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Seasonal Morphometric Variations of the Rustic Limpet Patella rustica (Linnaeus, 1758) from the Coastal Waters of Susah, Eastern Libya

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التغيرات المورفومترية الموسمية للرضفة روستيكا (لينيوس 1758) في المياه الساحلية لمنطقة سوسة، شرق ليبيا

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Abstract:
Seasonal morphometric variations in the rustic limpet, Patella rustica Linnaeus, 1758, were evaluated over a full annual cycle in the rocky intertidal zone of Susah, eastern Libya. A sampling size of 120 individuals (n = 30 per season) was analyzed for shell length, width, height, and total wet weight using descriptive statistics, one-way ANOVA, Tukey's post-hoc comparisons, and Pearson correlation tests. All morphometric parameters displayed significant seasonal fluctuations ($p < 0.001$), reaching maximum values during summer (mean length: 32.05 \pm 2.84 \text{mm}$; mean weight: 11.18 \pm 1.78 \text{g}) and minimum values in winter (mean length: 20.04 \pm 3.63 \text{mm}; mean weight: 3.64 \pm 1.58 \text{g}). Strong positive inter-parameter correlations were established ($r = 0.454 - 0.883$, $p < 0.001$). exhibiting a summer peak and a winter decline. These dynamics indicate that seawater temperature and resource availability primarily regulate growth trajectories and biomass accumulation in P. rustica, establishing essential baseline metrics for local ecological assessments and conservation planning.

Keywords: Patella rustica, morphometric analysis, seasonal variations, Mediterranean Sea, Libya, intertidal gastropods.

الملخص:
تم تقييم التغيرات الموسمية في الخصائص المورفومترية لنوع الرخويات البحرية Patella rustica Linnaeus, (1758) على مدار دورة سنوية كاملة في منطقة المد والجزر الصخرية بمدينة سوسة، شرق ليبيا. شملت الدراسة عينة عددها 120 فرداً (بواقع 30 فرداً لكل فصل)، حيث جرى تحليل طول الصدفة وعرضها وارتفاعها والوزن الرطب الكلي باستخدام الإحصاء الوصفي، واختبار تحليل التباين أحادي الاتجاه (ANOVA)، واختبارات "توكي" (Tukey) للمقارنات البعدية، واختبارات ارتباط "بيرسون". أظهرت جميع المعايير المورفومترية تقلبات موسمية معنوية ($p < 0.001$)، إذ

سجلت القيم القصوى خلال فصل الصيف (متوسط الطول: 32.05 ± 2.84 مم؛ متوسط الوزن: 11.18 ± 1.78 جم) والقيم الدنيا خلال فصل الشتاء (متوسط الطول: 20.04 ± 3.63 مم؛ متوسط الوزن: 3.64 ± 1.58 جم). كما رُصدت علاقات ارتباط إيجابية قوية بين هذه المعايير (0.883 - 0.454 = r، 0.001 > p)، متخذةً نمطاً يتمثل في ذروة صيفية وانخفاض شتوي. وتشير هذه الديناميكيات إلى أن درجة حرارة مياه البحر وتوفر الموارد هما العاملان الرئيسيان المتحكمان في مسارات النمو وتراكم الكتلة الحيوية لدى هذا النوع (P. rustica)، مما يوفر بيانات مرجعية أساسية للتقييمات البيئية المحلية وخطط الحفاظ على البيئة.

الكلمات المفتاحية: الرضفة روستيكا، التحليل المورفومتري، التغيرات الموسمية، البحر الأبيض المتوسط، ليبيا، بطنيات القدم في منطقة المد والجزر.

Introduction:

Intertidal mollusks serve as vital bioindicators of coastal ecosystem health, as their sessile or low-mobility nature renders them highly responsive to variations in abiotic factors. Consequently, monitoring their population dynamics provides valuable insights into the overall status of the marine environment (Cascales-Miñana et al., 2023). Within these ecosystems, the rustic limpet (*Patella rustica* Linnaeus, 1758) represents a keystone species along the rocky shores of the Mediterranean Sea and the northeastern Atlantic Ocean, playing a crucial role in shaping intertidal communities and maintaining

local ecological balance through active grazing on microalgae (Bensaâd-Bendjedid et al., 2022). The Libyan coastline encompasses diverse marine ecosystems within the eastern Mediterranean Sea that remain understudied compared to other regions of the Mediterranean basin. The coastal waters of Susah (ancient Apollonia), located in eastern Libya, represent a significant marine habitat characterized by rocky substrates that provide optimal conditions for limpet colonization. Despite the ecological importance of these habitats, comprehensive studies on the morphometric characteristics and seasonal dynamics of gastropods in Libyan waters are remarkably scarce.

Morphometric analysis serves as an essential tool for assessing growth patterns, physiological conditions, and evolutionary trends in mollusk populations. Previous biometric studies have demonstrated strong positive allometric relationships between shell dimensions (length, width, and height) and total body weight in *P. rustica* (Amer et al., 2018). However, these morphological relationships are not static; they are strongly influenced by seasonal cycles, where variations in food availability, reproductive stages, and metabolic rates induce substantial fluctuations in somatic growth and condition indices throughout the year. Typically, growth metrics and biomass peak during warmer months characterized by high primary productivity and decline under harsh environmental conditions (Prusina et al., 2014; Sempere-Valverde et al., 2024).

Comprehensive seasonal tracking that concurrently evaluates shell length, width, height, and body weight over a full annual cycle is essential for enhancing our understanding of local growth dynamics, particularly in understudied regions such as the Libyan coastline. Therefore, this study aims to conduct a detailed morphometric assessment of the rustic limpet *Patella rustica* inhabiting the coastal waters of Susah, eastern Libya, across four consecutive seasons. Specifically, this study seeks to quantify seasonal variations in shell dimensions and total body weight, evaluate the strength of correlations among these biometric parameters, and establish baseline data to support future environmental monitoring and the sustainable management of this key coastal species.

Materials and Methods:

This study was conducted in Susah, a coastal city in eastern Libya on the Mediterranean Sea. The study area features a rich, biodiverse rocky intertidal zone characterized by a Mediterranean climate with mild winters and hot summers. Sea surface temperatures fluctuate from approximately 17°C in winter to 28°C in summer, creating distinct seasonal environmental conditions that may affect the biology of intertidal organisms.

Sample Collection:

A total of 120 individuals of *Patella rustica* were collected from the rocky intertidal zone during low tide across four consecutive seasons (Summer 2025 to Spring 2026). Thirty specimens were randomly sampled per season to ensure an adequate sample size for statistical analysis. The specimens were

carefully detached from the substrate using a spatula to prevent shell damage and were immediately placed into labeled plastic bags.

Morphometric Measurements:

The samples were transported to the laboratory and thoroughly cleaned of debris and fouling organisms. The following morphometric parameters were measured for each specimen:

- **Shell Length (L):** Maximum anteroposterior dimension (mm).
- **Shell Width (W):** Maximum lateral dimension (mm).
- **Shell Height (H):** Vertical distance from the base to the apex (mm).
- **Total Weight (TW):** Total weight of the individual, including both the shell and soft tissues (g).

Linear dimensions were recorded using a digital caliper with a precision of 0.01 mm, whereas total weight was measured using an analytical balance.

Statistical Analysis:

All data were processed and analyzed using Python software (version 3.x) with the Scipy and Statsmodels libraries.

- **Descriptive Statistics:** Continuous variables (shell length, width, height, and body weight) were expressed as mean, standard deviation (SD), standard error (SE), minimum, maximum, coefficient of variation (CV%), skewness, and kurtosis for each season.
- **Normality Testing:** Data distribution normality was evaluated using the **Shapiro-Wilk test**.
- **Seasonal Differences:** Differences across seasons were analyzed using one-way Analysis of Variance (**ANOVA**). Where ANOVA indicated significant differences, **Tukey's Honestly Significant Difference (HSD)** post-hoc test was applied for pairwise seasonal comparisons.
- **Effect Size:** The magnitude of seasonal effect was evaluated using eta-squared (\eta^2).
- **Correlation Analysis:** Relationships between morphometric parameters were examined using **Pearson's correlation coefficient (r)**. In all tests, statistical significance was defined at $p < 0.05$.

Results:

Clear seasonal fluctuations were observed in all measured parameters, consistently exhibiting a general trend where maximum values were recorded during summer and minimum values during winter.

Morphometric measurements peaked in summer, with mean values of 32.05 ± 2.84 mm for length, 25.27 ± 3.93 mm for width, 13.88 ± 3.30 mm for height, and 11.18 ± 1.78 g for total weight. Conversely, the lowest means were registered in winter (20.04 ± 3.63 mm for length, 14.91 ± 3.22 mm for width, 8.69 ± 2.38 mm for height, and 3.64 ± 1.58 g for weight). The coefficient of variation (CV%) indicated that shell length in summer had the highest population homogeneity (CV = 8.85%), whereas winter weight demonstrated the highest variability (CV = 43.51%). Normality tests (Shapiro-Wilk) confirmed that the data generally followed a normal distribution ($p > 0.05$), validating the use of parametric inferential tests.

Table (1): Descriptive statistics of morphometric parameters of *Patella rustica* from Susah, Libya, across four seasons.

Season	Parameter	mean	SD	SE	Min	Max	CV%	Skewness	Kurtosis
Summer	Length	32.05	2.84	0.52	28.20	37.80	8.85	0.68	-0.67
Summer	Width	25.27	3.93	0.72	17.80	34.00	15.54	0.41	0.06
Summer	Height	13.88	3.30	0.60	9.00	21.10	23.75	0.44	-0.61
Summer	Weight	11.18	1.78	0.33	8.29	13.68	15.95	-0.24	-1.35
Spring	Length	29.00	3.09	0.56	24.50	33.80	10.65	0.09	-1.35
Spring	Width	21.51	3.62	0.66	15.40	28.00	16.83	0.18	-0.92
Spring	Height	13.40	3.04	0.55	7.70	19.60	22.66	0.10	-0.87
Spring	Weight	7.27	1.42	0.26	5.08	9.39	19.53	-0.08	-1.25
Autumn	Length	25.43	2.96	0.54	20.20	29.90	11.62	-0.07	-1.17
Autumn	Width	18.89	3.30	0.60	12.80	25.60	17.49	0.03	-0.78
Autumn	Height	11.79	2.89	0.53	6.30	16.90	24.52	-0.05	-0.76
Autumn	Weight	5.48	1.51	0.28	3.01	8.00	27.53	0.13	-1.08
Winter	Length	20.04	3.63	0.66	14.20	25.80	18.11	-0.08	-1.19
Winter	Width	14.91	3.22	0.59	9.40	21.00	21.57	-0.08	-1.00
Winter	Height	8.69	2.38	0.43	4.50	12.00	27.35	-0.27	-1.26
Winter	Weight	3.64	1.58	0.29	0.53	5.94	43.51	-0.44	-0.90

One-way ANOVA revealed statistically significant seasonal differences across all morphometric parameters ($p < 0.001$, Table 2).

Seasonal variation exerted the strongest effect on total weight ($F = 124.777$, $p < 0.001$, \eta^2 = 0.763$), indicating that seasonality accounts for **76.3%** of the total variance in biomass accumulation. Similarly, shell length showed a very large effect size ($F = 80.873$, $p < 0.001$, \eta^2 = 0.677), followed by width ($F = 45.856, p < 0.001, \eta^2 = 0.543) and height ($F = 19.293$, $p < 0.001$, \eta^2 = 0.333).

Table (2): Results of one-way ANOVA testing seasonal differences in morphometric parameters

Parameter	F-value	P- value	Eta-squared (η^2)	Effect size
Length	80.873	< 0.001***	0.677	Very large
Width	45.856	< 0.001***	0.543	Large
Height	19.293	< 0.001***	0.333	Medium to large
Weight	124.777	< 0.001***	0.763	Very large

Tukey's HSD post-hoc analysis confirmed a consistent hierarchy across all parameters: **Summer > Spring > Autumn > Winter**.

Significant differences were observed between most seasonal pairs ($p < 0.05$). The most pronounced divergence occurred between summer and winter across all traits. Specifically, shell length was significantly greater in summer compared to winter (mean difference = **12.01 mm**, $p < 0.001$). Likewise, wet weight showed the largest seasonal decline from summer to winter (mean difference = **7.54 g**, $p < 0.001$, Table 3).

Table (3): Selected post-hoc comparisons (Tukey's HSD) showing significant seasonal differences

parameter	comparison	Mean difference	P- value	Direction
Length	Summer/Winter	12.010	< 0.001***	Summer > Winter
Length	Summer/Autumn	6.623	< 0.001***	Summer > Autumn
Weight	Summer/ Winter	7.540	< 0.001***	Summer > Winter
Weight	Summer / Spring	3.912	< 0.001***	Summer > Spring
Width	Summer/Winter	10.357	< 0.001***	Summer > Winter
Height	Summer/Winter	5.183	< 0.001***	Summer > Winter

Pearson correlation analysis established strong, positive, and statistically significant relationships among all measured attributes ($p < 0.001$, Table 4).

The strongest linear relationship was recorded between shell length and shell width ($r = 0.883$, $p < 0.001$), reflecting a highly synchronized horizontal growth pattern. Additionally, strong positive correlations were found between length and weight ($r = 0.703$, $p < 0.001$), indicating that linear shell measurements serve as reliable predictors of overall body weight.

Table (4): Pearson correlation coefficients between morphometric parameters

parameters	Length	Width	Height	Weight
Length	1.000	0.883***	0.731***	0.703***
Width	0.883***	1.000	0.665***	0.646***
Height	0.731***	0.665***	1.000	0.454***
Weight	0.703***	0.646***	0.454***	1.000

Discussion:

The present study revealed clear seasonal variations across all measured morphometric parameters of Patella rustica in the coastal waters of Susah, eastern Libya. The observed pattern—characterized by peak values in summer and minimum values in winter—aligns with findings reported from other regions across the Mediterranean Sea. Similarly, Amer et al. (2018) identified comparable seasonal trends in Algerian populations, noting that shell growth predominantly occurs in height, followed by length, whereas total weight exhibits the slowest rate of increase. The pronounced seasonality observed in the morphometric parameters can be attributed to a combination of environmental and biological factors. Elevated sea surface temperatures during summer—reaching up to 28 °C in the study area—

may enhance metabolic rates and feeding activity, thereby stimulating growth and biomass accumulation. Furthermore, increased primary productivity during the warmer months provides higher food availability, supporting elevated growth rates (Bensaâd-Bendjedid et al., 2022). Conversely, winter conditions, characterized by lower temperatures and potentially reduced food availability, may suppress metabolic activity, leading to growth retardation or even weight loss. It is essential to clarify that the observed reduction in mean shell dimensions and biomass during winter ($20.04 \pm 3.63\text{ mm}$ for length and $3.64 \pm 1.58\text{ g}$ for weight) does not signify physical shell shrinkage or calcium carbonate resorption in individual organisms. Rather, this seasonal shift in population-level morphometrics is driven by demographic dynamics and recruitment processes. In Mediterranean Patella species, the winter period frequently coincides with or follows major spawning events, leading to an influx of newly settled juveniles into the intertidal zone (Prusina et al., 2014; Sempere-Valverde et al., 2024). The integration of these smaller individuals into the seasonal samples naturally shifts the size-frequency distribution, thereby decreasing the overall mean biometric values. Concurrently, post-spawning tissue depletion in mature individuals during late autumn and winter further contributes to the markeddrop in total wet weight.

Additionally, the high coefficient of variation observed for weight during winter (43.51%) indicates substantial inter-individual variation in physiological condition during this season. This variability may reflect differing energy allocation strategies among individuals, where some prioritize survival over growth, whereas others may have accumulated sufficient reserves to maintain their metabolic condition. Such variability has been documented in other bivalve and mollusk species and is frequently linked to reproductive cycles (Prusinaet al., 2014).

The strong positive correlations observed among morphometric parameters in the present study exhibit high consistency with findings reported for other Mediterranean populations of *Patella rustica.* Similarly, Belmokhtar et al. (2022) identified comparable correlation patterns in Algerian populations of *P. rustica,* where correlation coefficients between shell length and width exceeded $r = 0.85$. These robust relationships justify the use of linear morphometric dimensions as reliable proxies for biomass estimation in ecological field studies, thereby minimizing the necessity for destructive sampling.

The substantial effect sizes observed in this study (η^2 ranging from 0.333 to 0.763) demonstrate that season is a primary driver of morphometric variation in Libyan *Patella rustica* populations. This finding underscores the critical importance of accounting for temporal variability when designing monitoring programs or conducting comparative studies. Single-season sampling may fail to provide a representative profile of population characteristics, potentially introducing systematically biased conclusions.

Individuals of *Patella rustica* collected from Susah exhibited intermediate size ranges compared to populations from other regions across the Mediterranean Sea. The mean shell length in summer (32.05mm) was comparable to values reported along the Algerian coast (Amer et al., 2018), whereas the winter mean (20.04mm) aligned closely with those recorded in protected Mediterranean marine lagoons (Bensaâd-Bendjedid et al., 2022). This suggests that environmental conditions in eastern Libya support growth patterns typical of this species throughout the Mediterranean basin.

Conclusion:

This study demonstrates clear seasonal variations in the morphometric characteristics of *Patella rustica* within the coastal waters of Susah, eastern Libya. All measured parameters—length, width, height, and total weight—exhibited significant seasonal differences, with peak values recorded during summer and minimum values observed in winter. Furthermore, the strong positive correlations identified among these morphometric metrics support the application of linear dimensions as reliable proxies for biomass estimation. These findings establish essential baseline data to inform future environmental monitoring and conservation strategies along the Libyan coastline. The marked seasonality underscores the critical need to incorporate temporal variability into sampling designs. Consequently, further research is recommended to elucidate the specific environmental drivers governing these morphometric patterns and to assess the potential impacts of climate change on the life cycle and growth dynamics of this ecologically important species.

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