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SEASONAL AND SEXUAL VARIATION IN CHELIPED MORPHOMETRY AND ANOMALIES OF *CARCINUS AESTUARII* NARDO, 1847 IN THE ÇANAKKALE STRAIT

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Abstract

This study investigates the seasonal and sexual variations in cheliped morphometry and anomalies, including heterocely and cheliped loss, in *Carcinus aestuarii* populations from the Çanakkale Strait. A total of 240 crabs (120 males and 120 females) were sampled seasonally from Çardak Lagoon in 2018–2019 using traditional eel traps. Morphometric measurements of cheliped width, cheliped length, and width were recorded, and cheliped loss patterns were analyzed. Males exhibited significantly larger chelipeds than females, with the right cheliped generally being more dominant. Cheliped loss was more frequent during the breeding season (spring and summer), coinciding with increased predation pressure and competitive interactions. A positive correlation was observed between cheliped width and cheliped dimensions, highlighting sexual dimorphism and functional specialization in cheliped development. These findings provide valuable insights into the ecological functions of heterocely and cheliped loss, emphasizing their implications for crab population dynamics and management strategies. Further studies are recommended to explore the behavioral adaptations and long-term impacts of cheliped anomalies on *C. aestuarii* populations.

Keywords: cheliped, anomaly, heterocely, seasons, *Carcinus aestuarii,* Çanakkale Strait

Introduction

Crustaceans are morphologically distinguished by the presence of a hard exoskeleton (Alencar et al., 2014). Variations in body shape among crabs can yield significant ecological implications and evolutionary patterns in both males and females. The decapod chelipeds serve as a versatile organ, playing crucial roles in foraging, agonistic interactions, mate competition, and manipulation (Lee, 1995). The development of a morphological trait is a product of interactions within ecological and evolutionary processes. Moreover, chelipeds are the most susceptible crab appendage to loss during conflicts, both between and within species (McVean 1976; Shirley and Shirley 1988; Norman and Jones 1991; Abello, 1994). Cheliped dimorphism is common in decapod crustaceans, and many decapod crustaceans have a pair of differently sized chelipeds; that is, one side is larger (major) than the other (minor), a phenomenon known as heterochelia. Foraging, agonistic, and sexual interactions have been recognized as important selection pressures that shape the size and structure of the decapod cheliped (Lee, 1995; Mariappan et al., 2000; Hamasaki, 2022). In carnivorous brachyuran crabs, the major cheliped with molariform teeth is often used to crush hard-shelled prey, while the minor cheliped with incisor teeth is used to manipulate, cut, or groom food (Masunari et al., 2015). Decapod chelipeds are usually larger in males than in females, and males win the competition for females by having larger chelipeds (Emlen, 2008; Hamasaki, 2022).

The causes of cheliped loss in aquatic crustaceans can be diverse and include injury due to predation, fights or territorial disputes, and accidental damage from environmental factors such as rocks or other hard surfaces. In addition, cheliped loss can also be the result of parasitic infections or diseases that affect the integrity and functionality of the cheliped (Sponaugle & Grorud-Colvert, 2006). These factors can result in the partial or complete loss of the cheliped, which can have significant implications for the affected crustaceans. Aquatic crustaceans that lose their chelipede may encounter challenges in predation and self-defence, ultimately affecting their capacity to survive and reproduce effectively (Tully et al., 2003).

The formation of heterochelia has been linked to a number of factors, including sexual dimorphism, allometry and habitat effects, in a variety of crab species (Vermeiren et al., 2020; Hyžný et al., 2020). Studies have highlighted the importance of understanding heterochelia in crabs due to its potential role in functions such as defence, feeding, courtship displays and mate guarding (Quiñones-Llópiz et al., 2021). The species *Carcinus aestuarii* is a shallow-water species that chooses coastal, eelgrass areas as its habitat. Although it is widely distributed along the coasts of our country, it is classified as an invasive species in various geographical regions. A number of biological characteristics and population dynamics parameters of *C. aestuarii* have recently been described for coastal lagoons in Turkey (Özcan et al. 2009; Koçak et al. 2011; Özbek et al. 2012; Acar and Ateş 2020). Baklouti et al. (2013) and Lumare et al. (2009), Cilenti et al. (2014) have also reported the presence of this species in Tunisia and Italy, respectively. However, there is a paucity of studies on heterocely and keliped losses in crabs. This study aimed to determine the anomalies, structure and ratios of keliped structures according to sex in individuals of this species, which has become cosmopolitan and more important, exhibiting a worldwide distribution.

Material and Methods

Carcinus aestuarii samples were collected (Çanakkale Strait) seasonally in Çardak Lagoon in June 2018, October 2018, February 2019 and May 2019 using a static traditional eel trap. Crabs were sampled as 60 individuals per season. Crab individuals were collected from the lagoon area with traditional eel pinter.

The morphometric measurements of the crabs (cheliped width, right cheliped length and width, left cheliped length and width) were measured in mm using a digital caliper. The cheliped loss in the examined crab samples were classified as right missing, left missing, both missing, and both present. The cheliped losses were compared between sexes and length groups by performing Pearson chi-square tests.

Results

Morphometric measurement of Crab

A total of 240 individuals (120 females and 120 males), were examined. Several morphometric measurements of the crabs are shown in Table 1. The average cheliped length (CL) was 45.38±0.68 mm, the mean cheliped width (CW) was 37.59±0.56 mm and the mean weight was 29.77±1.3 g. For females, the average cheliped length is 45.01 mm, with a range of 34.3 to 58.95 mm. The average cheliped length is 45.38 mm, with a range of 30.36 to 65.92 mm for males. Males tend to have slightly larger average cheliped lengths and widths compared to females ($p < 0.05$).

Table 1. Morphometric measurements in *C. aestuarii* (min-max and mean±SE)

		Cheliped length		Cheliped width		Weight	
	N	CL (mm)	CL (min-max)	CW (mm)	CW (min-max)	W (g)	W (min-max)
Female	120	45,01±0,68	34,3-58,95	37,31±0,94	28,16-48,97	29,16±2,20	11,64-88,19
Male	120	45,38±0,85	30,36-65,92	37,59±0,69	16,49-53,64	29,77±1,62	10,59-58,76
Total	240	45,38±0,68	30,36-65,92	37,59±0,56	16,49-53,64	29,77±1,3	10,59-88,19

A total of 240 crab specimens were examined. The examined crab samples were classified into four groups according to the number and side of cheliped loss. Of the 240 crab individuals examined, 160 had both chelipeds intact, 46 were missing the left cheliped, 30 were missing the right cheliped, and 4 were missing both chelipeds. Among the male individuals, 28 left chelipeds and 17 right chelipeds were missing. In the female individuals, 14 left chelipeds and 13 right chelipeds were missing.

Table 2. Mean length of cheliped by sex (mm)

	Right Cheliped			Left Cheliped		
Sex	RCL min	RCL max	RCL mean (mm)	LCL min	LCL max	LCL mean (mm)
Female	1,89	16,25	14,65±0,25	1,24	19,87	12,35±0,45
Male	2,54	24,65	30,5±0,51	1,98	21,16	28,82±0,82
Total	3,25	25,54	21,66±0,31	2,89	26,12	17,98±0,29

Table 2 presents the distribution of right (RCL) and left cheliped lengths (LCL) according to gender. The mean right cheliped length was found to be 14.65 ± 0.25 mm in females, 30.5 ± 0.51 mm in males and 21.66 ± 0.31 mm in males. The length of the left cheliped was recorded as 12.35 ± 0.45 mm in females, 28.82 ± 0.82 mm in males and 17.98 ± 0.29 mm on average. The mean length of the right cheliped in males is significantly greater than that of females (30.5 mm vs. 14.65 mm). A similar trend is observed for the left cheliped, with males exhibiting a longer mean length than females (28.82 mm- 12.35 mm).

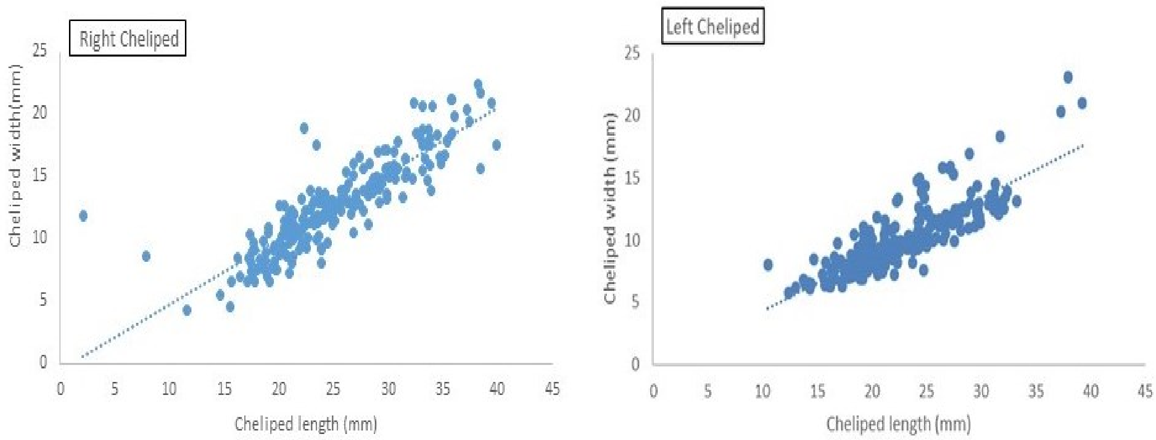

Figure 2. Cheliped length and width relative to right and left in *Carcinus aestuarii*

A positive correlation exists between the length and width of the right cheliped. As the length of the cheliped increases, so too does its width. The data set encompasses a broad range of cheliped lengths (0–40 mm) and widths (0–25 mm). A strong linear relationship between width and length is observed in the right cheliped. Similarly, a positive correlation is observed between length and width in the left cheliped. The data pertaining to the left cheliped are also distributed over a wide range of length (10–35 mm) and width (5–20 mm). In the left cheliped, a clear linear relationship is observed between width and length, with a slightly narrower distribution compared to the right cheliped.

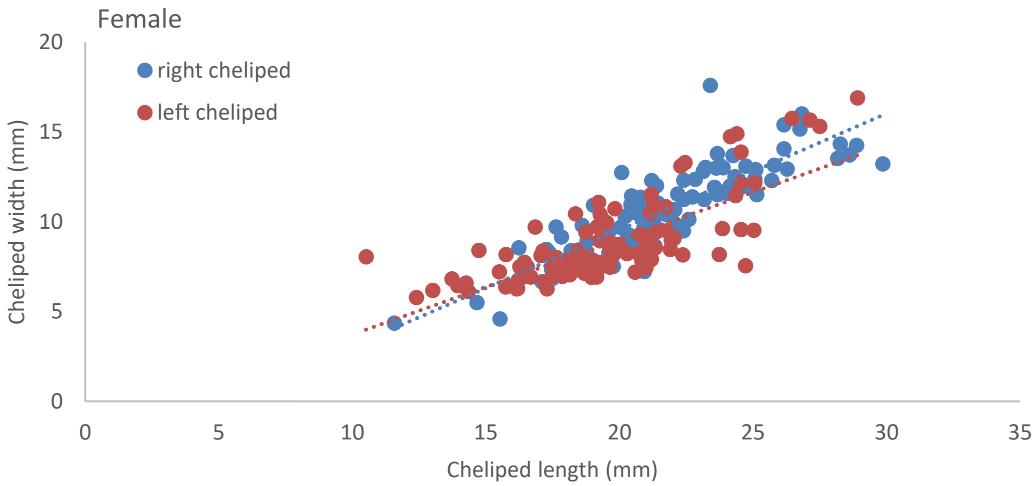

Figure 3. Cheliped length and width for female crabs

The graph shows the relationship between the length (x-axis) and width (y-axis) of the right (blue dots) and left (orange dots) cheliped in female crabs. For both the right and left cheliped, the width increases as the length increases. This indicates a positive correlation between cheliped length and width. The graph shows that there is a positive correlation between right and left cheliped lengths and widths in female crabs and that they are generally symmetrical.

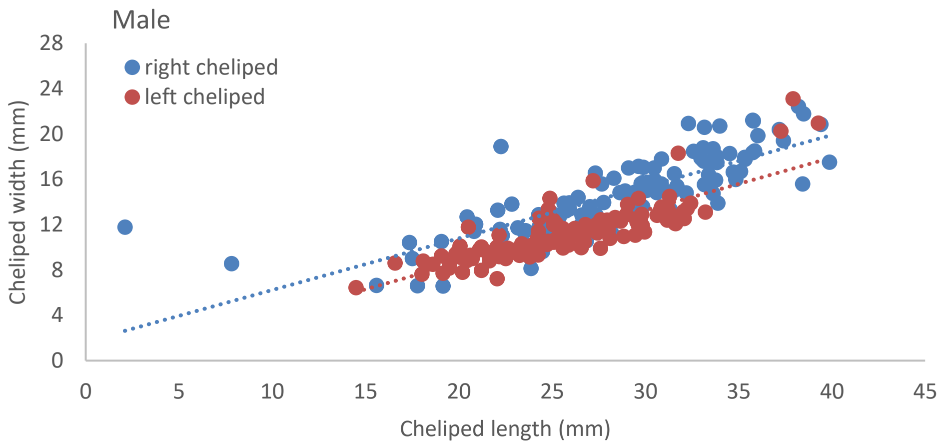

Figure 4. Cheliped length and width for male crabs

Cheliped Loss and Heterocely by season

In the present study, Table 3 demonstrates that cheliped loss and heterocely rates in Carcinus aestuarii are highest during spring and summer due to the breeding season and increased predation pressure. In spring, moderate cheliped loss (18 individuals) and high heterocely rates (34 individuals) reflect the onset of reproduction and competition. In summer, both rates peak (32 and 38 individuals, respectively) due to heightened predation and active mating behaviors. In contrast, these rates decline in autumn (16 and 20 individuals) as the crabs enter a recovery phase post-breeding and further decrease in winter (10 and 8 individuals) during dormancy, with reduced activity and predation pressure.

Table 3. Cheliped losses and heterocely rates by season

Seasons	Cheliped Loss (N)	Heterocely (N)	Cheliped Loss	Heterocely	Possibility
Spring	18	34	Medium	High	Start of breeding season, increased growth rate, competition
Summer	32	38	High	High	Increased predation pressure, active breeding season, high growth rate
Autumn	16	20	Medium	Medium	Recovery post-breeding season, cheliped regeneration
Winter	10	8	Low	Low	Low activity, decreased predation pressure, winter dormancy and energy conservation

Discussion

Research on heterocely in crabs helps us understand the effects of this trait in different species. Understanding heterochely helps us learn about crab biology, behaviour and how they adapt to different environments (Lee, 1995; Mariappan et al., 2000; Masunari et al., 2015; Hamasaki, 2022). Many things affect how cheliped develop. A number of biotic and abiotic factors influence cheliped development. Claws are particularly susceptible to autotomy, and their regeneration places a significant burden on the animal's regular energy budget, which in turn affects other regular somatic and reproductive processes. This demonstrates that the various functional and structural modifications of chelipeds are influenced not only by feeding and movement patterns, but also by environmental conditions and species (Abello et al., 1994).

The regeneration process of crab claws may vary by species and crab. Some crabs have the ability to regenerate their claws, while others may not have the same regenerative abilities (Pickering and Quijón, 2010). As previously reported for *C. maenas* populations, the proportion of Carcinus maenas with missing or regenerating chelipeds was significantly higher in males than in females (Abello et al., 1994). Crabs experiencing cheliped loss may exhibit adaptive behaviours to compensate for the loss of primary means of predation and defence. For example, they may rely more on their remaining claws to capture and manipulate food or engage in territorial disputes. Furthermore, crabs may change their foraging strategies or search for different prey species that are easier to catch and hold without using their claws (Flynn et al., 2015). In addition, research has shown that regenerated claws may not be as strong as the original claw, potentially affecting the crab's ability to effectively capture and manipulate prey (Juanes & Smith, 1995). This finding is consistent with the results observed in *Carcinus aestuarii*, where males tend to possess larger chelipeds and exhibit a higher incidence of cheliped loss, particularly during the breeding season when agonistic interactions and competitive behaviours reach their peak. This suggests that males, due to their frequent involvement in territorial disputes and mating-related conflicts, are more susceptible to claw loss than females.

The demonstration that males have larger, more robust chelae for a given size class of *C. maenas* is consistent with previous observations in this species (e.g. Elner 1980; Lee & Seed 1992). This finding is consistent with those of other studies on the same species (Behrens, Yamada, & Boulding, 1998; Paul, 1999; Schenk & Wainwright, 2001). Based on previous observations in the literature (Elner 1980; Bourdeau & O'Connor 2003; Cotton et al. 2004), it has been postulated that female crabs, due to their smaller chelae and consequently less crushing force (Kaiser et al. 1990), should favour prey with less handling time or requiring less force to crush. It has been demonstrated that the loss of one or both mandibles can have a significant impact on a crab's capacity to forage and defend itself from predators (Abello et al., 1997). The data show that male green crabs have significantly longer cheliped than females for both their right and left cheliped. This sexual dimorphism in cheliped size may be related to different ecological roles, behaviours such as mating competition, or predatory habits. Greater variability in male cheliped length may indicate a wider range of roles or strategies that males use in their natural habitat. Understanding these differences is crucial for ecological studies and developing management strategies for green crab populations. As a result, crabs that experience chela loss may have reduced feeding success and increased vulnerability to predation.

In addition to physical impacts, cheliped loss can also affect the reproductive success of crabs. In species where males use their chelipeds for courtship displays and competition for mates, individuals with cheliped loss may have reduced mating opportunities and overall reproductive success may decline. In addition, loss of chelae can upset the balance of power within a crab population. Crabs with intact cheliped are more likely to be successful in securing resources and mates, leading to a higher level of fitness. Research has shown that cheliped loss can indeed have a negative effect on mating success in male shore crabs (Juanes and Hartwick, 1990). This suggests that intact cheliped are crucial for successful mating interactions in male shore crabs. Additionally, the morphology and function of reproductive systems in crabs are significant for reproductive success. Studies have demonstrated that host feminization in green crabs, like Carcinus maenas, can result in reductions in copulatory appendages and cheliped size, potentially impacting mating interactions (Kristensen et al., 2012). In this study, as in others, a greater incidence of kelipet loss was observed in males. The impact of reproductive success on this phenomenon requires further investigation.

Seasonal changes significantly affect the rates of cheliped loss and heterocely in crabs. Cheliped loss are generally associated with environmental stress, predation pressure and reproductive competition. Heterocely varies depending on growth rates, mating competition and environmental conditions. In spring and summer, cheliped losses and heterocely are at high levels due to the reproductive period and increased predation pressure, while these rates decrease in autumn and winter (Johnson & Heck, 2006; Smith et al., 2014). This study showed similar results with the literature and it was observed that the highest cheliped loss and heterocely occurred in summer. In autumn and winter, it was observed that both cheliped loss and heterocely decreased and growth slowed down.

The approach to which cheliped to use in morphometric studies is more complex because it presents heterocely. It has been found that in many heterochelous crab species the major cheliped is usually on the right side. Normally both sexes of heterochelous species show heterocely, but sexual dimorphism of cheliped (where males have generally larger cheliped than females of equivalent size) is also often present (e.g. in *C. maenas*) (Abby-Kalio & Warner, 1989). There is a positive correlation between length and width in both chelipeds. This indicates that as the crabs' chelipeds grow, the width of the cheliped also increases. This may indicate that the crabs' chelipeds grow proportionally for both defence and feeding. Although a generally similar relationship was observed between the right and left chelipeds, the right cheliped showed a wider distribution and higher maximum width values (up to 25 mm). This may indicate that the right cheliped may be a more dominant or more actively used cheliped. The distribution of the left cheliped was narrower and the maximum width values (up to 20 mm) were lower, which may indicate that this pincer is less dominant or used for specific tasks.

Conclusion

In conclusion, the knowledge that *C. aestuarii* is heterocely and predominantly right-handed provides a basis for understanding its ecological functions. Our allometric growth analyses also revealed intrasexual and intersexual shape and size dimorphism in major and minor chelipeds; females had major and minor cheliped with similarly shaped cheliped, while males enlarged their major cheliped, leading to larger cheliped with increasing body size. In order to elucidate the ecological functions of heterocely and to ascertain whether hand preference is present in *C. aestuarii*, it is necessary to conduct laboratory experiments in which the behaviour of major and minor chelipeds involved in intraspecific agonistic and sexual communication is detailed for both sexes. Further research on the long-term effects of the loss of cheliped on crab populations and its potential impacts on conservation and management strategies is essential to maintain the health and stability of crab populations in their natural habitats.

Ethical approval

Not applicable

Informed consent

Not available

Data availability statement

The author declares that data can be provided by the corresponding author upon reasonable request.

Conflicts of interest

There is no conflict of interests for publishing this study.

Funding organizations

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