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FULL LENGTH ARTICLE

Occurrence of the blue crab *Callinectes sapidus*, Rathbun, 1896, and its fisheries biology in Bardawil Lagoon, Sinai Peninsula, Egypt

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Abstract This study reports the yearly occurrence and the biology of fisheries belonging to the blue crab *Callinectes sapidus* (Rath.) in the catch yield of Bardawil Lagoon (BL) in Sinai Peninsula, Egypt over the past 15 years. The study shows that between the years 2000–2015 the crustacean fishery increased (pooling both shrimp and crabs) with fluctuations from 40% to 63% of the total production of the lagoon. The crab yield, during this period, increased from 19% to 42% of the total lagoon production. Moreover, the results show that the crab catch of BL is composed mainly of two crab species *Portunus pelagicus* (L.) and *C. sapidus* (Rath.). The latter is considered the most dominant in the crab yield with 85% of the total crab production, while *C. sapidus* is only 15%. The size of *C. sapidus* ranged between 65 and 155 mm (carapace width) with a dominance of the class size 105 mm. Furthermore, the ratio of *C. sapidus* males to females was in favor of males. The regression of width–length relationship showed a marked deviation from the isometric growth. Length–width and body weight regressions also showed deviations from the isometric growth and the analysis of the covariance. This indicates the significant difference between sexes in respect to length weight relationship. The interrelationships between width–length and propodus length and depth of males and with abdomen in females of *C. sapidus* suggested that in most conditions the relationships were positive and highly significant. This study shows the first insights on the status of *C. sapidus* in Bardawil Lagoon, Egypt.

Introduction

The ecosystem of Bardawil Lagoon is different from the other Northern Delta Lakes of Egypt, due to its hypersaline water and shallow depth. Macrobenthic invertebrates in the lake are frequently used to evaluate the overall health of the

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ecosystem (Khalil et al., 2013) because these communities are important and sensitive to environmental contaminants. Crabs and shrimps have been recently considered as two of the most important crustacean fishery resources in Bardawil Lagoon (Ameran, 2004; Abdel Razek et al., 2006).

The distribution of *Portunus pelagicus* (L.) extends from the southern Mediterranean Sea, the east coast of Africa and across the Indian Ocean to Japan and the western Pacific Ocean (Smith, 1982; Potter et al., 1983; Josileen, 2011). It is considered the most important and economic crab species in the Bardawil Lagoon as well as in the Egyptian Red and Mediterranean Seas' fisheries (Abdel-Razek, 1987; Abdel Razek et al., 2006).

The crab production greatly changed in Bardawil Lagoon during the fishing seasons from the year 2000–2009. Crab yield increased from 754.2 to 2053.1 tons, which represented 24–38% of the total lagoon production respectively. This was followed by a continuous decrease in the crab catch making it reach 518.7 tons during 2014 according to Bardawil Lagoon annual reports, GAFRD (2015). Crab production during the fishing season of 2015 showed a sudden increase reaching to 1973.4 tons which was about 42% of the total lagoon yield.

The crab species *Callinectas sapidus* (Rath.) was firstly recorded in Lake Menzala, Egypt in 1940 and then in Lake Edku according to Banoub (1963). He also mentioned that the difficulty of recognizing its presence was due to its strong resemblance to the endemic swimming crab *P. pelagicus* (L.). Holthuis and Gottlieb (1958) suggested that *C. sapidus* was transported into the Mediterranean in ballast tanks; this was also confirmed by Nehring (2011). Ramadan and Dowidar (1972) reported that the catch of *C. sapidus* is a lot greater than that of *P. pelagicus* from 1962 to 1967. After that, its production decreased drastically as a result of the construction of the High Dam and the complete prevention of the Nile floodwaters, which mainly affected the Northern Delta lakes.

To the knowledge of the author, the exact time of the introduction of *C. sapidus* to the Bardawil Lagoon is unclear. There is a gap in the information about the species analysis of crab catch from Bardawil Lagoon since the last study of Abdel Razek et al., 2006 until the beginning of the present study in 2015. *C. sapidus* introduction to BL might have happened before 2015 and due to difficulties in its differentiation from the *P. pelagicus* was not recorded until now.

Both crab species had migrated to the Egyptian water. Thus, while *P. pelagicus* (L.) has an Indo-pacific origin and had migrated to the Mediterranean Sea through the Suez-canal, *C. sapidus* (Rath.) is native to western Atlantic coasts and widely recorded in various Mediterranean regions (Lucrezia et al., 2015). The *C. sapidus* (Rath.) was recently recorded in the crab fisheries of Bardawil Lagoon during the present study's fishing season (2015).

There were no detailed studies concerning the fisheries of *C. sapidus* in Egyptian water after the study of Banoub (1963). Moreover, no information is available pertaining to the morphometric analysis of *C. sapidus* in the lagoon to compare intraspecific variations of populations from different sites.

Therefore, in the present study the fisheries' abundance and the size of distribution of *C. sapidus* in Bardawil Lagoon are presented. Also the interrelationships between different morphometric parameters, viz., carapace length/width–weight, knowledge of the changes in the shape and size of the abdomen in females and propodus in males are presented. This study will be helpful in the comparison of different populations of the same species at various geographical locations and will also be beneficial for its good exploitation and management.

Materials and methods

Study area

Bardawil Lagoon is a natural lagoon located on the northern coast of the Sinai Peninsula, Egypt. It is one of the least polluted lagoons in Egypt's Northern Lakes (Fanos et al., 1994) as well as in the entire Mediterranean Sea (Fig. 1). The Egyptian authorities allow only very limited and eco-friendly human activities in the surroundings of the lagoon. At the eastern part of the lagoon lies the Zaranik protected area (PA) in which all developmental and industrial activities are banned except for the salt production industry. The lagoon's length is approximately 76.37 km (extending from 31°03′N to 31°14′N and 32°40′E to 33°30′E and has a maximum width of 16.65 km, occupying a total surface of approximately 518.99 km^2 (Abd Ellah and Hussein, 2009).

Seawater enters the lagoon through three inlets, two artificial tidal inlets (western and eastern inlets) and a natural eastern inlet of Zaranik (PA) which is occasionally closed by silting.

The water exchange in the lagoon is regulated by the Mediterranean Sea's tides and has a mean tidal excursion of 25 cm during neap tides and about 35 cm during spring tides, while wind is responsible for internal circulation. Water temperature of the lagoon is low in winter and high in summer (13.7–27.0 °c) and (13.9–24.6 °c) respectively; salinity ranges from the lowest value of 38.3% and the highest of 71.1% (Abd Ellah and Hussein, 2009).

Sampling and biometric measurements

The fisheries in the Bardawil Lagoon are seasonal, they extend from April or May to December of each year. Random samples of crabs were collected monthly from the commercial catch of the landing site (Mitzfag) in the lagoon during the fishing season of 2015 (from May 2015 to December 2015). During this year, bottom trawling gear (Kalsa as locally called) were not used after fishery regulations by the military authorities who forced the use of the trammel nets (Dabba and Dahbana) for collecting crabs and other fishes. After capture, a fixed weight of samples (about 10 kg) was caught monthly and placed in plastic bags over a layer of ice in a cooler and transported back directly to the laboratory at NIOF, Alexandria for further examination and analysis.

A total of 140 crabs *C. sapidus* were used in this study, specimens were sexed according to abdominal morphology and shapes and sizes were analyzed. Measurements were made for carapace width (CW), carapace length (CL) and total weight (TWt). In addition, abdomen width |(AW) and length (AL) were recorded for females and chelar (propodus) length (CPL) and depth (CPD) were taken for males.

Vernier Calipers with an accuracy of 0.5 mm were used for body dimensions and the total weight of the crabs was

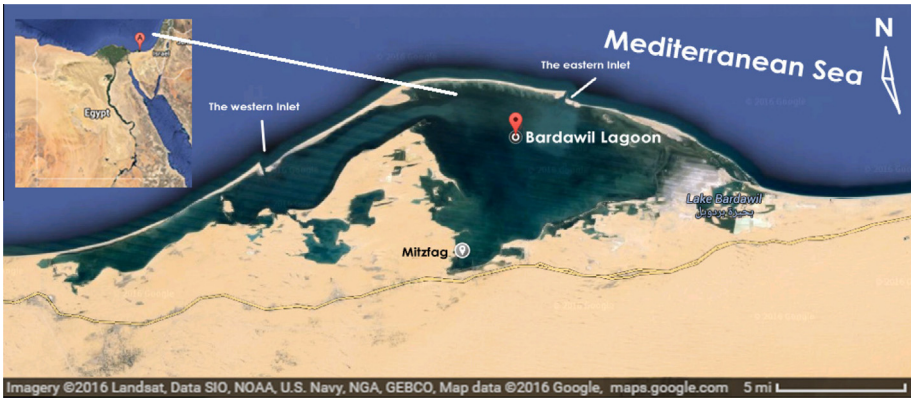

Figure 1 A map showing the location of Bardawil Lagoon and the selected fishing area.

determined to the nearest gram using a digital balance (0.01 g) using a direct reading electric balance (Sartorius GMBH).

Sample measurements

Carapace width (CW) was taken as the distance between the tips of the ninth antero-lateral spines. Carapace length (CL) was measured dorsally along the midline, between the frontal marginal teeth and the posterior margin of the carapace. The chelar propodus length (CPL) was measured from the tip of the fixed finger of the claw to the origin of chelar propodus and the depth (CPD) was measured across the broadest part of the chelar palm.

Abdominal width (AW) was measured at the maximum width (i.e. across the fourth somite) while the abdominal length (AL) was measured along the midline from the anterior margin of the first somite to the posterior margin of the telson. The monthly size frequency distribution of each sex was also done.

Statistical analysis

The interrelationships between various morphometric parameters, viz, CW/CL and CPL/CPH in males and CW/CL and AW/AL in females were analyzed and presented.

Regression analysis was used to assume an allometric growth equation ($y = a + bx$) to set relations between different morphometric parameters in males and females.

The correlation coefficient values (r) were calculated to learn the pattern of association between carapace and propodus/abdomen measurements (Snedecor and Cochran, 1967), with the purpose of establishing a scientific mathematical relationship between the variables, so any variable could be computed approximately, if one variable is known.

Estimating length–weight relationship allometric growth is defined as $y = ax^b$, (a) and (b) were estimated by linear regression a = intercept and b = regression coefficient (slop). ($B = 1$ means isometric growth, $b > 1$ means positive allometric growth and $b < 1$) imply a negative allometric growth (Hartnoll, 1982). The variation between the regression coefficient (b) in male and female was found using ANOVA (Analysis of variance). Correlation coefficient (r) was also determined.

Results

Crab fisheries in Bardawil Lagoon

During the period of the last sixteen years, crabs constituted a remarkable annual production in Bardawil Lagoon fisheries. Its production comprised about 27.8% in average of total lagoon fisheries. Fig. 2 shows the annual fluctuations of crustacean fishery (shrimps and crabs) with crabs being found only during the period from 2000 to 2015, according to the annual report of Bardawil Lagoon fishing reports (GAFRD, 2015). The total lagoon crab fishery during 2015 represented about 42% of the total lagoon fisheries, that was the maximum number recorded during the year at the crab fisheries. This was after the regulations done by the military authorities which prevented the fishermen from using the most destructive shrimp bottom trawling net (Kalsa) and forced them to use trammel nets (Dabba and Dahbana) during the 2015 fishery season. Fig. 3 describes the monthly percentage of crabs catch in the lagoon during 2015 fishing season. The crab catch increased from May to reach 73% of the total production in June. A gradual decrease of 19% was then observed until December.

Fig. 4 shows the monthly abundance of *C. sapidus* in the studied catch. Its population was represented by 15% of the total collected samples. The monthly size frequency distribution of each sex is shown in Fig. 6. The size of the studied population ranged from 65 mm to 155 mm carapace width. The dominant size groups were found to be from 85 mm to 115 mm, while the smaller and larger sizes were poorly represented in the catch (see Fig. 5).

Size composition of C. sapidus

The analysis of width/length weight relationship was carried out by using the minimum, maximum and mean CWs (mm), CLs and wts (g) (±SE), are as given in Table 1. A total of 140 individuals of *C. sapidus* were collected during the entire

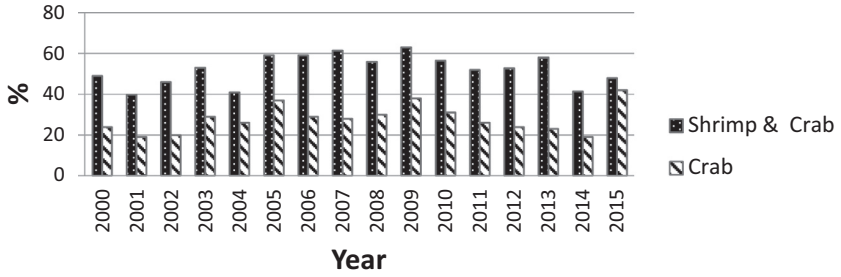

Figure 2 Crustacean fisheries in Bardawil Lagoon between the years 2000 and 2015.

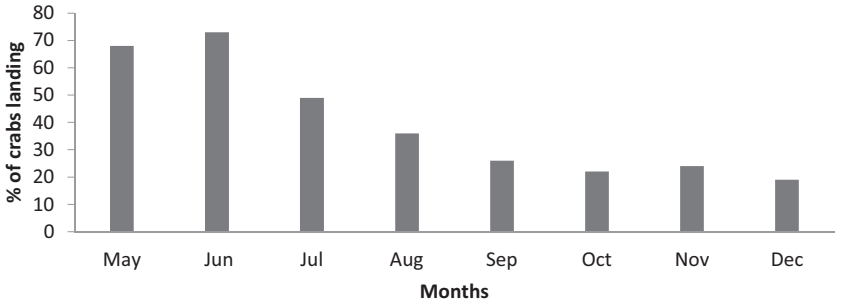

Figure 3 Monthly occurrence of two crab species, *P. pelagicus* & *C. sapidus,* during fishing season (2015) in Bardawil Lagoon.

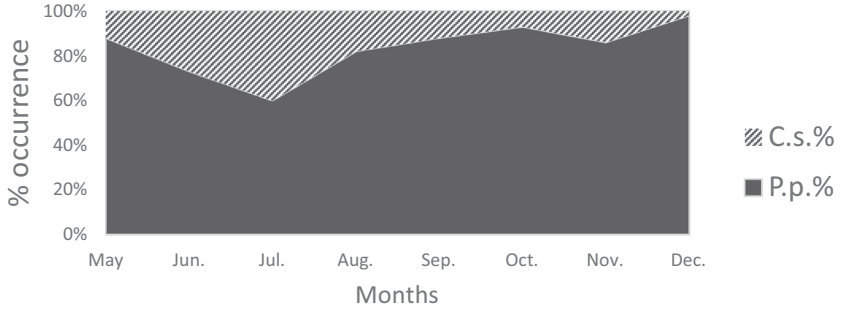

Figure 4 Monthly catch percentage crab yield during the fishing season 2015 in Bardawil lagoon (Bardawil annual report 2015).

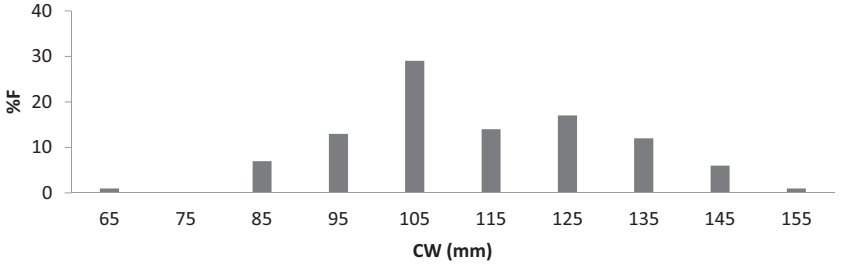

Figure 5 Length frequency distribution of *C. sapidus* total catch from Bardawil Lagoon in (2015).

present study. Males were found to be more abundant (60.7%) than females (39.3%) considering the overall sample. In males, carapace width (CW) ranged between 65.0 and 155.0 mm, carapace length (CL) ranged between 44.2 and 75.3 mm and weight (wt) ranged between 52.3 and 302.9 g. In females, carapace width (CW) ranged between 68.3 and 146.6 mm, carapace length (CL) ranged between 35.8 and 77.0 and weight (wt) ranged between 31.9 and 302.9 g as in Table 1.

Interrelationships between different morphometric characters of *C. sapidus*

Width–length relationship

The regression equations for the relationship for the carapace width and carapace length were CW = 0.4423 CL + 7.9322

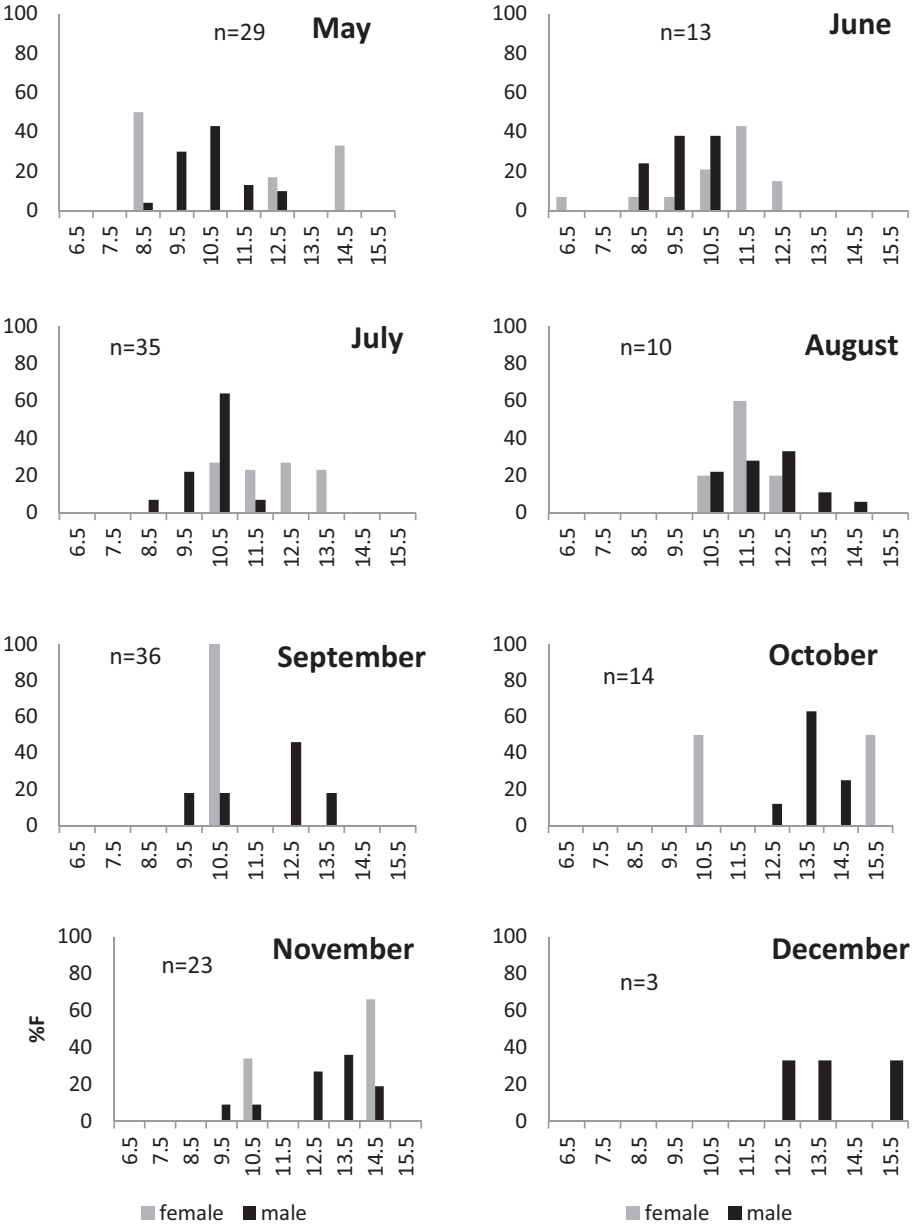

Figure 6 Monthly percentage occurrence of males and females of *Callinectus sapidus* during the fishing season 2015 in Bardawil Lagoon.

Table 1 Length, width and weight characteristics of *C. sapidus* caught in Bardawil lagoon (May–December, 2015).

Sex	Width characteristics (mm)				Length charact. (mm)			Weight characteristics (g)		
	n	Mean ± SE	Min	Max	Mean ± SE	Min	Max	Mean ± SE	Min	Max
Male	85	115.0 ± 17.37	65.0	155.0	57.8 ± 10.3	44.2	75.3	136.84 ± 59.0	52.3	302.89
Female	55	114.96 ± 17.21	68.3	146.6	54.81 ± 7.22	35.75	77.0	97.9 ± 35.34	31.94	180.17
Over all	140	115.05 ± 17.18	65.0	155.0	56.54 ± 8.86	35.75	77.0	121.50 ± 54.12	31.94	302.89

n = sample size, SE = standard error.

for males, CW = 0.3711 CL + 11.395 for females and CW = 0.415 CL + 9.1918 for the combined sexes. The estimated (*b*) values were 0.4423, 0.3711 and 0.415 for males, females and combined sexes respectively. The correlation coefficient, (*r*) values, of males, females and combined sexes were 0.9838, 0.9566 and 0.9267 respectively as shown in Table 1.

Length–weight relationship

The regression equation for the carapace length and body weight relationship was as follows: wt = 0.0004 $CL^{3.133}$ males, wt = 0.0008 $CL^{2.931}$ for females and wt = 0.0004 $CL^{3.1234}$ for combined sexes respectively.

The exponential values (b) for the carapace length–weight relationship in males, females and combined sexes (3.133, 2.931 and 3.124 respectively) indicate that there is a certain deviation from the isometric growth pattern. Also the 't' test confirmed that (b) is significantly different from 3 in values. The correlation coefficient (r) values of males, females and combined sexes were 0.9579, 0.9256 and 0.9512 respectively. The regression equation for the carapace width and body weight relationship of *C. sapidus* were $wt = 0.0003\ CW^{2.7693}$ for males, $wt = 0.001\ CW^{2.396}$ for females and $wt = 0.0006\ CW^{2.5615}$ for combined sexes respectively. The (b) values for the carapace width–weight relationship in males, females and combined sexes were (2.7693, 2.396 and 2.545 respectively). This also represented the deviation from isometric growth pattern. The coefficient of determination, (r^2) values of males, females and combined sexes were 0.9838, 0.9566 and 0.9267 respectively as in Table 2.

The interrelationship between carapace width/length and propodus length and depth of males is shown in Table 3 while abdomen width–length in females is shown in Table 4. The allometric relation between these parameters proposed that in most cases the relationship was positive and highly significant.

Discussion

The marine environments most subjected to invasion are coastal and estuarine regions, with decapod crustaceans commonly reported as non-native invertebrate (Ruiz et al., 2000). The blue crab *C. sapidus* (Rath.) is a large decapod and has been reported as a highly aggressive species. It has also been nominated among the "100 worst invasive species" in the Mediterranean with negative impact on both biodiversity and socioeconomics (Streftaris and Zenetos, 2006).

The majority of sites where the blue crab *C. sapidus* has been recorded in BL are lagoons and lakes, as this species is a euryhaline and eurythermal biocoenosis that withstands the great variations of salinity and temperature (Bellan-Santini et al., 2002). As mentioned before, *C. sapidus* was firstly recorded in Lake Menzala, Egypt in 1940, then in Lake Edku as reported by Banoub (1963), while it was first recorded in the Northern Adriatic Sea in 1949 (Lucrezia et al., 2015). Wolff (1954) suggested that this species was transported into the Mediterranean in ballast tanks, which was also confirmed by Holthuis and Gottlieb (1958) and Williams (1974). *C. sapidus* is native to western Atlantic coasts and widely recorded in various Mediterranean regions (Lucrezia et al., 2015).

After the drastic decrease of *C. sapidus* as recorded by Ramadan and Dowidar (1972), new information showed that *C. sapidus* is starting to appear in other Northern Lakes, specifically Lake Edku (in press data), which suggest that these past years were a readjusting period for its return to the Egyptian northern lakes.

In the present study, *C. sapidus* is recorded in the crab catch analysis with about 15% in abundance in the Bardawil Lagoon fishery population. The relationship between the carapace width/carapace length and the weight of the caught *C. sapidus*

Table 2 *C. sapidus*: regression analysis of morphometric data during study period of Bardawil Lagoon.

Sex category	Relationship	(b)	(r)	(R^2)	All
Male	CL–Wt	3.133	0.95179	0.9175	+
	CW–Wt	2.7693	0.9552	0.9125	+
	CW–CL	0.4423	0.9838	0.9679	–
Female	CL–Wt	2.931	0.9256	0.8568	+
	CW–Wt	2.396	0.9313	0.8673	+
	CW–CL	0.3711	0.9566	0.9151	–
Combined sex	CL–Wt	3.1234	0.9512	0.9048	+
	CW–Wt	2.5615	0.8632	0.7452	+
	CW–CL	0.415	0.9267	0.8588	–

CL: carapace length; CW: carapace width; Wt: weight (general allometric factors); b: slope (general allometric factor); r: correlation coefficient; R^2: coefficient of determination; All: allometry; +: positive allometry; –: Negative allometry; *: significant.

Table 3 Allometric equations and correlation coefficient "r" values between different variables in propodus in males of *C. sapidus*.

Independent variable (x)	Dependent variable (Y)	Allometric growth equation	"r^2" value
Carapace width	Chelar propodus length	CPL = −7.0194 + 0.6789 CW	0.9069*
Carapace width	Chelar propodus depth	CPD = −1.8241 + 0.2093 CW	0.6445*
Carapace length	Chelar propodus length	CPL = −17.673 + 1.5127 CL	0.9194*
Carapace length	Chelar propodus depth	CPD = −5.1465 + 0.4669 CL	0.6532*
Chelar propodus length	Chelar propodus depth	CPD = −0.5314 + 0.3196 CPL	0.6755*

* Indicates highly positive allometry, significant at 1% level.

Table 4 Allometric equations and correlation coefficient "r" values between different variables in abdomen in females of *C. sapidus*.

Independent variable (x)	Dependent variable (Y)	Allometric growth equation	"r^2" value
Carapace width	Abdomen width	AW = −1.6126 + 0.3493 CW	0.8493*
Carapace width	Abdomen length	AL = 6.4385 + 0.271 CW	0.8925*
Carapace length	Abdomen width	AW = −9.177 + 0.8831 CL	0.8173*
Carapace length	Abdomen length	AL = −0.7915 + 0.7122 CL	0.9389*
Abdomen width	Abdomen length	AL = 9.4562 + 0.7292 AW	0.8676*

* Indicates highly positive allometry, significant at 1% level.

had the values for the exponent (b) ranging from 2.396 to 3.133 as an allometric relation. This value of (b) remained below 3 for the same species in Beymelek Lagoon (Antalya) (Atar and Secer, 2003). The exponent (b) represents a constant which inhibits the weight growth rate of body size; it can be isometric ($b = 3$) or allometric positive, ($b < 3$); or negative, ($b > 3$) (Hartnoll, 1982). A positive allometric length–weight relationship indicates that weight increases as the carapace length increases and the change in (b) values depends primarily on the shape and fatness of the species (Dubey et al., 2014). The coefficient of determination r^2 value of all the variables studied is above 50% significance level in both sexes alike other studies for the same species (Abowei and George, 2009).

Various factors such as temperatures, salinity, sex, food, stage of maturity and time of year may be responsible for the difference in parameters of the length/width–weight relationships among seasons and years, (Pauly, 1984). The ratio of males to females in *C. sapidus* population in Bardawil Lagoon was in favor of males, while the reverse was in Beymelek Lagoon population where females outnumbered males (Sumer et al., 2013). This ratio may be related to the aging and growth of the crab population, as well as to the different migration patterns in the lagoon system; all these parameters seem to affect their relative occurrence. A similar pattern was obtained at Babitonga Bay, with females dominating in most samples, while in the samples from Bay of Santos, São Paulo State, males were dominant (Severino-Rodrigues et al., 2001).

Further studies on the population of *C. sapidus* and on its potential distribution in adjacent areas would be necessary to provide rich information on population structure and dynamics of the blue crab in Bardawil Lagoon. *C. sapidus* is considered one of the most notorious invasive cases and must be monitored closely in the Bardawil Lagoon in order not to inflict any negative impact on the main lagoon fishery.

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