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Zonation-Related Alteration in Shell Morphology of Patella caerulea (Linnaeus, 1758) Distributed in the Mersin Coastline (Mersin Bay, NE Mediterranean Sea)

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Abstract

In this study, it was aimed to examine the zonation-related changes in the shell morphology of Patella caerulea (Linnaeus, 1758) belonging to the Patellidae family of the Archaeogastopoda (Thiele, 1925) order, which is distributed along the Mersin coastline. The research area consists of three regions of 4 m2 covering the supralittoral at sea level and the mediolittoral and infralittoral zones below the sea water level determined from the Mersin Viranşehir coast. A total of 80 individuals were sampled from the study area. Species identification of the samples brought to the laboratory was made by considering the morphological appearance of the radula teeth. In addition, the Shell morphology of all individuals was determined. Finally, the statistical analysis of the data was evaluated by one-way analysis of variance (ANOVA) and the relationship between the variables by calculating the Pearson linear correlation coefficient. In the study, no individuals belonging to the P. caerulea were found in the supralittoral zone of all three areas of 4 m2. It was determined that all individuals collected from the mediolittoral and infralittoral zone belonged to the P. caerulea species. Morphometrically, individuals of P. caerulea distributed in the infralittoral zone were larger than those distributed in the mediolittoral zone ($p<0.01$). According to the shell shape analysis findings, individuals sampled from the mediolittoral zone had a narrower, elliptical shell, with the apex closer to the center. In contrast, individuals sampled from the infralittoral zone had a wider, ovule, and the apex was asymmetrical near the anterior end. Individuals sampled from both zones did not differ in terms of conicity ($p>0.01$). The shell surface area and shell volume of individuals sampled from the infralittoral zone are larger than those sampled from the mediolittoral zone.

1. Introduction

Patella caerulea (Linnaeus, 1758), a native species of the Mediterranean, is a limpet distributed on the rocks in the coastal zone. It belongs to the Patellidae family of the Archaeogastopoda (Thiele, 1925) order (Sella et al. 1993; Mauro et al. 2003; Sa´-Pinto et al. 2005; Boukhicha et al. 2013). Limpets are one of the most abundant mollusks on rocky shores. These animals, which continue to live by clinging to the rocks, only move to feed. Its movement occurs during stagnant times when the water rises (Williams et al. 1999). They are firmly attached to the base, even in motion, with the secretion of pedal mucus. When disturbed, they clump or collapse, allowing the shell sub-base to make direct contact with the ground to gain resistance. This behavior prevents the animals from being dislodged or detached (Ellem et al. 2002). In this process, their clinging to the ground also reduces water loss.

Rocky coastal ecosystems are influenced by complex environmental factors due to the hard blows of the waves and drying during the low tide periods. These conditions cause stress in the biota (Cabral 2007; Ayas 2010), so they develop various adaptation mechanisms against environmental stress caused by natural changes in abiotic factors under the influence of tides (Cretella et al. 1991; Öztürk and Ergen 1999; Sá-Pinto et al. 2010; Boukhicha et al. 2013). Limpets adapt to unsuitable

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environmental conditions with changes in shell morphology. It has been reported that *P. caerulea*, which remains above the water level during the tidal period, increases the shell height in order to reduce water loss (Öztürk and Ergen 1999).

The coastal regions of the Mersin have rocky and dune ecosystems. The gulf formed by the indentation of the coastline into the land towards the north and the richness of freshwater resources causes an increase in biodiversity. The coasts are influenced by industry in the east and agricultural activities in the west. In addition, the Mersin coasts are under the influence of maritime trade activities due to the port it has and tourism activities due to the long tourism season. Furthermore, the city has an ever-increasing population due to immigration, and domestic waste is increasing in parallel.

Morphometric studies aid in identifying a species and its classification, determining biological diversity and population dynamics, and determining the effects of ecological changes on the distribution of the species. In this study, it was aimed to determine the alteration on shell morphology of *P. caerulea*, which was sampled from the mediolittoral and infralittoral zones of the Viranşehir coastline, which is under urban pressure on the Mersin coastline.

2. Method

In the study, individuals of *Patella caerulea*, one of the Archeogastropoda species distributed in the Mersin Coastline, sampled from the Mersin-Viranşehir coasts, were used as a material. Samples were collected from three areas, each covering 4 m^2, 0.5 m above sea level and 0.5 m below sea level, 1 m vertically and 4 m horizontally in the rocky tidal zone.

Collected samples were placed in glass jars containing 4% formaldehyde and labeled. Species were identified for the samples brought to the laboratory. The morphological appearance of the radula teeth was used for species identification (Fisher-Piette and Gaillard 1959; Gaillard 1987; Öztürk and Ergen 1999). Shell morphometric properties were measured with a caliper with a precision of 0.01 mm. In determining the shell morphology of each individual, the shell length (SL), the distance between the apex and the anterior end of the shell (SAA), the distance between the apex and the posterior end of the shell (SAP), the shell width (SW), the shell width at the apex (SWA), the posterior shell length (PL), anterior shell length (AL) and shell height (SH) were determined (Figure 1).

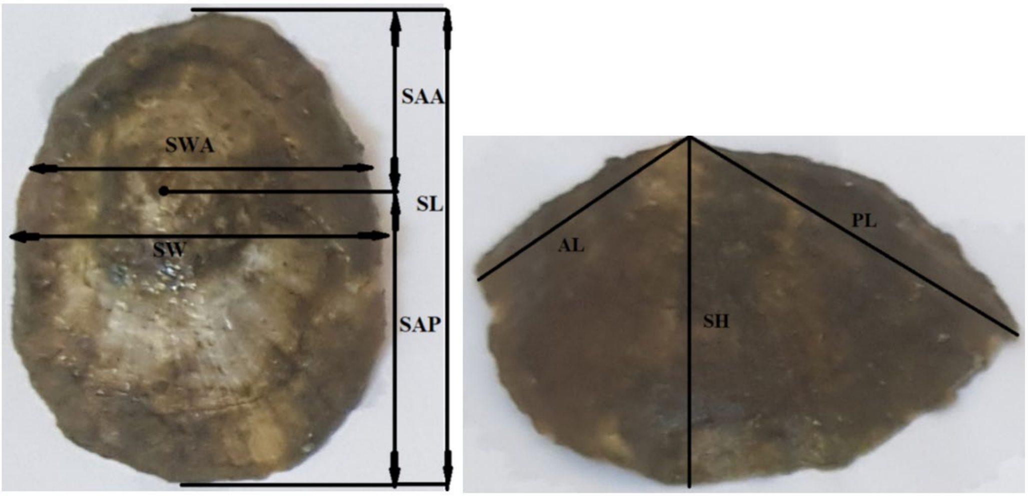

Figure 1. Determined morphometric features of P. caerulea sampled from Mersin Viranşehir coasts in the present study.

For each individual, after morphometric measurements, the conicity of the shell (SH/SL), the cone eccentricity (SAA/SAP), the base ellipticity (SW/SL), the base eccentricity (SWA/SW) ratios were determined, and their averages were compared using ANOVA. The shell surface area (SS) and shell volume (SV) were calculated using the formulas for surface area (1) and volume (2) of a parabolic cone. The shell base radius (BR) was calculated using formula (3), the base perimeter (BP) formula (4), base surface area (BS) formula (5), and the total surface area of exposure formula (6). The comparison of the mean values of the variables describing the shell shape was made with ANOVA. The relationship between the variables was evaluated by calculating the Pearson linear correlation coefficient. The least squares method was used in all regressions.

Table 1 shows the variables used in the analysis of shell shape and shape trends of Patella limpets.

$$SS = 3{,}6 \times BR \times \sqrt{(BR)^2 + (\left(\frac{4}{3}\right) \times SH)} \quad (1)$$

$$SV = \left[\frac{\pi \times BR^2 \times SH}{2}\right] \quad (2)$$

$$BR = \frac{SL + SW}{4} \quad (3)$$

$$BP = 2\pi \times BR \quad (4)$$

$$BS = \pi \times BR^2 \quad (5)$$

$$TSA = BS + SS \quad (6)$$

Table 1. The variables used in the analysis of the shell shape of Patella limpets (Cabral 2007)

Shape parameter	Variable	Trends
Base ellipticity	**SW/SL**	=1 Circle <1 Ellipse/Oval/Parabole/Ovule <1, the ratio increases with decreasing ellipticity
Base eccentricity	**SWA/SW**	≈1 Circle / Ellipse /Oval/Parabole <1 ovule <1, the ratio increases with the transition from ovule to ellipse
Conicity	**SH/SL**	Increases with increasing conicity
Cone eccentricity	**SAA/SAP**	=1 Centred apex/Symmetrical cone <1 Apex near the anterior end <1, the ratio increases with decreasing eccentricity

The comparison of the means of the variables describing the shell shape was made with ANOVA.

3. Results

No individuals belonging to the *P. caerulea* species were found in the supralittoral zones in the sampling areas. A total of 80 individuals were sampled from the mediolittoral and infralittoral zones in all sampling areas. In the species identification made by considering the radula morphological features of 80 individuals collected from all sampling areas, it was determined that all individuals sampled belonged to the *P. caerulea* species.

It was determined that individuals distributed in the mediolittoral zone and the infralittoral zone differed in terms of the morphometric features examined ($p<0.01$) (Table 2). In addition, individuals in the infralittoral zone were larger than those in the mediolittoral zone ($p<0.01$).

Table 2. Arithmetic mean and standard errors of morphometric characteristics of *P. caerulea* sampled from Mersin Viranşehir coast

Morphometric measurements (mm)	**Mediolittoral** (n=41) $\bar{x} \pm s_x$	**Infralittoral** (n=39) $\bar{x} \pm s_x$	ANOVA
SL	28.16 ± 7.76	30.80 ± 8.01	<0.01
SAA	17.45 ± 4.50	19.18 ± 4.55	<0.01
SAP	20.41 ± 5.77	23.83 ± 6.89	<0.01
SW	22.13 ± 7.69	25.03 ± 8.10	<0.01
SWA	19.74 ± 7.29	21.41 ± 7.61	<0.01
PL	17.20 ± 5.47	19.70 ± 6.66	<0.01
AL	15.13 ± 4.14	16.41 ± 4.34	<0.01
SH	7.45 ± 2,.0	8.24 ± 2.71	<0.01

$\bar{x} \pm s_x$: Arithmetic Mean and standard error

The base ellipticity, the base eccentricity, the conicity, and the cone eccentricity of *P. caerulea* sampled from Mersin Viranşehir coasts were calculated, and their averages were compared using ANOVA (Table 3).

Table 3. Shell shape analysis results of *P. caerulea* sampled from Mersin Viranşehir coasts

Shape parameter	Variable	**Mediolittoral** (n=41) $\bar{x} \pm s_x$	**Infralittoral** (n=39) $\bar{x} \pm s_x$	ANOVA
Base ellipticity	**SW/SL**	0.77 ± 0.07	0.80± 0.08	<0.01
Base eccentricity	**SWA/SW**	0.89± 0.06	0.69± 0.09	<0.01
Conicity	**SH/SL**	0.27± 0.04	0.27± 0.03	>0.01
Cone eccentricity	**SAA/SAP**	0.90± 0.09	0.86± 0.10	<0.01

$\bar{x} \pm s_x$: Arithmetic Mean and standard error

In the study, according to the shell shape analysis results of individuals sampled from the mediolittoral (n=41) and infralittoral (n=39) zones, the base ellipticity of the individuals distributed in the mediolittoral zone was determined as 0.77, and according to the shell shape trends classification, <1 Ellipse/Ovule/Parabole, can be defined as an ovule. On the other hand, the base ellipticity of individuals sampled from the infralittoral zone was found to be 0.80. Although, according to the shell shape trends, <1, ellipcity decreases as the ratio increases, individuals sampled from the mediolittoral zone have a narrower shell shape than individuals sampled from the infralittoral zone.

Regarding base eccentricity, individuals sampled from the mediolittoral zone were found to be 0.89. According to the shape trends, <1, a transition from an ovule to an ellipse as the ratio increases can be defined as an ellipse. Individuals sampled from the infralittoral zone were found to be 0.69. According to the shape trends, <1 can be specified ovule.

According to shell shape trends, the conicity increases as the SH/SL ratio increases. Therefore, the SH/SL ratio of individuals sampled from the mediolittoral and infralittoral zones was determined as 0.27, and there was no difference between individuals (p>0.01).

Cone eccentricity was determined as 0.90 in individuals sampled from the mediolittoral zone and 0.86 in individuals sampled from the infralittoral zone. According to the shell shape trends, individuals from both zones are suitable for grouping "<1 Apex near the anterior end". However, according to the statement "<1, the ratio increases with decreasing eccentricity", individuals sampled from the infralittoral zone were found asymmetric, while individuals sampled from mediolittoral zone were found closer to the center.

In the study, individuals sampled from the mediolittoral zone had a narrower, elliptical shell, with the apex closer to the center. In contrast, the individuals sampled from the infralittoral zone were found to be wider, with the ovule and the apex asymmetrical near the anterior end (p<0.01). Individuals sampled from both zones did not differ in terms of conicity (p>0.01).

Shell surface area (SS), shell volume (SV), and the total surface area of exposure (TSA) of *P. caerulea* sampled from mediolittoral and infralittoral zones of Mersin Viranşehir coasts were calculated (Table 4).

Table 4. The mean and standard errors of SS, SV, and TSA of *P. caerulea* sampled from Mersin Viranşehir coast

	Mediolittoral (n=41) $\bar{x} \pm s_x$	**Infralittoral** (n=39) $\bar{x} \pm s_x$	***Pearsson***
SS (mm²)	542.06 ± 78.58	775.33 ± 99.89	0.001**
SV (mm³)	2393.76 ± 554.25	3170.96 ± 661.05	0.01*
TSA (mm²)	1181.15 ± 169.88	667.49 ± 86.49	0.001**

$\bar{x} \pm s_x$: Arithmetic Mean and standard error
**Correlation (Pearson) is significant at the 0.001 level (2-tailed)
* Correlation (Pearson) is significant at the 0.01 level (2-tailed)

4. Discussion

It was aimed to examine the shell morphology of the individuals of *P. caerulea* collected from 3 different sampling areas on the Viranşehir coasts. No individual belonging to the species was found in the supralittoral zone. In a previous study, the distribution of *P. caerulea* and *P. rustica* in the Mersin-Viranşehir coast was reported as 88.89% and 11.11%, respectively. It has been stated that *P. caerulea* is located in the upper infralittoral and mediolittoral zone, and *P.rustica* is located in the supralittoral zone (Ayas 2010). Individuals belonging to the Patella genus were collected from the supralittoral, mediolittoral and superinfralittoral zones in the Gulf of Saros (Aegean Sea), and the distribution of *P. caerulea* in the mediolittoral and upper infralittoral zones was determined (Öztürk and Ergen 1999). Our findings that *P. caerulea* sampled from Mersin Viranşehir coasts was found in the mediolittoral, and infralittoral zones are consistent with previous research findings.

The effects of environmental factors on shell morphology have been reported in species belonging to the Patellidae family (Sá-Pinto et al., 2010). *Patella rustica* is characterized by brown spots near the top of the shell. Although these brown spots are also seen on the shell of *P. caerulea* in some regions, the shell height of *P. caerulea* is lower than that of *P. rustica*. *P. caerulea* and *P. ulyssiponensis* show wide morphological variations with overlapping shell morphology and color in various regions (Cretella et al. 1991). It was stated in a study that the shell height of *P. caerulea* sampled from the Aegean Sea, above the water level, increased, and the radula length was higher. It was noted in a previous study that individuals of *P. caerulea* sampled from above the waterline increased the shell height, and the radula length was higher. It is an adaptation that reduces the water loss of patellid individuals which stay in a dry environment for a long time.

It was determined in this study that *P. caerulea* individuals sampled from the mediolittoral zone differed statistically from the individuals sampled from the infralittoral zone in terms of their morphometric characteristics (p<0.01). In the present study, individuals sampled from the infralittoral zone were larger than those sampled from the mediolittoral zone. The mean SL: 29.48, SW: 23.58 and SH: 7.85 mm were found in individuals sampled from both zones of Mersin Viranşehir coasts. The average shell length of *P. caerulea* individuals sampled from Saros Bay was reported as 31.1 mm, shell width 25.9 mm, and shell height 8.3 mm (Öztürk and Ergen 1999). The results of both studies were similar.

Morphometric features are very important in systematically defining a species, determining its biological requirements, and examining ecological effects. In *P. rustica*, *P. ferruginea*, *P. caerulea* and *P. ulyssiponensis* distributed in the Mediterranean, the shell and radula characters and the shell surface area/shell volume ratio were examined, and the results of the stress effect they encountered in the rocky ecosystem depending on their zone were compared. It has been reported that there are specific differences in shell shape, the relative size of the radula, and SSA/SV ratio among the species examined in a study (Boukhicha et al., 2013). Morphologically, the conicity of the shell was found to be the highest in *P. rustica* and the lowest in *P. ulyssiponensis* in the same study. The shell cone eccentricity was noted to show a very asymmetrical cone in *P. ferruginea* and a more centered apex in *P. rustica*. The shell base ellipticity showed that they had a narrower shell base in *P. ulyssiponensis* and a wider shell base in *P. caerulea*. It was emphasized that the relative size of the radula increased in *P. rustica* from *P. ulyssiponensis* (Boukhicha et al. 2013).

In the present study, the shell was narrower, and elliptical, and the apex was closer to the center in the individuals sampled from the mediolittoral zone. In contrast, the individuals sampled from the infralittoral zone were found to be wider, with the ovule and the apex asymmetrical near the anterior end ($p<0.01$). Individuals sampled from both zones did not differ in terms of conicity ($p>0.01$). Shell surface area (SS), shell volume (SV) and total exposure surface area (TSA) of *P. caerulea* sampled from Mersin Viranşehir coasts were determined in individuals sampled from the mediolittoral and infralittoral zones. The SS is larger in individuals sampled from the infralittoral zone than those sampled from the mediolittoral zone in the present study. When individuals sampled infralittoral are compared with those sampled from the mediolittoral zone, there is a significant difference at the $p<0.001$ level in terms of SS. SV was higher in individuals sampled from the infralittoral zone than those sampled from the mediolittoral zone ($p<0.01$). On the other hand, TSA was higher in individuals sampled from the mediolittoral zone than in individuals sampled from the infralittoral zone ($p<0.001$). This separation in different zones can be associated with the effect of environmental factors.

It has been reported that changing environmental factors such as waves, sunlight, tidal intensity, and the geomorphological zone affect the shell morphology of the Patellidae, constituting the most critical living group of the rocky ecosystem. Therefore, the determined distinctions in the shell morphology of *P. caerulea* in this study are consistent with previous studies.

5. Conclusion

It is aimed to distinguish in terms of shell morphology in individuals of *P. caerulea*, one of the Patellidae species distributed along the Mersin coastline, sampled from two different tidal zones. The sampling area is under urban pressure, and the contribution of anthropogenic activities to the impact of natural changes in rocky ecosystems cannot be denied. Changes in the abiotic environment with the climate crisis also cause changes in the morphology of Archeogastropod shells. The main reason for this change is to adapt to changing environmental conditions. Environmental stress management may also be the main reason for the distinction between the mediolittoral zone and the infralittoral zone regarding shell morphology in individuals sampled from the Mersin Viranşehir coasts.

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Author contributions

The authors declare that they have contributed equally to the article.

Conflicts of interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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