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Growth, Reproduction and Mortality Rates of Green Tiger Prawn *Penaeus semisulcatus* De Haan, 1844 (Decapoda: Penaeidae) from the North-Eastern Mediterranean Coast of Turkey

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Abstract: This study aimed to determine the growth, reproduction and mortality rates of *Penaeus semisulcatus* De Haan, 1844. Samples were collected by bottom trawl net at monthly intervals between June1981 and June1982 from five locations throughout the coastal waters of the north-eastern Mediterranean, Turkey. A total of 1173 specimens were collected. The total length ranged from 7.0 to 25.0 cm with a mean of 16.4 ± 3.0. The total weight varied from 2.2 to 136.0 g with a mean of 41.1 ± 22.9. Length-weight relationship equations were expressed as $W = 0.0116 * L^{2.866}$ (R^2= 0.91, n: 495), $W = 0.0074 * L^{3.052}$ (R^2= 0.96, n: 678) and $W = 0.0070 * L^{3.057}$ (R^2= 0.96, n: 1173) for male, female and combined sexes, respectively. Asymptotic length ($L\infty$) and the growth coefficient (k) were estimated at 19.95 and 1.3 year^{-1} for males, 26.25 and 0.8 year^{-1} for females and 26.25 and 0.48 year^{-1} for combined sexes. The instantaneous rates of total (Z), natural (M) and fishing mortalities (F) were 4.34, 2.12 and 2.22 for males, 1.59, 1.02 and 0.57 for females and 2.65, 1.43 and 1.22 year^{-1} for combined sexes. Using the mortality rates given above, the exploitation rates (E) were 0.51, 0.36 and 0.46 year^{-1}, respectively. The population of *P. semisulcatus* along the north-eastern Mediterranean coast of Turkey was not strongly affected by fishing during the study period, according to the estimated E values.

Key words: Iskenderun Bay, Mersin Bay, LWR, Fulton's condition factor, growth type

Introduction

The green tiger prawn *Penaeus semisulcatus* De Haan, 1844, is the largest species of penaeid shrimp in the Mediterranean Sea. This species has an Indo-West Pacific distribution, being found from eastern Africa and the Red Sea east to Indonesia and northern Australia. It has also colonised the eastern Mediterranean through the Suez Canal. The first Mediterranean report of the species was (as *Penaeus monodon*) in 1928 from the Syrian coast (Gruvel 1928), then it was reported from the Turkish coast in 1930 (Gruvel 1930). Now, *P. semisulcatus* that has been established along the coast of the eastern Mediterranean Sea (Egyptian, Israel, Syrian and Turkish Levantine coasts) has been continuing to spread westward to the Mediterranean (Arnesano et al. 2015). It has become an important component of fisheries in the eastern Mediterranean Sea.

This species occurs in coastal waters down to 130 m depth, over sandy and muddy substrates (Galil et al. 2010). The seawater temperature, the nature

of the sediments and possibilities for concealment from predators are other important factors influencing the distribution of *P. semisulcatus* (Ragonese & Giusto 2011). The adults are distributed mainly offshore, while the juveniles prefer coastal and estuarine environments (Rabaoui et al. 2017, Ragonese & Giusto 2011). In the eastern Mediterranean, *P. semisulcatus* has become an important component of the fisheries in Turkey, Israel and Egypt. *Penaeus semisulcatus* is the most commercially important penaeid shrimp because of its high market value (Öztürk 2010). Like other penaeid shrimps, the species has high commercial value, generating substantial income for fishermen. As a result of the rising fishing pressure on this species and the illegal fishery, the stock of this species has been declining in recent years (Anonymous 2018, 2019, 2020). Following a fluctuating course in Turkey, the annual catch of *P. semisulcatus*, which was 640.9 tonnes in 2012, declined to 579.5 tonnes in 2019 and decreased to 478.7 tonnes in 2021 (TUIK 2022).

Length-weight relationships are very important in fishery biology and stock assessment of aquatic species (Gulland 1983). Relationships that allow interconversions among the various length and weight parameters are needed, e. g. to compare growth parameters (Dall et al. 1990). The L-WRs may also provide for converting growth-in-length equations to growth-in-weight, estimating biomass from length data and comparing relative conditions, life histories and population dynamics of given species among different regions (Da Costa et al. 2014). Growth rates may vary because of many factors, such as environmental conditions, environmental stresses, food availability, habitat type, sampling methodology, stomach fullness, distribution area and sample size (Cushing 1968, Pauly 1993a, Bageal & Tesch 1978). Therefore, the estimation of L-WRs parameters is important not only for a given species, but also in different habitats.

The condition factor is often used to quantify an animal's physical well-being and is thought to be a useful complement to growth estimates of crustaceans (Rochet 2000). The condition factor-gonadosomatic index interaction is often used to estimate the timing of the spawning season (Avsar 2005, Sarihan et al. 2007).

The LWR parameters and condition factors of *P. semisulcatus* have been determined in some studies (Shlagman et al. 1986, Mehanna 2000, Mohamed & Aiatt 2012). However, few studies were conducted in Turkey (Kumlu et al. 1999, Manasirli et al. 2014). Most of these studies are from the recent two decades and there is a lack of historical LWR data for this species. Historical studies are important and, in this study, archived data gathered between 1981 and 1982 by the government sampling programme were evaluated. Furthermore, there is a need to study the length–weight relationships at a wider size range in order to determine how these relationships may change with sample size, life stage, location and sexes (Chow & Sandifer 1991). The LWR parameters, condition factor, mortality rates and exploitation rates (*E*) of *P. semisulcatus* were estimated for both sexes, months and depth ranges along the north-eastern Mediterranean coast of Turkey. This knowledge may provide a basis for the establishment of a practical conversion protocol to simplify management practices in the different life phases of the species.

Materials and Methods

The Ministry of Agriculture and Forestry designed and funded this sampling project in response to the fishermen's requests for permission to fish up to three miles from the coast. The fishermen's hypothesis was that penaeid shrimp species are distributed within 3 miles, so shrimp fishing should be done within 3 miles. The sampling was done monthly, from 22 June 1981 to 16 June 1982 in the Mersin and Iskenderun Bays (north-eastern Mediterranean, Turkey) in five different study areas. At each station, two trawls operated, one within the 3 miles and the other one outside the 3 miles' area, ranging between 0.4 and 5.5 miles from the coast and at water depths ranging from 4.8 to 47.6 m (Fig. 1). A total of 40 trawl operations were carried out by the commercial trawler Sülünkuş (length 14.10 m and 67.5 HP) under the government sampling programme. A bottom trawl with a 10-m mouth opening, 30.0 m long with a 36 mm mesh cod-end made of PE material was used. The average towing speed was 2.5-3.5 knots and the trawled area was between 0.093 and 0.13 km^2 during the two-hour haul.

The total weight and length of each specimen were measured to the nearest 0.1 g and 0.1 cm, respectively. The gonads were observed under microscope and weighted to the nearest 0.001 g on precision digital scales in the laboratory.

The LWRs function, $W = a*L^b$, was fitted with a simple linear regression model, using log-transformed data, where W: total weight, L: total length, *a*: the intercept and *b*: the allometric coefficient (Le Cren 1951). The 95% confidence interval (CI) was determined for parameters *a* and *b* (Froese 2006). Prior to regression analyses, log-log plots of the length-weight pairs were performed to identify out-

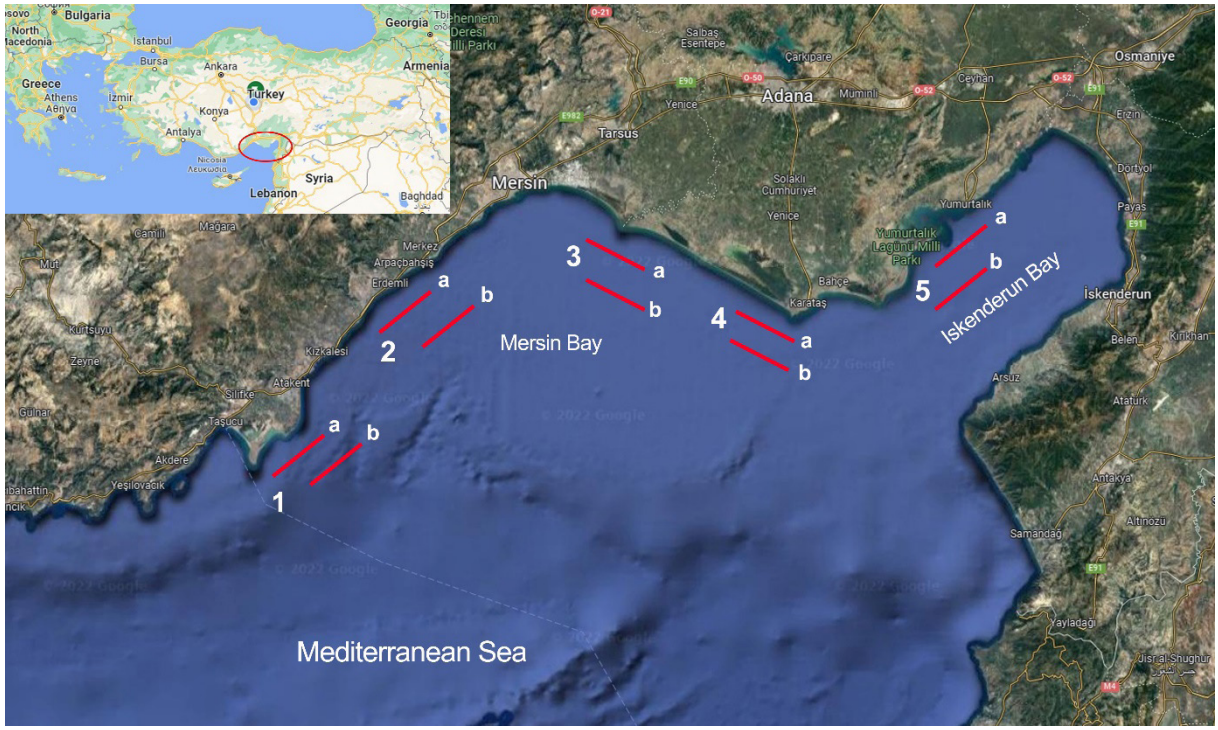

Fig. 1. Sampling stations

liers (FROESE et al. 2011). Outliers perceived in the log–log plots of all species were eliminated from the analysis.

Fulton's condition factor (K) was estimated using the formula $K = (W/L^3) \times 100$ (RICKER 1975, FROESE 2006).

The gonadosomatic index (GSI) was calculated for each sex; GSI = (GW/(W-GW))*100, where GW is gonad weight (SPARRE & VENEMA 1992).

Growth in length and weight was analysed separately for females, males and combined sexes using the Von Bertalanffy growth function (VBGF).

$$L_t = L_\infty (1 - \exp(-k(t - t_0)))$$

Data analysis was conducted with the most recent version of FISAT-II (GAYANILO et al. 2005) statistical software. Using monthly length frequencies data length frequency analysis (ELEFAN I) the asymptotic length (L_∞) and the growth coefficient (k) were estimated. Then the instantaneous rate of total mortality (Z) was calculated using the estimated growth parameters (k, L_∞) using the length converted catch curve method (PAULY et al. 1984):

$$\text{Log}_{10}(-t_0) = -0.392 - 0.275\ \text{Log}_{10}L_\infty - 1.038\text{Log}_{10}K$$

The instantaneous rate of natural mortality (M) was obtained using Pauly's empirical formula (PAULY 1983b):

$$\text{Log}_{10}M = - 0.0066 - 0.279\ \text{Log}_{10}L_\infty + 0.6543\ \text{Log}_{10}K + 0.463\ \text{Log}_{10}T,$$

Where T was the annual mean sea surface temperature. During the fishing survey, sea-surface temperature was measured by a mercury-in-glass thermometer for each station every month.

The instantaneous rates of fishing mortality (F) were calculated by subtracting the estimates of M from Z: $F = Z - M$. The exploitation rate was calculated as follows:

$$E = F / Z.$$

It was tested whether there was a difference between the weight values of the samples according to months, gender and depth layers. The assumption of normal distribution was tested using the Kolmogorov-Smirnov (K-S) test. When data were not normally distributed, a non-parametric Mann-Whitney U test was used to test for differences between groups, while a parametric one-sample T-test was used when data were normally distributed. All statistical analyses were performed using Excel 2016 and Past 4.05 software.

Results

During the fishing survey, we measured the highest sea-surface temperature of 30.2°C in September and

Table 1. Range and mean values for total length (L) and total weight (W) and parameters for the, length-weight relationships, condition factors (*K*) and mean gonadosomatic index (GSI) of *Penaeus semisulcatus* for males from the north-eastern Mediterranean coast of Turkey (n: number of specimens, GT: type of growth, SE: standard error, *a*: the intercept, *b*: the allometric coefficient).

	n	Lmin	Lmax	Lmean	SE of L	Wmin	Wmax	Wmean	SE of W	*a*	*b*	R^2	SE of *b*	CI of *a*	CI of *b*	GT	*K*	GSI
July	29	14.5	19.0	16.8	1.2	21.0	45.0	33.1	6.1	0.031	2.465	0.84	0.210	0.0079-0.1070	2.032-2.952	A-	0.70	0.28
August	60	10.0	19.0	15.1	2.3	9.0	51.0	30.9	11.1	0.021	2.666	0.92	0.102	0.0120-0.0345	2.478-2.862	A-	0.86	0.37
September	60	9.0	18.0	13.6	2.4	5.0	51.0	24.1	12.0	0.012	2.890	0.89	0.134	0.0051-0.0233	2.622-3.205	I	0.89	0.21
October	20	7.0	18.0	13.7	3.0	2.2	49.0	22.6	11.7	0.005	3.192	0.99	0.084	0.0027-0.0056	3.114-3.399	A+	0.77	0.26
November	42	12.0	18.5	15.6	1.5	12.0	50.0	29.6	8.9	0.004	3.231	0.93	0.145	0.0019-0.0114	2.853-3.492	I	0.76	0.49
December	65	11.0	18.0	15.2	1.7	11.0	50.0	30.3	10.3	0.008	3.033	0.91	0.117	0.0041-0.0142	2.799-3.257	I	0.82	0.56
January	38	11.0	19.0	14.2	1.7	12.0	56.0	24.7	10.0	0.012	2.865	0.89	0.165	0.0051-0.0294	2.529-3.178	I	0.83	0.62
February	52	8.5	17.0	14.4	1.7	5.0	38.0	24.8	7.7	0.007	3.044	0.95	0.099	0.0054-0.0124	2.839-3.174	I	0.80	0.66
March	36	11.0	17.0	14.6	1.2	14.0	45.0	25.8	6.7	0.014	2.798	0.77	0.262	0.0039-0.1020	2.062-3.272	I	0.82	0.66
April	33	10.5	17.0	14.8	1.7	12.0	45.0	28.2	8.9	0.013	2.838	0.94	0.131	0.0063-0.0312	2.512-3.107	I	0.85	0.58
May	35	12.0	17.5	14.5	1.5	11.0	50.0	25.9	9.6	0.002	3.491	0.91	0.190	0.0007-0.0057	3.124-3.888	A+	0.81	0.63
June	25	12.0	17.0	14.9	1.1	15.0	40.0	28.1	6.4	0.012	2.864	0.80	0.301	0.0031-0.0754	2.195-3.364	I	0.83	0.57
Total	495	7.0	19.0	14.8	2.0	2.2	56.0	27.5	9.9	0.012	2.866	0.91	0.041	0.0084-0.0154	2.761-2.983	A-	0.82	0.49
<3 miles	345	7.0	18.5	14.3	1.9	2.2	51.0	25.0	9.0	0.012	2.856	0.91	0.049	0.0083-0.0160	2.741-2.986	A-	0.81	0.47
>3 miles	157	8.5	19.0	15.7	1.7	5.0	56.0	33.0	9.6	0.021	2.661	0.87	0.083	0.0091-0.0391	2.437-2.967	A-	0.84	0.52

Table 2. Range and mean values for total length (L) and total weight (W) and parameters for the length-weight relationships, condition factors (*K*) and mean gonadosomatic index (GSI) of *Penaeus semisulcatus* for females from the north-eastern Mediterranean coast of Turkey (n: number of specimens, GT: type of growth (I, A and A+, as explained in the text), SE: standard error, *a*: the intercept, *b*: the allometric coefficient).

	n	Lmin	Lmax	Lmean	SE of L	Wmin	Wmax	Wmean	SE of W	*a*	*b*	R^2	SE of *b*	CI of *a*	CI of *b*	GT	K	GSI
July	33	11.0	23.5	19.6	2.3	10.0	100.0	57.6	17.4	0.011	2.868	0.96	0.105	0.0031-0.0157	2.748-3.289	I	0.74	6.29
August	111	10.0	24.0	18.3	3.1	10.0	135.0	57.4	23.2	0.014	2.833	0.95	0.064	0.0098-0.0215	2.692-2.957	A-	0.88	4.62
September	81	7.5	24.0	16.2	4.2	3.5	105.0	44.9	29.6	0.006	3.108	0.96	0.068	0.0040-0.0107	2.924-3.27	I	0.87	2.77
October	21	9.5	22.5	15.9	3.1	6.5	105.0	37.3	22.2	0.004	3.229	0.99	0.087	0.0030-0.0066	3.078-3.373	A+	0.82	1.87
November	37	9.0	24.0	17.2	3.2	3.0	133.0	46.6	26.8	0.002	3.545	0.98	0.092	0.0007-0.0038	3.268-3.846	A+	0.80	4.04
December	86	8.5	25.0	18.1	3.0	5.0	127.0	57.1	27.8	0.005	3.168	0.98	0.051	0.0042-0.0074	3.061-3.254	A+	0.88	6.02
January	53	12.0	23.0	17.5	2.6	15.0	113.0	50.6	23.3	0.007	3.085	0.98	0.061	0.0046-0.0105	2.937-3.223	I	0.88	4.70
February	64	12.0	23.0	17.7	2.4	15.0	136.0	52.2	23.1	0.010	2.972	0.95	0.091	0.0048-0.0184	2.746-3.212	I	0.89	4.57
March	62	10.0	23.0	17.7	2.3	6.0	111.0	49.8	18.2	0.006	3.099	0.94	0.102	0.0064-0.0131	2.850-3.498	I	0.85	6.44
April	35	11.0	23.0	16.7	2.8	10.0	100.0	44.3	22.7	0.006	3.129	0.96	0.118	0.0026-0.0114	2.904-3.421	I	0.87	4.71
May	57	9.0	24.0	17.1	3.2	6.0	115.0	47.3	27.7	0.004	3.231	0.98	0.068	0.0030-0.0071	3.059-3.360	A+	0.84	7.53
June	54	8.5	25.0	18.1	2.8	5.0	127.0	56.1	22.9	0.010	2.956	0.98	0.059	0.0060-0.0132	2.859-3.133	I	0.89	7.10
Total	678	7.5	25.0	17.6	3.1	3.5	136.0	51.0	24.7	0.007	3.052	0.96	0.023	0.0061-0.0090	2.985-3.118	I	0.86	5.09
<3 miles	473	7.5	24.0	16.9	3.1	3.0	136.0	45.4	23.1	0.007	3.090	0.96	0.029	0.0052-0.0086	2.999-3.173	I	0.85	4.60
>3 miles	224	9.5	25.0	18.9	2.6	6.5	135.0	61.9	23.8	0.011	2.924	0.94	0.051	0.0077-0.0149	2.816-3.041	I	0.88	6.14

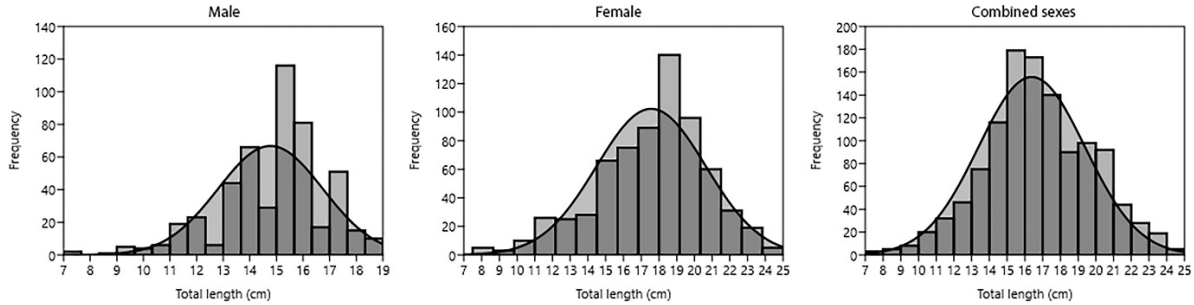

Fig. 2. Length frequency data for male, female and combined sexes of *Penaeus semisulcatus* in north-eastern Mediterranean coasts of Turkey

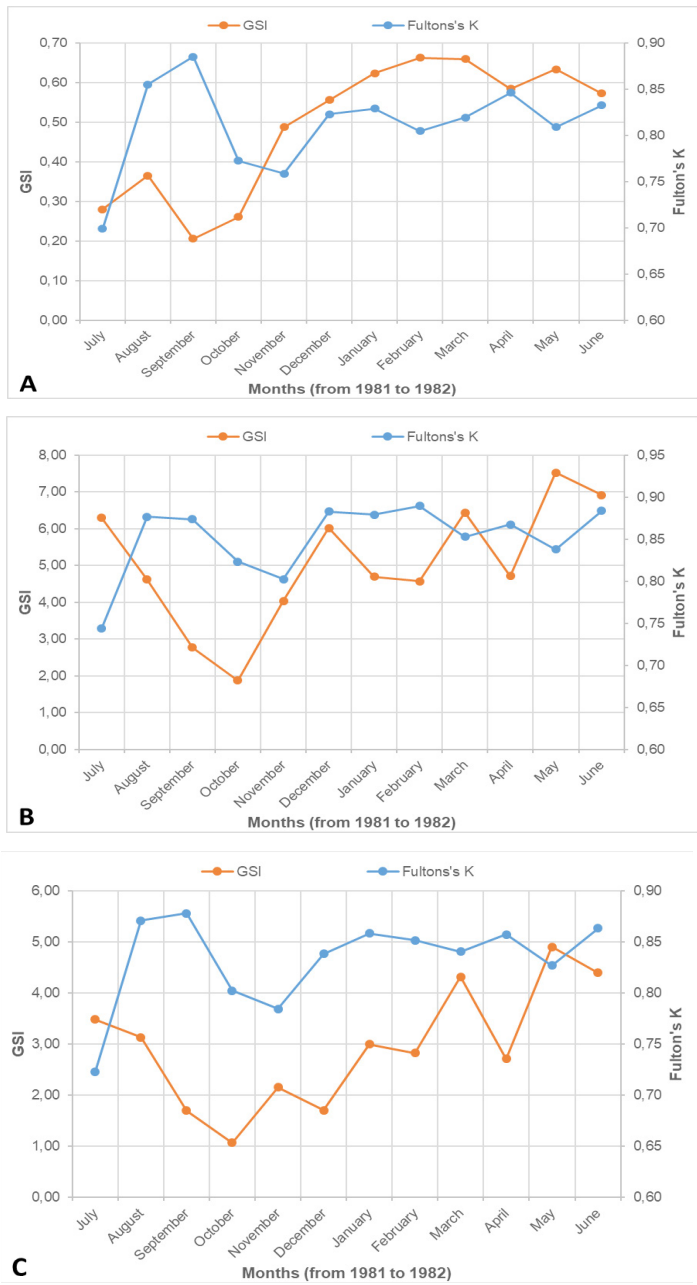

Fig. 3. Monthly distribution of Fulton's condition factor and GSI of *Penaeus semisulcatus* in north-eastern Mediterranean coasts of Turkey. (A) Males. (B) Females. (C) Combined sexes.

the lowest 14.8°C in February, with a mean of 21.8 ± 5.5°C.

A total of 1173 green tiger prawn were collected during the study period, 495 of them were males and 678 females; the sex ratio (M/F) was estimated as1/1.37. The total length ranged from 7.5 to 25.0 cm for females and 7.0 to 19.0 cm for males with a mean of 17.6 ± 3.1 cm and 14.8 ± 2.0 cm, respectively (Fig. 2; Tables 1 and 2). The total weight ranged from 3.0 to 136.0 g for females and 2.2 to 56.0 g for males with a mean of 51.0 ± 24.7 g and 27.5 ± 9.9 g, respectively.

LWR was estimated as $W = 0.012 * L^{2.866}$ and $W = 0.007 * L^{3.052}$ for males and females, respectively.

The lowest *b* value (2.465) was determined in July, while the highest (3.491) was in May for males. Wevdetermined the growth type was negative allometric (A-) in July and August; positive allometric (A+) in October and May; and other months represented isometric growth (I). Fulton's condition factor values ranged from 0.70 (July) to 0.88 (September).

For females, the lowest *b* value (2.833) was determined in August, while the highest (3.545) was in November. It was determined the growth type was negative allometric in August; positive allometric in September, October, November and May; and other months were characterised of isometric growth. Fulton's condition factor values ranged from 0.74 (July) to 0.89 (February and June).

Asymptotic length (L_∞) and the growth coefficient (*k*) were estimated to 19.95 cm and 1.3 $year^{-1}$ for male, 26.25 cm and 0.8 $year^{-1}$ for female and 26.25 cm and 0.48 $year^{-1}$ for combined sexes (Table 3). The instantaneous rates of total, natural and fishing mortalities were 4.34, 2.12 and 2.22 for males,

1.59, 1.02 and 0.57 for females and 2.65, 1.43 and 1.22 year^{-1} for combined sexes, respectively. Using the mortality rates given above, *E* values were 0.51, 0.36 and 0.46 year^{-1}, respectively. These *E* values indicate no fishing pressure on the population of *P. semisulcatus* in the north-eastern Mediterranean coast of Turkey in the studied period.

Discussion

The sex ratio (M/F) was estimated as 1/1.37 in this study. It is most likely to be 1:1 (Avsar 2005) and the sex ratio estimated by us, did not deviate from the 1:1 ratio significantly ($P > 0.05$). The ratio we observed was 1:1.02, which indicated there was no significant variation in the frequency of males and females (Manaşırlı et al. 2014).

The maximum length reported is 18.0 cm for male and 25.0 cm for female, while the maximum weight given in Sea Life Base is 130 g (Palomares & Pauly 2021). In this study, the maximum length and weight for female and male were 25 cm TL (136 g) and 19 cm TL (56 g), respectively. Females grow larger than males. In previous studies, similar results are reported also for other penaeid species (Gopalakrishnan et al. 2014, Manasirli et al. 2014, Udoinyang et al. 2016).

Similarly, von Bertalanffy growth parameters were also different in males and females. These results show that *P. semisulcatus* exhibit sexual dimorphism as regarding growth. Similarly, sexually dimorphic growth has been reported in other studies (Udoinyang et al. 2016, Manasirli et al. 2014). The results indicate that females are characterised by a higher growth rate than males (Figs. 3 and 4). While type of growth is allometric negative in males, in females it is isometric. These results also support evidence of sexual dimorphism in growth.

The LWR parameters estimated in other studies are similar (Table 4). Fulton's condition factor value in females (0.86) is higher than the one in males (0.82). However, it can be argued that there is no significant difference among sexes, depth layers and the months. (Fig. 3).

There is evidence of fluctuations of the GSI by month with a maximum in March-June and minimum in October-November. This indicates that the species reproduces in portions throughout the year and not in a certain breeding season. When the condition factor is compared with the GSI, it is revealed that the peak period of reproduction is the autumn period. It is reported in other studies that the species reproduces in along the entire year. Mohamed & El-Aiatt (2012) report about two spawning peaks for *P. semisulcatus* around March-April and October-November in Qatar waters, while Badawi (1975) found the greatest breeding activity - between October and April in the Arabian Gulf. (Abdel Razek 1985). In Yumurtalık Bight, *P. semisulcatus* also has two spawning peaks (Kumlu et al. 1999). The higher one takes place in early spring (May or even earlier) and in summer months (June to August), while the second - weaker one occurs in October - November. As stated in the studies above, although there are differences in the breeding season of the species according to the region, breeding takes place throughout the year. Female brood stock of *P. semisulcatus* occurs in Yumurtalık Bight

Table 3. Von Bertalanffy growth parameters, instantaneous rates of mortality and exploitation rate of *Penaeus semisulcatus* in north-eastern Mediterranean coasts of Turkey.

Parameters	Male	Female	Sexes combined
L_∞	19.95	26.25	26.25
k	1.30	0.48	0.80
Z	4.34	1.59	2.65
M	2.12	1.02	1.43
F	2.22	0.57	1.22
E	0.51	0.36	0.46

Table 4. LWRs parameters for the Mediterranean population of *Penaeus semisulcatus* in previous studies.

Location	Country	Sex	L		W		*a*	*b*	R^2	Source
			Min	Max	Min	Max				
Iskenderun Bay	Turkey	Male	7.0	22.0		104.0	0.0072	3.04		Kumlu et al., (1999)
Iskenderun Bay	Turkey	Female	7.0	17.0		32.4	0.0045	3.25		Kumlu et al. (1999)
Iskenderun Bay	Turkey	Male	9.2	18.3	7.1	50.0	0.0092	2.965	0.96	Manaşırlı et al. (2014)
Iskenderun Bay	Turkey	Female	8.2	23.2	5.4	123.6	0.0064	3.125	0.97	Manaşırlı et al. (2014)
Gulf of Suez	Egypt	Male	8.0	20.2	6.0	69.0	0.0066	3.068	0.97	Mehanna (2000)
Gulf of Suez	Egypt	Female	8.5	24.4	5.0	136.0	0.0064	3.092	0.97	Mehanna (2000)
Gulf of Suez	Egypt	Combined sexes	8.0	24.4	5.0	136.0	0.0065	3.075	0.97	Mehanna (2000)

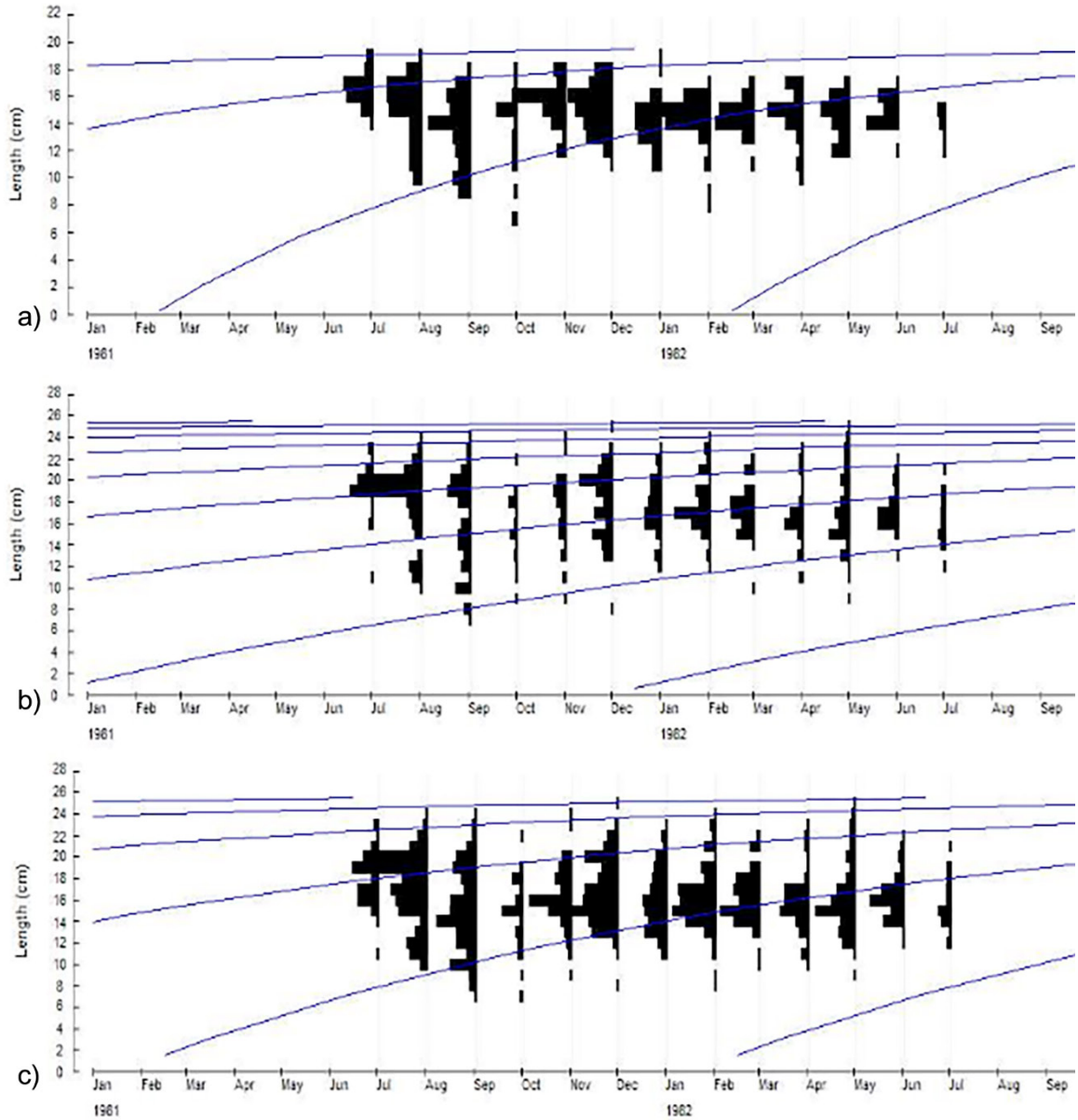

Fig. 4. Length-frequency and growth curve of *Penaeus semisulcatus* De Haan, 1844 in north-eastern Mediterranean coasts of Turkey A) male, B) female and C) combined sexes, respectively.

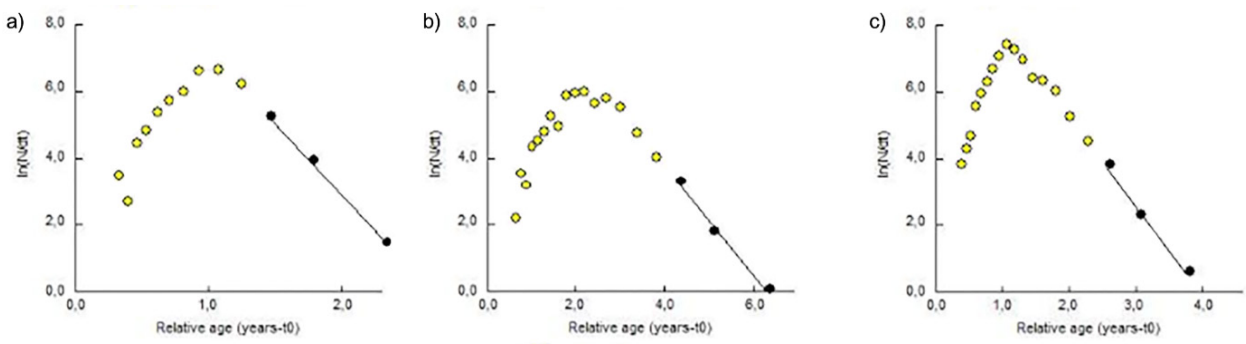

Fig. 5. The length-converted catch curve of *Penaeus semisulcatus* De Haan, 1844 in north-eastern Mediterranean coasts of Turkey A) male, B) female and C) combined sexes, respectively.

in high numbers in early spring and summer at water depths of 20-30 m. The adults are distributed in the sea, while the juveniles prefer estuarine environments (Kumlu et al. 1999).

The instantaneous rates of Z, M and F were estimated for each sex and pooled data (Table 3). Using the mortality rates, *E* were estimated as 0.51, 0.36 and 0.46 year^{-1}, in male, females and combined sexes, respectively. The *E* values indicate lower fishing pressure on the population of *P. semisulcatus* in the north-eastern Mediterranean coast of Turkey in the studied period. However, nearly three decades later *E* ratio increased to 0.65 and 0.69 year^{-1} for males and females, respectively and overfishing has been reported in the Iskenderun Bay (Manaşırlı et al. 2014).

This study aims to fill the gap in historical knowledge about population parameters of *P. semisulcatus*. LWRs parameters were previously determined in the Mediterranean Sea (Table 3), however, no previous studies have made separate calculations based on months, depth layers and sex and Fulton's condition factor has not been estimated before. Various factors may influence growth parameters including species' biology, food availability, environmental conditions, geographic region and climatic changes (Lubich et al. 2020). Our results provide useful information to compare the current situation with the previous state of the stock, to be used in fisheries management and fisheries research in future studies.

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