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Population dynamics of two morphotypes of green tiger shrimp *Penaeus semisulcatus* de Haan, 1844 in the northern coast of Iran

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ABSTRACT

Population biology of two morphotypes of *Penaeus semisulcatus* de Haan, 1844 was investigated from January to July 2017 and January 2018 to December 2019 in the Hormozgan coastal waters off Iran. Growth in both sexes was negative allometric. The sex ratio (M:F) was significantly different in terms of month and length classes in both the morphotypes. Year round, the female population dominated in the banded morphotype while males in the non-banded morphotype. Size-wise, the male population was more in smaller classes and females in larger classes for both the morphotypes. The spawning peak of shrimps occurred in spring season (from March to May) and in winter-spring (from January to May) for banded and non-banded morphotypes, respectively. The $L_{m50\%}$ for banded and non-banded shrimp was estimated at a carapace length of 37.86 and 43.43 mm, respectively. The K and CL_{∞} in banded shrimp were 1.6 y^{-1} and 46 mm for males and 1.8 y^{-1} and 57 mm for females and in non-banded shrimps were 1.7 y^{-1} and 55 mm and 2.1 Y^{-1} and 69 mm for males and females, respectively. The total mortality (Z) and fishing mortality (F) estimated in males were more than in females. The evidence showed that these are probably two different species in the region.

Keywords: Growth and mortality, Oman Sea, *Penaeus semisulcatus*, Persian Gulf, Reproductive biology, Size structure

Introduction

Penaeid shrimps are common decapod crustaceans in the marine habitats of southern Iranian coastal waters of the Persian Gulf and Sea of Oman. Catch statistics of the Iranian Fisheries Research Organisation (IFRO) shows an estimate of about 7942 t (average for 2003-2018) for this resource landed by different fishing gears (trawl net, gill net and set net or moshta) in the northern Persian Gulf and Sea of Oman (*pers. comm*. IFRO). Different species of penaeid shrimps are caught in the region, the legal operation time of which is different in the waters of the Persian Gulf and the Sea of Oman (southern coastal waters of Iran) and also the dominant species in the catch is different in each region. The exploitation of dominant species *Penaeus merguiensis* de Man, 1888 in the coastal waters of Hormozgan Province, often occurs in October and November of each year. The green tiger shrimp *Penaeus semisulcatus* de Haan, 1844 along with *P. merguiensis* is the most important commercial species in this region. Fisheries statistics showed that the density of green tiger shrimp in the Hormozgan Province, is after *P. merguiensis*, followed by *Metapenaeus affinis* (H. Milne Edwards, 1837) and *Parapenaeopsis stylifera* (H. Milne Edwards, 1837) in this region (Safaie *et al*., 2012; Safaie 2015, 2017; Momeni *et al*., 2018), but in coastal waters of the Bushehr Province, *P. semisulcatus* is considered as the dominant species in the fishery/landings (Niamaimandi *et al*., 2007). This species inhabits the continental shelf from shallow coastal waters to a depth of 130 m, but mostly in waters less than 60 m, on mud, sandy-mud, or sandy-grit. The species can form small shoals and is predominantly nocturnal, burying in the substrate in the daytime; mostly fished at night when the highest catches are obtained, but in some areas also by day (Fischer and Bianchi, 1984). The species is distinguished from other species of *Penaeus* by characteristic features on the carapace (Rostrum with 6-8 teeth in dorsal and 3 ventral teeth; adrostral crest extending beyond last post-rostral tooth; gastro-frontal crest absent; hepatic crest long and extending behind antennal crest, straight but distinctly sloping anteroventrally; 5th leg with exopod). There are at least two morphotypes of the green tiger shrimp, *P. semisulcatus* described hitherto in the Persian Gulf and Sea of Oman, namely the banded and non-banded antennae morphotypes; the *P. semisulcatus* with banded antenna and pronounced body transverse lines and another morphotype with uniform colour and non-banded antenna, pale greenish body colour and faint body transverse lines.

Previous studies on penaeid shrimps in the northern Persian Gulf mainly focused on population

parameters and reproductive biology of *P. semisulcatus* (Niamaimandi *et al*., 2007, 2008), *P. merguiensis* (Safaie, 2015; Momeni *et al.,* 2018), *P. stylifera* (Safaie, 2017) and also on some aspects of the reproductive biology of *M. affinis* in the north-western Persian Gulf (Gerami *et al.*, 2013). Although Tamadoni Jahromi *et al*. (2019) in their study on morphometrics and mitochondrial DNA genes of green tiger shrimp in the coastal waters of Hormozgan Province noted this species to have two morphotypes and probably the presence of a new species in the region, so far the population structure and reproductive biology of two morphotypes of the species have not been reported in the Persian Gulf and Sea of Oman and the results of this study can be of great help in distinguishing a new subspecies or species in the region. In response to this lack of knowledge and acknowledging the urgent need for action to better manage fisheries stocks of *P. semisulcatus*, this study aims to estimate various population parameters of the two morphotypes such as the asymptotic length (L_∞), growth coefficient (K), mortality (natural and fishing) rates and exploitation level (E) of *P. semisulcatus* resources. Also, in this paper, the male: female sex ratio, gonad development and spawning season are presented for the two morphotypes of green tiger shrimp in the area.

Materials and methods

Study area, sampling and measurements

Monthly sampling of green tiger shrimp stocks was done by artisanal vessels (Dhow) equipped with bottom trawl nets with 40 mm mesh size from wings to sac and 20 mm at the cod end in the Iranian coastal waters of the Persian Gulf and Sea of Oman. The shrimp specimens were collected during daytime (from 6.00 to 19.00 hrs and in some cases, was done at night) in an area extending from 26°25′E; 57°01′ N to 27°01′E; 56°00′N for two periods which were first discontinuous from January to July 2017 and then from January 2018 to December 2019. Stratified sampling was undertaken in three strata, including shallow area (range 2-5 m), intermediate area (range 5-10 m) and deep area (range 10-50 m) (Fig. 1). The total catch (kg) from each haul was recorded (hauling was done with different engine powers (range: 240-450 hp) and with different vessel trawling speeds (range and average: 0.7-3.7, 2.2 knots). After separating the morphotypes and sex-wise sorting, each shrimp was measured and records were made for carapace length (from the posterior margin of the orbit to the median dorsal posterior edge of the carapace) to the nearest mm and body weight (g). The maturity stages of ovaries were grouped into five main classes (Lim *et al*., 1987).

Analysis

To establish the length-weight relationship, the commonly used relationship $W = a\ CL^b$ was applied (Pauly, 1983), where W is the weight (g), CL is the carapace length (mm), *a* is the intercept (condition factor) and *b* is the slope (growth coefficient). A linear equation ($\log W = \log a + b \times \log CL$) was fitted for log-transformed data. Parameters *a* and *b* were estimated using power regression and the coefficient of determination (R^2) to show the carapace length-weight relationship. The parameter *b* is a shape parameter for the body form of the shrimp species. In theory, one might expect that the exponent *b* would have a value of roughly 3 because the volume of a 3- dimensional object is roughly proportional to the cube of length for a regularly shaped solid. Computing b value estimated with 3 was tested using *t*-test (Pauly, 1983):

$$t = \frac{s.d\ (L)}{s.d\ (W)} \times \frac{|b - 3|}{\sqrt{1 - r^2}} \times \sqrt{n - 2}$$

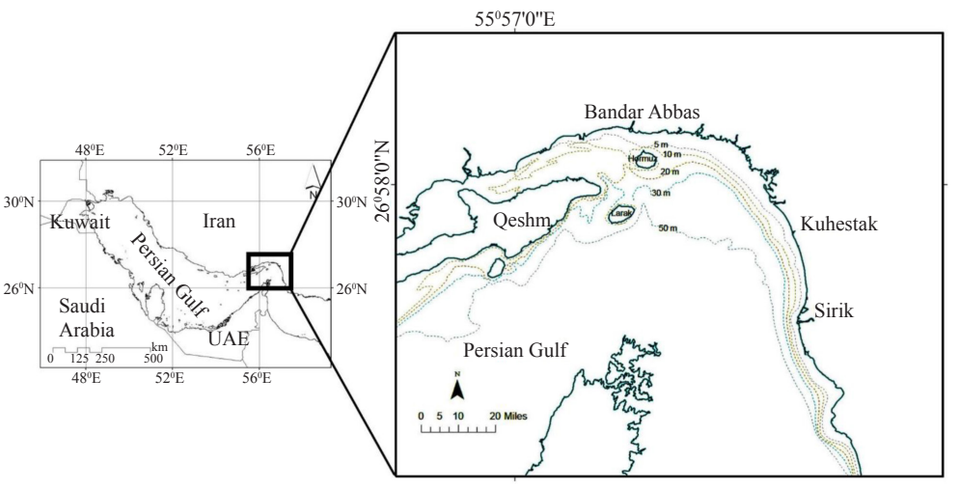

Fig. 1. Sampling sites for *P. semisulcatus* in the Persian Gulf and Sea of Oman, Iran

where s.d. (L) is the standard deviation of the log *CL* values and s.d. (W) is the standard deviation of the log *W* values, *n* being the number of shrimps used in the computation. The value of *b* is different from 3 if *t* is greater than the table value for *t* in n - 2 df (Pauly, 1983).

Monthly carapace length-frequency of the two morphotypes, sex-wise was used to estimate the parameters of the asymptotic length (CL_∞) and growth coefficients (*K*) in the von Bertalanffy growth equation: $Lt = CL_\infty (I - \exp\text{-}K(t\text{-}t_0))$ using ELEFAN1 program (Electronic Length Frequency Analysis) in FISAT II software (FAO-ICLARM Stock Assessment Tools), where *Lt* is the carapace length at time *t*, CL_∞ is the asymptotic length (mm), *K* is the growth coefficient and t_0 is the hypothetical age when the size of the shrimp is zero. To find the best growth curve passing through the maximum number of peaks, different starting samples and starting lengths were subjected to goodness-of-fit tests by assessing the ESP/ASP ratio (*R*n).

The Phi prime (Ø') index was used to compare the growth parameters of *P. semisulcatus* that was estimated in this study, with other studies. Details on growth comparison using Ø' as an index are discussed in Pauly and Munro (1984):

$$Ø' = \text{Log K} + 2 \times \text{Log } L_\infty.$$

The longevity of shrimp () was calculated as follows (Pauly, 1983):

$$T_{max} = 3/K + t_0$$

The instantaneous rate of total mortality (Z) was estimated using the length converted catch curve method in the FISAT II package from the estimated growth parameters (K and CL_∞) (Pauly, 1983). The natural mortality (M) was estimated using Pauly's empirical formula (1980):

$$\ln M = -0.0152 - 0.279 \times \ln L_\infty + 0.6543 \times \ln K + 0.463 \times \ln T$$

where L_∞ is asymptotic length (mm), *K* is the growth coefficient (Y^{-1}) and *T* is the annual average water temperature (°C) which was 26.5°C in the distribution area of *P. semisulcatus*.

Subtracting the estimates of M and Z, the instantaneous rate of fishing mortality (F) is given by:

$$F = Z - M$$

The exploitation rate E = F/ Z.

In this study, the sex-ratio analysis was done according to monthly data sets for total numbers of male and female shrimps. Chi-square statistical analysis was done to test the differences between ratios in both sexes.

The spawning season of this species was forecast from the percentage of ovaries in stages 4 and 5 recorded each month. $L_{m50\%}$ was estimated using the formula (King, 2007) and the least-square method (Solver Tools in Microsoft Excel ver. 2013):

$$P = L/\{1+\exp[- r_m(L - L_m50)]\}$$

where r_m is the slope of the curve, L_m is the mean carapace length (mm) at sexual maturity, L is the mean carapace length (mm) and P is the probability of presence of mature shrimp.

Results

Size structure and carapace length-weight relationship

The results showed that the male green tiger shrimps were smaller than females of the same age so that the carapace length of males and females of banded morphotype shrimp was 14-41 and 12-54 mm (with an average (±SE) of 26.41±0.22 for males and 30.03±0.31 mm for females, respectively. While in non-banded morphotype shrimps the carapace lengths were 16-52 mm for males and 17-63 mm for females. The average (±SE) CL was estimated as 29.47±0.43 and 35.85±0.04 mm for males and females, respectively. The results showed that young and adult shrimps were present throughout the year in the study period and the highest and lowest average carapace length of *P. semisulcatus* occurred from mid-winter to mid-spring and in summer, respectively (Fig. 2a, b).

The carapace length-weight relationship of *P. semisulcatus* was estimated as:

For banded morphotypes:

$$TW = 0.0072 \text{ X } CL^{2.42} \text{ (Male)}$$

$$TW = 0.0077 \text{ X } CL^{2.39} \text{ (Female)}$$

For non-banded morphotypes:

$$TW = 0.009 \text{ X } CL^{2.36} \text{ (Male)}$$

$$TW = 0.0071 \text{ X } CL^{2.42} \text{ (Female)}$$

The value of parameter *b* was estimated at 2.42 and 2.39 for male and female banded shrimp, respectively. This value in non-banded shrimp was 2.36 for males and 2.42 for females, which were significantly different from 3, indicating negative allometric growth.

Growth and mortality parameters, exploitation rates and performance index (Ø›)

The coefficient of growth (K) and asymptotic carapace length (CL_∞) of banded green tiger shrimp was 1.6 y^{-1} and 46 mm for males and 1.8 y^{-1} and 57 mm for females and in non-banded shrimp was 1.7 y^{-1} and 55 mm and 2.1 y^{-1} and 69 mm for males and females, respectively (Figs. 3, 4 and Table1). The estimated values for the

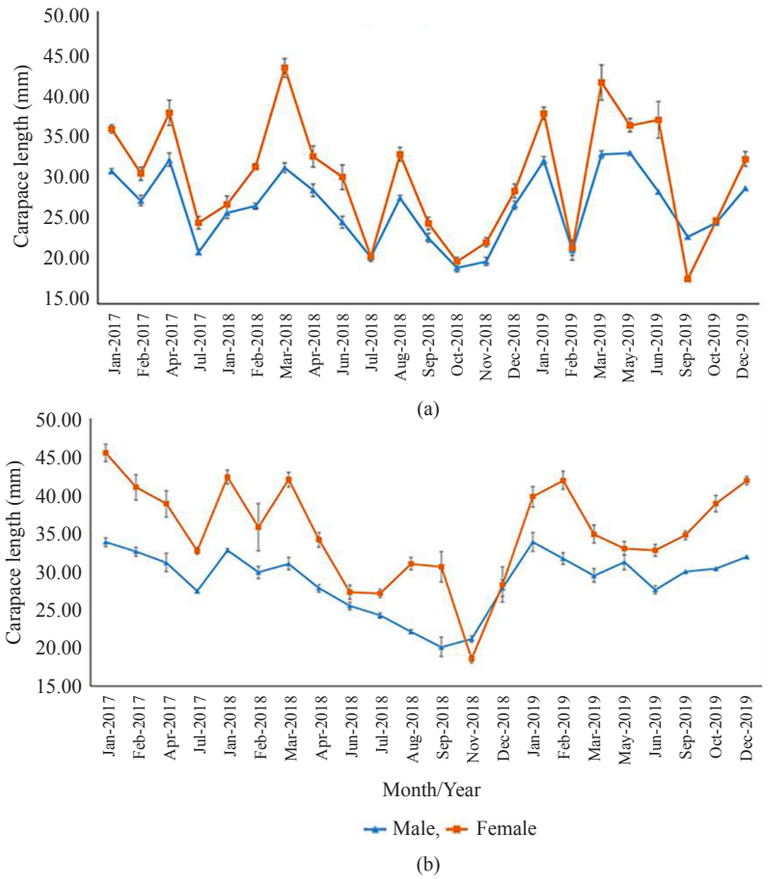

Fig. 2. Monthly variation of carapace length (Mean±SE) in (a) banded and (b) non-banded morphotypes of *P. semisulcatus* in the study area

growth performance index (Ø') of *P. semisulcatus* banded morphotype during the present investigation were 3.53 for males and 3.77 for females, respectively and in non-banded shrimp was 3.71 for males and 4 for females. The monthly growth curve of male and female (banded and non-banded) shrimps showed, at least two cohorts for each month during the study period (Figs. 3, 4). Also, according to the estimated growth data, the maximum age (T_{max}) of banded morphotypes was estimated as 24 and 19 months in male and female, respectively and in non-banded shrimp was 20 months in males and 17 months in females.

The total mortality (Z) and fishing mortality (F) estimated for *P. semisulcatus* showed that these values in males were more than for females, in male shrimps the Z and F values were 5.79 and 8.55 and 3.69 and 6.47

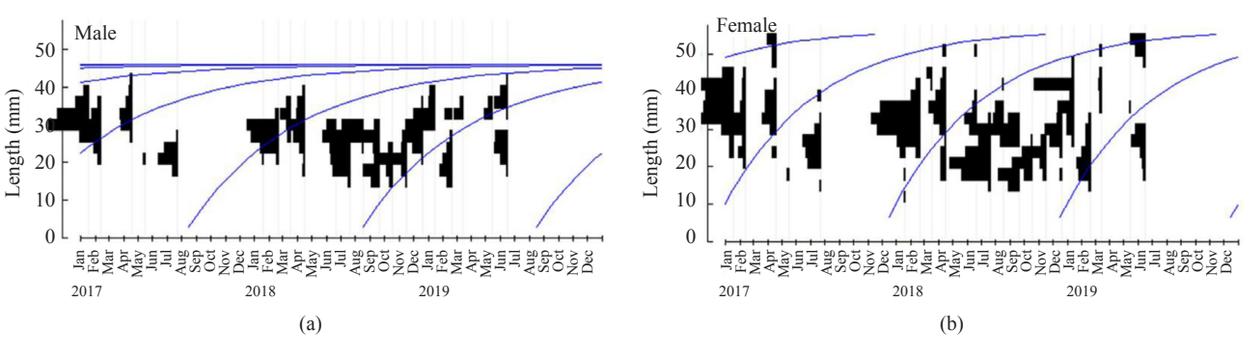

Fig. 3. Carapace length distribution and growth curve in (a) male and (b) female banded *P. semisulcatus* in the Persian Gulf and Sea of Oman, Iran

Table 1. Estimated growth and mortality parameters of *P. semisulcatus* in the south coast of Iran

Shrimp morphotypes antenna	Sex	CL_∞ (mm)	K (Y^{-1})	Life span (Months)	T_0	Z (Y^{-1})	M (Y^{-1})	F (Y^{-1})	E
Banded	Male	46	1.6	24	-0.087	5.79	2.10	3.69	0.64
	Female	57	1.8	19	-0.072	5.50	2.14	3.36	0.61
Non-banded	Male	55	1.7	20	-0.077	8.55	2.08	6.47	0.76
	Female	69	2.1	17	-0.058	6.05	2.24	3.81	0.63

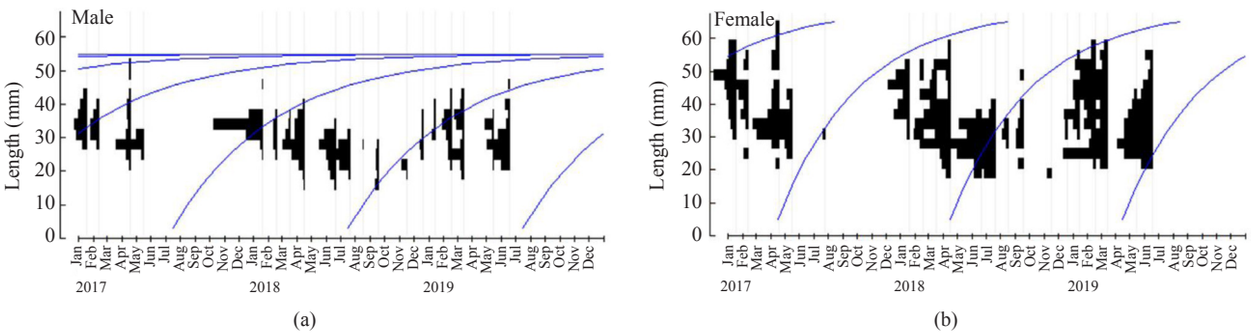

Fig. 4. Carapace length distribution and growth curve in (a) male and (b) female non-banded *P. semisulcatus* in the Persian Gulf and Sea of Oman, Iran

and in females were 5.50 and 6.05 and 3.36 and 3.81 in banded and non-banded shrimps, respectively. The natural mortality rate (M) for each sex was calculated as 2.10 and 2.14 y^{-1} for males and females banded shrimp, respectively and in non-banded shrimp was 2.08 y^{-1} for males and 2.24 y^{-1} for females. The exploitation rate (E) was estimated as 0.64 for males and 0.61 for female banded shrimps and in non-banded shrimps was 0.76 for males and 0.63 for females, respectively (Table 1 and Fig. 5).

Reproductive biology

The monthly sex ratio M: F of shrimp was significantly different from the expected 1:1 ratio ($p<0.05$), female

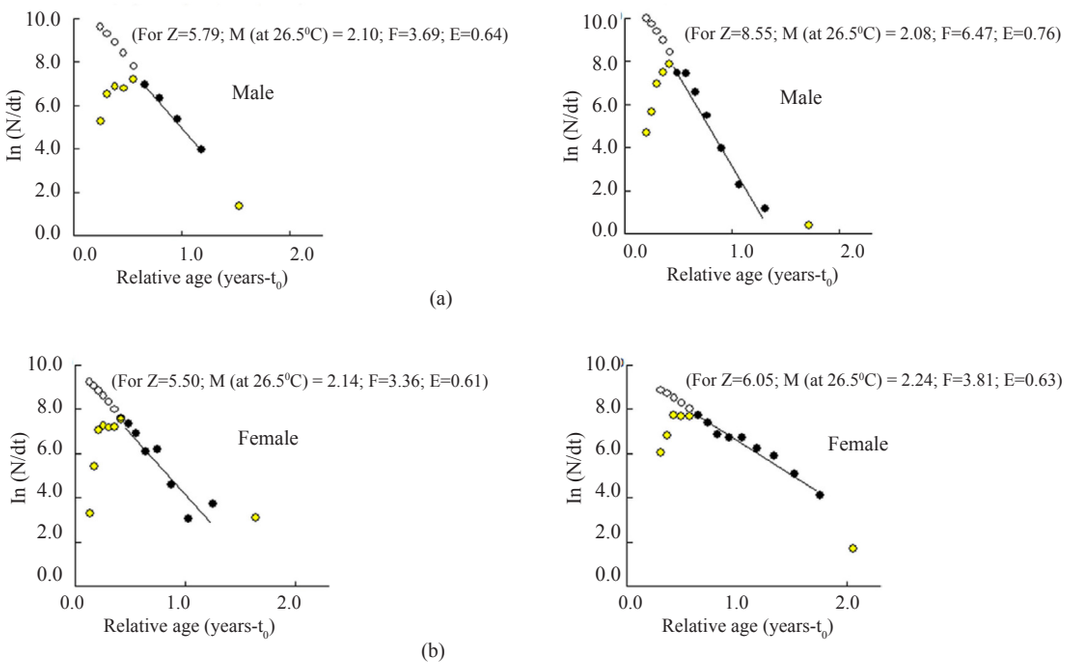

Fig. 5. Length-converted catch curve in males and females of (a) banded and (b) non-banded *P. semisulcatus* in the Persian Gulf and Sea of Oman, Iran

banded shrimp (with 53.6%) and non-banded males (with 51.4%) were dominant in the population; the M:F in banded shrimp was 1:1.16 and in non-banded was 1:0.94 (Figs 6a, b). Also, the size-specific sex ratio showed that the female shrimps were significantly dominant in higher length classes and *vice versa, i.e.* for males in lower classes and younger individuals ($p<0.05$). The number of male banded shrimps was higher in carapace length classes less than 30 mm and females generally dominated at lengths greater than 33 mm (Fig. 7a). In non-banded green tiger shrimps, males were usually predominant in size classes below 34 mm, and females were dominant above 40 mm length classes during the study period (Fig. 7b).

In the present study, all ovarian stages of *P. semisulcatus* were observed throughout the year (Figs. 8a, b). The monthly abundance of mature shrimps (stages 3 to 5) and also the juvenile shrimps (stages 1 and 2) had shown a relatively high percentage in the study period, indicating this species can actively breed throughout the year with a distinct peak in the spring season (from March to May) for banded shrimp and in winter-spring (from January to May) for non-banded shrimp (Figs. 8a, b). The minimum length of *P. semisulcatus* (banded and non-banded) at first sexual maturity was 28 mm carapace length indicating that the smallest shrimp become mature in the first year of their life which is attained in about

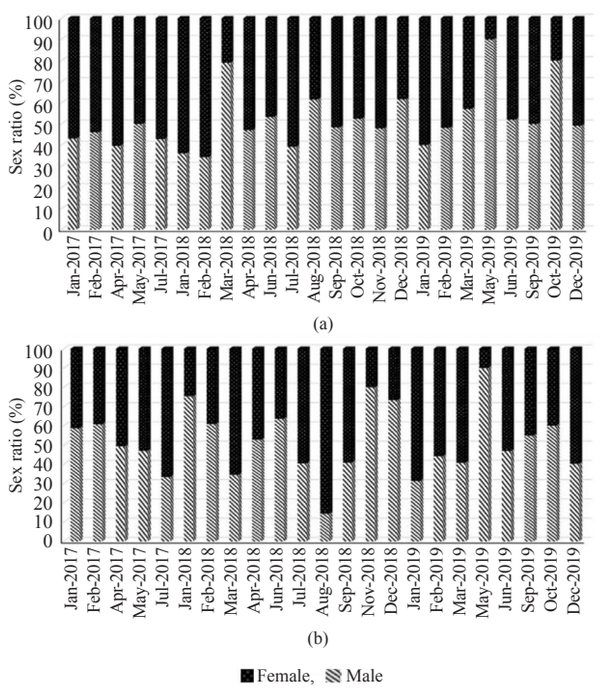

Fig. 6. Month-wise sex ratio between male and female in (a) banded and (b) non-banded tiger shrimp, *P. semisulcatus* from the Persian Gulf and Sea of Oman

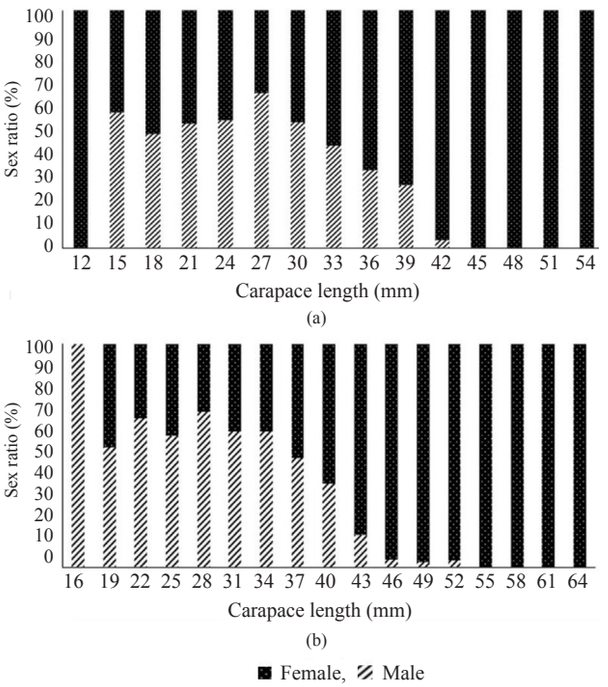

Fig. 7. Sex ratio between male and female by size classes in (a) banded and (b) non-banded tiger shrimp, *P. semisulcatus* from the Persian Gulf and Sea of Oman

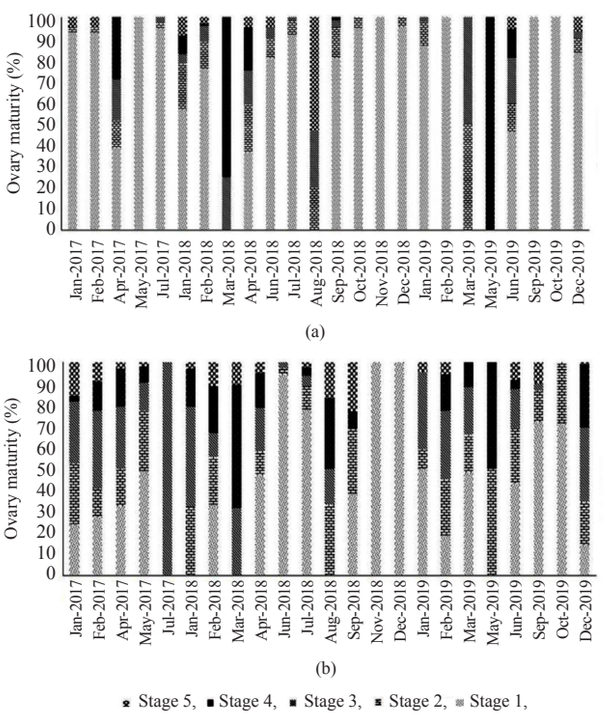

Fig. 8. Maturity stages of two morphotypes (a: banded and b: non-banded shrimps) of female *P. semisulcatus* from the Persian Gulf and Sea of Oman

4-6 months. The $L_{m50\%}$ index for banded and non-banded shrimps was estimated at 37.86 and 43.43 mm carapace length, respectively.

Discussion

The green tiger shrimp, *P. semisulcatus* is one of the important commercial penaeid species and common reserve shrimp stocks in the adjacent Persian Gulf and the Sea of Oman countries. This species, before the introduction of *Penaeus vannamei* Boone, 1931 in Iran for aquaculture, was used as the main shrimp in the aquaculture industry in southern Iran. During the seasonal fishery in Hormozgan Province (which usually takes place in October and November of each year), the shrimp is always caught by artisanal (Dhow) trawlers.

Results of the study showed that male shrimps differ in size compared to females of the same age and are usually smaller than females. Also, the average CL in male and female banded morphotypes was 26.41±0.22 (range 14-41 mm) and 30.03±0.31 mm (range 12-54 mm), respectively and in non-banded was 29.47±0.43 mm (range 16-52 mm) for males and 35.85±0.04 mm (range 17-63 mm) for females. Monthly CL distribution in the study period showed that the young and adult shrimps are present throughout the year, but the highest average carapace length was observed from mid-winter to mid-spring and the lowest in summer during the study period. Due to the observation of mature shrimps throughout the year, it is likely that young and mature shrimps are present in all months of the year. Although spawning occurs all around the year, there was a distinct peak of spawning from mid-winter to mid-spring. The increase in average CL of shrimps during the peak spawning season may be due to the spawning behaviour of mature shrimps and hence their catchability increased during this period. The difference in length between male and female *P. semisulcatus* has been recorded in the coastal waters of the Bushehr Province, Persian Gulf (Niamaimandi *et al*., 2007). Mehanna (2000) noted that the range of total length of *P. semisulcatus* in the Gulf of Suez, Egypt was 8-20.2 and 8.5-24.4 cm for males and females, respectively. Similar results about the juvenile and adult shrimp distribution and different size structures of male and female shrimps have been reported for other species of this family such as in *P. merguiensis*, *P. stylifera*, *M. affinis* and *M. stebbingi* in the southern Iranian coastal waters (Safaei *et al*., 2012; Safaie, 2015, 2017; Momeni *et al*., 2018).

Carapace length is generally considered an independent variable in the morphometric studies of Penaeidae because it can show physiological changes that occur during the life cycle. The estimated values for the slope *b* in the linear equation of logarithmic regression of the carapace-weight relationship in this study indicate negative allometric growth in both morphotypes of green tiger shrimp. The values of *a* and *b* vary not only in different species but also differ in individuals of the same species based on sex, stage of maturity and nutritional intensity (Pauly, 1984). According to many researchers, the value of b is between 2.5 -3.5, and if the value is close to 3, growth will be isometric (Pauly, 1984). Table 2 shows some of the values of *b* for green tiger shrimp and other similar species of the family penaeidae from other studies. The main reasons for differences in the values of *a* and *b* can be related to factors such as kind of species, seasonal changes, physiological conditions of shrimp during sampling, sex, growth of endocrine glands and nutritional conditions of their environment (Biswas, 1993).

Table 2. Values of parameters *a* and *b* in carapace length-weight relationship of *P. semisulcatus* in the Persian Gulf and Sea of Oman and comparison with the values estimated for the same species and other species belonging to the same genus in other studies

Species	Sex	a	b	R^2	Locality	Author
P. semisulcatus	Male	0.0072	2.42	0.96	Persian Gulf and Sea of Oman, Hormozgan, Iran	Present study
	Female	0.0077	2.39	0.96		
	Pooled	0.0076	2.40	0.96		
P. semisulcatus	Male	0.0005	3.15	0.94	Persian Gulf, Bushehr, Iran	Niamaimandi *et al*. (2008)
	Female	0.0012	2.86	0.96		
P. semisulcatus	Male	0.0066	3.07	-	Gulf of Suez, Egypt	Mehanna (2000)
	Female	0.0064	3.09	-		
	Pooled	0.0065	3.07	-		
P. merguiensis	Male	0.0015	2.80	0.88	Persian Gulf and Sea of Oman, Hormozgan, Iran	Momeni *et al*. (2018)
	Female	0.0015	2.79	0.94		
P. merguiensis	Male	0.0014	2.84	0.95	Persian Gulf and Sea of Oman, Hormozgan, Iran	Safaie (2015)
	Female	0.0019	2.74	0.97		
P. indicus	Male	0.003	2.48	-	Western Central Java, Indonesia	Saputra *et al*. (2019)
	Female	0.006	2.22	-		

Monthly sex ratio (male: female) of green tiger shrimp showed that there was a significant difference between the observed and expected frequency during the study period, and in banded and non-banded shrimp, the females and males were predominant, respectively. Also, the sex ratio by size classes of shrimp showed that the females were significantly predominant in higher length classes and males in lower classes. In a study on the reproductive biology of green tiger shrimp in Bushehr waters south of Iran, the frequency of female shrimps was reported to be higher than that of males, although the M:F sex ratio did not significantly differ in the study period (Niamaimandi *et al*., 2008). Momeni *et al*. (2018) in their study in the Iranian coastal waters of the Persian Gulf and Sea of Oman, reported that the annual sex ratio M:F of banana shrimp, *P. merguiensis* had a significant difference from the expected ratio and males were predominant; However, Safaie (2015, 2017) in a study on population dynamics of *P. merguiensis* and kiddy shrimp, *P. stylifera* in the same area, reported that the annual sex ratio in these species was significantly different from the expected ratio (1:1), while the females were dominant in both species. Similar results have been reported from other studies on *P. merguiensis* (Safaei *et al*., 2011), *M. affinis* (Kamrani *et al*., 2005; Safaei *et al*., 2011), *P. stylifera* (Safaei *et al*., 2011; Ghafourian *et al*., 2018) and *M. stebbingi* (Safaei *et al*., 2011) in the coastal waters of Hormozgan Province. In general, differences in M: F sex ratio observed for *P. semisulcatus* in this study and other studies on similar and other species of the family penaeidae may be due to the behaviour and migration of the species or even due to the effect of fishing gears that were used in the area. Numerous factors have been identified about the distribution of the penaeid shrimp in each region, mostly with environmental conditions (geographical distribution), bed conditions and the dependence of shrimps on circadian rhythms (light regime), lunar cycle and tidal rhythms that are very important factors in shrimp distribution (Garcia and Le Reste, 1981). In addition, the size of shrimp in each region is not uniform and along with the trend of migration from the estuaries to deep waters, young shrimps usually remain in coastal areas and adult shrimps in deeper waters, respectively (Garcia and Le Reste, 1981). As mentioned earlier, the average length of shrimp in the spawning season (mid-winter to mid-spring) increased with the presence of mature shrimp and then decreased in summer with the arrival of young shrimp in the region. During these periods, when the age structure of shrimps changed to younger individuals, the sex ratio was almost equal (1:1). In the Hormozgan coastal waters, various gears are used for catching shrimps. So, the effect of fishing gear on the distribution of shrimps in the region cannot be ignored. Main fishing for shrimp stocks is by trawlers, which severely impact their spatial-temporal distribution as these gears were used throughout the year (catches most adult shrimp during the spawning season and younger shrimp during the summer). The setnets (Moshta) operated in the intertidal areas under the influence of the tidal cycle, often catch younger commercial shrimp (*P. merguiensis*, *P. semisulcatus* and *P. indicus*) in the area. In recent years, especially from August to October, when the density of the dominant shrimp (*P. merguiensis*) increased, several gillnetters that catch sub-adult shrimps were active. Therefore, the seasonal distribution pattern of shrimps, which is related to their life cycle, is due to the temporal distribution of sex ratios in the region. During the period of recruitment, young shrimps remain in the coastal and shallow areas and the sex ratio is almost equal (shrimp population affected by set net gear in the coastal area) and during their reproductive period they have a different depth-wise distribution which can be affected by the effects of fishing gear that are operated at different depths.

Results of this study indicated that *P. semisulcatus* spawn throughout the year, with peaks in spring for banded morphotype (from March to May) and in winter-spring (from January to May) for non-banded morphotypes in the region. Also, the minimum length at which green tiger shrimps (banded and non-banded) reach sexual maturity is 28 mm carapace length and the length of shrimps that reach $L_{m50\%}$ for banded and non-banded shrimps was estimated at 37.86 and 43.43 mm CL, respectively. Niamaimandi *et al*. (2008) in their study on the reproductive biology of *P. semisulcatus*, reported that the peak spawning occurs between December to March in the Bushehr coastal waters of the Persian Gulf and noted that this species spawns in October also. They estimated the minimum length at which females reach sexual maturity as 24 mm carapace length and the length at which 50% of females reach sexual maturity as 40 mm of carapace length. Another study on the migratory behaviour of *P. semisulcatus* in the Bahrain waters noted that they migrated to deeper waters to spawn from October (Abdulqadef and Naylor, 1995). Crocos and Van der Velde (1995), reported that the young females of green tiger shrimps were added to the population, during the summer season. Some adults spawn in late summer to autumn (January-March) when they are six months old, but most of them spawn at the age of 12 months and in the spring season (August-November) in the Carpentaria Bay of Australia. Similar results were observed for other shrimps of this family in the region. The spawning peaks of *P. merguiensis* occurred from February to March or in the spring season in the coastal waters of the Hormozgan Province (Safaie, 2015; Momeni *et al*., 2018). Also, $Lm_{50\%}$ of this species in the same area has been estimated at 31.7 and 33.64 mm (Safaie, 2015; Momeni *et al*.,

2018). Another study on the reproduction of Jinga shrimp, *M. affinis* in the Persian Gulf (Hormozgan Province) stated the spawning peak of this species occurred in the spring season, although it was noted that spawning of this species has been observed throughout the year (Kamrani *et al*., 2005). Safaie *et al*. (2011) studied the reproductive characteristics of dominant species of shrimps *viz*. *P. merguiensis*, *M. affinis*, *M. stebbingi* and *P. stylifera* in the mangrove coastal areas around the Qeshm Island and predicted spring spawning period for these species. Perhaps one of the most important and influential factors in the trigger of gonads and the peak of spring spawning of *P. semisulcatus* and many species of this family in the waters of the Persian Gulf and the Sea of Oman is temperature change which increases almost from mid-winter until early spring.

The growth coefficient and asymptotic length of banded shrimps were 1.6 y^{-1} and 46 mm of CL for males and 1.8 y^{-1} and 57 mm of CL for females, respectively. In non-banded male green tiger shrimp, those were 1.7 y^{-1} and 55 mm CL and in females 2.2 y^{-1} and 69 mm CL. Short lived aquatic animals such as shrimps usually have a relatively high growth rate and therefore their size in the first or second year of life reaches asymptotic length (Garcia and Le Reste, 1981). In the present study, at least there were two cohorts for both sexes of shrimps (banded and non-banded) during the period. According to the results, female shrimps always have a higher asymptotic length as well as growth rate compared with males. Other studies on penaeid shrimps also indicated the same features *i.e*. larger size of females of *P. semisulcatus* (Somers and Kirkwood, 1991; Villarta *et al*., 2006; Niamaimandi *et al*., 2007), *P. merguiensis* and *P. stylifera* (Safaie, 2015, 2017), However, asymptotic length of female shrimps were reported as more than males, but the estimated parameters in the two different sexes also differed so that the shrimps with higher asymptotic length had a lower growth rate and *vice versa* (Mehanna, 2000; Mehanna *et al*., 2012; Momeni *et al*., 2018; Suputra *et al*., 2019). This feature may also be associated with the reproductive strategy, as females need more space to accommodate ovaries during the development period (Gab-Alla*et al*., 1990; Yamada *et al*., 2007). The differences that occurred in the estimation of growth rates for similar species in different regions can be affected by the use of different sampling methods and data analysis in various studies. In addition, regardless of the above, the difference in the growth estimates may be due to the differences in the length class interval used in the data analysis models.

Estimated growth parameters for *P. semisulcatus* in this study and from other studies on genus *Penaeus*, as well as the Ø index and its comparison with the estimated values in other studies, indicate that the values obtained in this study are acceptable. Sparre and Venema (1992) believed the species belonging to a similar family, usually have the normal distribution of Ø (Table 3). The T_{max} for females and males was estimated at 19-24 and 17-20 months for banded and non-banded shrimps, respectively. The estimated growth parameters of green tiger shrimp and results from certain species of this family (Table 3) showed that the species like other penaeid shrimps have a two-year life span pattern (Garcia and Le Reste, 1981).

In male *P. semisulcatus,* total mortality rate (5.79 and 8.55 in banded and non-banded morphotypes, respectively) and fishing mortality (with 3.69 and 6.47 y^{-1}) were higher than female shrimps (total mortality was 5.50, 6.05 and fishing mortality was 3.36, 3.81 in two morphotypes, respectively). Male and female shrimps had a relative equal natural mortality rate (M). The exploitation rates for males and females were estimated at 0.64, 0.61 and 0.76, 0.63 for banded and non-banded shrimps, respectively. Niamaimandi *et al*. (2007) in their study on *P. semisulcatus*, stated that the total and fishing mortality rates of this species were 8.2 and 5.8 y^{-1} for females and 4.6 and 3.4 y^{-1} for males, respectively in the Bushehr coastal waters of the Persian Gulf. They also estimated the exploitation coefficient for males and females at 0.67 and 0.70 respectively, which indicates overfishing of this species in the region. Also in another study from Philippines, the mortality rate of females was higher than that of males, and the exploitation rate for both sexes was about 0.5 and optimal (Villarta *et al*., 2006), while, in another study from Egypt, the mortality rate of males was reported to be higher than that of females for green tiger shrimp (Mehanna, 2000). Similar results were reported for *P. merguiensis* and *P. indicus* in Iranian coastal waters of the Persian Gulf and the Sea of Oman, as well as in Oman, it has been reported that male shrimps had a higher total mortality rate than females (Mehanna *et al*., 2012; Safaie, 2015, Momeni *et al*., 2018); however, in the study by Suputra *et al*. (2019) in Indonesia, the mortality rate of female *P. indicus* was estimated to be higher than that of males. In marine environment, many factors can influence the population of aquatic animals. These factors include unfavourable environmental conditions, food shortages, competition and perhaps most importantly, the presence of predators. On the other hand, the natural mortality rate may change from year to year, like environmental factors, especially the prevalence of predators in each region (King, 2007).

The two morphotypes of green tiger shrimps during the study period showed that the non-banded shrimps

Table 3. Summary of growth parameters (CL_∞ and K), Performance Index (ǿ) and longevity available for some penaeid shrimps in different localities

Species	Sex	CL∞ (mm)	K $(Y)^{-1}$	t_0 (month)	Ǿ	Life span (months)	Locality	Author
P. semisulcatus	Male (Banded)	46	1.6	-0.086	3.53	24	Persian Gulf and Sea of Oman, Hormozgan, Iran	Present study
	Female (Banded)	57	1.8	-0.072	3.77	19		
	Male (non-banded)	55	1.7	-0.077	3.71	20		
	Female (Non-banded)	69	2.1	-0.058	4	17		
P. semisulcatus	Male	38.1	1.3	-	3.28	18	North-western Gulf of Carpentaria, Australia	Somers and Kirkwood (1991)
	Female	62.2	3.2	-	4.09	24		
P. semisulcatus	Male	224*	1.77	-0.001	-	15	Gulf of Suez, Egypt	Mehanna (2000)
	Female	268*	1.56	-0.012	-	18		
P. semisulcatus	Male	263*	0.7	-	4.69	-	West Central, Philippines	Villarta *et al*. (2006)
	Female	271*	1.6	-	5.07	-		
P. semisulcatus	Male	38	1.6	-	3.36	15	Persian Gulf, Bushehr, Iran	Niamaimandi *et al*. (2007)
	Female	50.4	2.2	-	3.75	20		
P. indicus	Male	57.11	2.11	-	3.84	12	Arabian Sea, Oman	Mehanna *et al*. (2012)
	Female	68.56	1.69	-	3.90	18		
P. merguiensis	Male	48	1.6	-0.085	3.57	19	Persian Gulf and Sea of Oman, Hormozgan, Iran	Safaie (2015)
	Female	54	1.8	-0.073	3.72	24		
P. merguiensis	Male	39.5	1.8	-0.08	3.45	19	Persian Gulf and Sea of Oman, Hormozgan, Iran	Momeni *et al*. (2018)
	Female	50	1.5	-0.09	3.57	24		
P. indicus	Male	37	0.97	-	-	37	Western Central Java, Indonesia	Suputra *et al*. (2019)
	Female	38.5	0.85	-	-	38.5		

*Total length

had higher growth and mortality rates than the banded morphotypes and also the female population dominated in banded morphotypes while males in the non-banded shrimps. This evidence suggests that they are probably two different species (or perhaps subspecies). In support of this claim, Tamadoni Jahromi *et al*. (2019), in their study on the mitochondrial DNA genes of this species from the region, also mentioned there is probably the presence of a new species of this genus in the region. However, molecular methods, genetic structure and morphological features of this species must be used in future to prove these claims.

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