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Growth of blue crab, *Callinectes sapidus*, in the Yumurtalik Cove, Turkey: a molt process approach

Research Article

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Abstract: The blue crab (*Callinectes sapidus*) is native to the western Atlantic, but is an invasive species in the Mediterranean. This study examined the dynamics of growth in an invasive population of blue crab in the Yumurtalık Cove, Turkey (North Eastern Mediterranean). Growth was quantified using a discontinuous growth model, a molt process model. Crab growth histories were observed for individual crabs held in field enclosures in summer 2010 and 2011. Carapace widths ranged from 14.13 to 80.07 mm. A mean growth per molt of 120.6% increase in carapace width was observed. Chronological inter-molt periods ranging between 3 days and 67 days were observed. The average IMP was 16 days in Yumurtalık Cove. The mean physiological IMP was 270±163 degree-days, ranging from 72-781 degree-days.

Keywords: *Blue Crab • Callinectes sapidus • Yumurtalık Cove • Mediterranean*

1. Introduction

The blue crab, *Callinectes sapidus*, is endemic to the western Atlantic basin. It is a widely distributed, estuarine-dependent species that ranges from South America, throughout the Caribbean and the Gulf of Mexico, and along the eastern seaboard of North America as far north as New England [1]. Throughout this range, the blue crab is an important component of estuarine food webs, acting as a dominant, opportunistic benthic predator and scavenger [2]. In turn the blue crab is an important prey for fish, including striped bass (*Morone saxatilis*), red drum (*Sciaenops ocellatus*) and croaker (*Micropogonias undulatus*). Thus the blue crab represents an important link coupling benthic and pelagic food webs [2,3].

In addition to its ecological importance, the blue crab supports important commercial and recreational fisheries throughout much of its range. Within the United States, commercial fisheries exist from Texas to New York, with landings dominated by catches from Maryland, Virginia, North Carolina and Louisiana [4].

In addition to this endemic range, the blue crab has become established as a non-native species in the Mediterranean basin [5]. Holthuis and Gottlieb suggested that *C.sapidus* was transported to the Mediterranean in ships' ballast tanks [6]. The blue crab was first recorded in the Mediterranean in Egyptian waters in the 1940s [7]. Subsequently, it has been reported in the coastal waters of Italy [8], Israel [6], Greece [9] and Turkey [10]. Most recently, it has been reported in the Bay of Biscay, along the northwest coast of Spain [11]. The ecology of the blue crab populations in the Mediterranean has been studied most in Turkish waters, where it is distributed from the eastern side of the Mediterranean Sea northwards to the Black Sea [12]. It has been reported in 15 lagoonal systems along the Turkish coast [13]. These populations now support important commercial fisheries. The fisheries expanded quickly in the 1980s, and the catch reached 46 t in 2010 (http://tuikrapor.tuik.gov.tr/reports). All of Turkey's commercial blue crab landings are reported from the eastern Mediterranean. Due to its high economic value, the distribution and ecology of the blue crab in Turkish waters are receiving more attention [14].

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The ecology and population dynamics of the blue crab across its observed range in US waters have been widely studied [15]. Determining patterns of growth in the blue crab has been an important focus of these studies because of the central role of growth in understanding the life history of a species and its susceptibility to exploitation [16]. Several important aspects of blue crab growth have been documented in the endemic range (*e.g.* [17,18]). As expected, blue crab growth appears to be strongly temperature-dependent [17-19]. At the broadest scales, this temperature-dependency results in a latitudinal pattern in growth [19]. Empirical studies have supported Smith's [19] original meta-analysis indicating that growth ceases below temperatures of approximately 11°C [17]. As a result of latitudinal trends in temperature, blue crabs south of the latitude of approximately 34 N do not experience winter temperatures lower than 11°C and can grow year-round. In contrast, crabs north of approximately 34 N routinely experience winter temperatures below this threshold, and thus exhibit a period of dormancy during winter. This dormancy greatly delays maturation and recruitment to fisheries [18,20]. Within individual systems, temperature variability induces seasonal and inter annual variability in inter-molt periods. One consequence of temperature variation at this scale is inter-annual variability in recruitment to size-limited fisheries [17,20].

Despite many efforts to quantify crab growth using the von Bertalanffy model [21], there is increasing use of a molt process approach to describe the growth in blue crabs [16-18,20]. A principal assumption of the von Bertalanffy model is that growth is continuous. However, crustaceans do not exhibit continuous growth; rather, in these animals growth is discrete and biphasic [17]. The von Bertalanffy model, is likely to be inadequate for defining crustacean growth dynamics [17,22]. A more suitable model that takes into account discontinuous growth would be based on a combination of predicted growth per molt (GPM) and estimates of the frequency of molting [17].

In contrast, despite the extensive body research of the life history of the blue crab within its endemic range, there is little information on aspects of its life history and population dynamics outside of this range. Aspects of life history (*e.g.* maximum size, size at age) and the growth dynamic of the blue crab in Turkish waters are unknown. Here, we report the results of studies on the growth dynamics of the blue crab within the Yumurtalık Cove (Iskenderun Bay, Northeastern Mediterranean, Turkey).

2. Experimental Procedures

We monitored the growth of individual crabs held *in situ* in two sizes of cages in the Yumurtalık Cove in 2010 and 2011 (Figure 1). Crabs were separated by sex and carapace width (CW) into two size classes (small <30 mm, large 30-100 mm carapace width). The animals were randomly assigned to one of three chambers within a 163x43x43 cm mesh enclosure. The larger cages were used to monitor the growth of crabs from 30-100 mm carapace width (CW). Juveniles <30 mm, were monitored in small cages (Figure 2). The small cages were 101x23x23 cm in size and constructed in the same manner as the larger cages. Five large and small

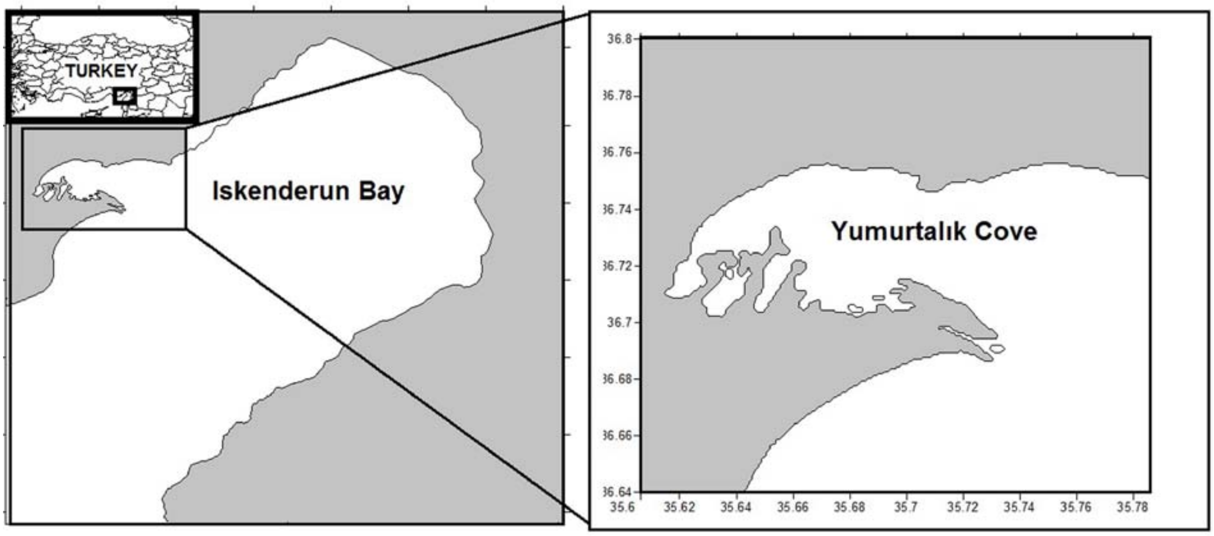

Figure 1. Yumurtalık Cove (Iskenderun Bay, Northeastern Mediterranean-TURKEY).

cages, containing a total of 30 crabs, in as equal a sex ratio as possible, were developed at two sites each year. No food was added to the cages. For the animals in the enclosures, the mesh was assumed to be sufficiently large to permit prey to enter, providing food. Carapace width was measured and each crab was checked daily for signs of molting or death. Water temperature and salinity were recorded daily. The presence of shell remains or a crab with an incompletely hardened new shell was used to determine a molt. After the new shell of a molted crab hardened significantly, the new CW was measured [17]. Dead crabs were removed and replaced with animals of the same size.

Records of CW changes were processed to insulate individuals exhibiting single and multiple molts to determine the growth per molt (GPM, a percentage of pre-molt CW). The GPM was estimated by dividing the post molt CW by the pre-molt carapace size and multiplying by 100 to get the percentage increase in crab size [17]. We estimated the influence of environmental variables on growth using a multiple regression model. We conducted simple linear regressions and stepwise multiple regressions for post-molt size as a function of pre-molt size, location (site), sex, years, temperature, salinity. Statistical signification for simple and stepwise regressions were set at α= 0.001.

We explored patterns in the inter-molt period (IMP) of crabs found in Yumurtalık Cove. We estimated IMP based on both chronological and physiological time. In chronological time, IMP is the period of time, in days, between one molt and the next molt of each crab. Inter-molt period (IMP) estimates were the number of days between observed molting events, based only on those crabs that had molted at least twice in each trial [17]. Additionally, we quantified the physiologic time between molts in degree-days (IMP_{DD}). The chronological inter-molt period changed to physiological degree-day. IMP_{DD} was calculated by subtracting the minimum temperature for torpor (11°C) from the current temperature, as given by the equation:

$$IMP_{DD}=\sum_{i=1} (T_i - 11)$$

Where this summation occurs from the first day after a molt (i=1) to the next molt [23]. Multiple simple regressions were conducted for chronological inter-molt days and physiological degree-day relationships with pre-molt size, sex, years, temperature and salinity as independent variables. Analyses were then refined using stepwise multiple regressions. Statistical signification for simple and stepwise regressions was set at α=0.001. All statistical analyses were conducted with the SPSS computer program(MS Windows, version 10.01.USA: SPSS Inc., 1999).

3. Results

We monitored up to 60 crabs per 2010 trials of 113 days and a 2011 trial of 133 days. Crabs varied from 14.13 to 80.07 mm CW. In 2010, temperature ranged from 16.60-30.40°C, and salinity ranged from 32.40-38.40 psu. In 2011, temperature ranged from 16.60-31.70°C, and salinity ranged from 32.30-38.80 psu. The average monthly temperatures ranged from 25.0-30.24°C in 2010 and 21.3-28.5°C in 2011. The average monthly salinity ranged from 37.3-38.3 psu in 2010 and 36.7-37.4 psu in 2011 (Figure 3). Temperature and salinity were not significantly different between sites (P=0.68).

We observed 124 estimates of GPM (Table 1). The average growth per molt was estimated at

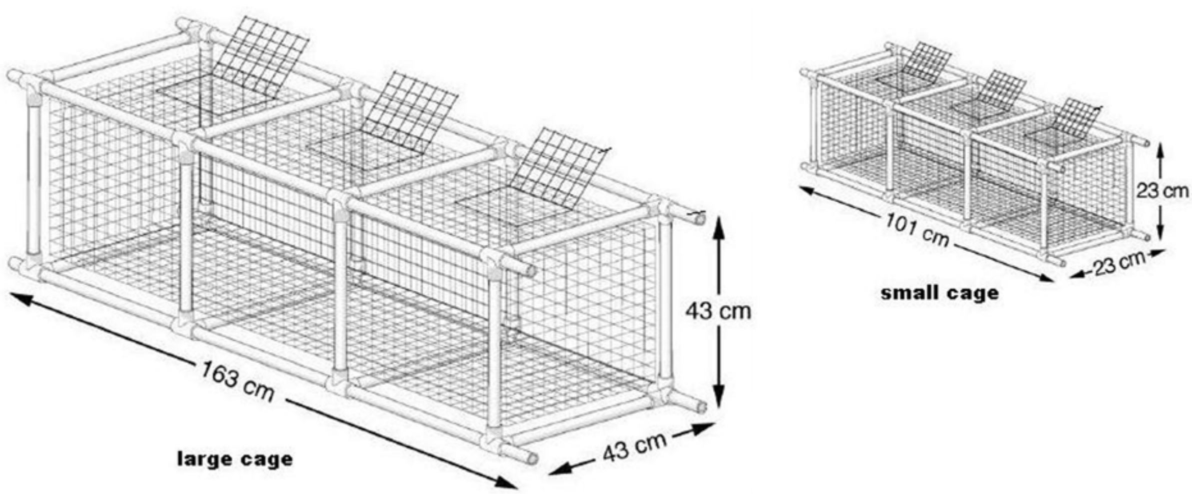

Figure 2. Large and small growth cages [23].

122.0±7.75 (± standard deviation, SD) for juveniles (14.13-25.0 mm CW) and 119.55±5.9 (37.38-71.15 mm CW) for adults in 2010. In 2011, there was growth per molt of 123.3±5.62 for juveniles (19.91-20.22 mm CW) and 117.1±5.89 (40.64-80.07 mm CW) for adults. The lowest observed GPM was a 106.12% increase in CW for a 19.13 mm juvenile crab. The largest GPM was 147.37% for a 16.13 mm juvenile crab in 2010. The average GPM for monitored crabs was 120.6±7.3% of the pre-molt CW overall years. GPM data was highly variable. GPM estimates were normally distributed (Kolmogorov-Smirnov test, $F_{(126)}=1.21$, $P=0.106$). A multiple regression was performed to determine the extent of the effect of pre-molt-size on post-molt size ($P<0.001$, Table 2, Figure 4). A positive and highly

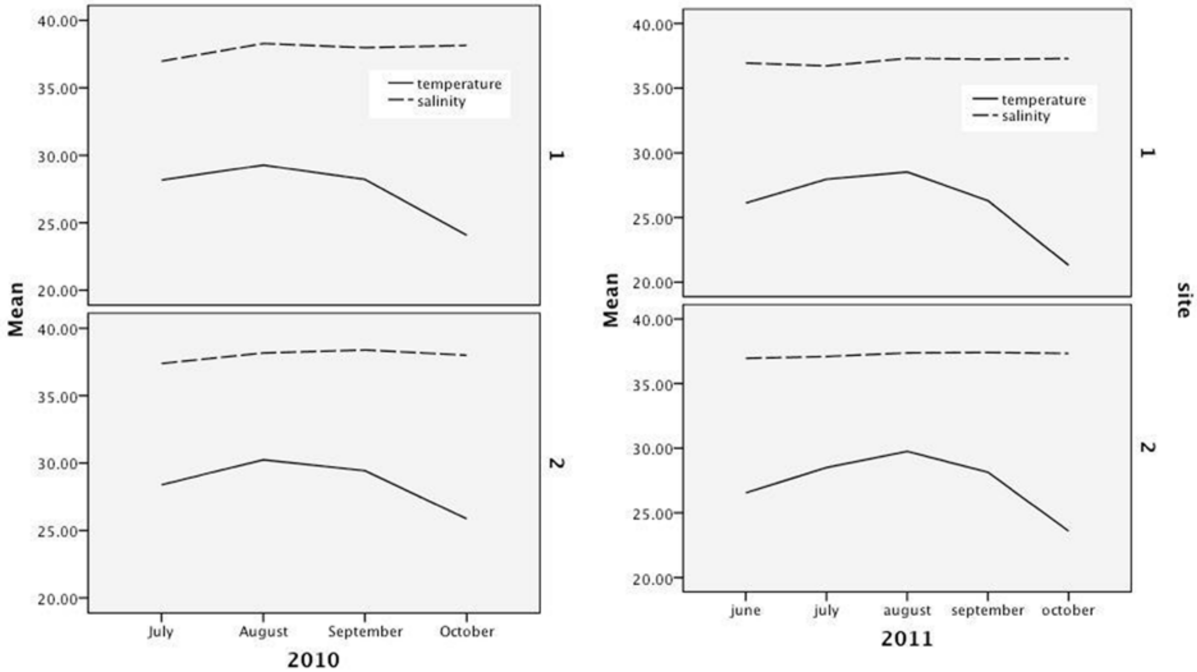

Figure 3. Temperature and salinity series for the Yumurtalık Cove in 2010 and 2011.

Years			GPM observation	Mean GPM	Minimum GPM	Maksimum GPM
2010	First molts	Female	12	119.6±7.8	107.41	137.18
		Male	11	119.4±3.4	114.47	125.80
		Juvenile	29	123.3±8.2	106.12	147.37
	Second molts	Female	3	113.1±5.1	108.48	118.66
		Male	2	110.9±0.7	110.43	111.56
		Juvenile	28	122.8±7.1	112.02	143.17
2011	First molts	Female	10	120.2±6.7	108.64	128.87
		Male	13	114.8±3.9	108.80	122.90
		Juvenile	2	127.3±5.3	123.56	131.06
	Second molts	Female	5	119.1±3.7	113.58	123.26
		Male	7	122.5±5.3	115.70	132.25
		Juvenile	2	119.2±1.6	118.15	120.45
	Overall		124	120.6±7.3	106.12	147.37

Table 1. Number of molts observation, growth per molt (GPM) mean sex class from Yumurtalık Cove of the growth of Blue crabs.

significant (R=0.993, P=0.000) relationship was identified using stepwise regressions defined by the following equation:

$$CW_{post}=1.16*CW_{pre}+1.08$$

In 2010, there were 20 observations of inter-molt in Yumurtalık Cove. Chronological inter-molt periods ranged from 3-67 days. The mean physiological IMP was 232±182, and ranged from 72-781 degree-days. In 2011 there were 15 observations of IMP. Chronological inter-molt periods ranged from 8-33 days. The mean physiological IMP was 335±98, and ranged from 159-540 degree-days. Overall, the mean IMPDD was 270±163 degree-days, ranged from 72-781 degree-days. The average IMP was 16 days in Yumurtalık Cove.

Simple linear regressions showed IMP and IMPDD were significantly related to pre-molt size but not to temperature, salinity, site, year or sex (Table 3, Figure 5). However, a stepwise regression indicated pre-molt size (P=0.000), and year (P=0.00) affected post-molt size. A positive and significant (R=0.726, P=0.000) relationship was identified using stepwise regressions and defined by the following equation:

$$IMP=0.548* CW_{pre} -4.3$$
$$IMPDD=6.663* CW_{pre}+12.9$$

4. Discussion

In this study, we estimate the growth rates of juvenile and adult blue crabs in Yumurtalık Cove using a discontinuous growth model, molt-process, outside of its endemic range. By the end of the experiment in 2010, four crabs had died. In 2011, there were none that had died. Based on 124 molts observed in field conditions, the average growth per molt was estimated to be 120.6±7.3% of pre-molt size, ranged from

Parameter	Estimate	T	P
Intercept	-12.030	-0.504	0.616
Year	-1.534	-1.315	0.193
Site	-0.153	-0.224	0.823
Temperature	0.720	0.928	0.357
Salinity	-0.102	-0.137	0.891
Sex	-0.639	-0.955	0.343
Premolt CW	1.165	35.56	0.000

Table 2. Regression output for growth per molt (GPM) estimates as a function of *Callinectes sapidus* premolt size (CW).

	IMP	IMPDD
Premolt CW	0.000	0.000
Year	0.002	0.008
Site	0.594	0.435
Sex	0.055	0.074
Temperature	0.321	0.348
Salinity	0.699	0.589

Table 3. Summary of IMP and IMPDD p-values for simple regression's results for Yumurtalık Cove blue crabs.

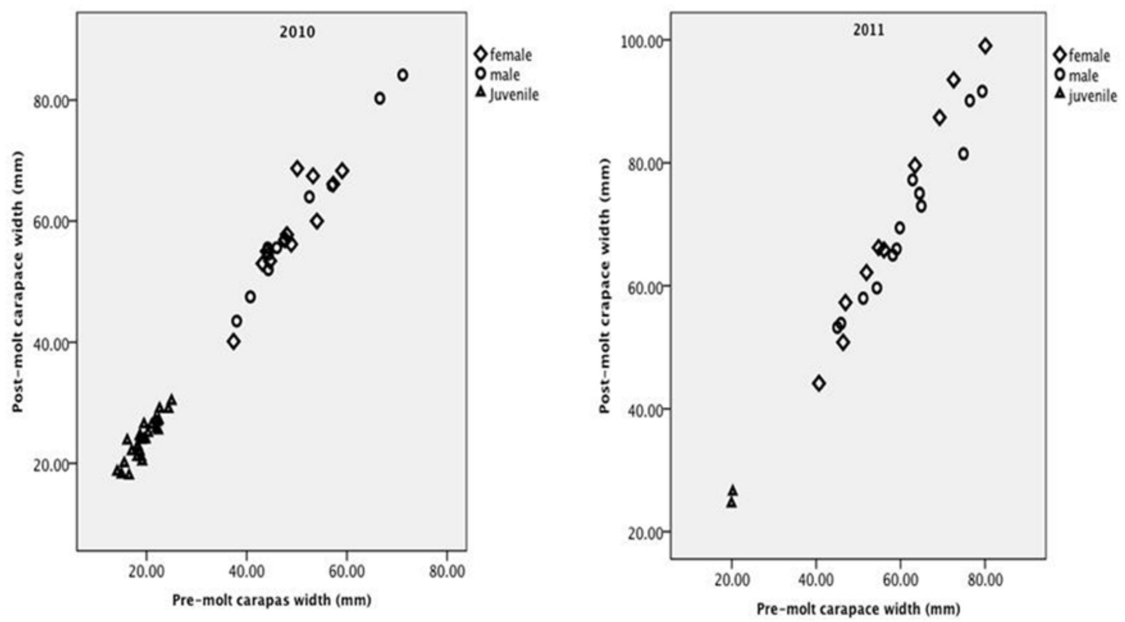

Figure 4. Relationships between pre-and post-molt sizes for 2010 and 2011.

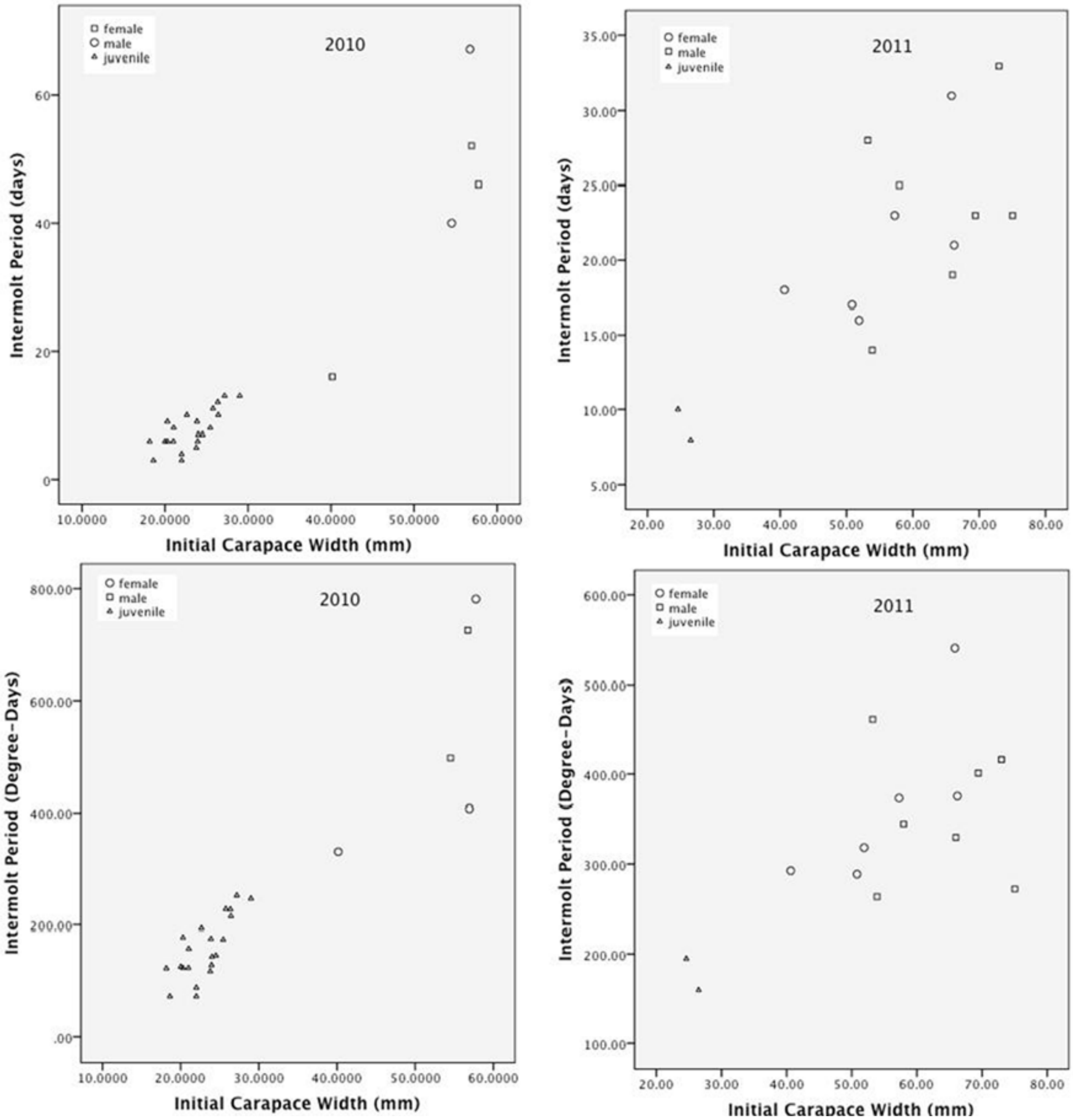

Figure 5. Relationship between pre-molt and intermolt period (days), and intermolt periods (Degree-days).

106.12-147.37%. The average growth per molt was estimated at 122.0±7.75% for juveniles (14.13-25.0 mm CW) and 119.55 ±5.9% (37.38-71.15 mm CW) for adults in 2010. In 2011, there was growth per molt of 123.3±5.62% for juveniles (19.91-20.22 mm CW) and 117.1±5.89% for adults (40.64-80.07 mm CW). An average inter-molt period of 270±163 degree-days was estimated from 35 observations of Yumurtalık Cove.

There have been numerous studies of blue crab growth from within its native range; some studies, such as Leffler [24], estimated GPM at 122%. Fitz and Wiegert's [25] estimate GPM at 120.9%. In other studies, Gray and Newcombe [26] estimated GPM to be 125-133%. Brylawski [27] reported an average growth per molt of 119.4±7.5% for Chesapeake Bay blue crab. Brylawski and Miller [17] estimated 119.5±7.5% of pre-molt size, and t_{min} was determined to be 10.8°C under laboratory and field conditions.

Several studies have indicated that mean GPM is the relatively constant proportional increase of pre-molt CW: 122% [24], 120.9% [25], 119.4% [27] and 122% [22]. Similarly, average GPM for blue crab in the Chesapeake Bay ranged from 117-123% in 2000, and ranged from 118-121% in 1999 and from 119-125% for the Hudson River in 2000 [23]. In our study, our estimate of 120.6±7.3% is comparable to estimates of native populations. Additionally, the variation observed in our GPM estimates is similar to that seen in previous native population studies.

Cheng and Chang [28] suggested that GPM was constrained by the amount of the new cuticle that could be folded under the old exoskeleton. The variability in GPM may be due to a set of biotic (*e.g.* body size) and abiotic (temperature, salinity) factors. In our study, a stepwise regression indicated that only pre-molt size was a significant variable. Puckett [29] suggested that the effects of temperature on GMP were contradictory. Hartnoll [30] generally reported a decrease in GPM with an increase in temperature. Additionally, Brylawski and Miller reported the effect of size and temperature on GMP laboratory conditions [17], but GPM relationship was minimal and not significant in field results. In the Hudson River, temperature was significantly related to post-molt size, but not to GPM. Chesapeake Bay crabs did not exhibit a significant relation between GPM or post-molt size and temperature [23].

A few estimates of T_{min} or IMP are reported in the literature. We assumed that molting ceases below 11°C, yet growth stasis has been reported to occur at 8.9°C [19], 11°C [27], 15°C [31] and 10.8°C [17].

We observed chronological inter-molt periods ranging between 3 days and 67 days. The average IMP was 16 days in Yumurtalık Cove. The average physiological IMP of 270±163 degree-days, from 35 observations, ranged from 72-781 degree-days. Some studies, such as Chenery, estimated that inter-molt periods for the Hudson River ranged from 7-56 days, and from 7-50 days for the Chesapeake Bay [23]. Churchill [32] and Tagatz [31] found that the duration of the inter-molt period increased with increasing carapace width, with inter-molt periods ranging from 11-42 days. The variation observed in our IMP estimates is similar to that seen in previous studies. However, Brylawki and Miller [17] reported highly variable IMP and IMPDD values, ranging between 18-153 days, and the mean IMPDD was 610±259 degree-days (laboratory conditions). Additionally, the average IMP for field animals was 428±121 degree-days.

The IMP and IMPDD did not indicate that temperature, salinity, sex or sites were significant variables. However, a step regression indicated that IMP and IMPDD were significantly related to pre-molt size and year. IMP estimates appear to increase with increasing pre-molt size (Figure 5). Chang *et al.* reported that the estimated IP and IP_{ddays} could also be related to pre-molt size [22]. Eggleston *et al.* [33] reported that the relationship between time first molt and pre-molt-CW were positive, indicating that IMP increases with crab size. In contrast, Brylawki and Miller determined that the field-raised animals showed no significant IMP differences between the different sizes or sex [17]. In addition, inter-molt was significantly related to temperature. IMP decreased as temperature increased. Yumurtalık Cove crabs did not show a similar relationship. This is thought to be due to the lack of significant changes in water temperature during our study. During favourable temperatures for growth, reductions in IMP are complicated by a significant size and temperature interaction, such that IMP increases as size increases, regardless of temperature [29]. Temperature measurements in Yumurtalik Cove water ranged from 15.2 to 31.5°C in 1999 [34]. During the monitoring period of May 2009 to January 2010 water temperature ranged from 17.5-29.7°C [35]. The blue crab in the eastern Mediterranean does not exhibit a period of winter stasis in growth. This supports our interpretation of the data that growth continues throughout the year.

Further research must to be conducted to determine the full dynamics of the blue crab on the Mediterranean coast of Turkey.

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