbitrary origin of growth.

Age at zero length (t_0) was back calculated using equation derived from von Bertalanffy growth equation[28] as:

$$t_0 = 1/K\ log_e\ [1 - (L_{t0}/L_\infty)]$$

Where, L_{t0} is length at birth. For the calculation of t_0, 0.25 mm was used as length at birth (L_{t0}) which is the usual size of the nauplius-1.

ELEFAN_SA (ELEFAN Simulated Annealing) with "TropFishR" in the 'R' software program was used to estimate L_∞ or asymptotic length, the growth constant k, and t_0 from length-frequency data. L_t represents the predicted length-at-age, t years and t_0 is the age at which the overall length of the shrimp is zero[29]. The life span, also known as the anticipated maximum age (t_{max}) that a population will reach, was calculated using the given equation[30]:

$$t_{max} = \frac{3}{k} + t_0$$

Where, k - growth coefficient, t - age, t_0 - Arbitrary origin of growth, and t_{max} - maximum age.

The calculation of the growth performance index ($\emptyset$) in relation to the growth in length was carried out by utilising the equation provided by Pauly & Munro[30]:

$$\emptyset = \log 10\text{k} + 2\log 10\ L_\infty$$

Where, $\emptyset$ - growth performance index, k - growth coefficient, and L_∞ - asymptotic length. The growth performance index ($\emptyset$) is to be in the range of $2 < \emptyset < 3$.

The optimal length (L_{opt}) at which the total biomass of a year-class reaches its greatest value was determined using the Beverton equation[31]:

$$L_{opt} = 3L_\infty/(3 + M/k)$$

Where, L_∞ - asymptotic length, L_{opt} - Length corresponding to W_{opt}, M - natural mortality, and k - growth coefficient.

The W_{opt}, which represents the maximum unexploited cohort biomass in terms of body weight, is determined by Holt[32]:

$$W_{opt} = W_\infty(k/(k + M/3))$$

Where, W_{opt} - unexploited cohort biomass reaches a maximum, W_∞ - asymptotic weight, k - growth coefficient, and M - natural mortality.

The age at which the unexploited cohort biomass reaches its maximum value, denoted as t_{opt}, was determined using the following mathematical equation[33]:

$$t_{opt} = \left(\frac{\ln\left(\frac{3+M}{M}\right)}{k}\right) + t_0$$

Where, t_{opt} - age at the peak of unexploited cohort biomass, k - growth coefficient, M - natural mortality, and t_0 - arbitrary origin of growth.

The mean length of L_{opt} in the catch and in the population that is being exploited is obtained by solving for L_c, which yields the length at first capture, L_{c_opt}. When fishing is started at this length, the population's mean length for both the capture and the exploits is L_{opt}(ref. 33).

$$L_{C\_opt} = L_\infty\,(2 + 3F/M)/((1 + F/M)(3 + M/k))$$

Where, L_{c_opt} - Mean catch length of L_{opt} in exploited population, L_∞ - asymptotic length, F - Fishing mortality, M - natural mortality, and k - growth coefficient.

The age t_{c_opt} that corresponds to L_{c_opt} is determined by utilising the following formula[33]:

$$t_{c\_opt} = \frac{\ln\left(\frac{(Z)(3k+M}{M(Z+k)}\right)}{k} + t_0$$

Where, t_{c_opt} - the time corresponding to L_{c_opt}, z - total instantaneous mortality, M - natural mortality, k - growth coefficient, and t_0 - arbitrary origin of growth.

The Length-Weight Relationships (LWRs) were determined using the exponential equation[34], where, W represents the body weight in grammes, L represents the total length (TL) in centimetres, and 'a' and 'b' are constants. The LWR was computed independently for males and females.

The Gonado-Somatic Index (GnSI) was determined using the formula developed by Crisp *et al.*[35]

$$\mathrm{GnSI} = \left[\frac{G}{W}\right] * 100$$

Where, *GnSI* is gonadosomatic index, G is the ovary weight in grammes, and W is the shrimp weight in grammes.

The condition factor was determined using the formula[34], $K = W / (aL^b)$. Where, K is the condition factor, W is the weight (g), L is the total length (cm), and 'a' and 'b' are the constants.

The size and appearance of the ovary determine the maturity phases of the females. The immature gonad is not visible through the exoskeleton and requires dissection to observe, whereas the mature gonad is clearly visible through the exoskeleton, with a dark-green or green-brown granular appearance[36].

The calculation of the size at which females reach maturity was estimated using the equation provided by King[37] in the 'sizeMat' package in the 'R' software program which is:

$$P = 1/(1 + \exp\,(-r(L - Lm)$$

This equation takes into account the projected proportion of mature individuals (P), the slope of the curve (r), and the total length (L). The analysis only included sexually mature females.

The sex ratio was assessed by monthly enumeration of males and females, and subsequently validated using the Chi-square (χ^2) test, following the methodology described by Rees[38].

$$\chi 2 = \Sigma\left[\frac{(O-E)2}{E}\right]$$

Where, O - observed frequency, and E - expected frequency. A significance test was conducted at a probability threshold of $P = 0.05$. The homogeneity was assessed for a 1:1 ratio.

The "TropFishR" package in the 'R' software program used length-converted catch curve (LCCC) analysis[39] to determine the total instantaneous mortality rate (Z, yr^{-1}), and it included Pauly's empirical formula[40] to estimate the natural mortality rate (M, yr^{-1}).

$$\log_{10} M = -0.0066 - 0.279 \log_{10} L_\infty + 0.6543 \log_{10} k + 0.4634 \log_{10} T$$

Where, M – natural mortality, k - growth coefficient, T - mean environmental temperature (in degrees Celsius), and L_∞ - asymptotic length.

Palk Bay serves as the ecological habitat for this shrimp, with a surface temperature range of 26.8 – 32.1 °C, salinity levels of 25 to 34 ppt, pH levels of 7.68 to 8.73, and DO levels of 4.38 to 6.58 ppm. The data points on the initial ascending portion were excluded from the calculation of Z due to their association with length groups that may not have been fully recruited to the fishery. Consequently, these data points were less likely to experience mortality from fishing or be susceptible to the fishing gear. Due to a lack of representation in the catch data, the analysis excluded two length classes (256 – 260 mm & 261 – 265 mm) in females and one length class (216 – 220 mm) in males from the descending limb.

The fishing mortality (F, yr^{-1}) was determined using equation $F = Z - M$. Where, Z represents the total instantaneous mortality, and M represents the natural mortality. The exploitation ratio E was obtained from Gulland equation[41], $E = F/Z = F/(M + F)$; where, F is fishing mortality, Z is the total instantaneous mortality, and M is natural mortality. The probability of capture was analysed following the Pauly[42] method. The exploitation rate (U) was calculated using the equation given by Beverton & Holt[43] and Ricker[44] as: $U = F/Z\,(1 - e^{-Z})$; where, F is fishing mortality, Z is the total instantaneous mortality, and M is natural mortality. Length Cohort Analysis (LCA) was employed individually for males and females to determine the stock status. LCA is commonly utilised in assessments of tropical crustaceans[44].

Results

Length-Weight Relationship (LWR)

The length-weight regression equation for males was $TW = 0.0064TL^{3.07}$ (n = 1071) with an R^2 value of 0.94. For females, the equation was $TW = 0.0042TL^{3.26}$ (n = 1206) with an R^2 value of 0.97. Both sexes showed a positive correlation between total length and total weight with the '*r*' value of 0.949 for males and 0.954 for females (Fig. 3). The analysis of covariance revealed significant variability in the slope ($F = 30.12$; $df = 1$ and 2274; $p < 0.01$) and elevation ($F = 37.40$; $df = 1$ and 2275; $p < 0.01$) of the regression equation between males and females.

Growth, mortality and recruitment

Table 1 provides *P. semisulcatus*'s growth and mortality characteristics, and Figures 4 – 7 display the von Bertalanffy growth curve. To prevent direct comparison of coefficients, specifically the asymptotic length and VBGF growth constant, a growth performance index (Ø) was computed using a multivariate technique that takes into account both L_∞ and k. Females had comparatively greater rates of exploitation, fishing mortality, and total annual mortality than males.

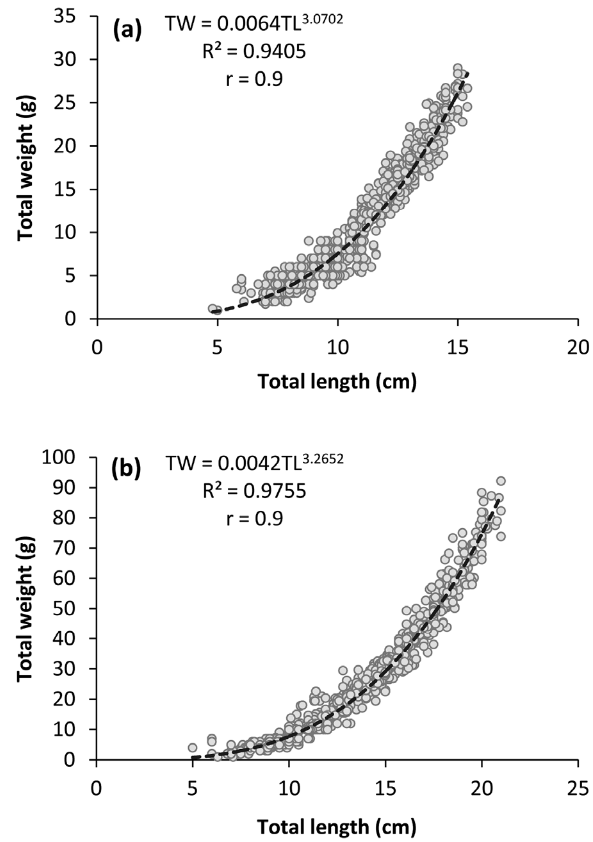

Fig. 3 — Length-weight relationship of *P. semisulcatus*: a) Male, and b) Female

Table 1 — The von Bertalanffy growth and mortality parameters of *P. semisulcatus* in Palk Bay

Variable estimated value	Symbol	Estimated value	
		Male	Female
Growth parameters			
Asymptotic length (mm)	L_∞	229.34	270.46
Asymptotic weight (g)	W_∞	95.75	199.08
Growth coefficient y^{-1}	k	1.24	1.14
Arbitrary origin of growth (yrs)	t_0	-0.00088	-0.00081
Life span (yrs)	t_{max}	2.42	2.63
Length at 50 % probability of capture (mm)	L_{50}	107.48	146.41
Length at 75 % probability of capture (mm)	L_{75}	115.99	158.05
Length at 95 % probability of capture (mm)	L_{95}	128.98	175.19
Age at 50 % probability of capture (yrs)	tL_{50}	0.51	0.68
Age at 75 % probability of capture (yrs)	tL_{75}	0.57	0.77
Age at 95 % probability of capture (yrs)	tL_{95}	0.67	0.92
Growth performance index	Ø	2.81	2.92
Unexploited cohort biomass reaches a maximum	W_{opt}	103.13	216.58

(*Contd.*)

Table 1 — The von Bertalanffy growth and mortality parameters of *P. semisulcatus* in Palk Bay (*Contd.*)

Variable estimated value	Symbol	Estimated value	
		Male	Female
Length corresponding to W_{opt}	L_{opt}	143.6	170.5
Age at the peak of unexploited cohort biomass	t_{opt}	1.12	1.22
Mean catch length of L_{opt} in exploited population (mm)	L_{c_opt}	123.6	149.7
The time corresponding to L_{c_opt}	T_{c_opt}	1.08	1.19
Mortality parameters			
Natural mortality	M	2.214	2.002
Total mortality	Z	5.301	5.474
Fishing mortality	F	3.087	3.265
Exploitation ratio	$E_{current}$	0.582	0.634
Exploitation rate	U	0.579	0.632

Length Cohort Analysis (LCA)

An independent length cohort analysis was conducted for males and females using the provided L_∞, k, M, and L_{m50} values (Fig. 8). The LWR constants '*a*' and '*b*' were also included in the analysis. Males and females with lengths 131 – 135 mm and 251 – 255 mm TL, respectively had the highest fishing mortality (Fig. 7).

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

The sampled shrimp population ranged in total length from 51 – 210 mm in males and 51 – 251 mm in females. The females were larger than the males and dominated in the larger length classes (> 145 mm TL). In the length classes up to 135 mm, males were dominant (Fig. 9). The length-at-age was 162 mm in

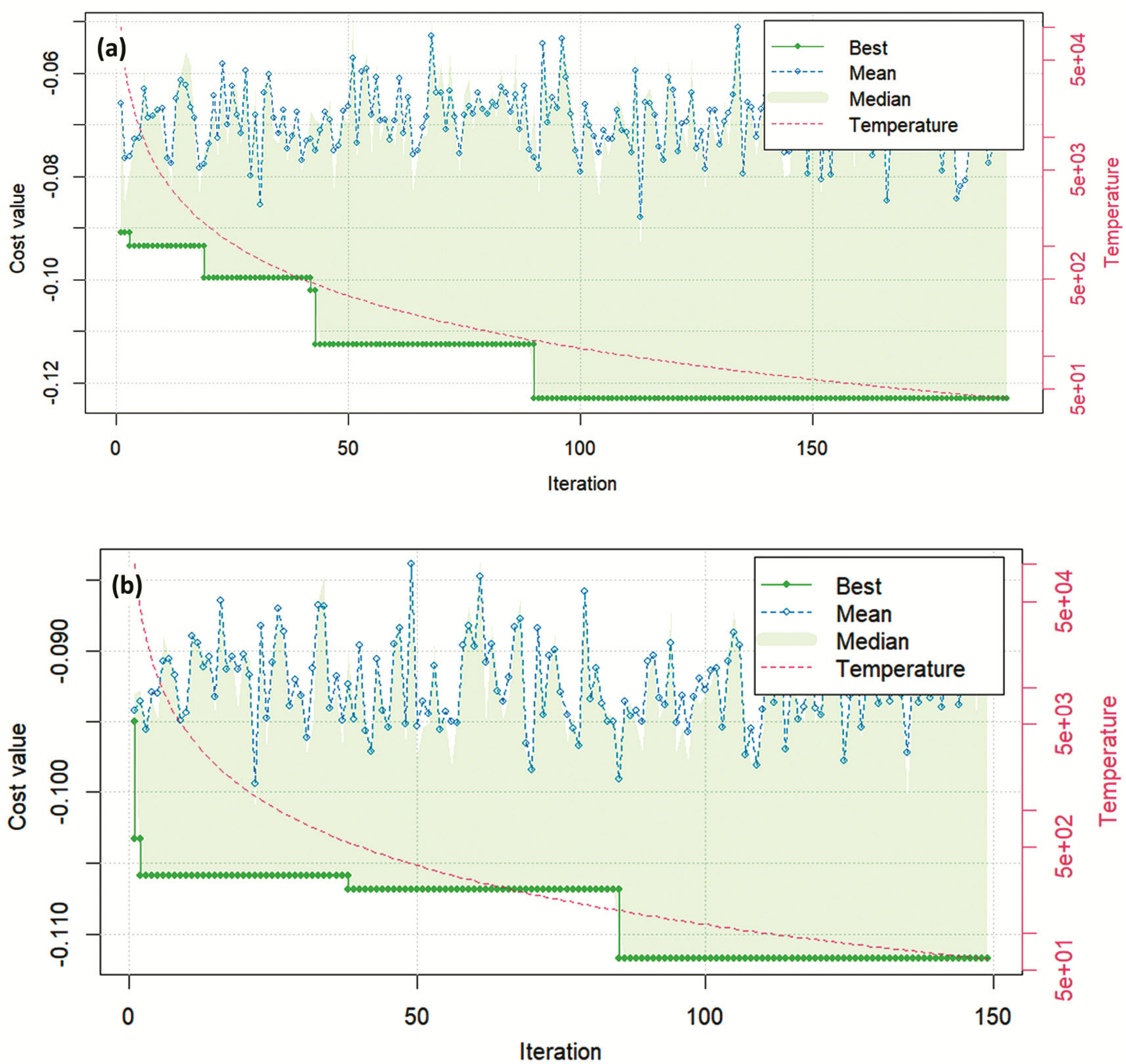

Fig. 4 — Length frequency simulated annealing of *P. semisulcatus* in ELEFAN-SA: a) Male, and b) Female

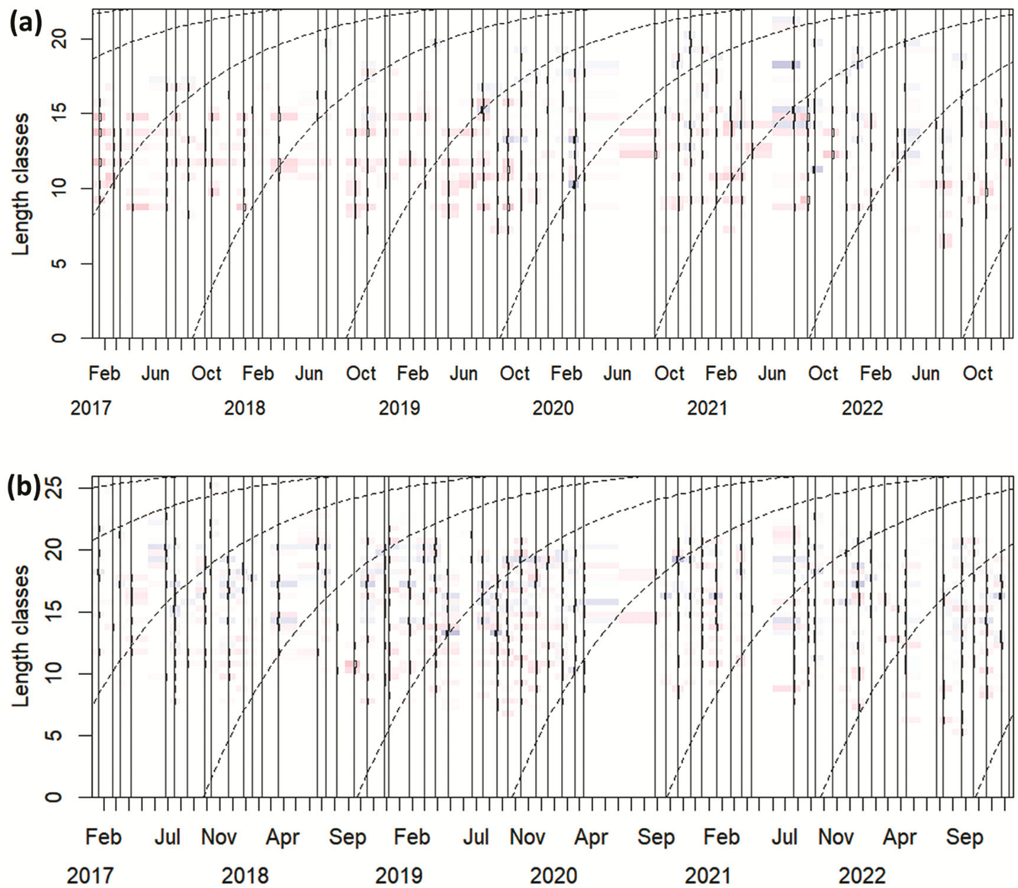

Fig. 5 — The von Bertalanffy growth function plot of *P. semisulcatus* in Palk Bay: a) Male, and b) Female. The ordinate shows the total lengths of the shrimp in cm, while on the abscissa the months of the year are plotted, from 2017 to 2022

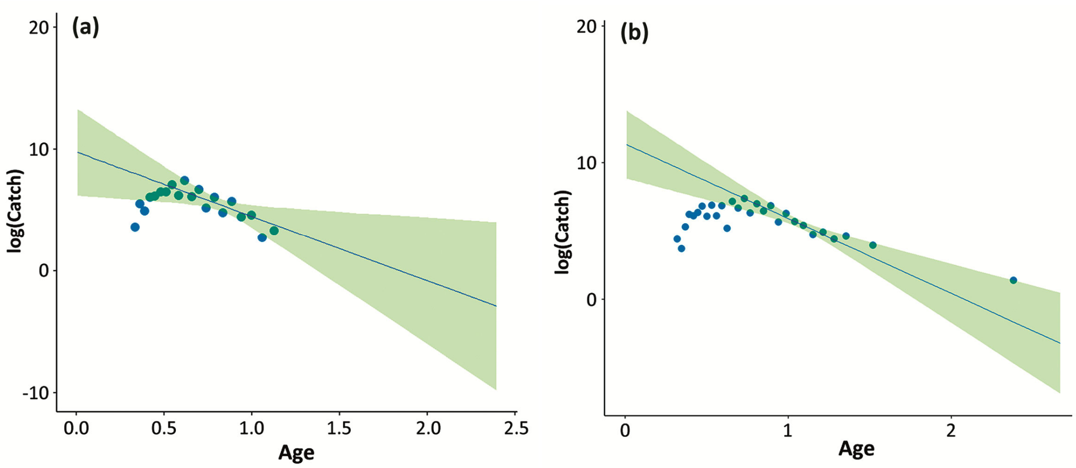

Fig. 6 — Length converted catch curve for Mortality of *P. semisulcatus*: a) Male, and b) Female

the first year and 209 mm in the second year for males, and 183 mm in the first year and 242 mm in the second year for females (Fig. 10). The size at first maturity was found to be 114.3 mm TL for females (n = 8346), and 99.6 mm TL for males (n = 4839). The estimated maximum life span was 2.63 years for females and 2.42 years for males.

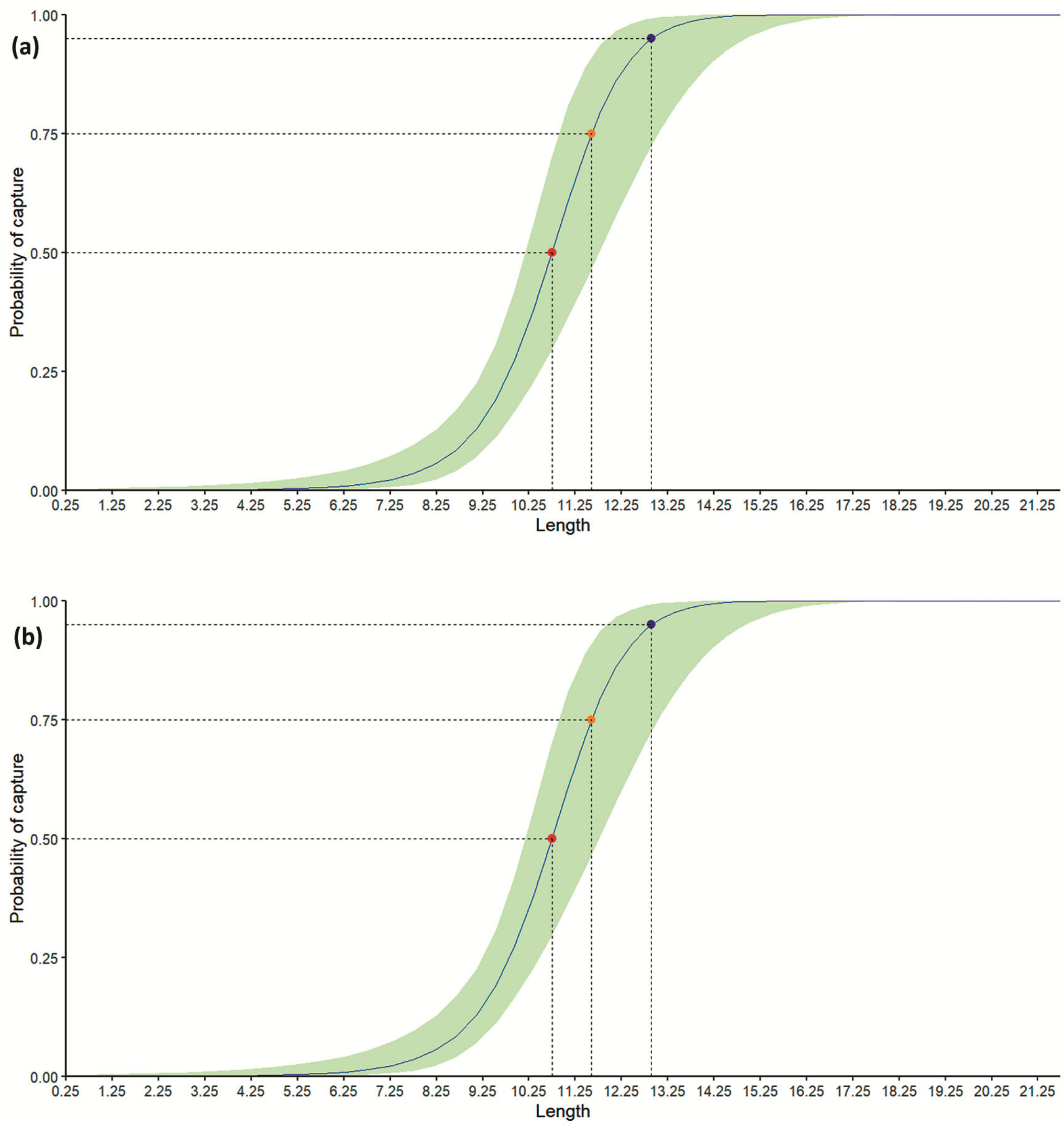

Fig. 7 — Probability of capture of each length class of *P. semisulcatus*: a) Male, and b) Female

Sex ratio, gonado-somatic index and spawning period

The monthly sex composition of green tiger shrimp in trawl landings exhibited variation, with an overall male-to-female ratio (M: F) of 1:1.52. Chi-squared (χ^2) tests resulted in a *p*-value of 0.05 for both sexes, indicating that the male-female ratio was statistically significant. The highest GnSI was seen in March, with July and December following closely behind (Fig. 11). *Penaeus semisulcatus* reproduces throughout the year, with higher levels of spawning occurring during the post-monsoon and monsoon seasons. A bimodal pattern comprising a large post-monsoon peak and a minor peak in the pre-monsoon characterised the seasonal variations in spawning activity.

Discussion

Compared to previous studies in Palk Bay, the asymptotic length is lowest for males and females in current study. Male shrimp had a higher growth coefficient (*k*) than females, but females had a higher growth performance index, indicating that female shrimp grow larger than males. This might be because the growth rate of females in the former months was faster compared to the latter months. However, in the latter months, males grew faster than in the former

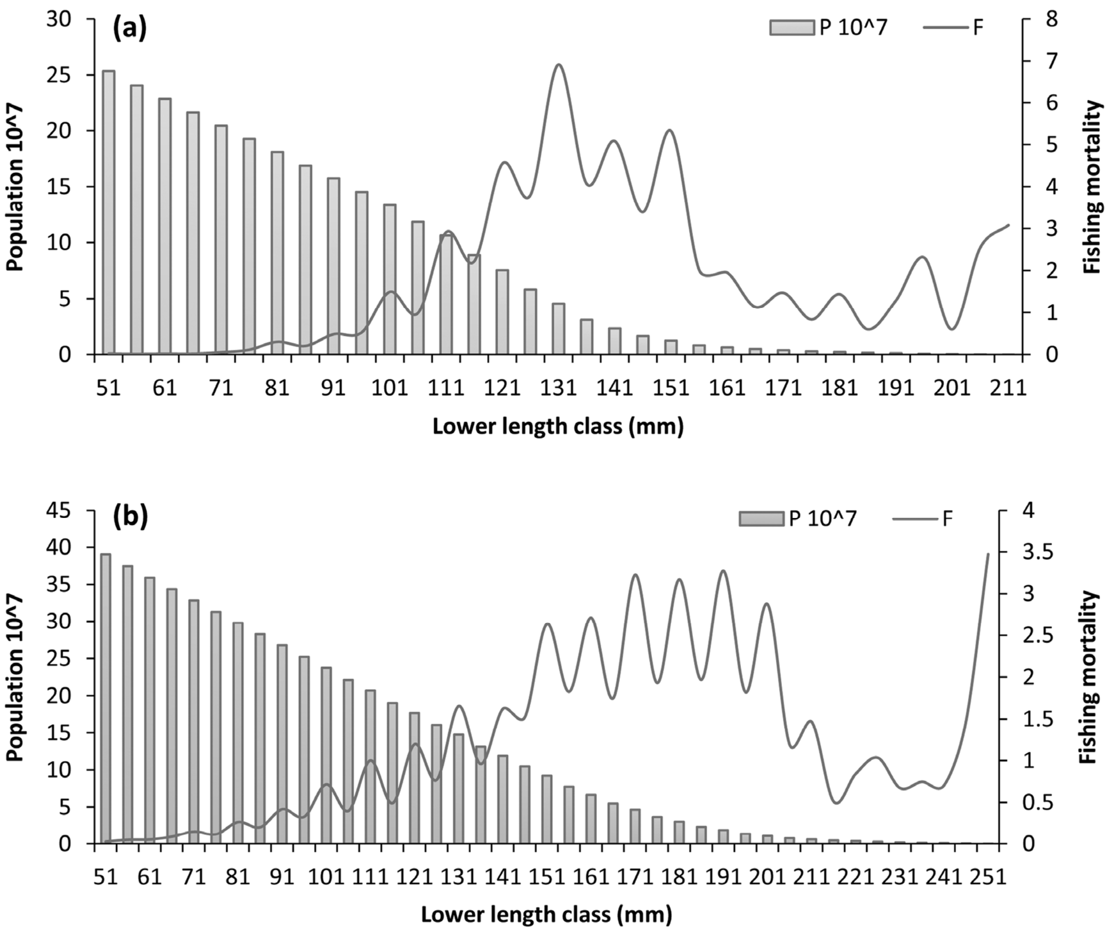

Fig. 8 — Fishing mortality and population of length class of *P. semisulcatus:* a) Male, and b) Female

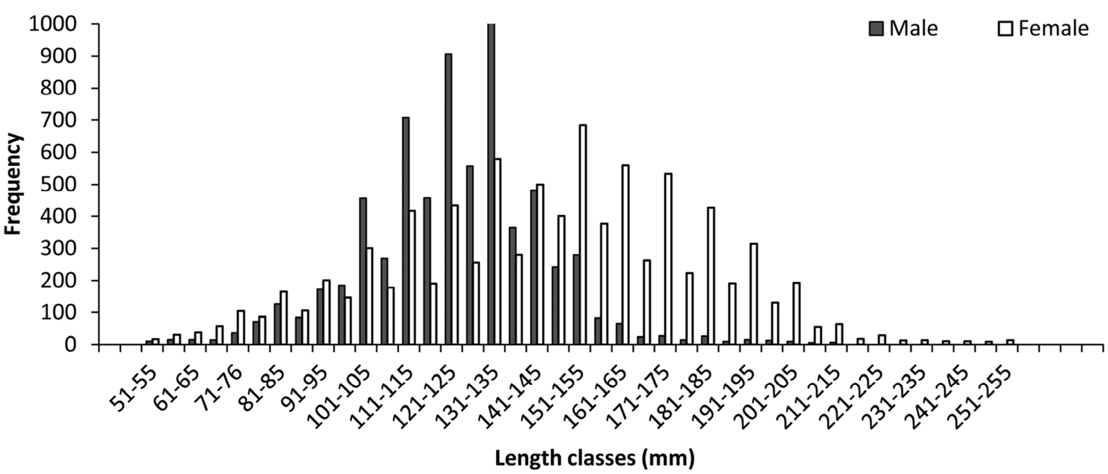

Fig. 9 — Stock structure of male and female *P. semisulcatus* in Palk Bay

months, which is consistent with the earlier findings in Palk Bay[3,19]. Mustaf & Ali[16] and Villarta *et al.*[17] reported higher asymptotic lengths from Bangladesh and the west-central Philippines, albeit with a lower growth coefficient. Ye *et al.*[14] estimates for females from Bahrain lead to growth rates as high as 63 mm CL per year over the size range, nearly triple those of Mathews *et al.*[45] and those in this work. The green

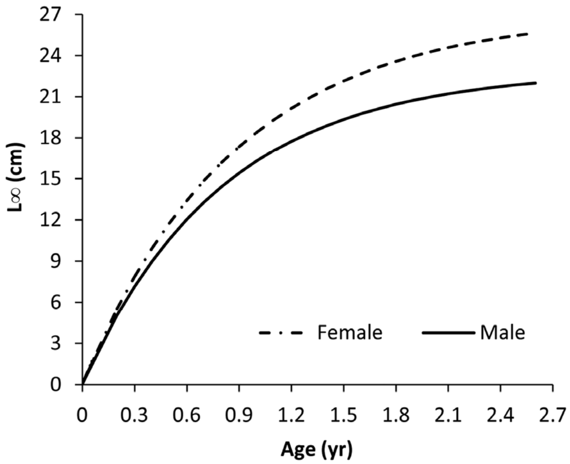

Fig. 10 — Length-at-age for males and females of *P. semisulcatus* in Palk Bay

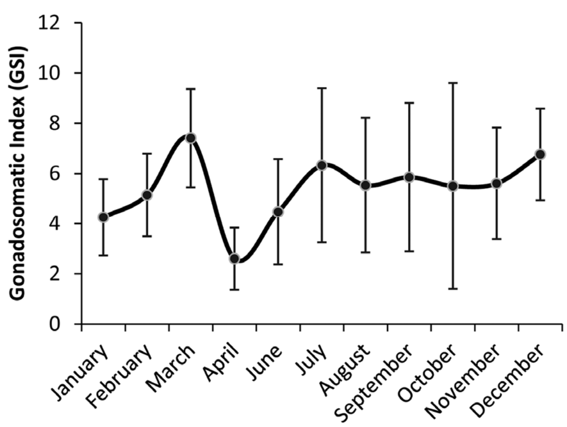

Fig. 11 — Gonadosomatic index of *P. semisulcatus* females (n = 473, Mean±SD)

tiger shrimp from the Gulf of Carpentaria also exhibits sex-related differences in growth, but unlike Ye *et al.*[14] and Niamaimandi *et al.*[10] results from the Persian Gulf, a lower growth rate coefficient *k* compensates for the larger asymptotic size of females[46]. Thus, in terms of growth rate over the size range, Gulf of Carpentaria shrimps show no differences between the sexes (45.8 mm CL per year in females, 46.6 mm CL per year in males). Moreover, the estimation of asymptotic length is greatly influenced by the observed maximum length of the species. The estimated t_0 was -0.00088 per year for males and -0.00081 per year for females, considered zero in most penaeid shrimps and is consistent with earlier studies[47]. *Penaeus semisulcatus* has similar patterns to other tropical penaeid shrimps, displaying accelerated growth and a reduced lifespan, completing its life cycle within a span of 2 to 3 years[48]. The maximum estimated life span (t_{max}) in this study was less than 3 years, which is different from previous findings[19]. The growth performance index (*Ø*) within the same family is observed to fall within the acceptable range of 2 < *Ø* < 3. Oceanographic conditions such as temperature, salinity, pollution, nutritional resources, and other population elements contribute to the differences in growth parameters. These parameters both affect the growth of the species and also can reduce the survivability of individuals in a population[49,50]. Growth parameters can vary within a species and vary from stock to stock within the same species. Additionally, the growth parameters of a specific species may also take on different values in different parts of its distributional range[21].

In Mandapam waters, Thomas[4] reported the size at first maturity of 23 mm carapace length, and the majority reached maturity at around 31 – 32 mm size; however, Sarada[20] found that the female matures and spawns at total lengths less than 128 mm in the Malabar region (Calicut). According to Kumlu *et al.*[51], *P. semisulcatus* reaches sexual maturity at a size of approximately 130 mm. Size at maturity is commonly used to determine the minimum allowable catch size[52]. *Penaeus semisulcatus*, initiates monsoon spawning by dividing its generation time into two distinct periods. The first period, known as the initial spawning period, takes place during the post-monsoon phase and can start as early as 6 – 7 months of age. The second period, referred to as the peak spawning period, occurs during the monsoon phase when the shrimp reach one year of age. Crocos & Coman[53] discovered that larval production rose between the ages of six and twelve months but decreased in 14-month-old shrimp. Other shrimp species have recorded two spawning peaks[54,55].

Researchers have reported the winter peak in Iranian waters of the Gulf[10,56], the wider Arabian Gulf region[57,58], and the Turkish Mediterranean[13]. Rabaoui *et al.*[59] reported continuous spawning throughout the year with two main peaks in the early summer and in December in Saudi waters of the Arabian Gulf. At 23 mm of CL, 50 % of females are mature, and at 29 mm CL, 95 % have reached maturity. The green tiger shrimp in the Saudi waters of the Gulf become sexually mature within a narrow size range, with L50 % at 23.2 mm CL and L95 % at 29.1 mm CL, which also corresponds to a narrow age range of 0.5 and 0.7 yr, respectively[59]. Crocos[60] reported first spawning at 6 months in the Gulf of Carpentaria, although L50 %

was much higher in the Australian waters, at 39 mm CL. The green tiger shrimp from the coastal waters of Bushehr, located in the eastern part of the Gulf in Iran, also mature at significantly larger sizes, reaching 40 and 54 mm CL for L50 % and L90 %, respectively. In the current study, two spawning peaks were identified based on the highest gonado-somatic index values in females: post-monsoon and monsoon.

According to Salim *et al.*[61], when $b = 3$, < 3, and > 3, it implies isometric, negative allometric, and positive allometric growth, respectively. The *b* values derived from the total length-total weight relationship were greater in females than in males, suggesting that females were more robust than males within the same cohort. The TL-TW relationship exhibits positive allometric growth in both sexes, as the *b* value surpasses 3. The *b*-values of TL-TW demonstrate that the increase in weight surpasses the increase in total length. The correlation coefficients for length-weight relationships in male and female shrimps exceeded 0.9. The results showed a very strong correlation between total length and body weight in both shrimp sexes of *P. semisulcatus*, signifying that the total length is directly proportional to the total weight. This condition was due to water environment quality factors favouring shrimp growth. In the present population, males are initially heavier than females of the same size. However, when shrimp mature, females become heavier than males of identical size. The CL-TW relationship reported negative allometric growth in both sexes of green tiger shrimp, with a strong correlation for females and a weak correlation for males[62]. This was found to be consistent with Chu *et al.*'s[63] study on the length-weight relationship of penaeid shrimps.

This study found that the total mortality rate (Z) was 5.301 in males and 5.474 in females, as shown in Table 2. Natural mortality (M) for male and female shrimp is within the range indicated by Garcia & Le Reste[64]. They stated that natural mortality for penaeid shrimp with a maximum life span of two years should be in the range of 2 to 3. Beverton & Holt[65] discovered that animals with fast growth rates had high natural death rates, which is also observed in shrimp populations. Mortality rates from fishing (F) are greater than those from natural causes (M) for both sexes. This could be due to excessive fishing pressure driving market demand. The majority of penaeid shrimp fisheries worldwide have high fishing mortality[12,66]. Gulland[67] found that in a population that is being fished at an ideal level, the rate at which fish are being caught (fishing mortality) is equal to the rate at which fish die naturally (natural mortality), resulting in an exploitation ratio of 0.50 ($E = 0.50$). Nevertheless, the fishing mortality reported in this study (3.087 for males and 3.265 for females) significantly exceeds the natural mortality rate. Consequently, the current exploitation rate for both males and females surpasses the optimal exploitation rate, indicating a high level of fishing pressure on the *P. semisulcatus* stock in Palk Bay[47]. Sparre & Venema[68] said that when the value of fishing mortality due to overfishing is higher than the natural mortality rate, it shows that the higher growth rate caused by overfishing has caused the population of adult green tiger shrimp to drop. Further, Sibagariang *et al.*[69] posited that a significant exploitation rate value signifies a susceptibility to overfishing.

Fishing pressure and prevailing environmental conditions may influence the variation in mortality rates across various aquatic environments. The natural mortality (M) value can influence the stock condition of *P. semisulcatus* and the ecological habitat in Palk Bay. Some factors that may influence natural mortality are diseases, old age, predation, spawning stress, and starvation[70]. Salim *et al.*[25] indicate that the exploitation rate varies between 0 and 1. The optimal point is at 0.5 ($E = 0.5$); it is considered under-exploited when it falls below 0.5 ($E < 0.5$), and it is deemed over-exploited when the estimate exceeds 0.5 ($E > 0.5$). The current exploitation rates of green tiger shrimp are 0.58 for males and 0.63 for females, both exceeding the optimum exploitation threshold of 0.5. This finding suggests a significant degree of exploitation of the green tiger shrimp stock. This is consistent with the findings of the study, which indicate that fishing mortality exceeds natural mortality ($F > M$), resulting in overexploitation.

Aulia *et al.*[71] explained that variations in fishing pressure and environmental conditions lead to differences in mortality rates in different waters within different ecological habitats. According to Michaletz[72], the waters exhibit a dynamic nature and the ecosystem's population stock undergoes periodic variation and complexity, necessitating research on ecosystem dynamics within the context of temporal impacts in ecosystem habitats. Therefore, from an ecological point of view, knowledge about stock size conditions and exploitation will be crucial in the coming years[73]. Sustainable management is crucial for the high-fecund[74], carnivorous[75] species *P. semisulcatus*, as it accounts for more than three-

Table 2 — Population characteristics of *P. semisulcatus* from different geographical locations. L_∞ - asymptotic length; t_0 - arbitrary origin of growth; Ø - growth-performance index; *Z* - total mortality; *F* - fishing mortality; *M* - natural mortality; L_C - length at 50 % probability of capture; t_{max} - life span; CL - carapace length; and yr - year

Sex	L_∞ (mm)	*k* (yr^{-1})	t_0 (year)	Ø	*Z* (yr^{-1})	*F* (yr^{-1})	*M* (yr^{-1})	L_C (mm)	t_{max} (years)	Locations	Authors
Male	229.34	1.24	-0.00088	2.81	5.301	3.087	2.214	107.48	2.42	Palk Bay, India	Present study
Female	270.46	1.14	-0.00081	2.92	5.474	3.265	2.002	146.41	2.63		
Male	231.4	1.34	0		7.2-17.27	5.06-15.34	2.06		3+	Palk Bay, India	Maheswarudu *et al.*[19]
Female	279.1	1.16	0		6.9-10.03	5.12-8.25	1.78		3+		
Male	204.7	1.7	0		9.2-15.56	6.59-12.95	2.61		3+	Gulf of Mannar, India	
Female	267.4	1.37	0		8.15-10.42	6.05-8.32	2.10		3+		
Male	210	1.7					1.7			Palk Bay, India	Rao *et al.*[3]
Female	261	1.3					1.3				
Male	51 (CL)	1.6	-0.13		7.3	4.7	2.6			Yemen	Abdul-Wahab[77]
Female	62 (CL)	1.5	-0.11		5.6	3.2	2.4				
Male	26.15-36.57 (CL)	1.64-3.68	-0.15 – 0.29							Kuwait, Eastern Saudi Arabia, Bahrain, and Qatar	Ye *et al.*[14]
Female	38.32-51.27 (CL)	1.94-3.5									
Male	263	0.7		4.69	3.61	1.91	1.7			West Central Philippines	Villarta *et al.*[17]
Female	271	1.6		5.07	5.65	2.0	3.65				
Male	42 (CL)	1.8	0		4.04	2.24	1.5		1.67	Iskenderun Bay, northeastern Mediterranean	Manasirli *et al.*[13]
Female	63 (CL)	1.9	0		6.39	4.42	1.97		1.57		
Male	44.65 (CL)	1.2	-0.15		6.55	4.36	2.19			Yemeni Red Sea waters	Abdul-Wahab[11]
Female	58.8 (CL)	1.4	-0.12		5.63	3.37	2.27				
Male	224	1.77	-0.001		8.18	5.66	2.52			the Gulf of Suez, Egypt	Mehanna[12]
Female	268	1.56	-0.012		6.77	4.57	2.40				
Male	235	0.8		2.654	5.2	3.47	1.73	158.8		Bangladesh	Mustaf & Ali[16]
Female	270	0.9		2.817	4.7	2.98	1.72	188.69			
Male	53.5 (CL)	0.92	-0.154	3.42	3.24	2.18	1.05	32		Bardawil Lagoon, Egypt	Mohamed & El-Aiatt[78]
Female	66.7 (CL)	1.1	-0.022	3.69	5.34	4.17	1.16	39.6			
Male	38 (CL)	1.6	0	7.73	6.4	4.3	2.11		1.66	Persian Gulf	Niamaimandi *et al.*[10]
Female	50.4 (CL)	2.2	0	8.6	8.2	5.8	2.41		1.25		
Male	36.6 (CL)	1.6			2.7-6.5	2.3	2.5	24.4		Kuwait waters	Mohammed *et al.*[9]
Female	51.2 (CL)	1.7			2.8-6.8	1.7	2.4	31.4			
Male	199.5	1.3			4.34	2.12	2.22			Turkey	Bayhan[18]
Female	262.5	0.8			1.59	1.02	0.57				

fourths of the shrimp landings in Palk Bay, supporting the livelihoods of local fishers[76]. Information on population parameters, such as growth and mortality, provides crucial information for managing fishery resources for sustainable development[24]. To ensure the sustainability of *P. semisulcatus* in these waters and the optimal use of shrimp biological resources, more research is required on the environmental conditions and habitat ecology of these shrimp in Palk Bay.

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Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

The authors do not have any potential conflict of interest.

Ethical Statement

The research did not involve human participants and/or animals.

Author Contributions

MR: Writing – original draft, visualization, software, resources, methodology, investigation, formal analysis, data curation, and conceptualization. SLP & RS: Writing – review & editing, and visualization. RS: Language editing; ST: Map creation; and SJK: validation and supervision.

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