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# Biological aspects of the blue swimming crab, *Portunus segnis* (Brachyura: Decapoda: Portunidae), inhabiting the Suez Canal Lakes, Egypt

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## ABSTRACT

*Portunus segnis* (Forskål, 1775) is an economically important crab species in Egypt; however, its yields have decreased in recent years. In this study, the morphometric characteristics and organ indices were analyzed to obtain baseline information about the population structure and sexual maturity of this species. Specimens were monthly collected from Timsah and Bitter Lakes, along the Suez Canal. A 1.4: 1 and 0.9: 1 male: female sex ratio was recorded in the Timsah and Bitter Lakes, respectively. Fifty percent of females were mature at a CW of 79 and 87 mm in Timsah and Bitter Lakes, respectively. Spawning peaked in the lakes under study in September (32%) and July (25%), respectively, while the smallest and largest berried female crabs were 73.5 mm CW, 119.3 mm CW and 86 mm CW, 121.9 mm CW in Timsah and Bitter Lakes, respectively. The gathered information is expected to help improve the sustainability of this crab fishery in the Suez Canal area.

## INTRODUCTION

Upon determining the growth progress in crustaceans, certain dimensions of its body may grow much more than others, resulting in the phenomenon known as "relative growth" **(Hartnoll, 1974)**. Studies of relative growth are often used to determine changes in the form and size of the abdomen, pleopods, or chelipeds during ontogeny **(Josileen, 2011)**. Knowledge about these distinguishing characters and size relationships in sexually mature individuals is particularly significant in the study of commercially valuable crustaceans **(Josileen, 2011)**. Research on the species' life history, as well as the development of its fishery, resource management, and culture, could benefit from this information **(Josileen, 2011)**. The mathematical length-weight relationship yields information on the general well-being of individuals, variation in growth according to sex, size at first maturity, gonadal development, and breeding season. On the other hand, the study of the length-weight relationship in aquatic animals has a wide application in delineating the growth patterns during their developmental pathways **(Bagenal & Tesch, 1978)**.

The blue swimming crab, *Portunus segnis* **(Forskål, 1775)**, previously named as *P. pelagicus* **(Linnaeus, 1758)** is the most significant economic brachyuran crab in Egypt **(Sabrah *et al*., 2020)**; it is highly demanded for its esteemed food its delicacy and support of the value of fishery **(Redzuari *et al*., 2012)**. *P. segnis* is native to the western Indian Ocean, from Pakistan westwards to the Arabian Gulf, the east coast of Africa, Madagascar and Mauritius and the Red Sea **(Lai *et al*. 2010)**. It is one of the early Lessepsian migrants recorded along the Egyptian coasts of the Mediterranean Sea as early as 1898, few years after the opening of the Suez Canal **(Fox, 1924)**. The characteristics of *P. segnis* population in the Suez Canal have not been extensively studied, especially the reproductive pattern which is considered critical input data for stock assessment and management **(Froese, 2004)**.

Extensive studies of the blue crab population structure, morphometric analysis and reproductive patterns have been conducted in various locations around the world. **Hosseini *et al*. (2014)** and **Tureli and Yesilyurt (2017)** studied the size at maturity, sex ratio and variant morphometric of blue swimming crab *Portunus segnis* from Boushehr Coast, Persian Gulf and the north-eastern Mediterranean, Turkey respectively. **Hajjej *et al*. (2016)** focused on the morphometric characters relationship of *Portunus segnis* from the gulf of Gabes, Tunisia. **Giraldes *et al*. (2016)** studied the important biological, ecological, and taxonomic information about *P. segnis* in the western Arabian Gulf. **Gaber *et al*. (2021)** focused on the gonadal cycle of the blue crab *Portunus segnis* in the Mediterranean Sea at Alexandria, Egypt and **Hadj Hamida *et al*. (2022)** described the reproductive biology of *P. segnis* in the gulf of Gabes, including sex ratio, ovarian maturation, size at sexual maturity, spawning season and fecundity. **Zaghloul (2003)** addressed the reproductive biology of *P. pelagicus* with some rearing trials under different temperatures. However, only two studies were carried out on the population of the Suez Canal, and they focused on that of the Bitter Lakes only. The first study was carried by **Mehanna (2005)**, which described the population dynamics and the stock assessment through length-frequency distribution and the age composition of *Portunus pelagicus*; while the second **(Sabrah *et al*., 2020)** studied its reproductive characteristics.

Since the biology of this species populations has never been studied in Timsah Lake, and only a few studies have been carried out on those of the Bitter Lakes, the aim of this work was therefore focused to investigate some of the biological aspects of *P. segnis* off Timsah Lake such as population structure, allometric growth, size at sexual maturity, and seasonality of spawning. It also aimed to follow up on this economic species in order to determine whether there have been any recent variations in those parameters throughout the previous years in the Bitter Lakes.

## MATERIALS AND METHODS

### 1. Study areas

### 1.1. Timsah Lake

Timsah Lake (Fig. 1) is located on the coast of the city of Ismailia, Egypt, near the Suez Canal's midpoint and about 80 kilometers south of Port Said. It has a roughly surface area of 16 $km^2$, with a depth range of 3 to 16 meters, and a capacity volume of about $90m^3$ of seawater. The lake is connected to a small and shallow western lagoon at its western side. It receives around 833,000 $m^3$/day of domestic and agricultural wastewaters from several drains Abu-Attwa, Abu-Gamouss, and Elmahsama drains (**ETPS 1995**). **ETPS (1995)** and **Madkour *et al*. (2006)** stated that, on the northern side, the lake receives occasional inputs from the Ismailia freshwater Canal. The existence of several freshwater sources has greatly contributed to the considerable fluctuation in salinity (from 40.10% in summer to 7.30% in winter) **(Hamed *et al*., 2012; Dar *et al*., 2015)**.

### 1.2. The Bitter Lakes

The Bitter Lakes (Fig. 1) are a series of hypersaline lakes located between the Suez Canal's north and south ends. They have a surface area size of around 250km$^2$, lying between coordinates of 30° 19' 60.00" N and 32° 22' 59.99" E. The Bitter Lakes are considered the largest water body of the Suez Canal. The depths varied between 5.0 and 28.0 meters **(El-Serehy *et al*., 2018)**. They are the Canal’s main fishing area and serve as a stopover point for ships transiting the canal.

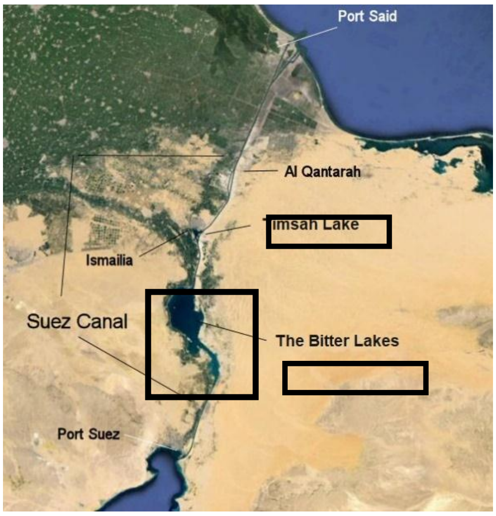


**Fig. 1.** A map of the Suez Canal showing the study areas

### 2. Sampling and Measurements of crabs

Between October 2020 and September 2021, random samples of *Portunus segnis* were collected from the commercial catch of both Timsah and Bitter Lakes. Trammel nets are employed by fishermen in the two lakes. Following capture, specimens were placed in plastic containers filled with seawater before being transferred to the laboratory for analysis.

The morphology of the pleon was examined to determine the sex of the crabs. Those with missing legs and broken carapaces were excluded since they could introduce bias into the weight regression. All measurements were taken according to **Williams (1974)** as indicated in Figs. (2, 3). Body weight (W) was determined to the nearest gram using a digital balance, while carapace width (CW) was measured between the tips of the ninth anterolateral teeth; carapace length (CL) was dorsally measured along the midline, between the frontal marginal teeth and the posterior margin of the carapace; chelar propodus length (CPL) was measured from the tip of the fixed finger to the base. Abdomen width (AW) was measured from the greatest width of the fifth abdominal segment in females, and pleopod length (PL) was measured from the tip to the base in males. All were taken by means of a Vernier Calipers with an accuracy of 0.1 mm.

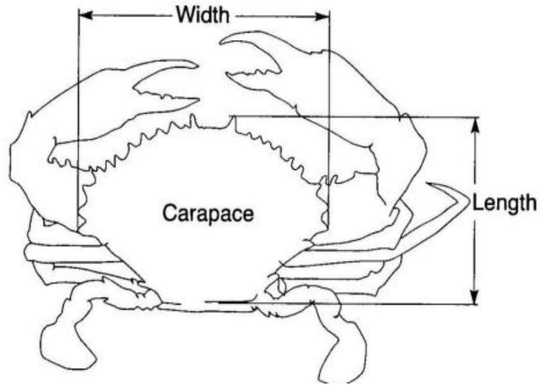


**Fig. 2.** Dorsal surface of a brachyuran crab showing the measured dimensions.

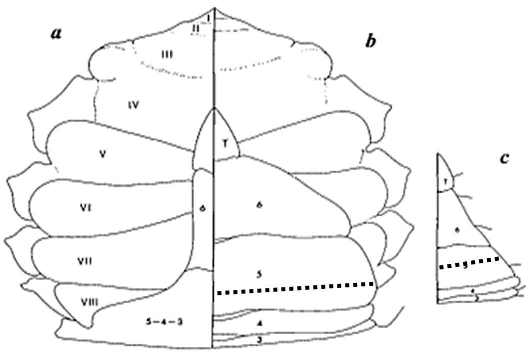


**Fig. 3.** Ventral view of a crab abdomen. a: mature male; b: mature female; c: immature female. The measured width of the 5th abdominal segment of mature and immature females is indicated by dashed lines (After **Williams, 1974**).

### 3. Gonadal maturity

All male and female crabs had their carapaces removed using dissecting scissors so that the gonadal condition could be macroscopically examined (by the naked eye) according to **De Lestang *et al*. (2003)**. Males were identified as immature when the testes and vas deferens were not clearly distinguishable (the vas deferens is a thin translucent tube). Mature males were identified by their enlarged testes and swollen vas deferens in the body cavity. Female ovaries were inspected, and their maturation stages were recognized and classified according to **De Lestang *et al*. (2003)** as: a) <u>Immature:</u> Ovaries appear as translucent thread like structures and occupy a small area of the body cavity, b) <u>Maturing:</u> Ovaries are light yellow in color, somewhat enlarged, but do not extend into the hepatic region, c) <u>Mature:</u> Ovaries are dark yellow/orange with well-developed lobes extending into the hepatic region, d) <u>Ripe:</u> Ovaries with deep orange color and occupying all the hepatic region, and e) <u>Spent:</u> Ovaries are tiny, translucent, and very much like the ovary in the immature stage but observed only in individuals above the size at first maturity **(Ravi *et al*. 2013)**.

### 4. Statistical analysis

SPSS and microsoft excel statistical software were used for statistical analysis. For the CW-WW relationships, the logarithmic form of the exponential equation $y = a \times x^{b}$ **(Huxley, 1950)** was used by the least square method, where y = WW (wet weight) and x = CW. For the relative growth rate of the carapace length, chela, abdomen width and pleopod, regression equations were calculated assuming an allometric growth equation: $y = a + bx$, where x = CW and y = organ length. The allometric coefficient was the slope of the linear equation. To determine the constant of allometry of " *b*", all data were transformed to logarithms and log-log regression was performed following the linearized equation **(Hartnoll, 1982)** $\log y = \log a + b \log x$.

The relative growth of organs in relation to body size was estimated by the value of "*b*". When "*b*" is larger than 1, allometry is positive and the organ grows faster than the whole body. In contrast, allometry is negative when the organ grows slower than the body ($b < 1$). When the value of "*b*" is equal to 1, the organ grows at the same rate as the body which is called isometric growth **(Hartnoll, 1974)**. Student's *t*-test **(Zar, 1995)** was used to find out the significance of the observed values.

## RESULTS

### 1. Population structure

Between October 2020 and September 2021, a total of 723 individuals were sampled from Timsah Lake and 679 from the Bitter Lakes. In Timsah Lake, the sample included 425 males (58.8%) and 298 females (41.2%), while that of the Bitter Lakes included 322 males (47.4%) and 357 females (52.6%).

The 723 individuals from Timsah Lake had CWs ranging from 66.7 to 132.7 mm, and body weights ranging from 22 to 190 g. Males were larger than females with CWs ranging from 69.5 to 132.7 mm, and total body weights (W) ranging from 25 to 190g. In contrast, females' dimensions ranged between 66.7 and 129.6-mm CW, and 22 to 147g total body weight (Table 1). On the other hand, the 679 individuals from the Bitter Lakes ranged from 62.6 to 135 mm in CW, and from 22 to 165g for body weight (Table 2). Males had their CW ranging between 62.6 and 128.3 and total body weight (W) between 26 and 165g. However, females had a CW ranging between 68.1 and 135, and total body weight (W) between 22 and 155g.

**Table 1.** Ranges and means of size and weight of *P. segnis* collected from Timsah Lake during the study period (October 2020- September 2021)

| Morphometric parameter | | Minimum | Maximum | Mean ± S.D. |
|---|---|---|---|---|
| **Carapace width** | ♂ | 69.5 | 132.7 | 95.18 ± 12.5 |
| | ♀ | 66.7 | 129.6 | 94.60 ± 11.4 |
| **Carapace length** | ♂ | 31.7 | 60.7 | 43.68 ± 5.82 |
| | ♀ | 31.1 | 58.2 | 42.63 ± 5.10 |
| **Body weight** | ♂ | 25 | 190 | 70.28 ± 31.59 |
| | ♀ | 22 | 147 | 62.37 ± 22.6 |

S.D. = Standard deviation of the mean.

**Table 2.** Ranges and means of size and weight of *P. segnis* collected from Bitter Lakes during the study period (October 2020- September 2021)

| Morphometric parameter | | Minimum | Maximum | Mean ± S.D. |
|---|---|---|---|---|
| **Carapace width** | ♂ | 62.6 | 128.3 | 98.1 ± 10.5 |
| | ♀ | 68.1 | 135 | 98.69 ± 11.9 |
| **Carapace length** | ♂ | 32.2 | 60.1 | 43.82 ± 4.99 |
| | ♀ | 29.5 | 60.3 | 43.55 ± 5.32 |
| **Body weight** | ♂ | 26 | 165 | 69.77 ± 25.87 |
| | ♀ | 22 | 155 | 66.43 ± 24.46 |

S.D. = Standard deviation of the mean.

## 2. Sex ratio

In Timsah Lake, the overall male: females sex ratio was 1.43: 1, which significantly differed from the expected 1: 1 ratio ($X^2$ = 50.68, df = 11, $P$ <0.05). In the Bitter Lakes, the total number of females was significantly greater than the total number of males (0.9 male: 1 female, $X^2$ = 37.28, df = 11, $P$ <0.05) (Fig. 4).

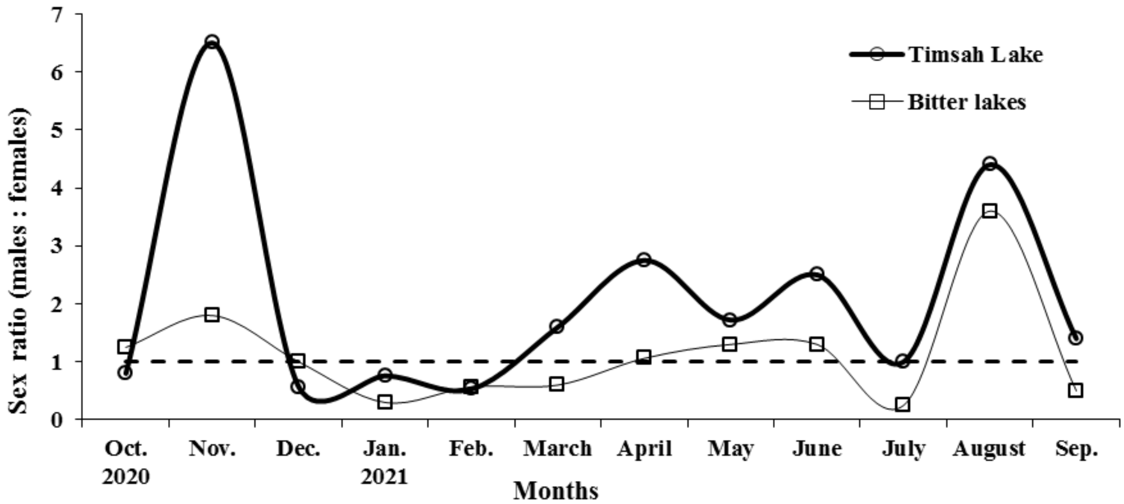


**Fig. 4.** Variations in the sex ratios of *P. segnis* in Timsah and Bitter Lakes

## 3. Size frequency distribution

The size distribution of *P. segnis* CW showed nearly same patterns in both lakes (Fig. 5). In Timsah Lake, the size distribution revealed that most individuals (79.6%) fell between 80- 109.9 mm CW for both sexes (Fig. 5A). Only 0.83% of the population was smaller than 70 mm, and approximately 11.3% was found between 110 and 129.9 mm CW. In the Bitter Lakes, size distribution showed that most individuals (76.1%) were between 80 & 109.9 mm CW for both males and females (Fig. 5B). Only 0.59% of the population was smaller than 70 mm, and 14.9% was between 110 and 139.9 mm CW.

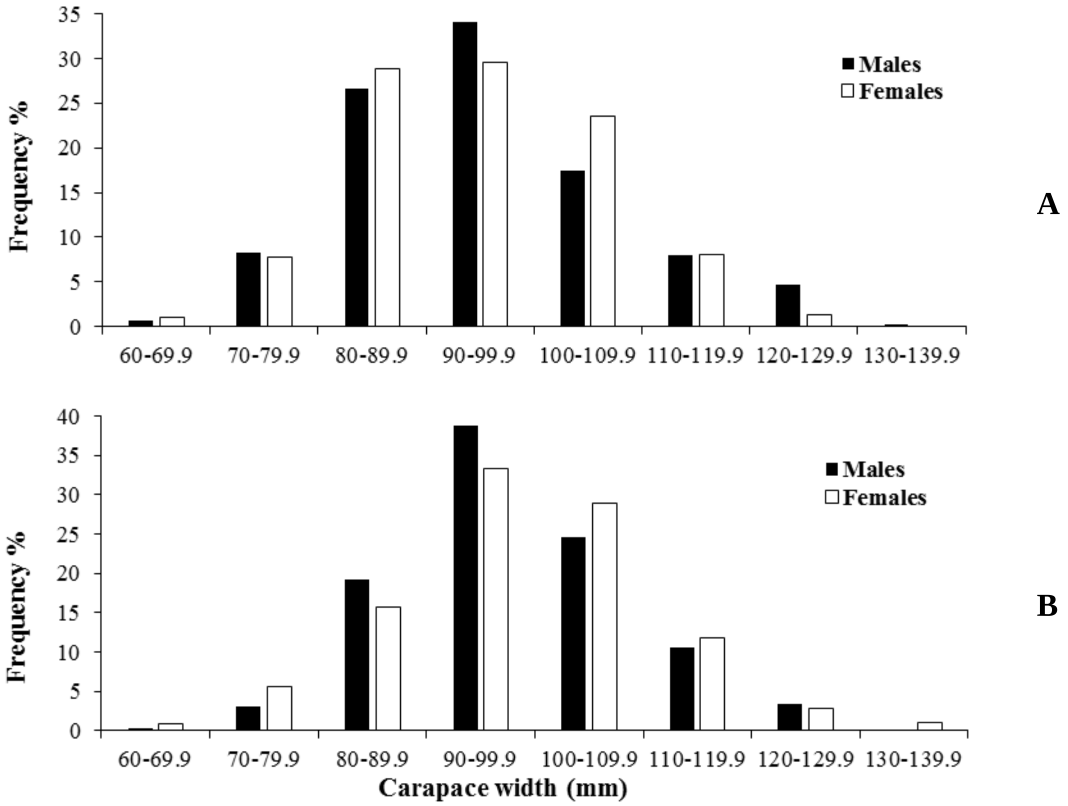


**Fig. 5.** Carapace width-frequency distribution of *P. segnis*; **A:** Timsah Lake, **B:** The Bitter Lakes

### 4. Relationship between carapace width and carapace length

Regression equations were calculated for the relationship between carapace width and carapace length of *P. segnis* for separate sexes as well as the whole population in Timsah Lake and represented in Table (4) and Fig. (6A). The Student's $t$ -test revealed that "$b$" significantly differs from 1 ($t$ = 106.626 and 87.742 for males and females, respectively; $\alpha$ = 0.05, $P$ < 0.01). For the Bitter Lakes population, regression equations were also calculated for separate sexes as well as the whole population and represented in Table (6) and Fig. (6B). The Student's t test showed that " $b$" significantly differs from 1 ($t$ = 77.670 and 91.930 for males and females, respectively; $\alpha$ = 0.05, $P$ < 0.01).

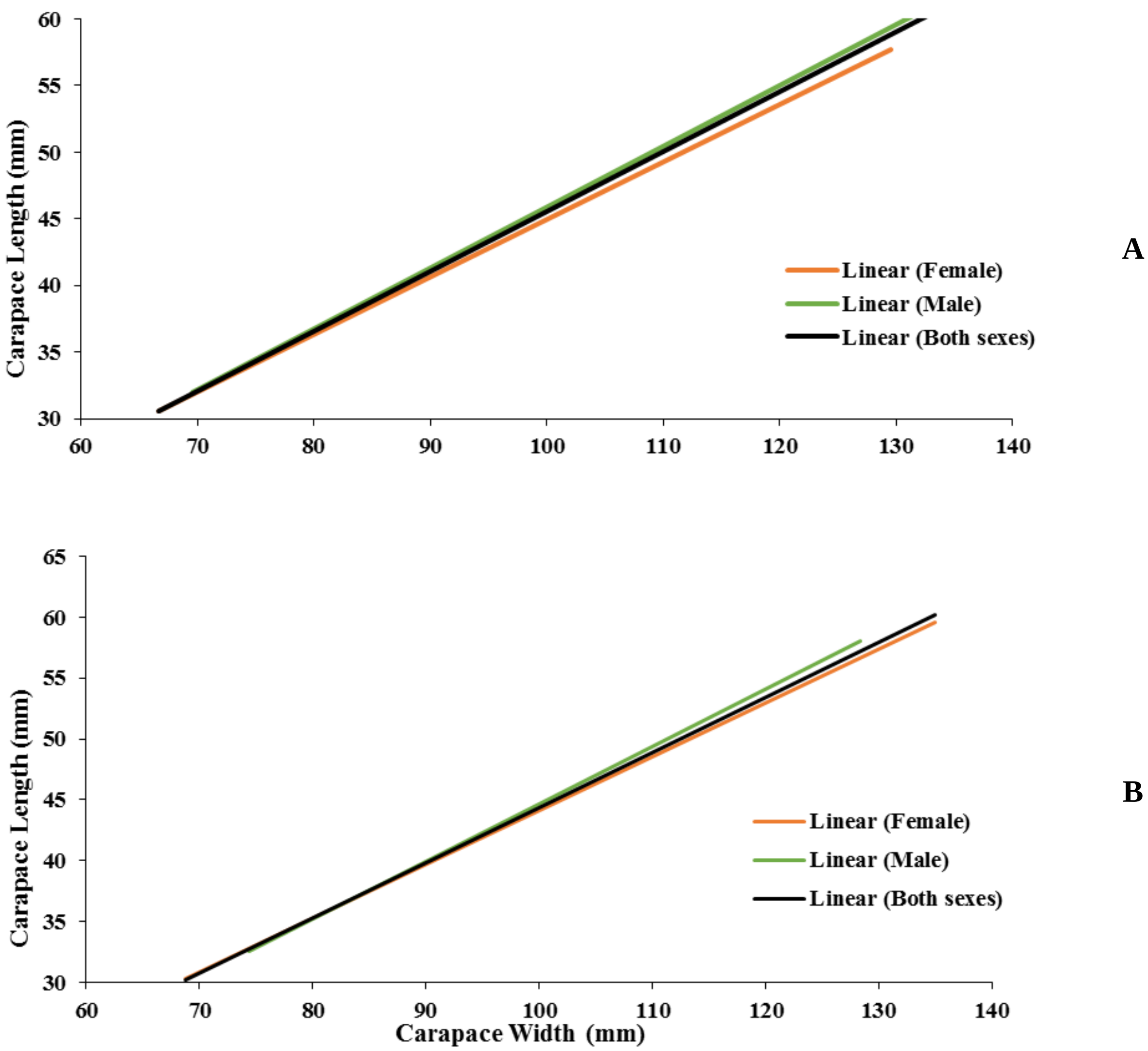


**Fig. 6.** Carapace width – carapace length relationships for males, females and both sexes of *P. segnis*; **A:** Timsah Lake, **B:** the Bitter Lakes.

### 5. Relationship between carapace width and wet weight

In Timsah Lake, the exponential values "*b"* in males and females (3.0491 and 2.8362) markedly deviated from the isometric growth pattern. The Student's *t* test indicated that *"b*" significantly differs from 3 ($t$ = 106.202 and 67.878 for males and females, respectively; α = 0.05, $P$ < 0.01) and was significantly different between males and females ($t$ = 3.921, α = 0.05, $P$ < 0.01) (Table 3 & Fig. 7A).

In the Bitter Lakes, the values of the regression coefficient *"b*" in males and females were 3.2404 and 2.95042, respectively. The Student's *t* test indicated that *"b*" significantly differs from 3 ($t$ = 82.954 and 77.168 for males and females, respectively; α = 0.05, $P$ <0.01) and was not significantly different between males and females ($t$ = 1.1761, α = 0.05, $P$ > 0.05) (Table 5 & Fig. 7B).

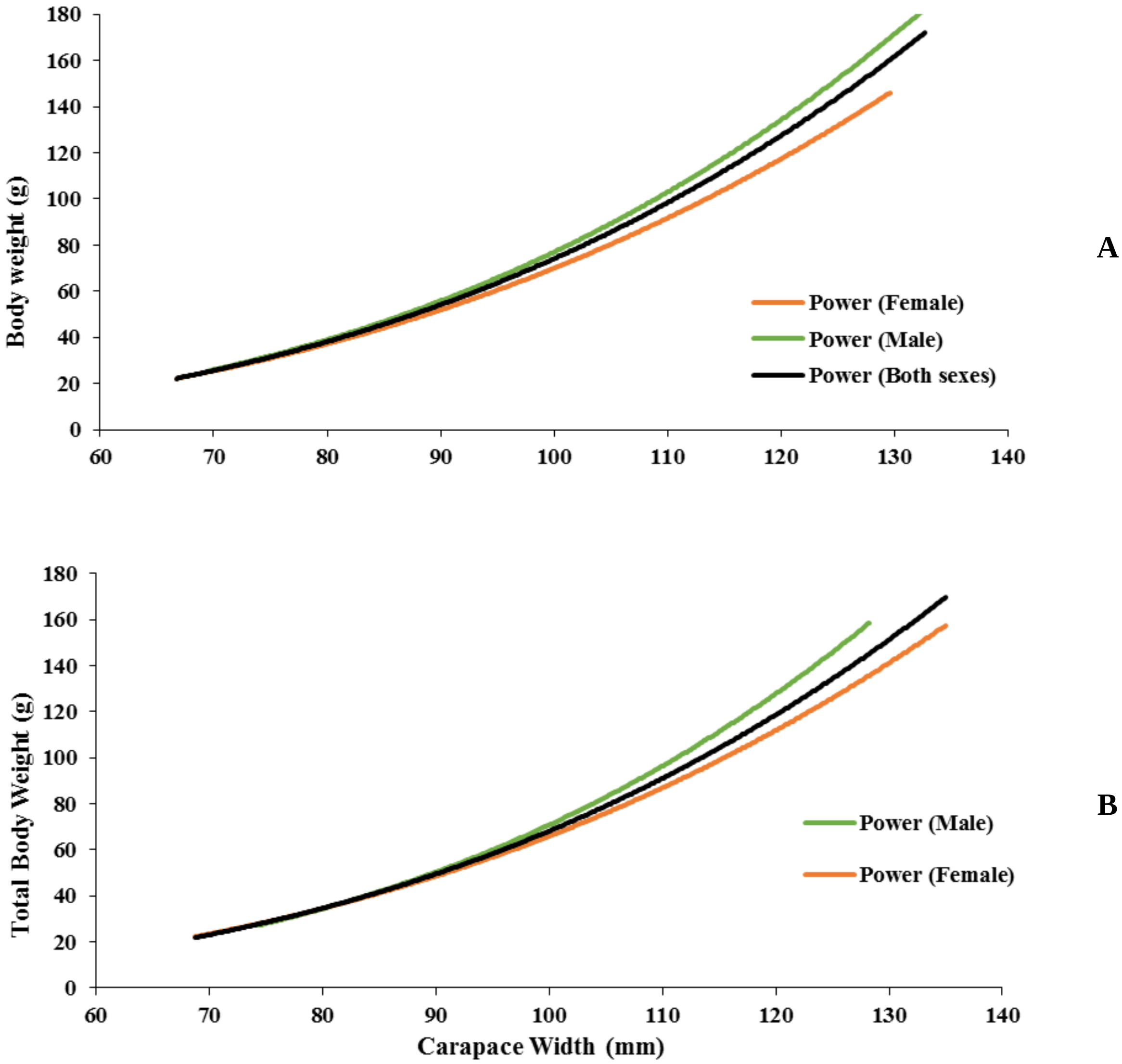


**Fig. 7.** Carapace width – total body weight relationships for males, females and both sexes of *P. segnis*; **A:** Timsah lake, **B:** Bitter lakes.

**Table 3.** Analysis of allometric and log-transformed equations of relationship between body weight and carapace width in males and females of *P. segnis* in Timsah Lake. $R^2$ Coefficient of determination; b regression coefficient; Al allometric level: (All) isometric, (+) positive and (−) negative; * significant at the 5% level.

| y-variable | Sex/maturity | Allometric equation | N | b | $R^2$ | AL | *t* (*b* = 3) |
|---|---|---|---|---|---|---|---|
| **Body weight** | Females | $W = 0.0001\ CW^{2.8362}$ | 298 | 2.8362 | 0.9271 | - | 67.878* |
| | | log W = 2.8362 log CW - 3.8273 | | | 0.9396 | | |
| | Males | $W = 0.00006\ CW^{3.0491}$ | 425 | 3.0491 | 0.9561 | + | 106.202* |
| | | Log W = 3.0491 log CW - 4.2115 | | | 0.9639 | | |
| | Combined sexes | $W = 0.00008\ CW^{2.9737}$ | 723 | 2.9737 | 0.931 | - | 109.916* |
| | | log W = 2.9737 log CW - 4.0774 | | | 0.9437 | | |

**Table 4.** Analysis of linear and log-transformed equations of relationship between organs and carapace width in males and females of *P. segnis* in Timsah Lake. $R^2$ Coefficient of determination; b regression coefficient; Al allometric level: (All) isometric, (+) positive and (−) negative; * significant at the 5% level.

| y-variable | Sex/maturity | Allometric equation | N | b | $R^2$ | AL | *t* (*b* = 1) |
|---|---|---|---|---|---|---|---|
| **Carapace length** | Females | CL = 0.4308 CW + 1.8501 | 296 | 0.9524 | 0.9633 | - | 87.742* |
| | | log CL = 0.9524 log CW - 0.2524 | | | 0.9611 | | |
| | Males | CL = 0.4567 CW + 0.2198 | 425 | 0.9833 | 0.9641 | - | 106.626* |
| | | log CL = 0.9833 log CW - 0.3053 | | | 0.9637 | | |
| | Combined sexes | CL = 0.4488 CW + 0.6465 | 721 | 0.9745 | 0.9567 | - | 126.068* |
| | | Log CL = 0.9745 log CW - 0.2912 | | | 0.9565 | | |
| **Pleopod length** | Immature males | PL = 0.201 CW - 0.3551 | 20 | 1.0013 | 0.862 | + | 10.603* |
| | | log PL = 1.0013 log CW - 0.7094 | | | 0.8356 | | |
| | Mature males | PL = 0.2368 CW - 2.8796 | 405 | 1.1482 | 0.9009 | + | 60.534* |
| | | log PL = 1.1482 log CW - 0.9794 | | | 0.9017 | | |
| **Abdomen width** | Immature females | AW = 0.3606 CW - 0.7555 | 60 | 1.0286 | 0.8381 | + | 17.329* |
| | | log AW = 1.0286 log CW - 0.5093 | | | 0.8371 | | |
| | Mature females | AW = 0.3506 CW + 0.6567 | 238 | 0.9822 | 0.9045 | - | 47.274* |
| | | log AW = 0.9822 log CW - 0.4117 | | | 0.9048 | | |
| **Chelar propodus length** | Immature males | CPL = 0.8235 CW - 17.265 | 20 | 1.3318 | 0.9179 | + | 14.187* |
| | | Log CPL = 1.3318 log CW - 0.849 | | | 0.9158 | | |
| | Mature males | CPL = 1.0328 CW - 33.225 | 405 | 1.4735 | 0.9097 | + | 63.720* |
| | | Log CPL = 1.4735 log CW - 1.1052 | | | 0.9084 | | |

**Table 5.** Analysis of allometric and log-transformed equations of relationship between body weight and carapace width in males and females of *P. segnis* in the Bitter Lakes. $R^2$ Coefficient of determination; b regression coefficient; Al allometric level: (All) isometric, (+) positive and (−) negative, * significant at the 5% level.

| y-variable | Sex/maturity | Allometric equation | N | B | $R^2$ | AL | *t* (*b* = 3) |
|---|---|---|---|---|---|---|---|
| **Body weight** | Females | $W = 0.0001\ CW^{2.9042}$ | 355 | 2.9042 | 0.9296 | - | 77.168* |
| | | log W = 2.9042 log CW - 3.9895 | | | 0.944 | | |
| | Males | $W = 0.00005\ CW^{3.0806}$ | 320 | 3.2404 | 0.9561 | + | 82.954* |
| | | log W = 3.2404 log CW - 4.6308 | | | 0.9558 | | |
| | Combined sexes | $W = 0.00009\ CW^{2.9505}$ | 676 | 3.0412 | 0.9078 | + | 100.90* |
| | | log W = 3.0412 log CW - 4.249 | | | 0.9379 | | |

**Table 6.** Analysis of Linear and log-transformed equations of relationship between organs and carapace width in males and females of *P. segnis* in the Bitter Lakes. $R^2$ Coefficient of determination; b regression coefficient; Al allometric level: (All) isometric, (+) positive and (−) negative, * significant at the 5% level.

| y-variable | Sex/maturity | Allometric equation | N | b | $R^2$ | AL | *t* (*b* = 1) |
|---|---|---|---|---|---|---|---|
| **Carapace length** | Females | CL = 0.4416 CW - 0.0547 | 357 | 0.8565 | 0.9598 | - | 91.930* |
| | | log CL = 0.8565 log CW - 0.0697 | | | 0.9825 | | |
| | Males | CL = 0.4716 CW - 2.4711 | 322 | 0.8558 | 0.9498 | - | 77.670* |
| | | log CL = 0.8558 log CW - 0.0635 | | | 0.9637 | | |
| | Combined sexes | CL = 0.4532 CW - 0.9475 | 679 | 0.8559 | 0.9517 | - | 115.327* |
| | | log CL = 0.8559 log CW - 0.0663 | | | 0.9812 | | |
| **Pleopod length** | Immature males | PL = 0.1745 CW + 1.8206 | 14 | 0.9002 | 0.7819 | - | 5.988* |
| | | log PL = 0.9002 log CW - 0.5158 | | | 0.7799 | | |
| | Mature males | PL = 0.2509 CW - 4.7818 | 307 | 1.23 | 0.8983 | + | 51.916* |
| | | log PL = 1.23 log CW - 1.1534 | | | 0.8958 | | |
| **Abdomen width** | Immature females | AW = 0.3227 CW + 1.7404 | 68 | 1.0576 | 0.8967 | + | 23.935* |
| | | log AW = 1.0576 log CW - 0.5769 | | | 0.9022 | | |
| | Mature females | AW = 0.378 CW - 2.6693 | 288 | 1.0745 | 0.9389 | + | 66.300* |
| | | log AW = 1.0745 log CW - 0.6035 | | | 0.9342 | | |
| **Chelar propodus length** | Immature males | CPL = 0.9918 CW - 34.386 | 14 | 1.6041 | 0.9164 | + | 11.470* |
| | | Log CPL = 1.6041 log CW - 1.3981 | | | 0.9219 | | |
| | Mature males | CPL = 1.0556 CW - 39.929 | 307 | 1.6037 | 0.8865 | + | 48.820* |
| | | Log CPL = 1.6037 log CW - 1.3934 | | | 0.886 | | |

## 6. Chela allometry

The CPL of immature and mature males in both lakes exhibited positive allometry. In Timsah Lake, the "*b*" values were 1.3318 and 1.4735, respectively, and were significantly different ($t$ =9.508, α = 0.05, $P < 0.01$), indicating a sudden change between these two periods (Table 4 & Fig. 8A).

In the Bitter Lakes, the *"b*" values were 1.6041 and 1.6037, respectively, and were significantly different ($t$ =3.721, α = 0.05, $P < 0.01$), indicating a sudden change between these two periods (Table 6 & Fig. 8B).

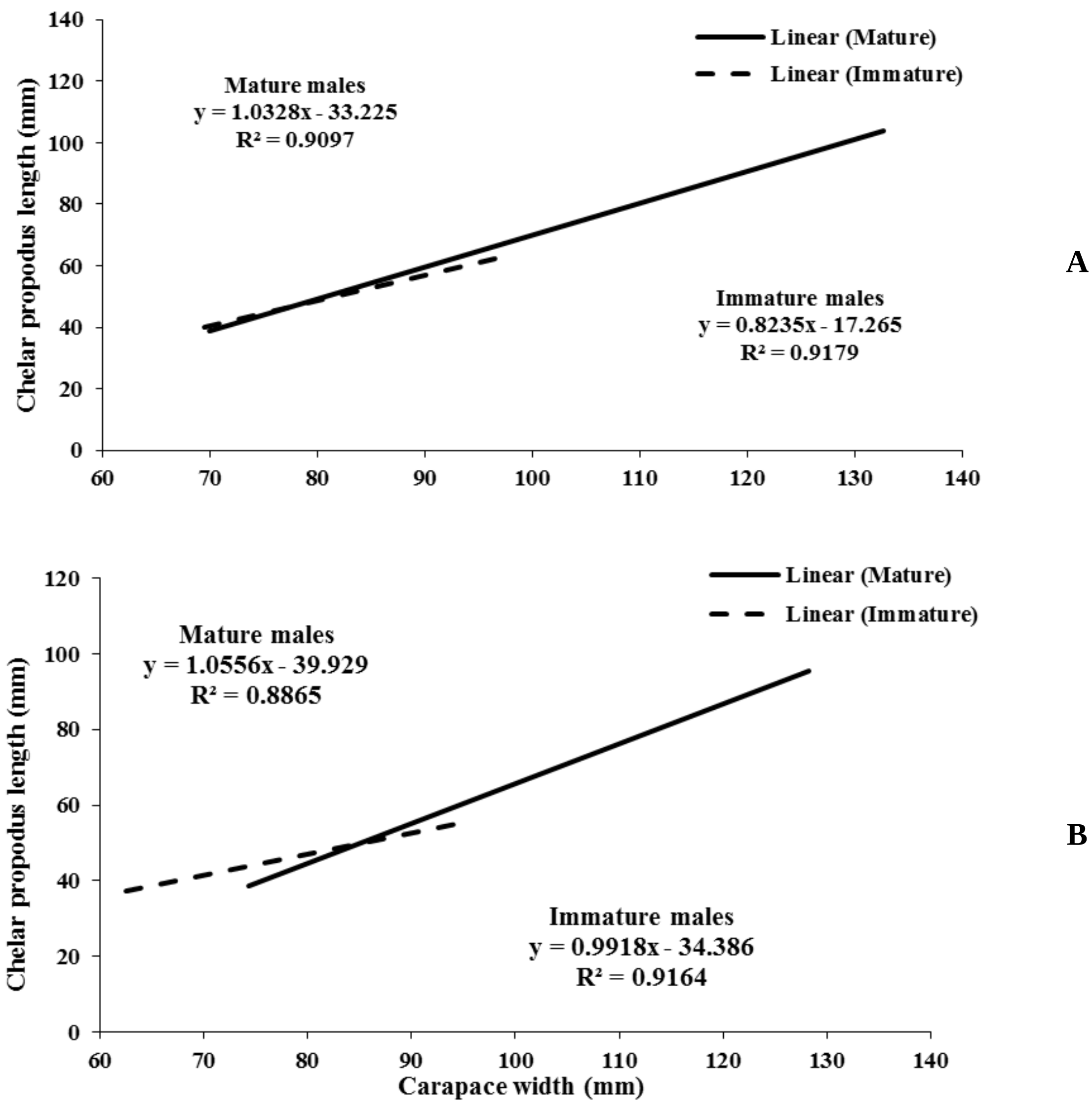


**Fig. 8.** Carapace width – chelar propodus length relationships for males *P. segnis*; **A:** Timsah Lake, **B:** The Bitter Lakes.

## 7. Pleopod allometry

The relationship between carapace width and pleopod length was calculated for *P. segnis* males in Timsah and Bitter Lakes. The results are given in Tables (4, 6) and represented in Figs. (9A, B), respectively. In Timsah Lake, pleopod length ranged from 13 to 31 mm, while CW ranged from 69.5 to 132.7 mm. The length of pleopod in the Bitter Lakes ranged from 13 to 29 mm, while CW ranged from 62.6 to 128.3 mm. The Student's *t*-test revealed a significantly different regression coefficient *"b"* between immature and mature males in Timsah and the Bitter Lakes ($t$ = 9.111 and 4.230 respectively, $\alpha = 0.05$, $P < 0.01$).

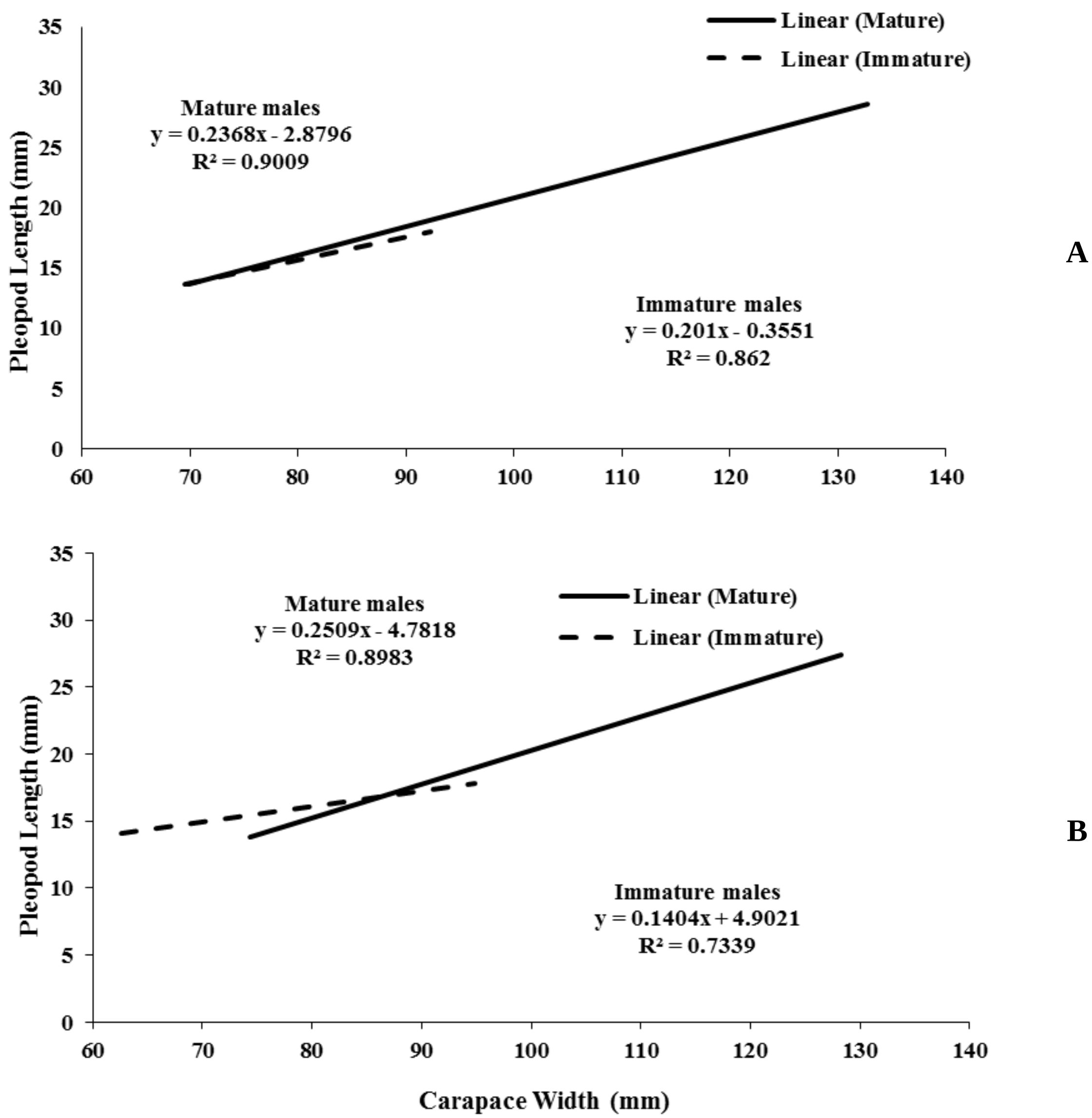


**Fig. 9.** Carapace width – pleopod length relationships for males of *P. segnis*. **A:** Timsah Lake, **B:** The Bitter Lakes**.**

## 8. Abdomen allometry

The relationships between carapace width (CW) and abdomen width (AW) were calculated for females of *P. segnis* in Timsah and Bitter Lakes. The results are given in Tables (4, 6) and represented graphically in Figs. (10A, B). In Timsah Lake, female abdominal width ranged from 23 to 45.3 mm, while CW ranged from 66.7 to 129.6 mm. The width of female abdomens in the Bitter Lakes ranged from 48.7 to mm, while CW ranged from 68.1 to 135 mm. The *"b"* values between immature and mature females significantly differed in Timsah and the Bitter Lakes ($t$ =12.716 and 14.699 respectively, $\alpha = 0.05$, $P < 0.01$).

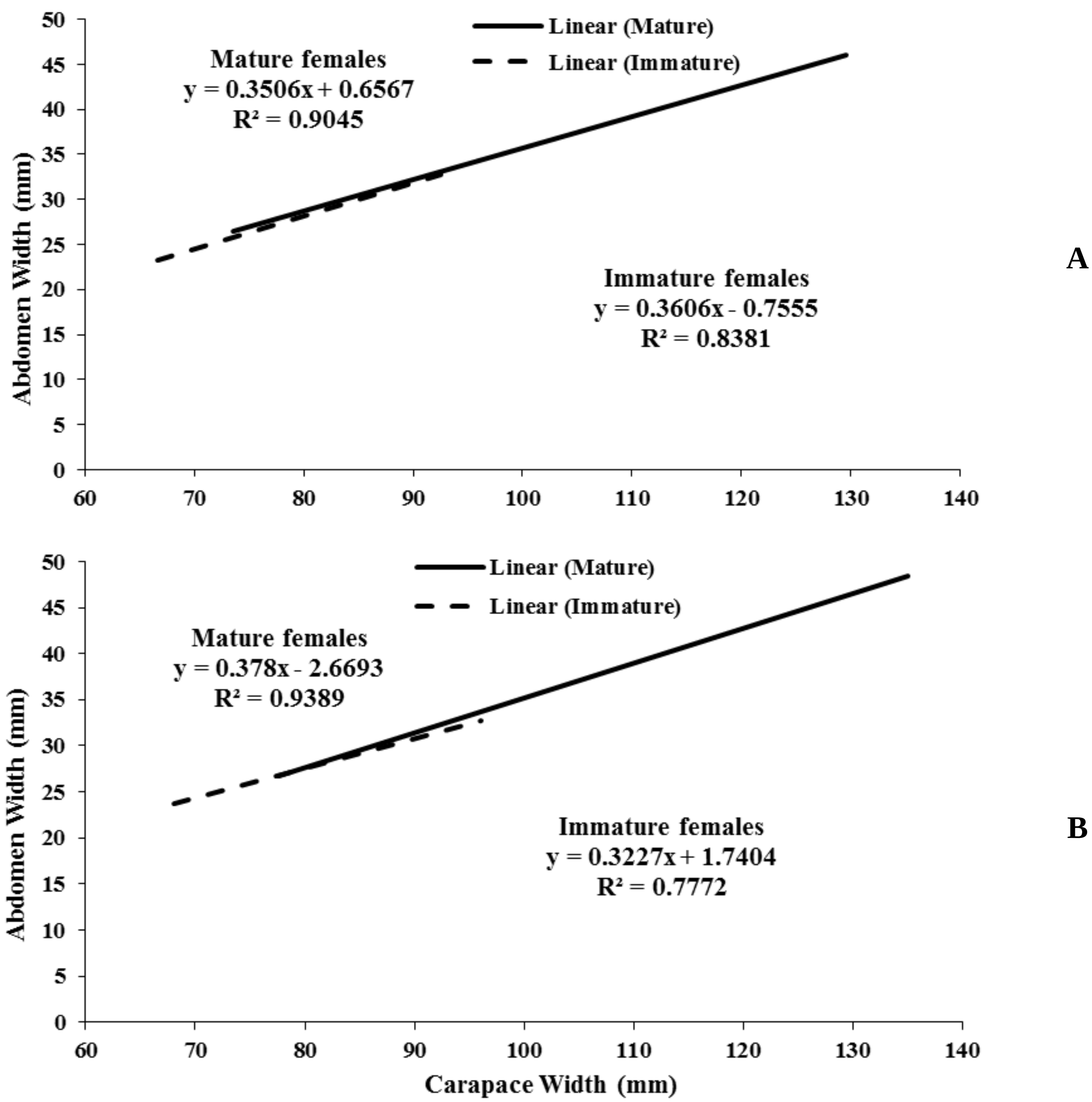


**Fig. 10.** Carapace width – abdomen width relationships for females of *P. segnis.* **(A)** Timsah Lake, **(B)** Bitter Lakes.

## 9. Gonad condition and spawning season

Immature females of *P. segnis* in Timsah Lake were found throughout the year with a high percentage (81.1%) in August 2021 (Fig. 11). On the other hand, the high percentages of individuals in the maturing stage appeared in the period from February to May 2021, while mature females were recorded throughout the year except in August, showing high percentages in December and January. Ripe females were recorded only during May, June, July and September 2021, with the maximum in May (9.1%), while spent females appeared from February to the following October but were absent in May and showed high percentages in June and July. Ovigerous females were detected throughout the year except between November 2020 and January 2021, and during August 2021 (Fig. 12).

In the Bitter Lakes, immature females were found throughout the year with a high percentage (39.3%) in October 2020 (Fig. 13). Maturing stage appeared through the year except in December 2020 and August 2021, while mature stage appeared throughout the year except in November 2020. Ripe females were recorded in February 2021 and extended from April to September 2021, with the maximum in February (14.3%). Spent females were detected with variable percentages all the year around. Ovigerous females were detected through the year except between November 2020 and January 2021, with the maximum in July (Fig. 14).

## 10. Size at first sexual maturity

In Timsah Lake, the 298 females examined ranged from 66.7 to 129.6 mm CW. Of these, 238 females (79.86%) were in a sexually mature condition. At the Bitter Lakes, the 357 females examined ranged from 68.1 to 135 mm CW, and 288 (80.67%) of them were mature. In Timsah Lake, the CW of smallest mature female and male was 73.5 and 69.9-mm CW, while in the Bitter Lakes, the CW of smallest mature female and male was 77.6 and 75.4-mm CW. Tables (7, 8) show the proportions of sexually mature females within each 10 mm carapace width (CW) size class in Timsah and Bitter Lakes, respectively. The estimated size for 50% sexually mature females in Timsah Lake was 79 mm CW (Fig. 15A), and 87 mm CW for Bitter Lakes females (Fig. 15B).

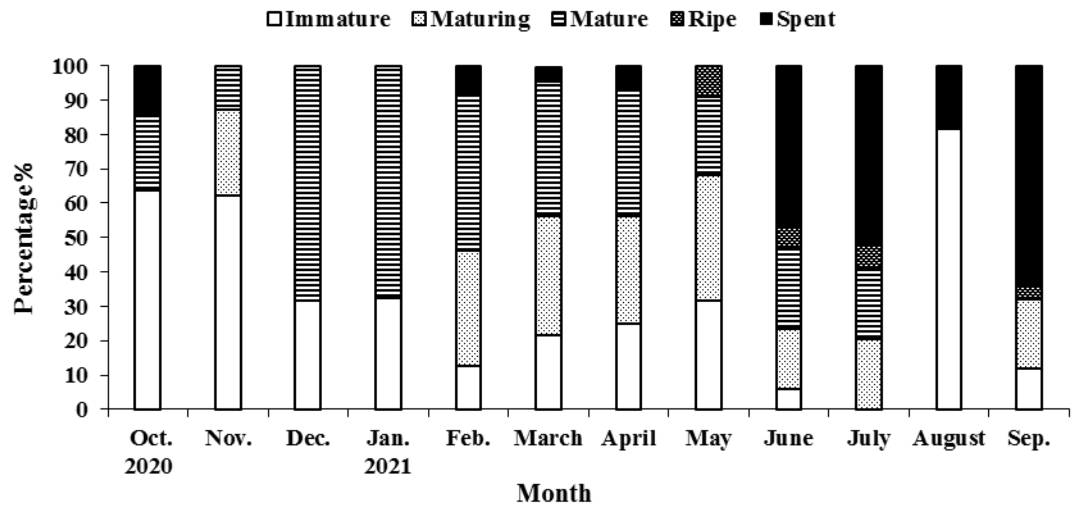


**Fig. 11.** The variation in the maturity stages of females *P. segnis* from Timsah Lake

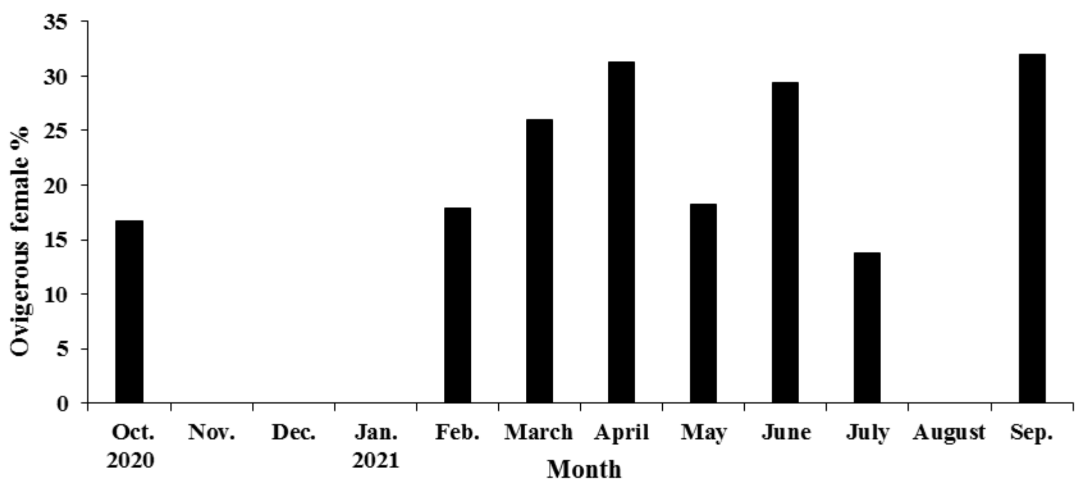


**Fig. 12.** The variation in the percentages of ovigerous females *P. segnis* from Timsah Lake

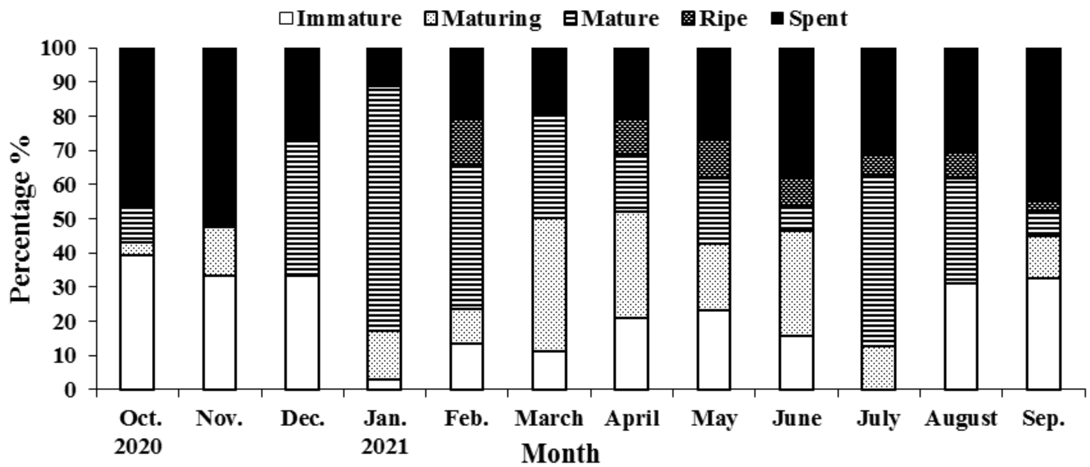


**Fig. 13.** A graph showing the variation in the maturity stages of *P. segnis* females from the Bitter Lakes

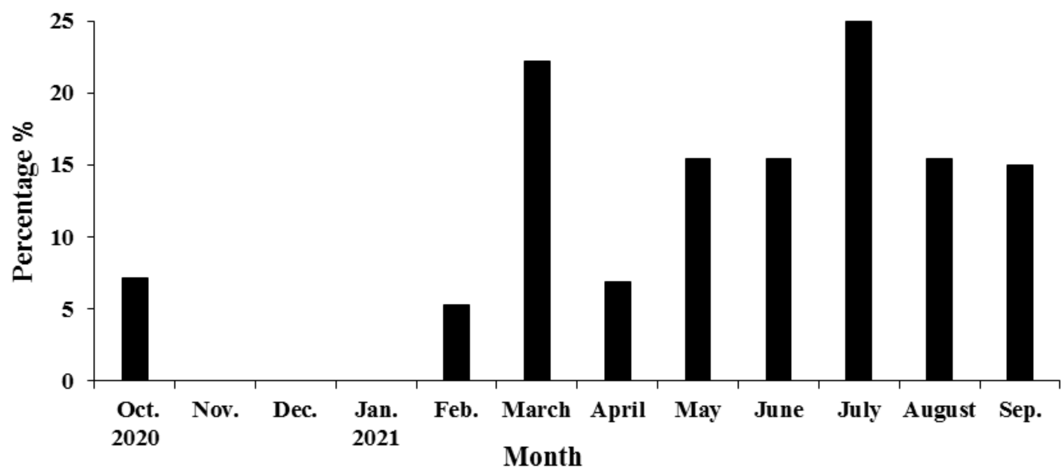


**Fig. 14.** A graph showing the variation in the ovigerous stage of *P. segnis* females from the Bitter Lakes

**Table 7.** Number of total and mature *P. segnis* females by size classes, and corresponding proportion of mature females in Timsah Lake

| Size classes Carapace width (mm) | Total number of females in sample | Number of mature females | Proportion of mature females (%) |
|---|---|---|---|
| 60 - 69.9 | 3 | 0 | 0 |
| 70 - 79.9 | 23 | 9 | 39.1 |
| 80 - 89.9 | 86 | 53 | 61.63 |
| 90 - 99.9 | 88 | 78 | 88.64 |
| 100 - 109.9 | 70 | 70 | 100 |
| 110 - 119.9 | 24 | 24 | 100 |
| 120 - 129.9 | 4 | 4 | 100 |
| **Total** | **298** | **238** | **79.86** |

**Table 8.** Number of total and mature females of *P. segnis* by size classes, and corresponding proportion of mature females in Bitter Lakes

| Size classes Carapace width (mm) | Total number of females in sample | Number of mature females | Proportion of mature females (%) |
|---|---|---|---|
| 60 - 69.9 | 3 | 0 | 0 |
| 70 - 79.9 | 20 | 1 | 5 |
| 80 - 89.9 | 53 | 23 | 43.4 |
| 90 - 99.9 | 119 | 106 | 89.07 |
| 100 - 109.9 | 106 | 102 | 96.23 |
| 110 - 119.9 | 42 | 42 | 100 |
| 120 - 129.9 | 10 | 10 | 100 |
| 130 - 139.9 | 4 | 4 | 100 |
| **Total** | **357** | **288** | **80.67** |

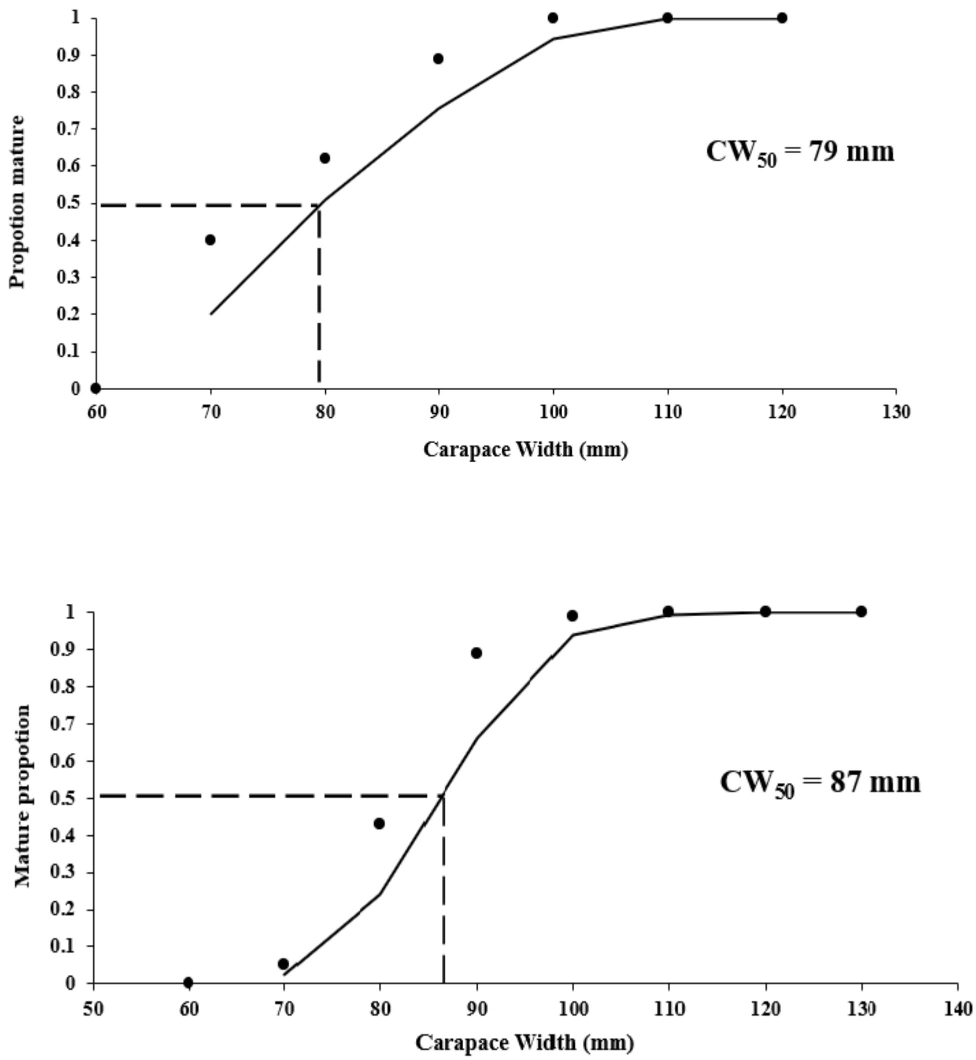


**Fig. 11.** Size of 50% maturity in the different size classes of *P. segnis* females estimated by evaluating the cumulative curve. The value of $CW_{50}$ which corresponds to a proportion of 0.5 is indicated. **A:** Timsah Lake, **B:** the Bitter Lakes.

## DISCUSSION

### 1. Sex ratio

The sexual population structure of *P. segnis* in both Timsah and Bitter Lakes varies across the months of the year with the overall male: female ratio beings 1.4:1 and 0.9:1 respectively, which differs from the expected 1:1 ratio. In Timsah Lake, males outnumbered the females; this result supports those recorded for *P. sanguinolentus* **Wenner (1972)** in the USA (Hawaii), **Sumpton *et al.* (1989)** in Australia (Queensland),

and **Yang *et al*. (2014)** in South China Sea (Honghai bay). In addition, this finding agrees with those of **El-Kasheif *et al*. (2021)** for *Portunus pelagicus* in Hurghada, Egypt. In the Bitter Lakes, females dominated over males as reported by **Mehanna (2005)** and **Tadi *et al*. (2012)** along the Persian Gulf (Hormozgan coast) and **Jazayeri *et al*. (2011)** on the Khuzestan coasts. On the other hand, it differs from those recorded by **Sabrah *et al*. (2020)** in the Bitter Lakes. **Zaghloul (2003)** reported the dominance of males over females in the gulf of Suez.

**La Sara *et al*. (2016)** explained that the differences in sex ratio may be affected by seasonal changes, habitat characteristics differences (spatial differences), differential life span, migration pattern, food availability, and the changes in feeding behavior of female blue swimming crab during spawning seasons **(Potter & de Lestang, 2000; de Lestang *et al*., 2003)**, methods of capture and fishing gears used **(Xiao & Kumar, 2004; La Sara & Halili, 2016; La Sara *et al*., 2016)**. In addition to the factors mentioned above, gillnet catchability between sexes **(Ingles, 1996)**, sampling frequency, growth and mortality rates, and geographical position (tropical and subtropical regions) are also considered **(Kumar *et al*., 2000; La Sara, 2001)**.

**2. Length– width relationships**

Biometric analysis can help determine the biological patterns particularly for crustaceans in which there is an antagonistic relationship between the amounts of energy allocated to somatic growth **(Pinheiro & Fiscarelli, 2009)**. Consequently, determining the relationships between the lengths of different portunids is very important for comparative growth studies.

Carapace length and carapace width are the most frequently used dimensions in the study of crustaceans **(Sukumaran & Neelakantan, 1997)**. In the current study, the carapace width – carapace length relationships of *P. segnis* at both sites exhibited negative allometric growth ($b<1$) for males, females, and whole population. The values of regression coefficients $b$ were similar to those estimated by **Abdel-Razek *et al*. (2016)** for *Portunus pelagicus* in Bardawil lagoon, Egypt and **El-Kasheif *et al*. (2021)** for *Portunus pelagicus* in Hurghada, Egypt.

**3. Width–weight relationships**

Length/width-weight relationships are more suitable for evaluating crustacean populations **(Olmi & Bishop, 1983; Suhalya & Rashan, 1986)**. In the present study, the growth generally exhibited a negative allometric growth for females; however, males showed a positive allometric growth in both study sites. In addition, males attained greater size and weight than females. The size differences among sexes would be attributed to the males investing metabolic energy in somatic growth, while females give priority to egg production **(Hartnoll, 1982)**. **Pinheiro and Hattori (2006)** explained these differences as an important reproductive strategy since the large size enables males in intermolt to protect the recently post-molted females during and after copulation and permits an easy pair formation. The results of the present study coincide with those of **Abdel Razek *et al*. (2019)** for *Portunus pelagicus* in the eastern Mediterranean Sea and **Mehanna *et al.* (2019)** for *C. sapidus* in Bardawil lagoon. In contrast, **El-Kasheif *et al*. (2021)** reported a slightly positive allometric growth for *Portunus pelagicus* from Hurghada.

**4. Chela and abdomen allometry**

In brachyuran crabs, chela in males and abdomen in females are considered as secondary sexual characters because of their functions in reproduction **(Hartnoll, 1978)**. Male uses its chela for combat, territorial defense, courtship and mating as well as in carrying and holding the female during copulation. The abdomen in adult females acts as an incubation chamber for the developing eggs, which are attached to the pleopods' setae. The relative growth of chela in males and abdomen in females has been used to determine size at which functional maturity attained or puberty molt occurs. During the present investigation it was observed that, the functional and physiological maturities occur almost at the same size. This finding concurs with that of **Reeby *et al.* (1990)** who studied sexual maturity in males of *P. pelagicus* and *P. sanguinolentus* from Karwar, the west coast of India, and the study of **Hosseini *et al.* (2014)** along the Boushehr coast, Iran and **Leme (2005)** who determined size at sexual maturity of female grapsid crab *Sesarma rectum* from Brazil.

**5. Pleopod allometry**

The relative growth of the 1st pleopod (the intromittent organ during copulation) is another character, frequently used in the determination of the functional maturity in male crabs. The relative growth of 1st pleopod decreases after puberty molt, which enables the male crabs to copulate even with small female crabs as well **(Warner, 1977**). During copulation, the male crab extends the pleon and inserts the first copulatory pleopod into the genital apertures of the female, with the second pleopod plunging back and forth to transfer the spermatophores from the cirrus to the spermathecae of female **(Fielder & Eales, 1972)**. The sudden change in the growth rate of the first pleopod of males occurs at nearly the same CW size as chela growth. Thus, the development of physiological and functional maturity in male *P. segnis* is synchronized. This result supports those of **Reeby *et al*. (1990)** for males of *P. pelagicus* and *P. sanguinolentus* in India (Karawar), and **Rasheed and Mustaquim (2010)** for *P. sanguinolentus* in Pakistan (Karachi).

**6. Gonad condition and spawning season**

In this study, egg bearing females were recorded throughout the year, with a well-defined resting period between November and January in both lakes, indicating that this species is a multiple spawner, with the highest number of ovigerous females in April and September in Timsah Lake, and in March and July in the Bitter Lakes. These findings are in accordance with that of **Sallam (2000)** on the mantis shrimp *Eurgosquilla massavensis* from the Suez Canal and that of **Zaghloul (2003)** where the resting phase of *P. pelagicus* in the Suez Gulf extended from October to January.

Brachyuran crabs inhibiting tropical waters tend to spawn year-round because the environmental conditions remain favorable for gonad development **(Emmerson, 1994)**, whereas those inhabiting temperate waters only spawn in certain months **(Sarada, 1998)**. In general, both continuous and seasonal reproductive patterns are found in subtropical and tropical regions **(Warner, 1977)**.

**7. Size at first sexual maturity**

The size at which brachyuran crabs reach sexual maturity varies between regions, which could be related to abiotic variables that act locally and seasonally **(Wenner *et al*., 1974).** Fishing pressure may impact marine and crustacean species by the means if changing their life history parameters such as the size at maturity **(Sharpe and Hendry, 2009)**. This study showed that females of *P. segnis* at Timsah Lake reached the maturity size earlier than those of the Bitter Lakes which is in accordance with the values reported by **Sumpton *et al*. (1989)** for females of *P. sanguinolentus* in (Queensland), Australia. **Rasheed and Mustaquim (2010)** reported that females of *P. sanguinolentus* in Karachi, Pakistan were fully mature at 81-93 mm. **Tureli and Yesilyurt (2017)** reported that the female crabs of *Portunus segnis* attained sexual maturity when they reached the size of 115-119.99 mm CW in Yumurtalik Bay, Turkey. **Sabrah *et al*. (2020)** reported that females of *P. pelagicus* reached physiological maturity at 89 mm CW in the Bitter Lakes. **Hosseini *et al*. (2014)** reported that the female crabs of *Portunus segnis* attained sexual maturity at 75 mm CW from Boushehr coast, Iran.

**Table 9: Comparative findings of different morphometric parameters and the size at $1^{st}$ sexual maturity of the blue swimming crab, *Portunus segnis* along Suez Canal.**

| Region | Size composition | | | | Size at $1^{st}$ sexual maturity (cm) | | Smallest mature (cm) | | Reference |
|---|---|---|---|---|---|---|---|---|---|
| | CW (cm) | | BW (gm) | | | | | | |
| | ♂ | ♀ | ♂ | ♀ | ♂ | ♀ | ♂ | ♀ | |
| **The Bitter Lakes** | 7-17.2 | 7-16.3 | 22-475 | 19.9-300 | - | - | - | 4.8 CL | **(Mehana, 2005)** |
| **The Bitter Lakes** | 5- 16 | 5- 15 | - | - | 9.9 | 8.9 | 5.5 CW | 5.0 CW | **(Sabrah *et al*., 2020)** |
| **The Bitter Lakes** | 6.3-12.8 | 6.8-13.5 | 26-165 | 22-155 | 7.4 | 8.7 | 7.3 CW | 8.6 CW<br>3.7 CL | **Present Study** |
| **Timsah Lake** | 6.9-13.3 | 6.7-12.9 | 25-190 | 22-147 | 7.0 | 7.9 | 7.1 | 7.35 CW | |

On a comparative perspective, our data pointed out that the populations of *P. segnis* inhabiting both lakes suffer from a huge fishing pressure that resulted in the apparent decline in the size and weight of both sexes that took place through the years **(Table 9)**. On the other hand, the values of the different parameters of this species in Timsah Lake are distinguishably lower than those of the Bitter Lakes indicating high exploitation. The fact that females select for early maturation of gonads reflects the need for the population to compensate the decline in its numbers. Should the fishing pressure remain at its rate, the fishery of *P. segnis* in Timsah Lake will reach alarming levels.

Drastic measures should be urgently taken to deal with the huge fishing pressure that is exerted on the population of *P. segnis* in the Suez Canal lakes. Without sustainable management, the fishery of this economically important crab will definitely face collapse.

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