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Full Length Research

Stock assessment of the green tiger shrimp *Penaeus semisulcatus* De Haan, 1844 from Northwest Arabian Gulf, Iraq

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ABSTRACT: This study presents the initial stock assessment of the green tiger shrimp, *Penaeus semisulcatus* De Haan, one of the most productive fisheries in Iraqi marine waters. The growth, mortality, recruitment, yield-per-recruit, and virtual population analysis (VPA) of *P. semisulcatus* in Iraqi marine waters in the northwest Arabian Gulf were studied from November 2022 to October 2023, to manage and conserve the population of this species. Total length-frequency data of 2,394 specimens of *P. semisulcatus* were analyzed using the FiSAT II software. The length-weight relationship was $W= 0.0044TL^{3.208}$, indicating an isometric growth pattern. The asymptotic length ($L\infty$) and growth rate (K) were 28.7 cm and 0.50 respectively. Total, natural and fishing mortalities were 2.81, 1.01 and 1.80, respectively. The current exploitation rate (E_{cur}) was 0.64. Recruitment continued throughout the year with one major peak in May. Length at first capture L_{c50} (15.1 cm) was higher than length at first maturity L_{m50} (14.5 cm), indicating that they may be vulnerable to capture by the available fishing gear after they mature. VPA results show that most of the catches of the individuals occurred at mid-lengths of 17-23 cm, and the maximum fishing mortality was at a length of 21 cm. The yield per recruit analysis shows that the current exploitation rate (E_{cur}) was below the biological target reference points ($E_{0.1}$ and E_{max}), indicating that the stock of *P. semisulcatus* is being exploited rationally. To promote sustainable management, shrimp nursery grounds should be identified for protection, and the law regulating the exploitation and protection of aquatic life to regulate fishing in Iraqi marine waters should be updated.

Keywords: *Penaeus semisulcatus*, fishing, management, conservation, Arabian Gulf.

INTRODUCTION

Penaeid shrimps are commercially important and widely distributed worldwide in sub-tropical and tropical regions. They make up the majority of the catch in shrimp fisheries, with total catches in 2020 reaching 3.2 million tons from a total of 5.6 million tons of crustaceans (FAO, 2022). The green tiger shrimp, *Penaeus semisulcatus* De Haan 1844, belongs to the Penaeidae family and is a particularly abundant species found around the Indian subcontinent, through the Malay archipelago to Japan, the Gulf of Mexico, Northern Australia, the Red Sea, eastern Africa, and the Arabian Gulf. The species has also been colonized all along the coasts of Egypt, Lebanon, Syria and southern Turkey and entered the eastern Mediterranean through the Suez Canal (Fischer and Bianchi, 1984).

Kebtieneh *et al*. (2016) suggest that the main objective of the stock assessment is to provide decision-makers with the necessary information to make informed decisions regarding the optimal level of exploitation of aquatic living resources. Studies conducted on the stock assessment and population dynamics of *P. semisulcatus* in various coastal waters around the world using ELEFAN I or FiSAT II Software, including Mohammed *et al*. (1996) in Kuwait waters, Arabian Gulf; Mehanna (2000) in the Gulf of Suez, Egypt; Ye *et al.* (2003) in the coastal waters of Kuwait, eastern Saudi Arabia, Bahrain, and Qatar; Sabry *et al*. (2006) in the Jizan Area, Red Sea Coast, Saudi Arabia;

Villarta *et al*. (2006) in the Pilar and Capiz Bays, West Central Philippines; Hosny (2007) in the Manifa, Saudi Arabia, Arabian Gulf; Niamaimandi *et al.* (2007) and (2008) in Bushehr coastal waters, Arabian Gulf; Mehanna *et al*. (2012) in the Arabian Sea, Oman; Mohamed and El-Aiatt (2012) in the Bardawil Lagoon, North Sinai, Egypt; Abdul-Wahab (2014) in the Yemeni Red Sea waters; Alrashada *et al*. (2019) in the Saudi coast of the Arabian Gulf; Alizadeh *et al*. (2022) in the northern coast of Iran and Suman *et al.* (2023) in Bombana and Adjacent Waters, Southeast Celebes, Indonesia.

In Iraqi marine waters, shrimps of the family Penaeidae, particularly *P. semisulcatus, Metapenaeus affinis* and *Parapenaeopsis stylifera* are prevalent in the fisheries (Ali, 2001; Al-Maliky, 2013; Ali and Ahmed, 2015). The shrimp fishery in these waters is entirely artisanal, and the landings have varied over the past two decades. They have increased from 123.4 tons (1.85% of the total catch) in 2008-2009 to 7,288 tons (14.4% of the total catch) in 2020-2022 (Mohamed and Abood, 2024). According to Mohamed and Abood (2020), these increases in total landings may be attributed to the development of infrastructure, the upgrading of navigation technology, the increasing mechanized power of fishing boats, local demand and high prices.

Few studies have been conducted on *P. semisulcatus* found in the marine waters of Iraq. These studies have focused on the fishery (Ali, 2001; Ali and Ahmed, 2015) and reproductive biology (Ghazi, 2015). However, none of these studies have addressed the stock assessment of this species in Iraq. This study is the first attempt to assess the stock of *P. semisulcatus* in Iraqi marine waters to manage and conserve the population. The growth, mortality, recruitment, yield-per-recruit, and virtual population analysis (VPA) of the species were used in this assessment from November 2022 to October 2023.

MATERIALS AND METHODS

Study area and sampling

The study was undertaken in the Iraqi marine waters within the northwest Arabian Gulf. Iraq has a coastline of 105 km with a continental shelf of 1034 km^2 (EarthTrends, 2003), represents the most estuarine part of the northwestern Arabian Gulf, and consists of Shatt AL-Arab estuary and many open creeks such as Khor Al-Kafka, Khor Al-Amaya and Khor Abdullah (Albadran *et al*., 2016; Al-Mahdi *et al*., 2009). The coastal area is dynamic and highly productive, supporting a large number of marine species that coexist and thrive due to receiving substantial fluvial input from the Shatt Al-Arab River. This river has historically played an important role in providing the northwestern Arabian Gulf with nutrient-rich fresh water (Al-Yamani, 2021). It also serves as a significant nursery, feeding, and reproduction ground for several economically important species, including shrimp (FAO, 2014). The sediment morphology of this region differs from the other parts of the Gulf due to terrigenous sediments brought by the river, and the texture of the sediments is muddy, making modifications and reworking by the tidal current or waves in the area (Albadran *et al*., 2016).

The marine waters of Iraq have a long-standing tradition of artisanal fishing that involves catching multiple species of fish and shrimps. Fishing operations are concentrated in the Shatt Al-Arab estuary, Khor Abdulla, and Khor Al-Amaya regions (Figure 1), and the main site for landing marine resources is the Al-Fao port located at the northwest corner of the Arabian Gulf (Mohamed, *et al*., 2005). At present, there are 1612 licensed boats, 1,337 fiberglass powered by 65-250 horsepower (hp) and 275 steel-hulled dhows (boats) powered by 120-950 hp using traditional fishing gears including drift gill nets, trawl nets, traps (gargoor) and long and hand lines (Mohamed and Abood, 2024).

Samples of all shrimp species were collected from artisanal fishermen who landed their catch at the main landing site at the Al-Fao port from November 2022 to October 2023. Specimens were stored in the ice box and transported to the Department of Fisheries and Marine Resources laboratory for further examination.

Laboratory and data analyses

In the laboratory, each sampling of shrimp was sorted according to species using the identification keys by Fischer and Bianchi (1984) and the main species *P. semisulcatus,* was isolated. A total of 2394 *P. semisulcatus* specimens were involved in the present study. The total length (TL) was measured from the tip of the rostrum to the end of the telson, carapace length (CL) from the posterior margin of the orbit to the posterior margin of the carapace, and total weight (W). TL and CL were measured to the nearest 0.1 cm using a digital vernier calliper, while W was measured to the nearest 0.1 g using a digital balance. The length at 50% maturity (L_{m50}) was designed using the following equation (Binohlan and Froese, 2009): $\log (L_{m50}) = -0.1189 + 0.9157 * \log (L_{max})$, where L_{max} is the largest individual observed in the samples.

The total length (TL) and carapace length (CL) relationship of *P. semisulcatus* was calculated by applying the regression equation CL= a + b TL, where a (intercept) and b (slope) are constants. The total length-weight relationship was determined with the power equation $W= a*L^b$ (Froese *et al.*, 2011), where, W= weight (g), L= total length (cm), and (a) and (b) are constants. To determine the significance of coefficient b at a 5% significance level, the student's t-test was done.

For the stock assessment study, only total lengths (combined sexes) were involved using the FAO-ICLARM Stock Assessment Tools II (FiSAT II) software (Gayanilo

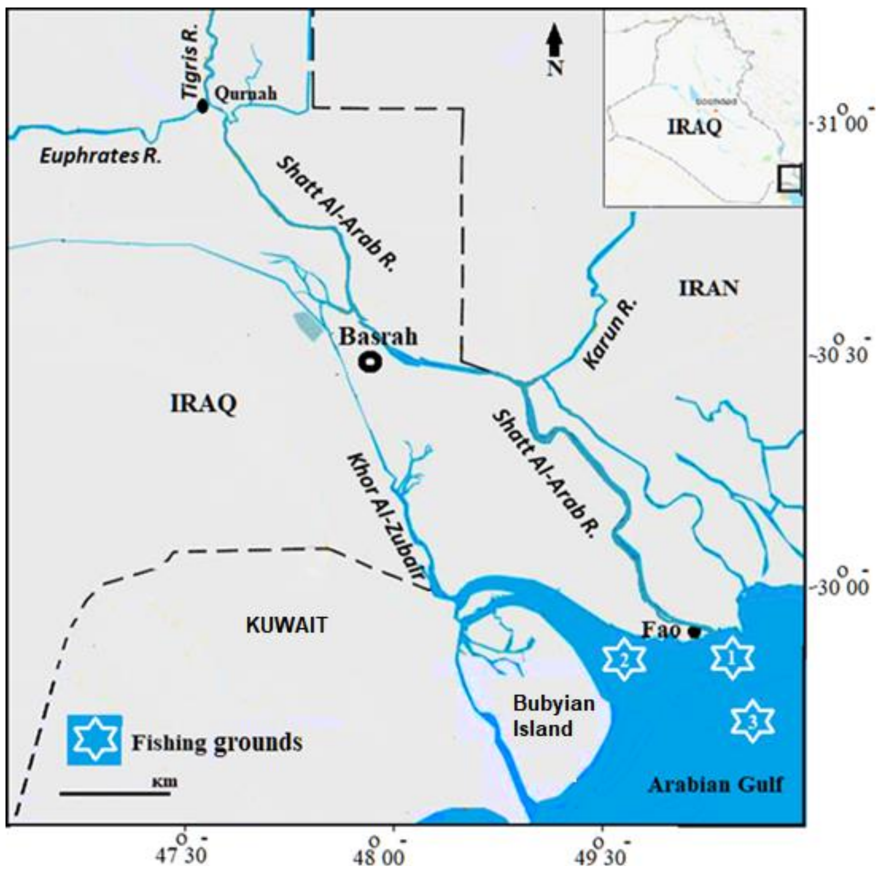

Figure 1. Fishing grounds of *P. semisulcatus* in Iraqi marine waters, northwest Arabian Gulf.

et al., 2005). The length frequency data was pooled into groups with 1.0 cm length intervals, to have about 10 to 20 length intervals, for proper performance of the FiSAT analysis (Gayanilo *et al.,* 2005). Monthly total length frequency data were analyzed using the software package of FiSAT II, and the method of ELEFAN I program (Electronic Length Frequency Analysis) as implemented in the FiSAT II software was applied for the estimation of the growth parameters including asymptotic total length (L_∞), growth coefficient (K) and growth performance index. The theoretical age at which the length is zero (t_0) was estimated using the equation of Pauly (1983):

$$\log_{10}(-t_0) = -0.3922 - 0.275 \log_{10}L_\infty - 1.0381 \log_{10}K$$

The length-converted catch curve method was used to estimate the instantaneous total mortality rate (Z) as implemented in the FiSAT II software from the estimated growth parameters (K and L_∞). The natural mortality rate (M) was calculated using the technique (Pauly, 1980) using the mean annual water temperature of 24.7°C (Al-Shamary *et al*., 2020). The fishing mortality coefficient (F) was computed as F= Z-M while the exploitation rate was calculated from the ratio F/Z (Gulland, 1971). The left ascending part of the length converted catch curve as implemented in the FiSAT software was used to determine the probabilities of length at 50, 75, and 95 capture which correlates with the cumulative probability at 50, 75 and 95 per cent, respectively (Pauly, 1984).

The recruitment pattern was estimated using the FiSAT-II length-frequency data management program by taking a backward projection of length frequencies onto the time axis based on growth parameters (Pauly, 1983).

The relative yield-per-recruit (Y´/R) was estimated using the knife-edge method as modified by Pauly and Soriano (1986) and incorporated into the FiSAT software. Accordingly, the biological target reference points, maximum economic yield ($E_{0.1}$), optimum sustainable yield ($E_{0.5}$) and maximum sustainable yield (E_{max}) were computed using the input parameters of L_c/L_∞ and M/K values. The current rate of exploitation ($E_{current}$) value is compared with the values of the biological referenced points ($E_{0.1}$ and E_{max}) to assess the status of the species' stock (Cadima, 2003).

The length-based virtual population analysis (VPA) was performed using the length convert curve procedure in the FiSAT routine. This model requires the input values of L_∞, K, M, F, and the constants (a and b) of the length-weight relationship for the species to estimate the population size, catches and natural and fishing rates by length group.

The regression analysis for the linear and power relationships and the t-test were conducted using the Microsoft Excel program.

RESULTS

Growth pattern of *P. semisulcatus*

In this study, 2,394 *P. semisulcatus* were collected with a total length range of 10.2 to 25.1 cm, with the highest peak being 14.0 cm, forming 16.25% of the total caught. The relationship of total length (TL) to its carapace length (CL) for all individuals of the species was CL= 0.3857*TL-0.4054, r^2= 0.910 for 483 specimens. The length-weight relationship of 1876 specimens from *P. semisulcatus* ranging from 10.2 to 25.1 cm in total length (TL) and weighing (W) 8.7 to 146.7 g was W= 0.0044$TL^{3.208}$, r^2= 0.949 (Figure 2). The t-test revealed that the regression slope (b) was significantly different from value 3 (t= 12.163, P>0.05), which indicates positive allometric growth. The total length at which *P. semisulcatus* first reaches sexual maturity (L_{m50}) was 14.5 cm (5.2 cm CL).

The initial seed value for $L\infty$ was 26.7 cm, as the observed extreme length (L_{max}) was 25.2 cm. This initial seed value was used in the ELEFAN-I incorporated in the FiSAT package to construct the optimum growth curve. The response surface (R_n) was calculated as 0.208 (Figure 3), which selected the best combination of growth parameters $L\infty$= 28.7 cm and K= 0.45 yr-1. The optimized growth curve was superimposed on the restructured length-frequency histograms shown in Figure 4. The theoretical age at zero (t_0) and the growth performance index (Ǿ) were estimated as -0.326 and 2.569, respectively.

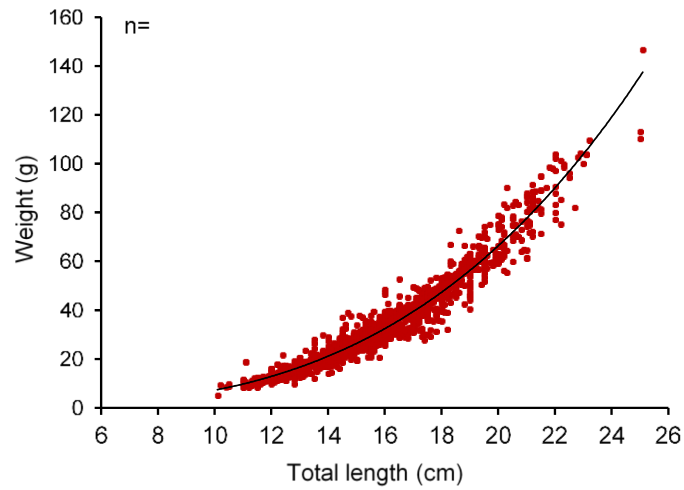

Figure 2. The length-weight relationship of *P. semisulcatus.*

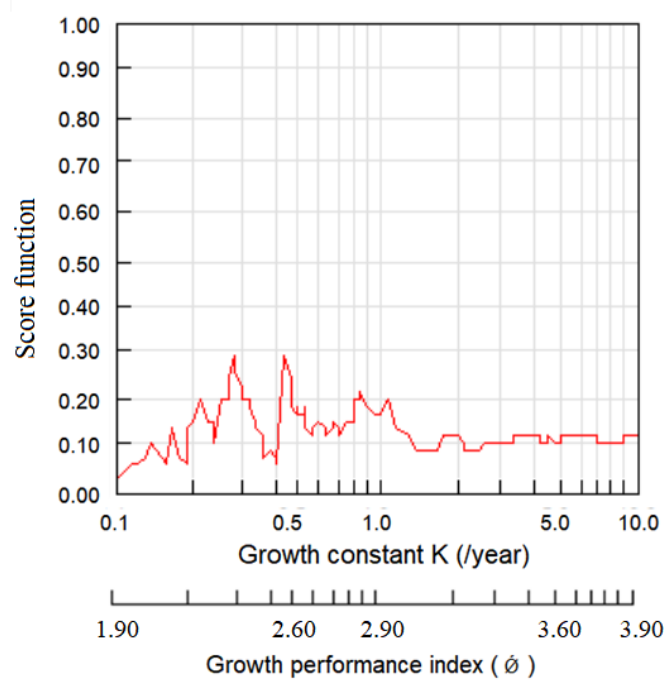

Figure 3. K-scan routines of *P. semisulcatus.*

Mortality and exploitation rates of *P. semisulcatus*

The obtained length converted catch curve from the FiSAT II software gave an estimate of the total mortality coefficient (Z= 2.81). The darkened circles represent the points used in calculating Z through least squares lines regression (Figure 5). The blank circles represent points either not fully recruited or nearing $L\infty$ and hence discarded from the calculation. The best fit to the descending right-hand limits of the catch curve was considered (r^2= 0.985). The natural mortality (M) and fishing mortality (F) were then estimated as 1.01 and 1.8, respectively. Finally, the current exploitation rate (E_{curr}) was estimated at 0.64.

Capture probability, recruitment pattern and yield-per-recruit of *P. semisulcatus*

As part of the length-converted catch curve analysis, the lengths at which 25% (L_{25}), 50% (L_{50}) and 75% (L_{75}) of *P. semisulcatus* caught with the fishing gears were determined by the analysis were 13.84, 15.05 and 16.25 cm, respectively (Figure 6). Therefore, the length of first capture (L_{c50}) of the species was found to be 15.1 cm (cm CL).

The recruitment pattern of *P. semisulcatus* was continuous throughout the year with only one prominent peak in May (Figure 7). The recruitment varied from 0.67% in November to 26.65% in May. The most recruitment extended from March to June constituted 79.19% of the overall recruitment.

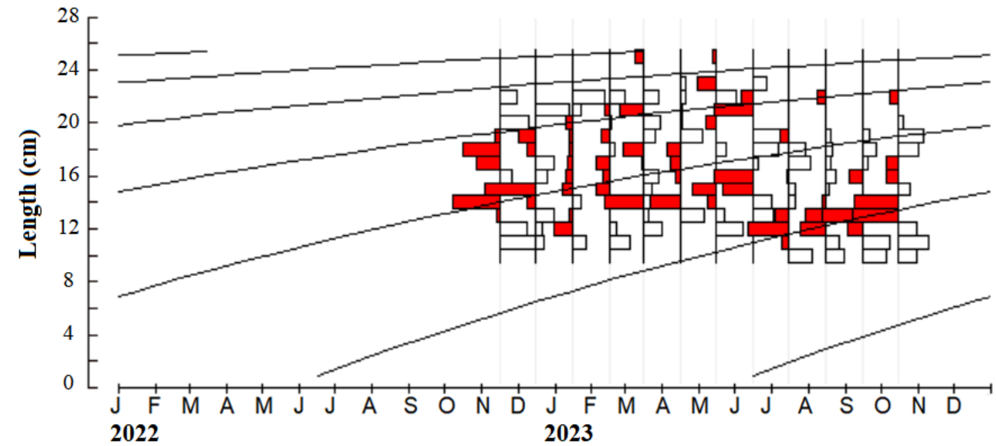

Figure 4. Restructured length-frequency distribution with growth curves superimposed using ELEFAN-1 for *P. semisulcatus.*

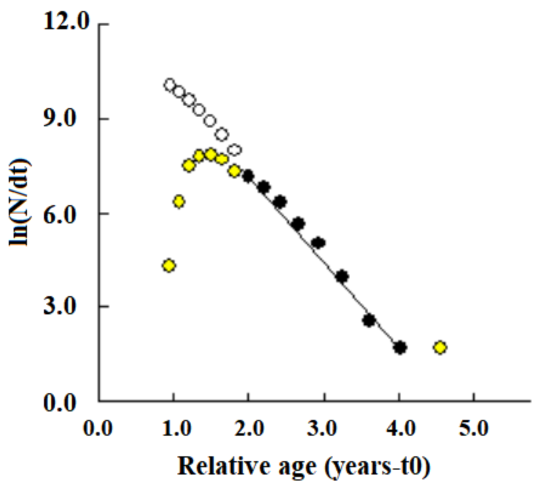

Figure 5. Length converted catch curve for estimation of Z for *P. semisulcatus.*

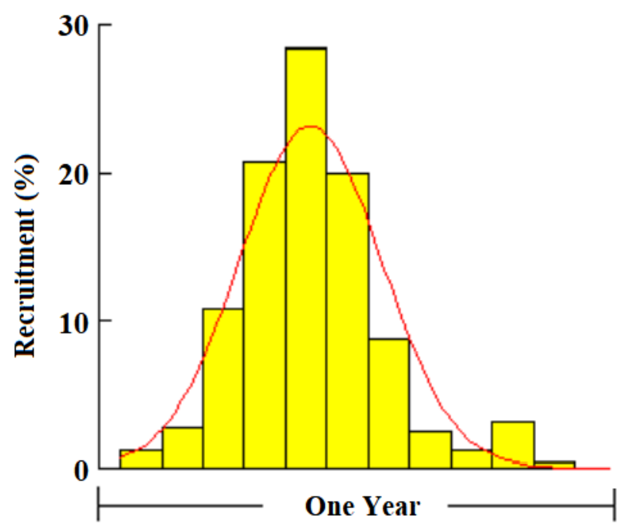

Figure 7. Recruitment pattern of *P. semisulcatus.*

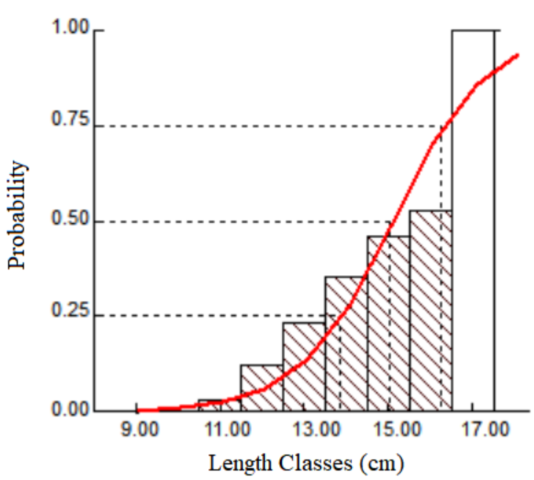

Figure 6. Probability of capture for *P. semisulcatus.*

The Beverton-Holt relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) were estimated using the knife-edge selection routine incorporated in FiSAT software as a function of M/K (2.244) and L_c/L_∞ (0.524), which derived from the previous analyses (Figure 8). The relative yield-per-recruit (Y'/R) and relative biomass-per-recruit (B'/R) were 0.024 and 0.219, respectively. The biological target reference points for the species were found to be 0.756, 0.375 and 0.877 for $E_{0.1}$, $E_{0.5}$ and E_{max}, respectively.

Virtual population analysis of *P. semisulcatus*

Figure 9 illustrates the virtual population analysis of *P. semisulcatus*. The highest natural losses were observed among individuals with lengths ranging from 10.0 to 14.0

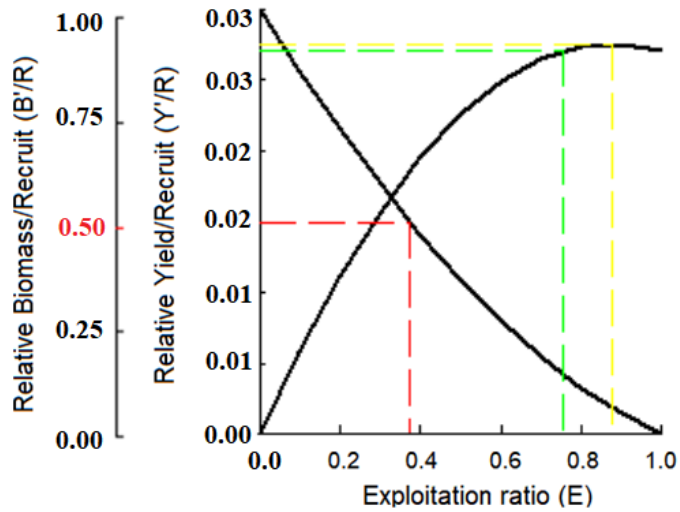

Figure 8. Relative yield per recruit (Y'/R) and biomass per recruit (B'/R) analyses for *P. semisulcatus.*

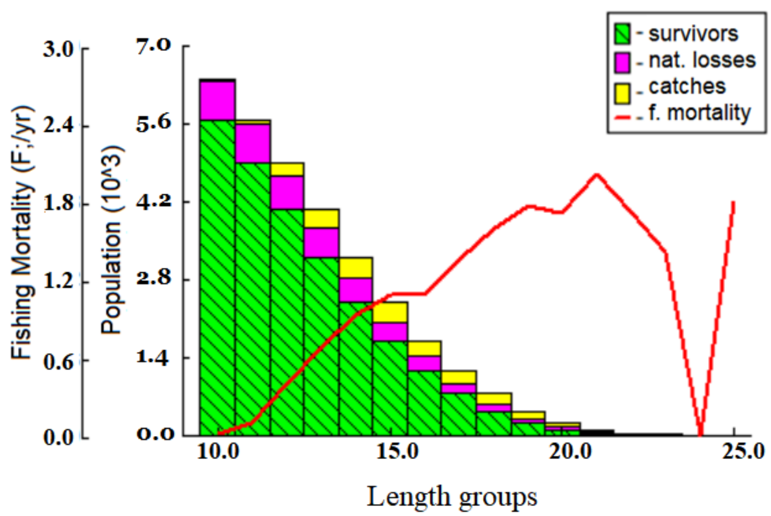

Figure 9. Length-structured virtual population analysis of *P. semisulcatus.*

cm, and the losses decreased gradually for the length group of 25.0 cm. The surviving individuals in the stock showed a declining trend as the cause of the increasing fishing pressure. The highest number of survivors in the stock was observed in the length range of 10.0 cm. Most of the fishing mortality of the individuals occurred at mid-lengths of 17-23 cm, and the highest was 2.02 for individuals at a length of 21 cm and the lowest (F= 0.01) for individuals at a length of 10 cm.

DISCUSSION

Jennings *et al.* (2000) stated that the assessment of species population is essential to meet one of the main objectives of fishery science, involving maximizing yield to fisheries while safeguarding the long-term viability of populations and ecosystems. King (2007) explained that the primary goal of fisheries science is to offer decision-makers recommendations regarding the best possible management strategies. These recommendations may include predictions of how the stocks and fishers may respond to different levels of management.

The results of growth model parameters computed by applying the ELEFAN I module implemented in FiSAT II, besides those reported by other authors, are summarized in Table 1. In the present study, the asymptotic length ($L\infty$) of *P. semisulcatus* was 28.7 cm TL (10.7 cm CL), which was relatively higher than those stated by Mehanna (2000) in the Gulf of Suez, Egypt ($L\infty$= 26.6 cm TL), Villarta *et al.*

Table 1. The results of the FiSAT analyses for *P. semisulcatus* in different ecosystems.

Authors	Sex	L∞ (cm)	K	L_{c50}	Z	M	F	E	Location
Mohammed *et al*. (1996)	M	3.7 [a]	1.6	2.3[a]	4.20	2.50	1.70	0.40	Kuwait waters, Arabian Gulf
	F	5.1	1.7	2.3	4.70	2.40	2.30	0.49	
Mehanna (2000)	M	22.4 [b]	1.8	-	8.18	2.52	5.66	0.69	Gulf of Suez, Egypt
	F	26.8	1.6		6.77	2.40	4.75	0.68	
Sabry *et al.* (2006)	M	4.5 [a]	0.7	1.9[a]	3.60	1.59	2.01	0.55	Jizan Area, Red Sea Coast, Saudi Arabia
	F	5.9	0.8	2.0	3.94	1.65	2.29	0.58	
Villarta *et al*. (2006)	M	26.3[b]	0.7	-	3.61	1.70	1.91	0.53	Pilar and Capiz Bays, Philippines
	F	27.1	1.6		5.65	3.65	2.00	0.35	
Hosny (2007)	All	6.6 [a]	1.2	3.2[a]	5.74	1.53	4.21	0.73	Saudi Arabia, Arabian Gulf
Niamaimandi *et al*. (2007)	M	3.8 [a]	1.6	3.2[a]	6.40	2.11	4.30	0.67	Bushehr waters, Arabian Gulf
	F	5.0	2.2		8.20	2.41	5.80	0.70	
El-Ganainy & Yassien (2012)	All	10.4 [a]	1.8	5.5[a]	8.64	3.64	5.28	0.61	Gulf of Suez, Red Sea, Egypt
Mehanna *et al.* (2012)	M	5.8 [a]	1.8	2.9[a]	7.84	2.11	5.73	0.73	Oman coast, Arabian Sea
	F	6.4	1.7	3.5	9.67	2.39	7.28	0.75	
Mohamed & El-Aiatt (2012)	M	5.4 [a]	0.9	3.2[a]	3.24	1.05	2.18	0.67	Mediterranean Sea, Bardawil Lagoon, Egypt
	F	6.7	1.1	4.0	5.34	1.16	4.17	0.78	
Abdul-Wahab (2014)	M	18.4[b]	1.2	2.6[a]	6.55	2.19	4.36	0.67	Yemeni Red Sea waters
	F	23.2	1.4	3.4	5.64	2.27	3.37	0.60	
Rabaoui *et al*. (2017)	All	5.7 [a]	1.9	3.3[a]	3.69	2.39	1.30	0.35	Saudi coasts, Arabian Gulf
Alrashada *et al*. (2019)	M	5.2 [a]	1.8	4.2[a]	4.65	2.12	2.53	0.54	Saudi coast, Arabian Gulf
	F	6.2	1.1	4.2	3.37	1.47	1.90	0.56	
Alizadeh *et al*. (2022)	M	4.6 [a]	1.6	2.6[a]	5.79	2.10	3.69	0.64	Hormozgan coastal waters, Arabian Gulf
	F	5.7	1.8	3.4	5.50	2.14	3.36	0.61	
Suman *et al*. (2023)	All	5.9 [a]	1.7	3.7[a]	2.57	1.45	1.12	0.44	Bombana and Adjacent Waters, Indonesia
Present study	All	28.7[b] 10.7[a]	0.5	15.1[b] 3.7 [a]	2.81	1.01	1.80	0.64	Iraqi marine waters, Arabian Gulf

([a] CL= carapace length, [b] TL= total length, L∞= asymptotic length, K= growth coefficient, L_{c50}= first captured length, Z= total mortality rate, M= natural mortality rate, F= fishing mortality rate and E= exploited rate).

(2006) in the Pilar and Capiz Bays, Philippines (26.3 and 27.1 cm TL for males and females, respectively) and El-Ganainy and Yassien (2012) in the Gulf of Suez, Red Sea, Egypt (10.4 cm CL). On the other hand, Niamaimandi *et al.* (2008) recorded the lowest values of L∞ for *P. semisulcatus* in the Bushehr coastal waters of the Arabian Gulf. The estimated growth coefficient (K) for *P. semisulcatus* in this study was lower than those reported for species by other studies. According to Pauly and Munro (1984), the K value for penaeid shrimps ranges from 0.39 to 1.6. Generally, the value of K ranged from 0.7 for males in the Jizan Area, Red Sea Coast, Saudi Arabia (Sabry *et al*., 2006) to 2.2 for females in the Bushehr coastal waters of the Arabian Gulf (Niamaimandi *et al*., 2008). The variation observed in the growth parameters of the same species in different regions can be influenced by various factors, such as environmental conditions, nutrient abundance, metabolic and reproductive activities, genetic makeup of the individual, fishing pressure, and sampling method (Sparre and Venema, 1998; Wootton, 2011; Panda *et al.* 2018; Çiloğlu and

Ateş, 2022).

The results revealed that the size at first capture (L_{c50}) for *P. semisulcatus* in the present study was 15.1 cm (5.4 cm CL) and was within those stated for the species in other geographic locations (Table 1). The length at first capture (L_{c50}) of the species varied from 1.88 and 2.03 cm CL for males and females, respectively in the Jizan Area, Red Sea Coast, Saudi Arabia (Sabry *et al.,*2006) to 5.52 cm CL for combined sexes in the Gulf of Suez, Red Sea, Egypt (El-Ganainy and Yassien, 2012). Length at first capture is important and depends on mesh size and gear selectivity (Makmur *et al*., 2019). The differences in the mesh size of fishing gears used in fishing may have accounted for the observed variation in length at first capture in the various studies, where fishing gears with large mesh sizes were likely to capture shrimps of larger sizes and vice versa (Ofori-Danson *et al*., 2018; Amponsah *et al*., 2021). It is clear to conclude that the estimated length at first capture (L_{c50}) in this study was higher than the length at first maturity (L_{m50}= 14.5 cm), which means that the species catch meets the criteria for good conservation and management ($L_{c50}< L_{m50}$). According to Almeidaa *et al*. (2018), sexual maturation is a crucial milestone in an animal's life cycle and should be taken into account for successful species management.

The value of the total mortality rate (Z) of *P. semisulcatus* in the present study was intermediate between other values for the species recorded in other waters (Table 2). The lowest value of Z for the species (2.57) was noted in the Bombana and Adjacent Waters, Indonesia (Suman *et al*., 2023), while the highest one (9.67) for females was in the Oman coast, Arabian Sea (Mehanna *et al.*, 2012). The estimated value of the fishing mortality rate (F) for males of *P. semisulcatus* in this study was 1.80, which also falls within the range of previous studies. The minimum value was 1.12 (Suman *et al*., 2023), and the maximum was 7.28 for females (Mehanna *et al.*, 2012). In contrast, the natural mortality rate (M) was found to be the lowest value compared to previous records, except for the females of the species in the Bardawil Lagoon, Mediterranean Sea, Egypt (Mohamed and El-Aiatt, 2012), while the highest value was 3.65 for females in the Pilar and Capiz Bays, Philippines (Villarta *et al*., 2006). On the other hand, the current exploitation rate (E_{cur}) of *P. semisulcatus* in this study was 0.64 indicating that the stock of the species was overexploitation according to Gulland (1971) who suggested that in an optimally exploited stock, fishing mortality should be about equal to natural mortality, resulting in an exploitation rate of 0.5, while less than 0.5 refers to under-exploitation and greater than 0.5 refers to over-exploitation. Similar findings were recorded earlier by most authors in Table 1, where the exploitation rate ranged between 0.35 for the female shrimp in the Pilar and Capiz Bays, Philippines (Villarta *et al*., 2006) and in the Saudi coasts, Arabian Gulf (Rabaoui *et al*., 2017) to 0.78 in the Bardawil Lagoon, Mediterranean Sea, Egypt (Mohamed and El-Aiatt, 2012).

From the recruitment pattern analysis, it is clear that *P. semisulcatus* in the present study has one major peak recruit into the fisheries, which happened in May 2023. Also, Mohammed *et al*. (1996) reported that a major recruitment of *P. semisulcatus* was detected from June/July in all seasons and a minor recruitment in some seasons in August/September in the Kuwait waters of the Arabian Gulf, and they did not support the spring and fall recruitment pattern in these waters. Certain studies have reported that the recruitment of *P. semisulcatus* can have two peaks that differ in strength and duration depending on the location. Villarta *et al*. (2006) noted that both male and female *P. semisulcatus* have two recruitment peaks, with the main peak occurring in May-June and a smaller peak in January in the Pilar and Capiz Bays, Philippines. In their study conducted in the Bombana and Adjacent Waters of Indonesia, Suman *et al*. (2023) stated that the recruitment of the species takes place throughout the year, with two peaks occurring in June and October. The recruitment pattern is concerned with the spawning time (Fiorentino *et al*., 2008). Suman *et al.* (2023) stated that the peak period of the new addition of *P. semisulcatus* occurred in the transition season from the rainy season to the dry season when the conditions of the waters were clear and the temperature was relatively cold, which stimulated the species to reproduce optimally.

Yield per-recruit (Y'/R) and biomass per-recruit (B'/R) analysis were used to obtain reference points and evaluate the exploitation status of the species. The biological reference points are the performance indicators of the exploited stock, it often takes various stock dynamics parameters, such as growth, recruitment and mortality, and reflects them to a single index (Collie and Gislason, 2001; Cadima, 2003). In the present study, the current exploitation rate (E_{cur}= 0.64) of *P. semisulcatus* was lower than both the maximum economic yield ($E_{0.1}$= 0.756) and maximum sustainable yield (E_{max}= 0.877) biological reference points, which means that the stock of species was underexploited according to Cadima (2003), however, the current exploitation rate was higher than the optimal level of exploitation according to Gulland (1971). Mohammed *et al*. (1996) declared that the relative yield-per-recruit (Y'/R) of *P. semisulcatus* in the Kuwait waters in the Arabian Gulf was close to the maximum length at first capture for males, but much lower for females, the exploitation of males was quite good, but that for females could be improved, at least theoretically. Sabry *et al*. (2006) stated that E_{cur} (0.581) of females *P. semisulcatus* in the Jizan Area, Red Sea Coast, Saudi Arabia was slightly lower than E_{max} (0.583) and higher than its optimal level ($E_{0.1}$= 0.316), while E_{cur} (0.55) of males was lower than E_{max} (0.695) and matched its optimal level ($E_{0.1}$= 0.55), which indicates that males were optimally exploited while females were fully exploited. Mohamed and El-Aiatt (2012) found that the biological target reference points of combined sexes *P. semisulcatus* in the Bardawil Lagoon, Mediterranean Sea, Egypt were $E_{0.1}$= 0.66 and E_{max}= 0.78, and the current exploitation rates (0.67 of males and 0.78 of females) were higher than $E_{0.1}$ and females corresponded E_{max}, therefore the current exploitation rate should be reduced by at least 16% from 0.78 to 0.66.

The virtual population analysis (VPA) is a method commonly used in the assessment of fisheries for reconstructing the historical species numbers at age or length using the information on the deaths of individuals each year, the deaths are usually partitioned into catch by fisheries and natural mortality, to calculate the population that must have been in the water to produce this catch (Sparre and Venema, 1998; Shepherd and Pope, 2002; Baharti, 2017). The outputs of the VPA revealed that most of the catches of *P. semisulcatus* occurred at mid-lengths of individuals (17-23 cm), with a maximum fishing mortality rate at the length of 21 cm (7.7 cm CL). However, the maximum fishing mortality rate for *P. semisulcatus* documented by Hosny (2007) from the Saudi coasts of the Arabian Gulf was 4.1 cm CL, highly lower than estimated in the current study. The estimated length at first capture (L_{c50}) of the species in this study was higher than the length at first maturity (L_{m50}), indicating that they may be vulnerable to capture by the available fishing gear after they mature so that every individual would get at least one chance to breed in their lifetime, which would help renew the stock over the long term to ensure resource availability and sustainability (Udoh and Ukpatu, 2017; Panda *et al.,* 2018).

Conclusion

This is the first study on the stock assessment of *P. semisulcatus* from Iraqi marine waters. Considering this study, the current level of exploitation (E_{cur}) of *P. semisulcatus* in Iraqi marine waters is below the recommended biological target reference points ($E_{0.1}$ and E_{max}). Additionally, the length at first capture (L_{c50}) was greater than the size at first maturity (L_{m50}), indicating that the stock of *P. semisulcatus* is being rationally exploited and there is no immediate danger of overfishing. To promote sustainable management of shrimp resources, fishery managers should identify shrimp nursery grounds for protection. It is also important to update the law regulating the exploitation and protection of aquatic life (Law No. 48 of 1976), specifically by issuing article No. 9 designed to regulate fishing in Iraq's territorial waters.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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