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Growth and Reproduction Biology of the Blue Crab, *Callinectes sapidus* Rathbun, 1896, in the Beymelek Lagoon (Southwestern Coast of Turkey)

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Abstract

Seasonal growth and reproduction biology of the blue crab, *Callinectes sapidus* were studied in the Beymelek lagoon, southwestern coast of Turkey between July 2009 and September 2010. The seasonal von Bertalanffy growth parameters were obtained by Hoenig method using the LFDA (Length Frequency Distribution Analysis) for each sex. The LFDA analyses showed that male crabs had higher L_∞ and lower K and higher Φ' values (L_∞ =230.1 mm, K=0.860 year^{-1}) than females (L_∞ =181.9 mm, K=1.064 year^{-1}). Seasonal variation of growth for females (C=0.93) were found stronger than males (C=0.29). The slowest growth period started in October (WP=0.79) for females and in January (WP=0.06) for males. Ovigerous females were appeared in the population in February and peaked in August and September. The spawning period of *C. sapidus* was between July and September. The length of maturity of 50% was estimated as 118.5 mm length for females.

Keywords: Blue crab (*Callinectes sapidus*), seasonal growth, reproduction, maturity size, Beymelek Lagoon (Mediterranean).

Beymelek Lagün Gölündeki (Türkiye'nin Güneybatı Kıyısı) Mavi Yengeçlerin, *Callinectes sapidus* Rathbun, 1896, Üreme Biyolojisi ve Büyümesi

Özet

Türkiye'nin Güneybatı kıyısında yer alan Beymelek Lagün Gölündeki mavi yengeçlerin Temmuz 2009 ve Eylül 2010 tarihleri arasında mevsimsel büyümesi ve üreme biyolojisi incelenmiştir. Mevsimsel olarak von Bertalanffy Büyüme Parametreleri her bir cinsiyet için LFDA paket programı (Boy Frekans Dağılım Analizleri) kullanılarak Hoenig metodu ile elde edilmiştir. LFDA ile yapılan analizler sonucunda erkek mavi yengeçlerin (L_∞=230,1 mm, K=0,86 yıl^{-1}) dişilere göre (L_∞ =181,9 mm, K=1,064 yıl^{-1}) yüksek L_∞, düşük K ve yüksek büyüme performansı (Φ') değerine sahip olduğu görülmüştür. Büyümenin dişilerdeki mevsimsel değişiminin (C=0,93) erkeklerden (C=0,29) daha kuvvetli olduğu bulunmuştur. Büyümenin en yavaş olduğu dönem dişilerde Ekim ayında (WP=0,79) erkeklerde ise Ocak ayında (WP=0,06) başlamıştır. Yumurtalı dişiler populasyonda Şubat ayında görünmeye başlamış ve Ağustos ve Eylül aylarında yoğunlaşmıştır. Mavi yengeçler için üreme zamanı Temmuz-Eylül arası olarak belirlenmiştir. Dişiler için %50 olgunluk boyu 118,5 mm karapaks genişliği olarak tespit edilmiştir

Anahtar Kelimeler: Mavi yengeç (*Callinectes sapidus*), mevsimsel büyüme, üreme, ilk üreme boyu, Beymelek Lagün Gölü (Akdeniz).

Introduction

The blue crab, *Callinectes sapidus* Rathbun, 1896 was known with the broadest latitudinal distribution introduced into Europe, California, Hawaii and Japan (Williams, 2007). This invasive species has been widely recorded in different Mediterranean regions (including Adriatic) and Aegean Sea, especially in the eastern parts (Koukouras *et al.*, 1992; Enzenrob *et al.*, 1997; Atar and Secer, 2003; Streftaris and Zenetos, 2006; Onofri *et al.*, 2008; Tuncer and Bilgin, 2008; Dulcic *et al.*, 2010; Eleftheriou *et al.*, 2011).

The lifespan of a blue crab can be separated three stages: larval stage (approximately 6 months), juvenile stage (approximately 12 months), and adult stage, which is characterized by sexual maturity (Dudley and Judy, 1973). Different history stages are exposed to subtidal environmental conditions of freshwater, estuarine and coastal habitats. Over the life cycle of *Callinectes sapidus*, adults prefer to low salinity areas of estuaries and females migrate to the estuaries to release larvae, which develop in coastal/offshore areas. Then the postlarvaes return estuaries for settlement and metamorphosis (Tankersley and Forward, 2007).

There are some studies about blue crabs in Turkey concerning length-weight relationships (Atar and Secer, 2003; Gokce *et al.*, 2006; Ozcan and Akyurt, 2006; Gulsahin and Erdem, 2009; Sangun *et al.*, 2009), population biology (Tureli, 1999), fishing gear efficiency (Atar *et al.*, 2002), growth (Tureli and Erdem, 2003; Tureli-Bilen and Yesilyurt, 2012) genetic differences (Keskin and Atar, 2012). There is no information on its seasonal growth rate. Knowledge on the reproduction biology of the blue crab from Turkish seas is very limited. The aim of this study was to estimate the seasonal von Bertalanffy growth parameters by using length frequency distribution data for both sexes and also to investigate the reproduction biology with respect to ovigerous blue crab females in the Beymelek Lagoon, southwestern coast of Turkey.

Materials and Methods

Samplings were caught monthly basis between July 2009 and September 2010 in the Beymelek lagoon (Figure 1), with about 250 hectare surface area in the southwestern coast of Turkey. Temperature and salinity were ranged between 11.9 to 30.3°C, 13.9 to 17.8 psu and the average values (±standard error) were 21.5±1.7°C, 15.7±0.3 psu, respectively in the lagoon. Average depth was 1-1.5 m. Lagoon has a lake (Kaynak lake) with an area of about 6 ha connecting to lagoon with a channel.

Samples were collected by using the fyke-nets and trap (Figure 2). Traps were located to entrance in lagoon. Fyke-nets were set up at three different locations in lagoon. Sampling was done with double

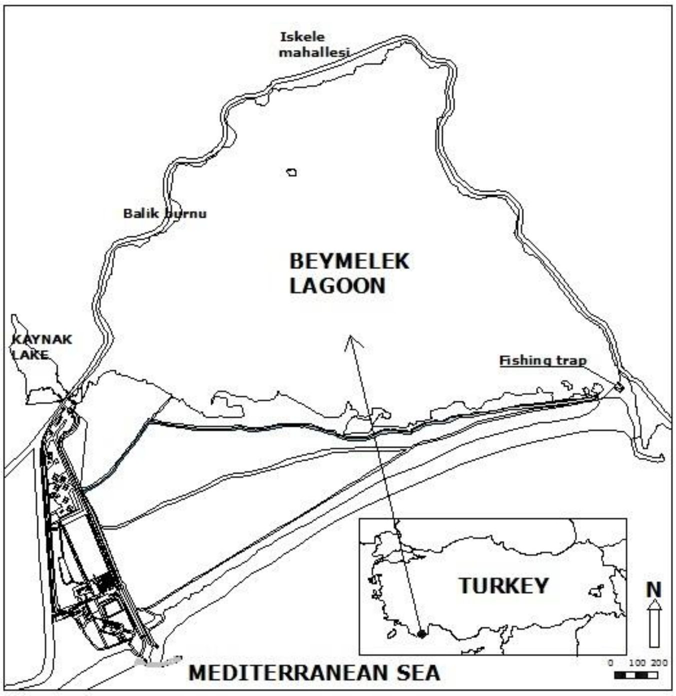

Figure 1. Beymelek lagoon.

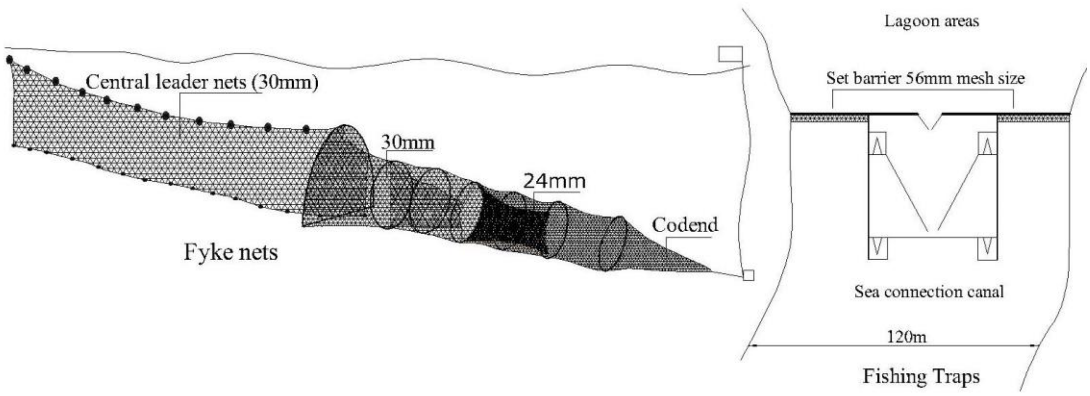

Figure 2. Fyke-nets and fishing traps.

fyke nets, the mouth openings were connected with a vertically central leader nets. Fyke-nets had a single central leader nets (3.5 m long), and six internal chamber; with two different mesh sizes, central leader and the first four chamber parts was 30 mm, codend was 24 mm mesh. The first chamber was a horseshoe-shaped frame, height of 0.55 m, width of 0.70 m. The ends of cod-end were fastened before deployment. Fyke-nets were fished for four or five consecutive nights and the contents of fyke nets were transferred to a keep bags for later measurements in the laboratory. Carapace width and weight were measured to the nearest 0.1 mm and 0.1 g, respectively.

The length-weight relationship was estimated using "log-transformed" carapace width and weight data for females and males as:

$$\mathrm{Log}\,(W) = \mathrm{Log}\,(a) + b*\mathrm{Log}\,(L)$$

where W is the total wet weight (g), L is the carapace width (mm), a is the intercept, and b is the slope of the regression line (Ricker, 1975).

The Pauly's *t*-test was used to test of the calculated b values for females and males (Pauly, 1984). The significance of the regression (r) for the carapace width-weight data pairs was assessed by ANOVA, analyzed using ordinary least squares regression (95% confidence).

Immature females and males have a triangular-shaped abdomen. Mature females have a broader, semicircular-shaped abdomen and mature males have a T-shaped abdomen (Millikin and Williams, 1984). Sex ratio of the *C. sapidus* was analyzed using Chi-square test (χ^2).

The Fulton's condition factor was calculated from $(W/L^3)*100$ for females (excluding ovigerous females) and males (juvenile males and mature males), where W and L are total weight and carapace width of a blue crab (Bagenal and Tesch, 1978).

There are a number of forms of the von Bertalanffy in use. The commonest form is:

$L_t=L_\infty\,[1-e^{-K(t-to)}]$ predicts length as a function of age and is used when growth has a non-seasonal pattern.

Seasonal growth was described using the Somers' (1988) version of the VBG equation:

$$L_t = L_\infty\left[1-e^{\left[-K(t-t_o)+\left(C\frac{K}{2\pi}\right)\sin 2\pi(t-t_S)-\left(C\frac{K}{2\pi}\right)\sin 2\pi(t_o-t_S)\right]}\right]$$

where, L_∞ is the asymptotic carapace width to which the crabs grow, K is the growth-rate parameter, t_0 is the nominal age at which the carapace width is zero, L_t is carapace width at age t, C is a parameter that measures the size of the seasonal variation in growth. When C=0, the equation has no seasonal variation. When C=1 growth becomes zero during the low growth season. The parameter *ts* is the time between t=0 and the start of a growth oscillation ($-0.5\leq ts\leq 0.5$) denoting the time of year corresponding to the start of the convex segment of sinusoidal oscillation.

ts help to define the time of the year when the growth rate is slowest, known as the winter point. The winter point (WP), was calculated as:

$$WP=t_S + 0.5.$$

Seasonal VBG curves were fitted to the length distributions to obtain the most suitable values of the goodness of fit (*Rn*). The goodness value of fit was calculated as:

$$Rn=\frac{10^{ESP/ASP}}{10}$$

where *ASP* is the available sum of peaks, computed by adding the best values of the available peaks, and *ESP* is the explained sum of peaks, computed by summing all the peaks and troughs hit by the VBG curve.

Analysis of the length data were fitted to length frequency distributions grouped in 5 mm total length size classes using the ELEFAN procedure in the PC-based computer package Version 5.0 of Length Frequency Distribution Analysis (LFDA) (Kirkwood *et al.*, 2001).

Growth performance comparisons of *C. sapidus* were made using the growth performance index (Φ') which is preferred rather than using L_∞ and K individually (Pauly and Munro, 1984) and is computed as:

$$\Phi'=\mathrm{Log}\,(K) + 2\,\mathrm{Log}\,(L_\infty)$$

The length at first maturity of females (the length at which 50% of the fish had become mature) was determined from the relationship between the percentages of mature crab and the length classes of 5 mm.

The proportion (P) of sexually mature of length was fitted to the logistic equation:

$$P = 1/\left(1+\exp\left[-r\left(L-L_m\right)\right]\right)$$

which in straight line form is:

$$\ln\left[\left(1-P\right)/P\right] = rL_m - rL$$

where r ($-b$) is the slope of the curve and L_m is the mean length at sexual maturity on the length which corresponds to a proportion of 0.5 (or 50 percent). Size at sexual maturity (L_m) was calculated from $-(a/b)$. A logistic function was fitted to the proportion of mature individuals by for non-linear least squares parameter estimation (Agresti, 1990; King, 1995). The length at first maturity of males was not estimated due to obtained enough individuals.

Table 1. Length-weight relationship's parameters for each sex of *C. sapidus* (SE: Standard error, r^2: Determination coefficient, CI: confidence interval, n: Sample size)

Sex		n	L_{min}–L_{max} (Mean±SE)	W_{min}–W_{max} (Mean±SE)	$W = aL^b$ a	b	SE(b)	r^2	CI(b)	Significant Level Pauly's t-test
Females	JF	160	48.2-132.8 (101.2±1.36)	8.7-118.1 (66.8±2.11)						
	MF	1029	75.5-186.3 (153.1±0.42)	30.3-284.0 (165.0±1.18)	0.0009	2.4133	0.018	0.93	2.378-2.448	t= 32.8161, P<0.05
	OF	153	100.3-175.0 (145.3±1.02)	71.0-250.0 (160.5±3.02)						
Males	JM	13	28.4-154.0 (98.3±8.97)	1.6-165.0 (70.4±13.02)	0.0002	2.7716	0.021	0.95	2.731-2.813	t= 10.9567, P<0.05
	MM	856	59.6-212.7 (137.0±0.85)	14.1-544.2 (173.2±2.71)						

JF: Juvenile female, F: Mature females, OF: Ovigerous females, JM: Juvenile males, M: Mature males

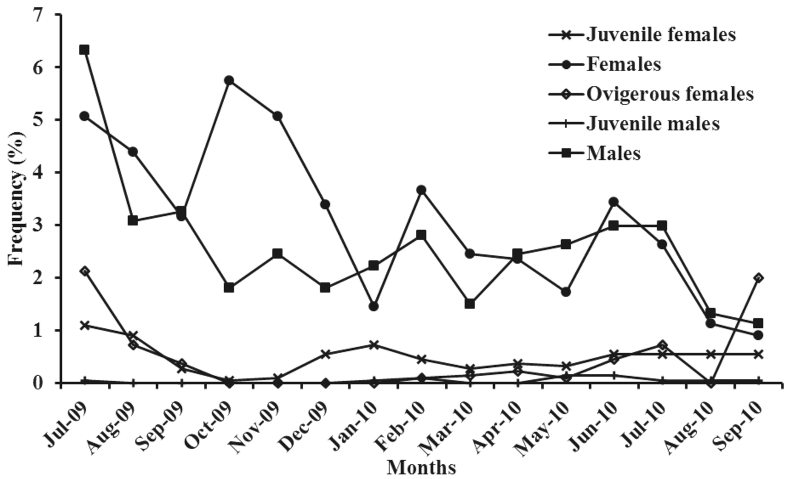

Figure 3. Monthly catch percentages of blue crabs.

Results

A total of 2,211 blue crabs, 1,342 females (160 juvenile, 1,029 mature and 153 ovigerous females) and 869 males (13 juvenile and 856 mature males) were studied. Carapace width and total wet weight data of both sexes were given (Table 1). Monthly catch percentages of both sexes were given (Figure 3). The mean carapace width was significantly different for among females (juvenile, mature and ovigerous) and males (juvenile and mature) (P<0.05). The length frequency distributions were found significantly statistical different by using Kolmogorov-Smirnov test between all females (juvenile, mature and ovigerous) and males (juvenile and mature) (Figure 4).

The estimated ratio was in favor of females 1:0.65 and the difference between the sexes was highly significant (χ^2= 18.9; d.f.= 1; P<0.05). We find that the sex ratio (female: male) was found to be highly biased towards females (60.7:39.3%) (χ^2 test=101.189 P<0.05), except in some months (September 2009 (53.8:46.2%), January (49%:51%), April (54.6:45.4%), May (43.5:56.5%) and August 2010 (55.2:44.8%)).

Condition factor of females and males ranged from 31.8 to 94.0 (with mean: 48.1±0.22) and 29.5 to 105.1 (with mean 63.2±0.29), respectively. The minimum CF values for the females and males were observed in October 09 and March 10, respectively. The maximum CF values were observed in July 09-January 10 for the females and July 09 for males, respectively. There was statistically significant differences (P<0.05) between sexes.

The length-weight relationships of the blue crabs in the Beymelek lagoon were W=0.0009 $L^{2.4133}$ for females and W=0.0002 $L^{2.7716}$ for males (Figure 5). Negative allometric growth (Pauly's t-test P<0.05) was observed for all female and male crabs (Table 1).

The seasonal von Bertalanffy growth parameters obtained by Hoenig method using the LFDA for each sex are summarized in Table 2. The LFDA analyses showed that male crabs had higher L∞ and low K values (L∞=230.1 mm, K=0.86 year^{-1}) compared to the values of females (L∞=181.9 mm, K=1.064 year^{-1}). Seasonal variation of growth for females (C=0.93) were found stronger than males (C=0.29) (Figure 6).

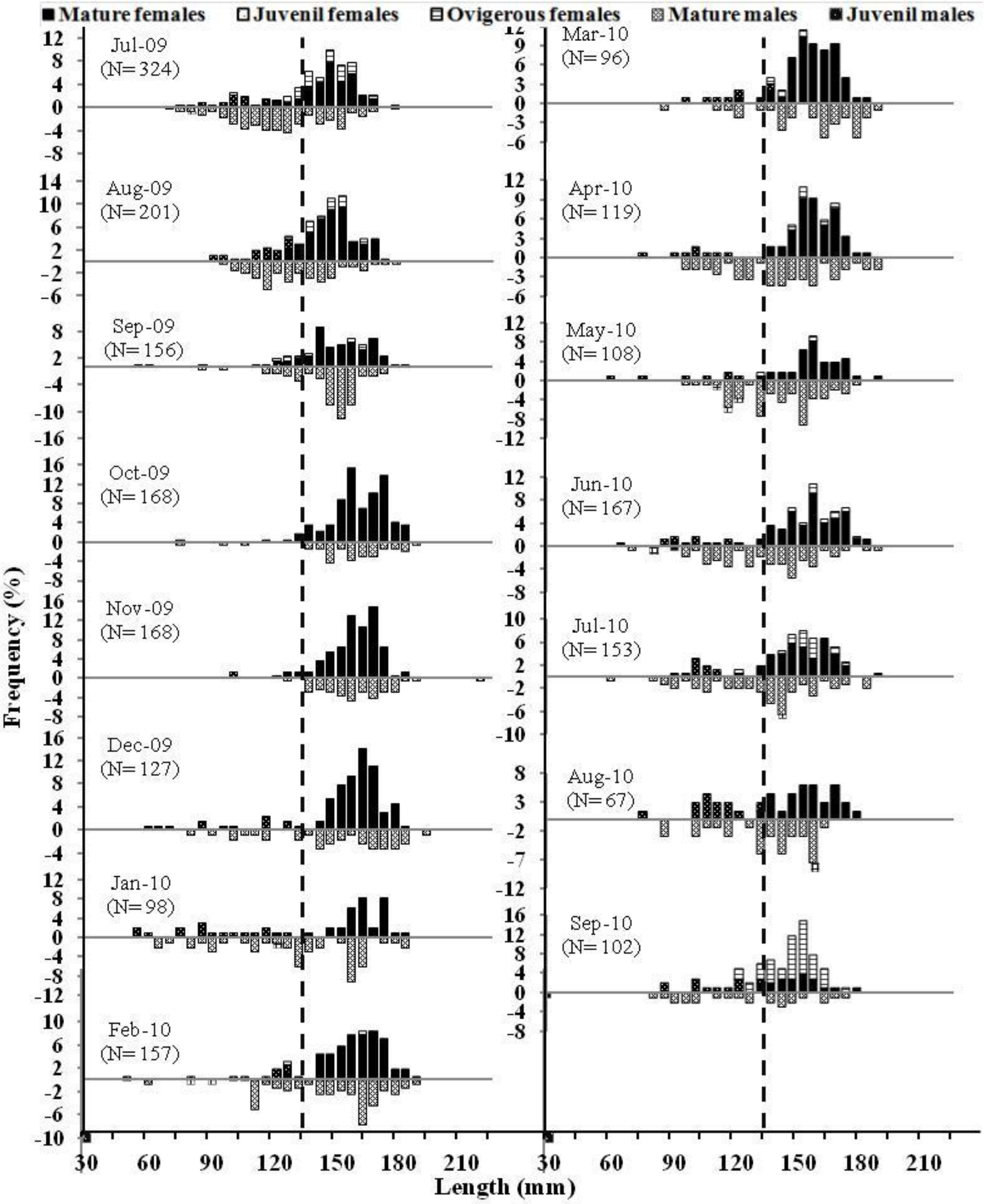

Figure 4. Length–frequency distribution (in percentages) for both sexes of *C. sapidus*.

The slowest growth period was obtained in October (WP= 0.79) for females and January (WP= 0.06) for males. The *Rn* value of males and females for non-seasonal growth curve did not improve when a seasonal growth curve was fit. The *Rn* value of non-seasonal VBG curve improved by about 1% for both sexes after fitting a seasonal VBG curve.

Ovigerous females appeared in February and peaked in August and September. The spawning period of *C. sapidus* was between July and September (Figure 4). Size for 50% sexual maturity for females was estimated as 118.5 mm length (Figure 7).

Discussion

In the Beymelek lagoon, both blue crab sexes showed negative allometric growth considering the length-weight relationship (Pauly's t-test $P<0.05$). Some other studies gave also the similar results (Atar and Secer (2003) and Gokce *et al.* (2006)), others reported the different results (Gokce *et al.*, 2006; Stickney, 1972). The parameters of length-weight relationships may be affected by various factors, such as time of years, temperature, food, environmental conditions, stomach fullness, differences in age, stage of maturity and sex (Bagenal and Tesch, 1978; Pauly,

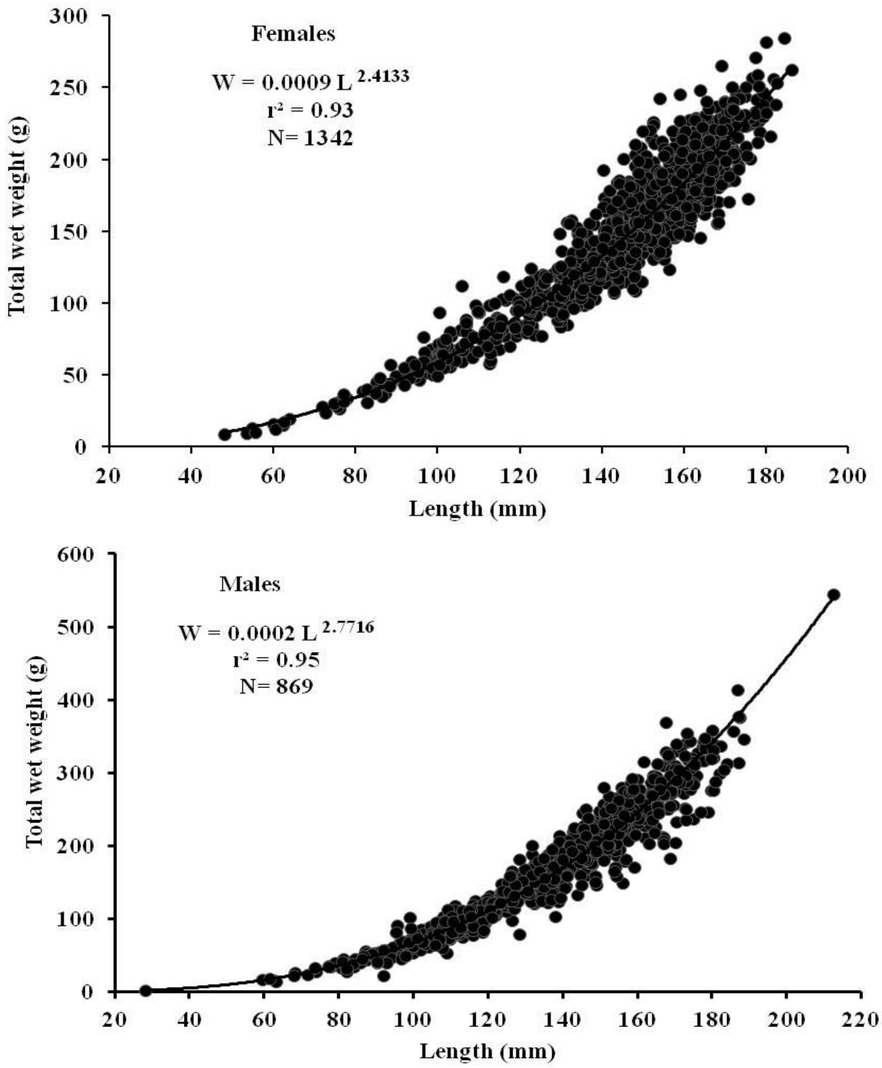

Figure 5. Length-weight relationship for both sexes of *C. sapidus.*

Table 2. von Bertalanffy growth parameters for both sexes of *C. sapidus*

Sex	Parameters						
	L_∞	K	t_0	C	WP	Φ'	Rn
Females	181.9	1.064	-0.85	0.93	0.79	4.520	0.254
Males	230.1	0.86	-0.16	0.29	0.06	4.724	0.178

1984).

Berglund (1981) suggested several hypotheses to interpret variation sex ratio in palaemonid species such as *Palaemon elegans* and *P. adspersus*. The sex ratio in *C. sapidus* population in Beymelek lagoon was in favor of females. Sex ratio may be related to the longevity and growth of crab populations. According to Berglund (1981), males presented reduction in energy investment for growth so as to lower predation risks. Variation in sex ratio could be explained by the different total mortality's rates between sexes, different migration pattern in the lagoon system and these parameters seem to affect their relative occurrence.

The condition factor is usually used in order to compare the condition, fatness or well being of the marine organisms. It is based on the hypothesis that heavier fish of a given length are in a well physiological condition (Bagenal and Tesch, 1978). In this study, condition factor of females (48.1) and males (63.2) were found higher than those reported in a previous study (Atar and Secer, 2003) carried out in Beymelek lagoon. These values showed that the condition of the blue crabs in the above area increased gradually from 2000 to 2009, possibly due the increased prey abundance for the studied decapod.

A seasonal growth pattern is very common in decapod crustaceans such as *C. sapidus*, *Palaemon*

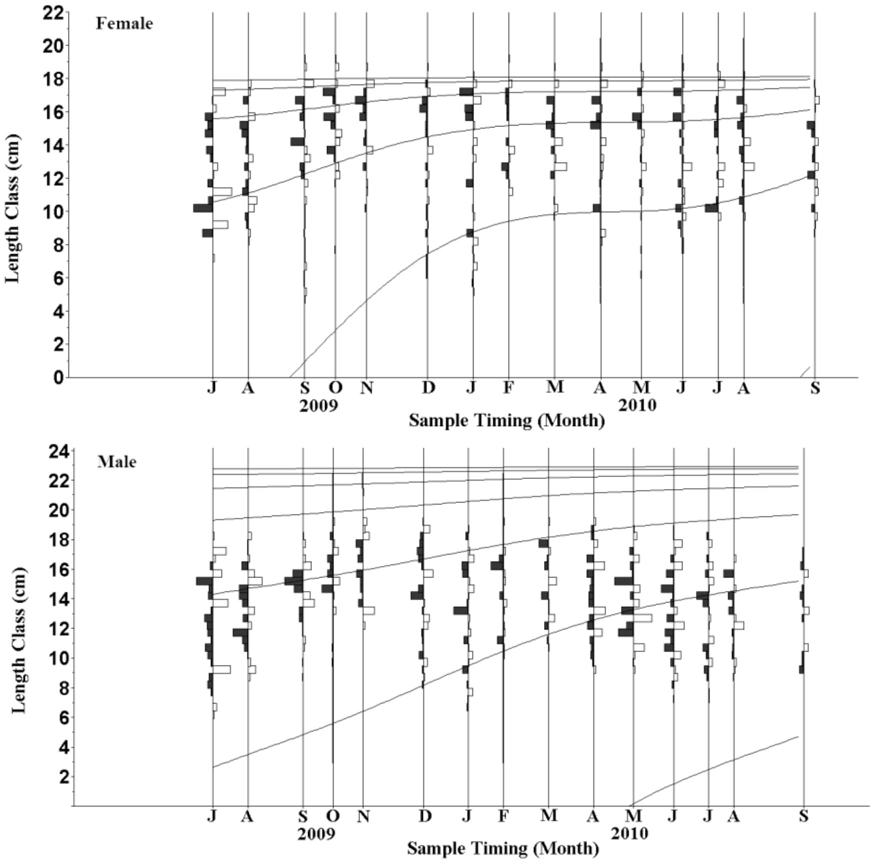

Figure 6. Length-frequency distribution with seasonal von Bertalanffy growth curves for both sexes of *C. sapidus.*

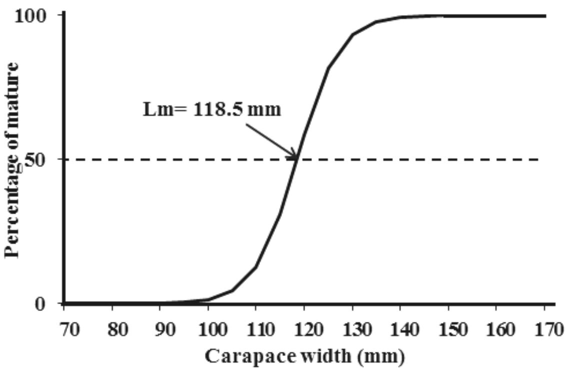

Figure 7. Sexual maturity ovigerous females of *C. sapidus* from Beymelek Lagoon.

adspersus, P. gravieri, Crangon crangon, Parapenaeus longirostris (Oh *et al.*, 1999; Helser and Kahn, 2001; Kim, 2005; Bilgin *et al.*, 2009a,b). Our results showed that *C. sapidus* had also seasonal oscillation pattern and the seasonal variation of growth for females (C= 0.93) was stronger than males (C= 0.29). The slowest growth period was obtained in summer (WP= 0.79) for females and in winter (WP= 0.06) for males. Seasonality of growth for many crustacean species was reported due to energy allocation of during the reproduction season, water temperature fluctuating, light cycle and food supply (Tagatz, 1968; Hartnoll, 2001).

The LFDA analyses showed that $L\infty$ was higher and K was lower *C. sapidus* males. VBG parameters of *C. sapidus* were estimated different areas for both sexes (Table 3). The growth performance index (Φ') value of males was higher than the majority of other studies, with the exception of Chesapeake Bay population (Rugolo *et al.*, 1997; Ju *et al.*, 2001), the coast of Florida (Pellegrin *et al.*, 2001) and Delaware Bay (Helser and Kahn, 2001). Females' value of Φ' is lower than the all value of Φ' was showed in Table 3, exception of the Smith Island's coast (Rothschild *et al.*, 1988), the Chesapeake Bay population (Smith, 1997; Ju *et al.*, 2001), the Hudson River (Chenery, 2002) and Delaware Bay (Helser and Kahn, 2001). On the other hand, the Beymelek lagoon environments are highly productive (Emiroglu and Tolon, 2003) and growth performance of lagoon

Table 3. Summary of von Bertalanffy growth parameters and growth performance index of *C. sapidus*

L_∞	K	t_0	Φ'	Location	Reference
176.0	1.080		4.491	Coast of Smith Island, MD	Rothschild *et al.* (1988)
187.0	0.506		4.544	Chesapeake Bay	Rothschild *et al.* (1991)
191.9	0.640	0.31	4.566	Chesapeake Bay	Smith (1997)
175.9	1.450	0.13	4.491	Coast of Louisiana	Smith (1997)
262.5	0.587	0.12	4.838	Chesapeake Bay	Rugolo *et al.* (1997)
240.0	1.090	0.40	4.760	Chesapeake Bay	Ju *et al.* (2001)
180.9	0.490	0.08	4.515	Chesapeake Bay	Ju *et al.* (2001)
276.0	0.663	0.17	4.882	Coast of Florida	Pellegrin *et al.* (2001)
151.1	0.750	-0.16	4.359	Hudson River	Chenery, 2002
234.7	0.750		4.741	Delaware Bay	Helser and Kahn (2001)
200.6	0.620		4.605	Delaware Bay	Helser and Kahn (2001)
200.3	0.930		4.603	Delaware Bay	Helser and Kahn (2001)
181.9	1.064	-0.85	4.520	Beymelek Lagoon	Present study*[1]
230.1	0.860	-0.16	4.724	Beymelek Lagoon	Present study*[2]

*[1] value of the female blue crabs, *[2] value of the male blue crabs, Φ' was calculated from the provided L_∞ and K.

species could be higher than compared to coastal marine environments (Amanieu, 1973; Chauvet, 1979).

The spawning period of *C. sapidus* lasted eight months in the Beymelek lagoon population and recruitment to the benthic population started at the end of January. Juvenile crabs were found in the benthic population almost throughout the year. Severino-Rodrigues *et al.* (2013) reported that ovigerous females were more abundant between December and March in the Southest coast of Brazil. Tagatz (1968) found that spawning of blue crab occurred one or two months after mating during spring and summer in the St. Johns River in the northeastern Florida. According to Eggleston *et al.* (2004), spawning was seen from the spring through the fall and mainly during May and August at inlets. In Chesapeake Bay, blue crab larvae, termed zoea, are released by females from high-salinity waters during late spring and early summer (Olmi, 1995).

Salinity and temperature range of blue crabs for hatching fluctuated by geographic distribution and life history. Hatching of eggs continued at between 19 and 29°C, but below 17°C and above 30°C, the release of the eggs is not possible. Optimum salinity range for hatching was 23 to 28 psu, but hatching was not occurred at the salinities below 9 and above 33 psu (Sandoz and Rogers, 1944). The temperatures and salinities values were ranged from 23.08 to 29.58°C and from 15.00 to 16.10 psu, respectively in Beymelek lagoon, between May and September. According to the above theories these parameters are not appropriate for the blue crabs' spawning. Batches of ovigerous female blue crabs migrate to the sea for spawning.

The size at sexual maturity (L_m) was estimated as 118.5 mm for *C. sapidus* in this study. The size at sexual maturity of *C. sapidus* was estimated as 150-160 mm in Florida's St. John River (Tagatz, 1968), as a mean carapace width (measured 135 ovigerous females), 147 mm in Chesapeake Bay (Prager *et al.*, 1990), 130 mm in Tampa Bay (Steele and Bert, 1994), 120 mm in Chesapeake Bay (Rugolo *et al.*, 1997), 129 mm in North Carolina (Eggleston, 1998) 102 mm in Babitonga Bay, the southwestern Atlantic (Pereira *et al.*, 2009) and 103.3 mm in the Southeast coast of Brazil (Severino-Rodrigues *et al.*, 2013). Fisher (2013) reported that size at sexual maturity could vary along the Texas coast, as temperature and salinity vary from bay to bay. At the same time, geographic variations may be affecting the size at sexual maturity. Size at sexual maturity is a common minimum size for retention in decapod fisheries (Cobb and Caddy, 1989). Texas imposes a 127 mm minimum size limit, and harvest of egg bearing females is illegal (Fisher, 2013). The legal size of *C. sapidus* is 130 mm in Turkey. According to the results of the present study the above size could be applicable in order to protect of immature stock, also fishing of egg bearing females should be banned.

Consequently, this study will be probably helpful for future studies on the same species in Turkey and could be used for comparative purposes with studies obtained in other countries.

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