

Seasonal variation, shell selection, and morphometric relationships of the hermit crab *Clibanarius erythropus* on the rocky shores of Tolmeitha, eastern Libya

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Abstract

This study investigated four main aspects of the hermit crab *Clibanarius erythropus* along the rocky shores of Tolmeitha, eastern Libya. Monthly sampling was conducted from June 2023 to May 2024 using quadrats on subtidal rocky bottoms. A total of 46 crabs were collected across all sampling events. The first objective examined seasonal variation in density, body weight, and carapace length. Density varied significantly among seasons, with the highest values in summer and the lowest in winter. Body weight peaked in spring, while carapace length showed no significant seasonal change. The second objective identified the gastropod shell species occupied by this crab. Nine gastropod shell species were recorded, with *Phorcus articulatus* being the most frequently occupied shell, particularly in summer. The third objective described the demographic structure. Adults dominated the population, and the sex ratio did not differ from equality, with ovigerous females present across seasons. The fourth objective quantified morphometric relationships between crab size and shell dimensions. Positive correlations were observed between crab length and shell length, crab weight and shell weight, and shield length with both shell length and shell width. The relationship with shell width was stronger than that with shell length. These results fill a specific knowledge gap for the Tolmeitha coast, as no previous study has documented shell selection patterns or population structure of *C. erythropus* in this part of eastern Libya. This baseline provides a reference for future monitoring of intertidal communities in the southern Mediterranean, particularly in understudied coastal areas of North Africa.

Keywords: *Clibanarius erythropus*; hermit crab; seasonal variation; shell occupation; gastropod shells; population structure; morphometric relationships; Mediterranean Sea; Libya.

التغير الموسمي، اختيار الأصداف، والعلاقات المورفومترية للسرطان الناسك *Clibanarius*

erythropus على الشواطئ الصخرية لظلمية، شرق ليبيا

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الملخص

بحثت هذه الدراسة أربعة جوانب رئيسية لسرطان الناسك *Clibanarius erythropus* على طول الشواطئ الصخرية لمنطقة ظلمية بشرق ليبيا. تم جمع العينات شهرياً خلال الفترة من يونيو 2023 إلى مايو 2024 باستخدام مربعات (كوادرات) في القيعان الصخرية تحت منطقة المد والجزر. بلغ إجمالي عدد العينات المجمعة 46 سرطاناً. الهدف الأول كان دراسة التغير الموسمي في الكثافة ووزن الجسم وطول الدرع الصدري. اختلفت الكثافة بشكل معنوي بين الفصول، إذ كانت أعلى القيم في الصيف وأدناها في الشتاء. بلغ وزن الجسم ذروته في الربيع، بينما لم يُظهر طول الدرع الصدري تغيراً موسمياً. أما الهدف الثاني فتمثل في تحديد أنواع أصداف بطنيات القدم التي يسكنها هذا السرطان. تم تسجيل تسعة أنواع من الأصداف، وكان *Phorcus articulatus* الأكثر استخداماً، خاصة في الصيف. الهدف الثالث وصف البنية السكانية، حيث سيطرت الأفراد البالغة على المجتمع، وكانت النسبة الجنسية متوازنة (1:1)، مع تواجد الإناث الحاملة للبيض على مدار الفصول. الهدف الرابع قاس العلاقات المورفومترية بين حجم السرطان وأبعاد الصدفة. لوحظت علاقات طردية بين طول السرطان وطول الصدفة، ووزن السرطان ووزن الصدفة، وطول الدرع مع كل من طول الصدفة وعرضها. وكانت العلاقة مع عرض الصدفة أقوى من العلاقة مع طولها. تسد هذه النتائج فجوة معرفية محددة لساحل ظلمية، حيث لم تقم أي دراسة سابقة بتوثيق أنماط اختيار الأصداف أو البنية السكانية لهذا النوع في هذا الجزء من شرق ليبيا. يوفر هذا البحث خطأً أساسياً للرصد المستقبلي للمجتمعات الساحلية في جنوب البحر المتوسط، خاصة في المناطق الساحلية غير المدروسة من شمال قارة أفريقيا.

الكلمات المفتاحية: *Clibanarius erythropus*؛ سرطان الناسك؛ التغير الموسمي؛ إستيطان

الأصداف؛ أصداف بطنيات القدم؛ البنية السكانية؛ العلاقات الشكلية؛ البحر المتوسط؛ ليبيا.

Introduction

Hermit crabs (infraorder Anomura, superfamily Paguroidea) are among the most distinctive and ecologically significant decapods in intertidal and subtidal habitats worldwide (Reese, 1969; Hazlett, 1981). They have colonized a wide range of environments, from rocky shores and mangroves to coral reefs and estuaries, which has driven diverse behavioural and physiological adaptations (Bracken-Grissom et al., 2013; Tudge et al., 2012). One of their most remarkable features is their dependence on empty gastropod shells for shelter. A suitable shell protects the soft, uncalcified abdomen from predators, reduces desiccation during low tide, provides space for brooding eggs in females, and offers defence against aggressive conspecifics (Vance, 1972; Bertness, 1981; Oliveira et al., 2018).

Because hermit crabs cannot produce their own shells, they rely entirely on shells provided by gastropod mortality. This makes shell availability a limiting resource that can strongly influence population density, growth rates, and reproductive success (Vance, 1972; Bertness, 1981). Hermit crabs are known to assess multiple shell characteristics before occupying a shell, including weight, internal volume, aperture width and length, and even colour (Rotjan et al., 2004). In many species, individuals actively compete for better shells, and shell exchange often involves complex behavioural negotiations (Hazlett, 1983; Elwood & Neil, 1992).

One of the most common hermit crab species in the Mediterranean Sea and the eastern Atlantic is *Clibanarius erythropus* (Latreille, 1818). It inhabits rocky shores from Brittany to the Azores and throughout the Mediterranean (Benvenuto & Gherardi, 2001). Population structure, shell use, and larval development of this species have been studied in various locations, including Italy, France, and Spain (Gherardi, 1991; Benvenuto & Gherardi, 2001). Ecologically, *Clibanarius erythropus* plays a significant role in benthic food webs as a scavenger and detritivore, contributing to nutrient cycling and energy transfer in rocky intertidal zones (Benvenuto et al., 2003).

However, along the Libyan coast, particularly in the eastern region, no ecological study has yet investigated the shell selection patterns or population dynamics of *C. erythropus*. This represents a clear knowledge gap for the southern Mediterranean basin, where baseline data on intertidal invertebrate communities are scarce. The Tolmeitha coast, with

its rocky shores and mixed sandy rocky substrates, offers a typical habitat for *C. erythropus* and numerous gastropod species, making it an ideal site to study hermit crab shell selection and population dynamics.

The present study aimed to fill this knowledge gap by examining seasonal variation in density, body weight, and carapace length of *C. erythropus*. One objective was to identify the gastropod shell species occupied by this hermit crab and to assess any seasonal changes in occupancy. The study also aimed to describe the demographic structure including sex ratio and the proportion of adults, juveniles, and ovigerous females. Additionally, the study aimed to quantify the morphometric relationships between crab size (length, weight, shield length) and shell dimensions (length, width, weight).

Materials and methods

Study area

The study was conducted at Tolmeitha, a coastal village situated in the northern Cyrenaica region of eastern Libya. The site lies approximately 30 km east of Almerj (Berqa) at coordinates 32°42'19.48"N, 20°56'41.09"E. The shoreline in this area is predominantly rocky, and the substrate consists of a mixture of sandy and rocky soil (Figure 1).

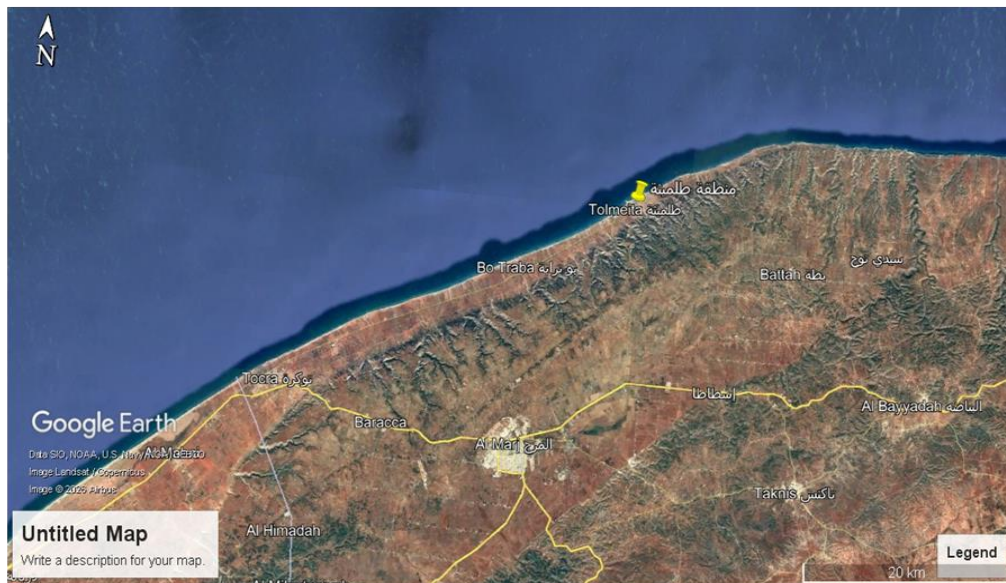


Figure 1. Showing the location of Tolmeitha city on the Mediterranean Sea coast of Libya . Experimental procedure Crabs were collected by hand using a quadrat of 1 m × 1 m, replicated three times at each sampling event. Sampling was conducted monthly and randomly in different sites on subtidal rocky bottoms at depths ranging from 20 cm to 3

m, over the period from June 2023 to May 2024. A total of 46 individual crabs were collected during the study period. Each shell was inverted and examined for several seconds to determine whether it is live, occupied, or empty. Live gastropod shells have an operculum, empty shells without a live gastropod, and for occupied shells, the hermit crabs reveal their legs or antennae when shells are inverted. All specimens preserved in 10% seawater formalin, then transported to the laboratory. In the laboratory; crabs were removed carefully from their shells using forceps. The gastropod shells were identified following the classification of Giannuzzi-Savelli et al. (1994, 1997). Shell length (SL) and width (SW) were measured. Also shell weight (ShW) was estimated after removing the crab. Crab specimens were measured for cephalothoracic shield length (CSL = from the tip of the rostrum to the groove at the posterior edge), total length of crab and weighed (WW = wet weight). All Measurements were made with a caliper (nearest 0.01mm) under a stereoscopic microscope. Specimens were sexed by the position of gonopores on the pereopods: on the third pair for males and on the fifth pair for females. Ovigerous females were identified by the presence of eggs on the pleopods. Cephalothoracic shield length (CSL) was measured from the tip of the rostrum to the posterior groove of the shield. Based on the criterion of Lima et al. (2014), the smallest CSL recorded among ovigerous females was 3.1 mm. Individuals with $CSL < 3.1$ mm were classified as juveniles regardless of sex, while those with $CSL \geq 3.1$ mm were considered adults and further confirmed by the presence of distinct gonopores. Accordingly, five demographic categories were established: juvenile, adult male (AM), adult female (AF), ovigerous female (OF), and non-ovigerous female (NOF).

Statistical analysis

One-way analysis of variance (ANOVA) was used to test for significant differences among seasonal groups (density, body weight, carapace length, and shell occupancy), followed by Tukey's post-hoc test for pairwise comparisons. Two-sample t-tests compared the mean numbers of males versus females, ovigerous versus non-ovigerous females, and adults versus juveniles. A one-way ANOVA also tested for differences in occupancy among shell species. Pearson correlation and linear regression were used to examine relationships between crab size and shell dimensions. All tests were performed with significance set at $\alpha = 0.05$ using MINITAB 17 software.

Results and Discussion

Seasonal variation in hermit crab density, weight, and length

A total of 46 individual crabs were collected during the study period (June 2023 – May 2024). Sampling was conducted using three quadrats (1 m² each) per season. Seasons were defined as: summer (June–August), autumn (September–November), winter (December–February), and spring (March–May). The number of crabs collected per season was: summer (17 crabs), autumn (9), winter (11), and spring (9).

A one-way ANOVA (n = 3 quadrats per season) tested whether crab density (individuals per m²) differed among seasons and showed a significant seasonal effect ($F_{3,8} = 4.32$, $p = 0.043$). Summer had the highest mean density (5.67 ± 1.20 ind. m⁻²), which was significantly greater than winter (3.67 ± 0.88 ind. m⁻²). Spring (3.00 ± 0.58 ind. m⁻²) and autumn (3.00 ± 0.58 ind. m⁻²) showed intermediate values (Figure 2).

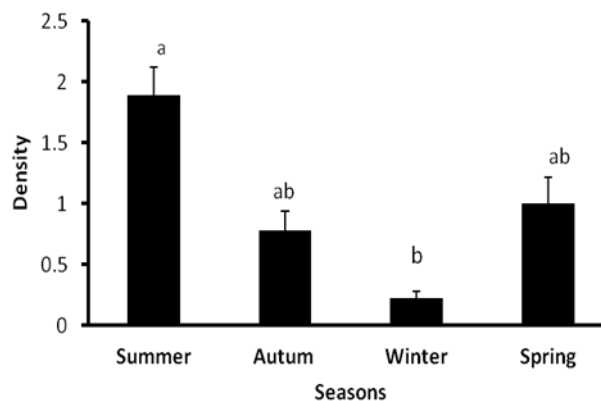


Figure 2. Mean \pm SE density of *Clibanarius erythropus* across four seasons. Values with different letters differ significantly.

The seasonal pattern of *Clibanarius erythropus* density, with a peak in summer and a minimum in winter, is consistent with previous findings from other Mediterranean localities (Benvenuto & Gherardi, 2001; Hazlett, 1981). Warmer water temperatures in summer increase metabolic rates, foraging activity, and movement, while the winter decline may be caused by reduced food availability, lower temperature, or migration to deeper waters (Turra & Leite, 2000). The dominance of *C. erythropus* in summer suggests that this species plays a key role in the rocky intertidal food web during the warm season, potentially competing with other invertebrates for shelter and food resources. Its high

abundance during peak tourist season also implies that anthropogenic disturbance may affect its population dynamics, though this hypothesis requires further investigation.

Wet weight (g) also varied significantly across seasons ($F_{3,8} = 9.03$, $p = 0.006$). Spring ($n = 9$) had the highest mean weight (1.67 ± 0.04 g), significantly heavier than winter (0.68 ± 0.20 g, $n = 11$), summer (0.48 ± 0.04 g, $n = 17$), and autumn (0.21 ± 0.05 g, $n = 9$) (Figure 3). In contrast, carapace length (mm) did not show significant seasonal differences ($F_{3,8} = 0.19$, $p = 0.903$). Mean lengths were: autumn 20.70 ± 1.6 mm ($n = 9$), spring 20.80 ± 1.5 mm ($n = 9$), summer 20.08 ± 2.5 mm ($n = 17$), and winter 16.07 ± 4.9 mm ($n = 11$) (Figure 4).

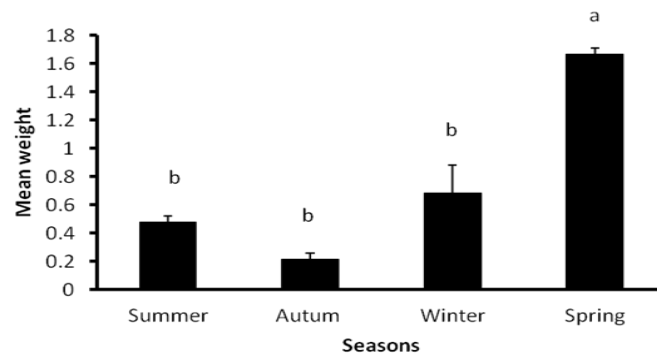


Figure 3. Mean \pm SE weight of *Clibanarius erythropus* across four seasons. Values with different letters differ significantly.

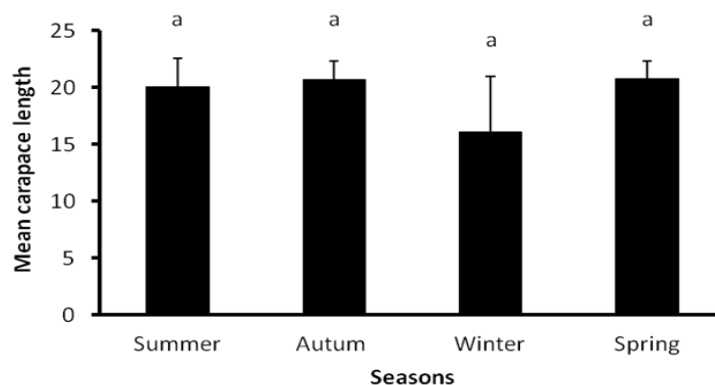


Figure 4. Mean \pm SE carapace length of *Clibanarius erythropus* across four seasons. Values with the same letter did not differ significantly.

Body weight peaked in spring, which did not coincide with the summer peak in density. This suggests that crabs accumulate energy reserves during spring, most likely in preparation for reproduction. A spring weight increase prior to the breeding season has

been documented in *C. erythropus* from other areas, where gonadal development begins in spring (Benvenuto & Gherardi, 2001). In the Mediterranean, ovigerous females of *C. erythropus* appear in late spring and early summer (Gherardi, 1991). The absence of seasonal variation in carapace length implies that the size structure of the population remains stable. Therefore, the weight changes are not due to larger individuals appearing seasonally but probably reflect better nutritional condition or higher water content in spring (Hazlett, 1981). This pattern has also been observed in other hermit crab species (Vance, 1972; Bertness, 1981).

Sex ratio and demographic composition

Among the 46 individuals, 25 were males, 14 were females (9 non-ovigerous, 5 ovigerous), and 7 were juveniles (as defined below). The sex ratio (25 males : 14 females) did not deviate significantly from 1:1 ($p > 0.05$, Figure 5). No significant difference was detected between the mean number of ovigerous and non-ovigerous females per quadrat ($t_{21} = 0.97$, $p = 0.345$, $n = 22$ quadrats total; Figure 6), the analysis was performed on quadrat means ($n = 22$ quadrats total). The smallest ovigerous female had a cephalothoracic shield length (CSL) of 3.1 mm. Following Lima et al. (2014), all individuals with $CSL < 3.1$ mm were considered juveniles. Based on this criterion, 7 individuals (all with $CSL < 3.1$ mm) were classified as juveniles. Adults ($CSL \geq 3.1$ mm) numbered 39 individuals. The mean number of adults per quadrat (3.25 ± 0.48 , $n = 12$ quadrats) was significantly higher than that of juveniles (0.58 ± 0.19 , $n = 12$ quadrats) ($t_{22} = 5.61$, $p < 0.001$, Figure 7)

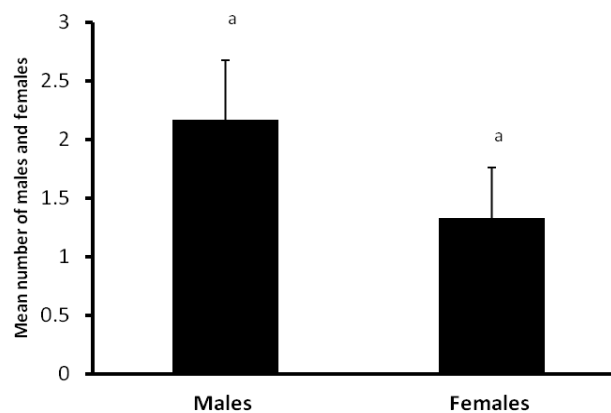


Figure 5. Mean \pm SE numbers of female and male *Clibanarius erythropus* across all seasons. Values with the same letter did not differ significantly.

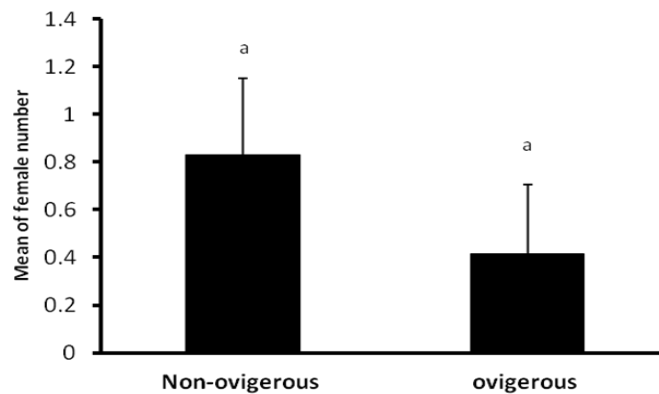


Figure 6. Mean \pm SE numbers of Non-ovigerous and ovigerous females of *Clibanarius erythropus* across all seasons. Values with the same letter did not differ significantly.

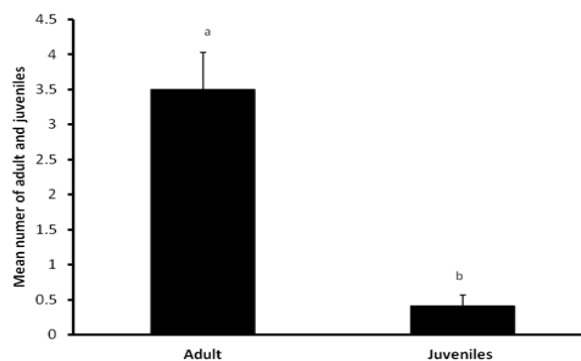


Figure 7. Mean \pm SE numbers of adults and juveniles of *Clibanarius erythropus* across all seasons. Values with different letters differ significantly.

The sex ratio (25 males : 14 females) did not deviate significantly from 1:1, which is consistent with many hermit crab populations (Hazlett, 1981). In the Gulf of Tunis, Benvenuto and Gherardi (2001) found a slight female bias in *C. erythropus*, but the difference was not consistent across all seasons. Our finding of a balanced ratio suggests that no sex-specific bias occurs in this part of the Libyan coast. The similar abundance of ovigerous and non-ovigerous females may indicate that breeding females are present throughout most of the year. However, the sample size may not have been sufficient to detect seasonal peaks in ovigerous female abundance. In other Mediterranean sites, ovigerous females of *C. erythropus* are most common in late spring and summer (Gherardi, 1991; Benvenuto & Gherardi, 2001). The absence of a clear peak in our data could be due to the relatively small sample size or to a longer breeding season in the

southern Mediterranean. A more cautious interpretation is that reproduction may occur over an extended period, but additional sampling with larger numbers is needed to confirm this pattern.

This dominance of adults over juveniles across all seasons could be explained by several factors. Juvenile hermit crabs often occupy different microhabitats, such as intertidal pools or very shallow water (Reese, 1969). The present study sampled subtidal rocky bottoms from 20 cm to 3 m depth, which may have missed the preferred nursery areas of juveniles. Another possibility is that juvenile mortality is high or that recruitment occurs in a very narrow time window. Similar adult-dominated populations have been reported for *C. erythropus* in the Mediterranean (Benvenuto & Gherardi, 2001) and for other hermit crab species (Turra & Leite, 2000).

Shell-occupying gastropod species: abundance and seasonal occupancy

Nine gastropod shell species were occupied by *C. erythropus* (Figure 8). One-way ANOVA ($n = 3$ quadrats per season) showed that most species exhibited no significant seasonal variation. The only species with a significant seasonal difference was *Phorcus articulatus* ($F_{3,8} = 4.75$, $p = 0.035$). Its mean occupancy (individuals per quadrat) was highest in summer (5.67 ± 1.20 , $n = 3$ quadrats), followed by winter (3.67 ± 0.88 , $n = 3$), autumn (3.00 ± 0.58 , $n = 3$), and spring (3.00 ± 0.58 , $n = 3$). The total numbers of *P. articulatus* individuals collected in each season were: summer 17, winter 11, autumn 9, spring 9 (Figure 9).

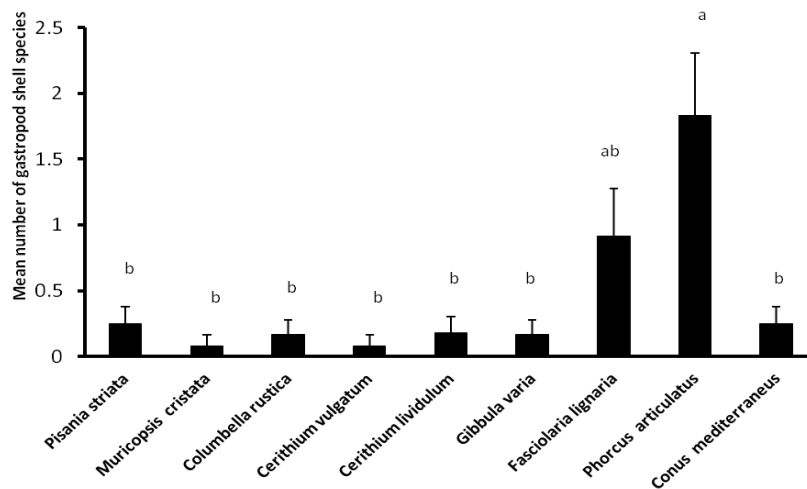


Figure 8. Mean \pm SE numbers of specimens of each gastropod shell species occupied by *Clibanarius erythropus* across all seasons. Values with different letters differ significantly.

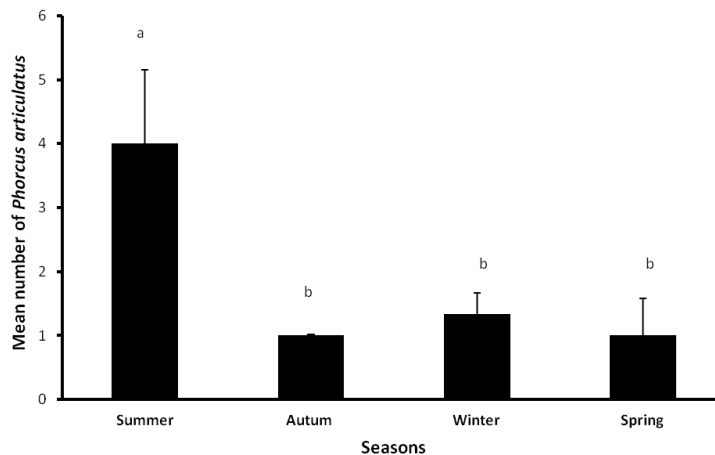


Figure 9. Mean \pm SE number of *Phorcus articulatus* across four seasons. Values with different letters differ significantly.

The strong preference for *Phorcus articulatus* shells is clear. This gastropod is a common inhabitant of Mediterranean rocky shores, and its shell offers a good combination of weight, internal volume, and shape (Rotjan et al., 2004). The summer peak in occupancy of *P. articulatus* coincided with the overall peak in crab density. This suggests that crabs actively select these shells when they become more available or when competition is lower. In the Balearic Islands, earlier studies found that *C. erythropus* also preferred *Phorcus* shells over other types (Gherardi, 1991). Using multivariate analyses, Caruso and Chemello (2009) demonstrated that shell size is more important than shell shape for *C. erythropus* in the southern Mediterranean, and that shape variations (e.g., degree of elongation) are clearly accounted for by crab size only in larger males, which have access to heavier, globose shells like *Osilinus turbinatus*. This suggests that sexual and size-related differences in shell use may reflect both competition and energetic constraints. A study from the Libyan coast (Misrata) reported that *C. erythropus* (there named *C. erythroplus*) occupied 11 gastropod shell species, with *Pisania striata*, *Cerithium lividulum*, *Cerithium vulgatum* and *Phorcus turbinatus* being the most common, but *Phorcus articulatus* was also recorded (Abd El-Aziz et al., 2015). The rare use of *Muricopsis cristata* and *Cerithium vulgatum* in our study indicates strong selectivity, which is adaptive because a poor-fitting shell increases predation risk and reduces growth (Vance, 1972; Hazlett, 1981).

Dressler et al. (2021) experimentally investigated shell selection in *C. erythropus* on the French Atlantic coast and found a clear preference for conical shells (e.g., *Tritia reticulata*, *Nucella lapillus*) over globose ones. They also showed that shell availability is a limiting factor modulating selection under natural conditions, and that preference may be driven more by ecological demands (protection from predation, hydrodynamic forces) than by species-specific traits. These findings support the view that the strong preference for *Phorcus articulatus* observed in our study may be influenced by local availability and the physical conditions of the Tolmeitha rocky shore.

Morphometric relationships: crab size versus shell dimensions

For morphometric regressions, all 46 crabs ($n = 46$) were measured. Pearson correlation and linear regression revealed a significant positive correlation between crab total length (mm) and shell length (mm) ($r = 0.594$, $n = 46$, $p < 0.001$). The regression equation was: crab length = $10.44 + 0.4568 \times$ shell length ($F_{1,44} = 24.03$, $p < 0.001$) (Figure 10). Crab wet weight (g) also correlated positively with shell dry weight (g) ($r = 0.380$, $n = 46$, $p = 0.009$), with the equation: crab weight = $0.518 + 0.1043 \times$ shell weight ($F_{1,44} = 7.44$, $p = 0.009$) (Figure 11). Shield length (mm) correlated positively with shell length ($r = 0.427$, $n = 46$, $p = 0.003$) and shell width ($r = 0.527$, $n = 46$, $p < 0.001$). The regression on shell length gave: shield length = $2.56 + 0.1418 \times$ shell length ($F_{1,44} = 9.79$, $p = 0.003$) (Figure 12), while the regression on shell width gave: shield length = $0.70 + 0.2908 \times$ shell width ($F_{1,44} = 16.88$, $p < 0.001$) (Figure 13).

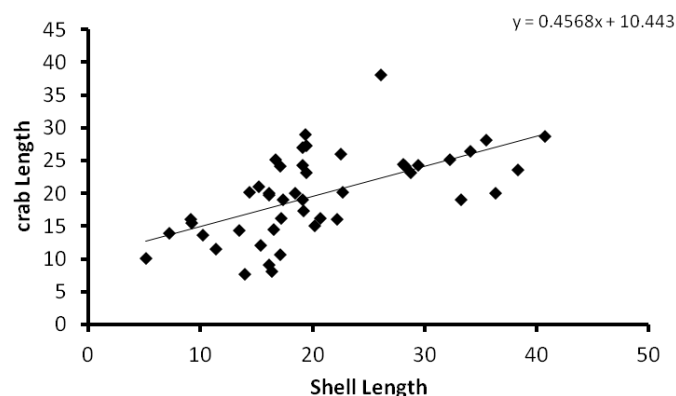


Figure 10. Linear relationship between *Clibanarius erythropus* length and occupied shell length, showing the regression line and regression equation.

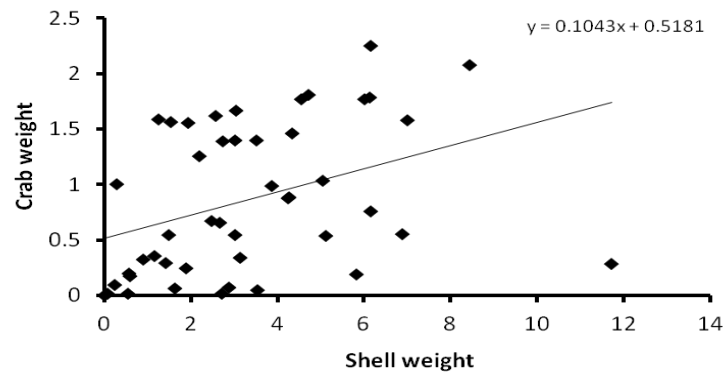


Figure 11. Linear relationship between *Clibanarius erythropus* weight and occupied shell weight showing the regression line and regression equation.

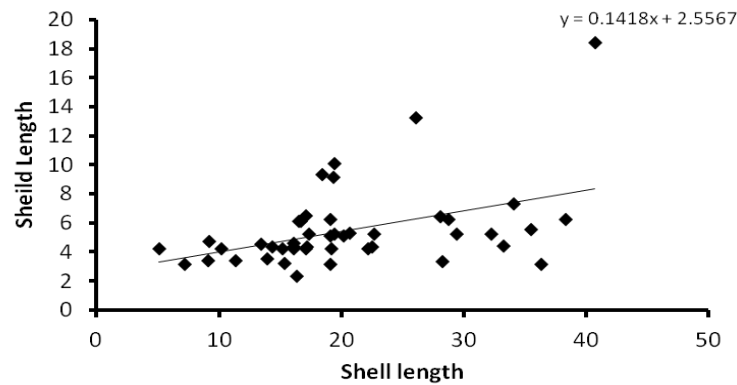


Figure 12. Linear relationship between *Clibanarius erythropus* Shield length and occupied shell length showing the regression line and regression equation.

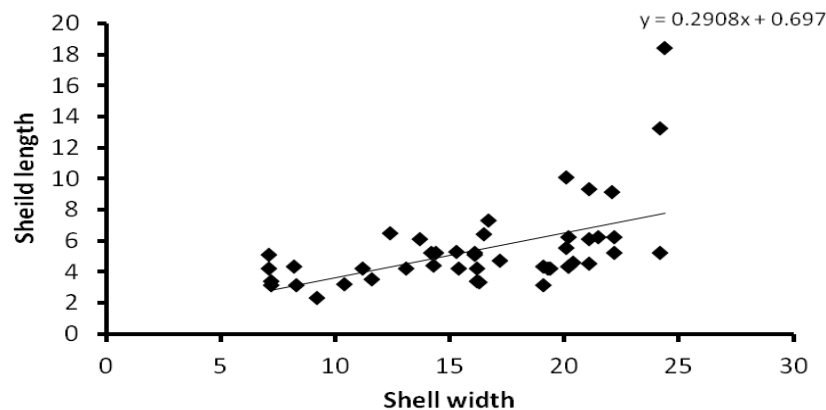


Figure 13. Linear relationship between *Clibanarius erythropus* Shield length and occupied shell width showing the regression line and regression equation.

These positive correlations are expected and consistent with the literature. A hermit crab must find a shell that fits its body to retract fully and protect itself from predators (Reese, 1969). The correlation between crab length and shell length ($r = 0.594$) is similar to that

reported for *C. erythropus* in the western Mediterranean (Benvenuto & Gherardi, 2001) and for *Pagurus bernhardus* in the North Atlantic (Hazlett, 1981). Several studies have documented that shell size and weight directly affect crab growth, survival, and reproductive output (Vance, 1972; Bertness, 1981; Elwood & Neil, 1992). The weaker correlation between crab weight and shell weight ($r = 0.380$) may be due to shell weight variability among species and the degree of shell erosion. Shell weight is not only a function of size but also of shell thickness and wear (Bertness, 1981). Positive morphometric relationships have also been reported for other hermit crab species, including *Pagurus longicarpus* (Rotjan et al., 2004), *Calcinus tibicen* (Mantelatto & Garcia, 2000), and *Paguristes tortugae* (Dominciano & Mantelatto, 2004). Abd El-Aziz et al. (2015) also found positive correlations between crab size (shield length, carapace length) and all measured shell variables (shell length, aperture length, aperture width, shell weight) in *C. erythropus* from the Libyan coast, with the strongest correlation being with shell aperture width. The stronger relationship between shield length and shell width ($r = 0.527$) in our data suggests that shell width is a critical dimension for the fit of the crab's shield, which is the broadest part of the body. Similar findings have been reported for other hermit crab species (Hasegawa et al., 2009; Oliveira et al., 2018).

Conclusion

In conclusion, this study provides the first quantitative baseline on the population ecology and shell selection of *Clibanarius erythropus* along the Libyan coast of the southern Mediterranean. The findings showed pronounced seasonal dynamics (summer density peak, spring weight maximum) with stable carapace length and a balanced sex ratio, alongside a strong preference for *Phorcus articulatus* shells, which supports the hypothesis that local shell availability and morphological constraints drive selection. Despite limitations such as the moderate sample size and the restricted subtidal depth range (which may have under-sampled juvenile habitats), the data fill a critical knowledge gap for North African rocky shores. Future research should integrate shallower intertidal sampling, larger seasonal collections, direct assessments of empty shell supply, and long-term monitoring to disentangle the effects of resource competition, tourism pressure, and climate change on this ecologically important species.

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