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QUANTITATIVE ASSESSMENT OF SHELL MORPHOMETRY, ARCHITECTURE AND SPIRE INDEX VARIATION IN *BABYLONIA SPIRATA* FROM THE COASTAL WATERS OF PAKISTAN

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ABSTRACT

This study presents a demorphometric and shell architectural analysis of *Babylonia spirata* collected from the coastal waters of Pakistan. A total of 146 specimens were evaluated to morphometric variations included total length, body length, width, height, spire length, apex, four whorls, and weight. Descriptive statistics revealed consistent proportions in shell size, with mean total length (30.91 ± 8.047 mm) closely aligned with body length (30.51 ± 8.05 mm). High variability in width (22.89 ± 5.490 mm) and height (19.44 ± 4.89 mm) suggests differences in shell growth, while spire mean length (19.70 ± 9.41 mm) shows significant variation in shell elongation. Regression slopes (b-values) indicated positive isometric to allometric growth across most pairwise comparisons. ANOVA confirmed significant relationships ($p < 0.001$) between total length and width, height, and weight. Shell morphology and architecture assessed using the Spire Index (SI = 0.64) and width-to-length ratio (WLR = 0.75) classified the shell as low-spired and broad, suggesting a globular morphology. Correlation analysis showed strong positive associations between shell weight, water content, and sediment retention. The shell morphometric variability reflects age, environmental influences, and genetic diversity that contribute to understanding species-specific growth and shell morphology in *B. spirata*, relevant for ecological, taxonomic, and evolutionary assessments.

Keywords: gastropod, shell architecture, spire index, allometric growth, linear regression, ANOVA, Pakistan.

INTRODUCTION

Gastropods have high economic value and are crucial for ecosystems, like nutrient cycling, food web dynamics, habitat engineering, bio indication, erosion control, and species interactions (Islam *et al*., 2025). Babyloniidae is a family consisting of 21 species, one of which is *Babylonia spirata* a member of the genus *Babylonia*, found throughout the Indo-West Pacific region, from Yemen to the Philippines. It inhabits soft bottoms at littoral and sublittoral depths, rocky and muddy shores as predators or scavengers, primarily feeding on smaller organisms and detritus (Doustdar *et al*., 2023). It contributes to the marine ecosystem through nutrient cycling and energy flow within sediment. *B. spirata* is a commercially significant species, harvested for its meat, shells, and operculum (Caddy,1989). Its shell is used as a material for industrial lime and for omamen (Fatoni *et al.*, 2020). Its demands in fisheries come from Southeast Asia and the Persian Gulf. In India, it constitutes a significant component of the whelk fishery with targeted landings (Bal and Rao, 1994). Similarly, its fisheries have been established in Thailand, where aquaculture trials and stock enhancement programs have been implemented to support sustainable harvesting (Chaitanawisuti and Kritsanapuntu, 1998a, b). Harvesting of *B. spirata* began in 1992, as bycatch from shrimp trawling, and exported as frozen, boiled, and live specimens to Taiwan, reaching prices as high as USD 3,500 per metric ton in international markets. *B. spirata* also sold frozen as seafood in India, Sri Lanka, Thailand, Malaysia, China, Taiwan, and Japan (Fraussen and Stratmann, 2013; Tan and Martyn, 2013). *B. spirata* has been reported from the coastal waters of Pakistan (Khan and Dastagir, 1972; Ghani *et al*., 2018; Kazmi *et al*., 2018, 2022; Moazzam and Moazzam, 2023). The rise in targeted trap fisheries along the coast of Pakistan has increased the harvesting pressure, while the operculum, sold as a by-product, further enhances its commercial value. However, the absence of management measures has led to overexploitation, which is evident in declining catch volumes, changes in population dynamics, and a rise in smaller shells, indicating recruitment overfishing. The reduced operculum supply further underscores the unsustainable nature of current harvesting methods. Despite various studies on different aspects of *B. spirata* along the coast of Pakistan, information on the morphometric relationships of this species remains scarce. Current study hypothesized that the shell morphology of *B. spirata***,** expressed through total length, body length, shell height, width, apex height, whorl dimensions (1–4), and spire length, varies significantly among individuals and reflects predictable patterns of shell shape variation. This study also provides assistance to investigate the socioeconomic dimensions of *B. spirata* fisheries in Pakistan by assessing population structure through morphometric variables and gastropod architecture to evaluate growth patterns, phenotypic variability, and potential indicators of overexploitation, also analyzing temporal trends in catch data and their socioeconomic implications for local communities.

MATERIALS AND METHODS

Sample Collection

Random specimens of *B. spirata* were collected along the coast of Pakistan during the year 2019-2021 (Fig.1). Landing data of *Babylonia spirata* in metric tons were obtained from the *Handbook of Fisheries Statistics of Pakistan* (HFSP, 2012) and from the Moazzam and Moazzam (2023).

Morphometric Analysis

The morphometric variables of *B. spirata* (Fig. 2) were measured by using Vernier calipers (±0.01 mm precision), and the total weight, empty shell weight (ESW) of each sample was determined by using a digital balance with an accuracy (±0.01 grams' precision). Variables include Total Shell Length (TSL), Body Length (BL), Shell Width (SW), Shell Height (SH), and Total Weight (TW), Apex Length (AL), Whorl (1-4) length and Spire Length (SPL).

Measurements of Spire length and Whorl

The spire is the pointed, top part of the shell (all the coils above the largest whorl). Spire length is measured from the apex down to the point where the spire ends and the body whorl begins. A whorl is each complete 360° turn of the shell. Counting whorls starts at the apex and continues down to the last, largest coil. Individual whorl width can also be measured at the widest point perpendicular to the shell's axis.

Statistical Analysis of Data

The estimation of morphometric relationships among observed variables was made by using the formula: $Y=aX^b$, where Y is the dependent variable, X is the independent variable, and b is the allometric coefficient that linearizes the equation by applying log10 to both sides: $\text{Log}(Y) = \log(a) + b \cdot \log(X)$. To test for allometric growth, if b=3 represents isometric growth, while b≠3 represents allometric growth (Froese, 2006). Statistical analyses were conducted using the Minitab version 20. The analysis includes: descriptive statistics, regression analysis, analysis of variance (ANOVA), and correlation. The difference s were detected at the 0.05 percent probability, and denoted as significant or statistically significant, significant levels showed by an asterisk (*<0.05, ***<0.01, **** < 0.001).

Gastropod shell size and architecture

Empty shell was weighed after cleaning and drying by using a digital balance (precision ±0.001 g accuracy). Therefore, the shell was filled with dry sand and weighed also shells were filled with water by using a pipette, ensuring no air bubbles remained, and then weighed, Empty shell weight, shell + sand weight, and shell + water weight. Pearson's correlation coefficient (*r*) was calculated to evaluate the relationships between sand weight and empty shell weight, water weight and empty shell weight, water weight and sand weight, significance was assessed at a threshold of $p < 0.001$.

Shell Shape Indices

Shell shape indices were estimated by the two indices: The Spire Index (SI) and the width-to-length ratio (WLR). The Spire Index (SI) is defined as the ratio of shell height (SH) to shell length (SL) and calculated as SI = SH/SL and the width-to-length ratio (WLR) is defined as the ratio of shell width (SW) to shell length (SL), calculated as: WLR = SW/SL this index indicates shell robustness or inflation, with higher values suggesting a more robust shell form.

RESULTS

Descriptive statistics of Morphometric variables

A total of 146 *B. spirata* were randomly collected from the coastal waters of Pakistan and subjected to morphometric analysis. The total mean length of shell (30.91±8.047 mm) and mean body length (30.51±8.0) was observed and both length similar in their averages, suggesting constant shell proportions across specimens. Mean height (19.44 ± 4.892) and mean width (22.89 ± 5.490 mm) show variability, with height ranging from 4.96-37.83 mm, and width ranging from 7.93-40.34 mm, indicating differences in shell growth and shape. Apex mean measurements was smaller (0.82 ± 0.3821 mm), reflecting the fine nature of the shell's tip. Whorl measurements (Whorl 1-Whorl 4) show liberal changes, with Whorl 1 shows the largest mean (10.33 mm) and Whorl 4 shows the smallest (1.42 mm), consistent with the tapering nature of the shell structure. Spire length was showing a relatively large mean (19.70 mm) but high variability (SD = 9.41 mm), indicating diversity in shell elongation among specimens. Weight ranges between (0.90-49.95 g), suggesting differences in age or shell thickness. Some variables show high standard deviations relative to their means, particularly Whorl 2, Whorl 1, and spire length, suggesting substantial variation among individuals, possibly due to age factor, environmental factors, or genetic diversity. The maximum and minimum values highlight the magnitude of variation i.e. Whorl 3 shows a maximum of 18.28 mm, much larger than its mean (2.98 mm), indicating a few unusually large specimens. Similarly, Spire length ranges from 6.08 to 42.68 mm (Table 1). The morphometric characters measured were total length, body length, width, height, spire length, apex, first to fourth whorl, and weight, data obtained were independently evaluated by using descriptive statistics, and morphometric relationships through linear regression, correlation, and analysis of variance. The estimation of morphometric relationships of important variables was made by using the formula $Y = a + bx + u$ when the parameter “b” is equal to 1.0 for length and width. Length and width were estimated as the independent variables, whereas total weight, empty shell weight, and muscle weight as the dependent variables and tended to show an isometric growth pattern when the values were greater or lesser than the isometry situation. It can be said that the sampled species are growing in a positive isometric manner when ($b>1.0$ or $b>3.0$) or a negative isometric condition ($b<1.0$ or $b<3.0$). The regression analysis includes total length versus width, total length versus total height, body length versus width, body length versus height, body length versus total length, total length versus weight and body length versus weight. In the current study, the linear regression analysis of morphometric measurement revealed that the values of “b” for total length versus width (0.9009, r^2=80.21), total length versus total height (0.9586, r^2=75.18), body length versus width (0.8484, r^2=75.1), body length versus height (0.8990, r^2=69.45), body length versus total length (1.010, r^2=96.58), total length versus weight (2.026, r^2=65.45) and body length versus weight (1.884, r^2=60.44) (Table 2).

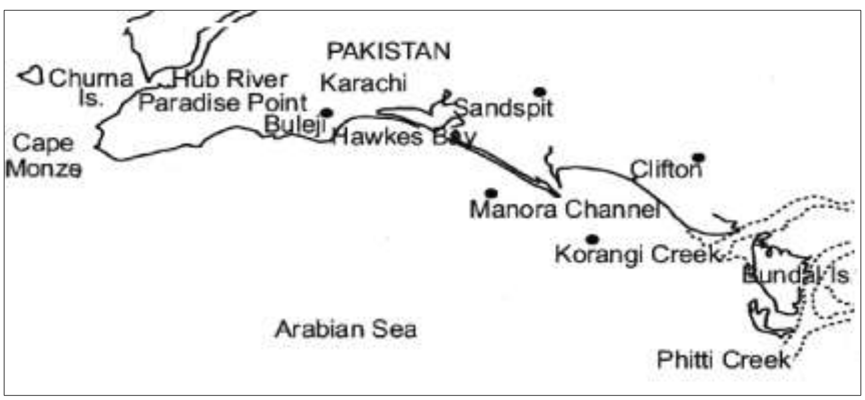

Fig. 1. Map of the study site coastal waters of Pakistan.


Fig. 2. *Babylonia spirata* collected from the coast of Pakistan.

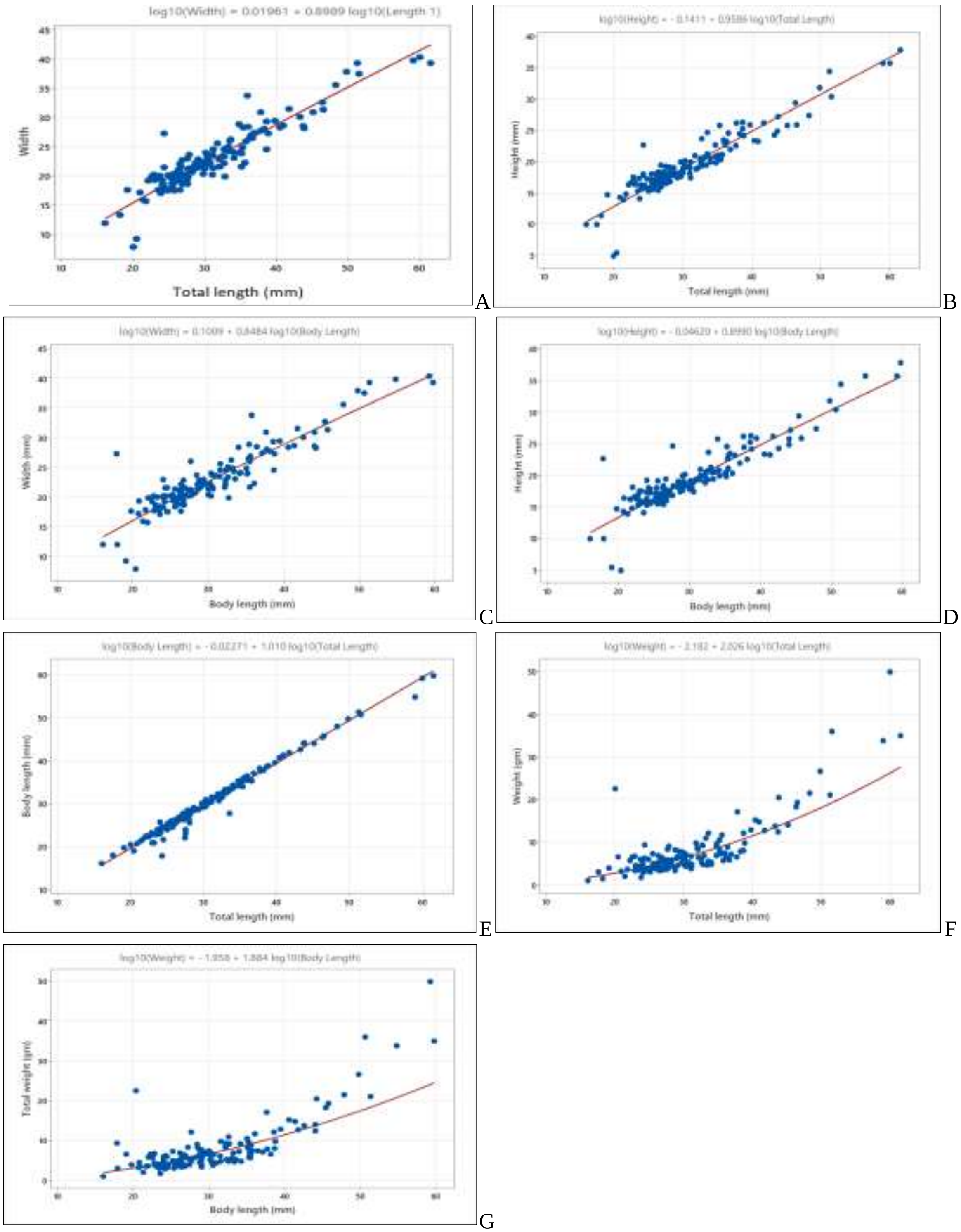

Fig. 3. Fitted line plot of *B. Spirata* relationship between Width Vs Total Length (A), Height Vs Total Length (B), Width Vs Body Length (C), Height Vs Body Length (D), Body Length Vs Total Length (E), Weight Vs Total Length (F), Total weight Vs Body Length (G).

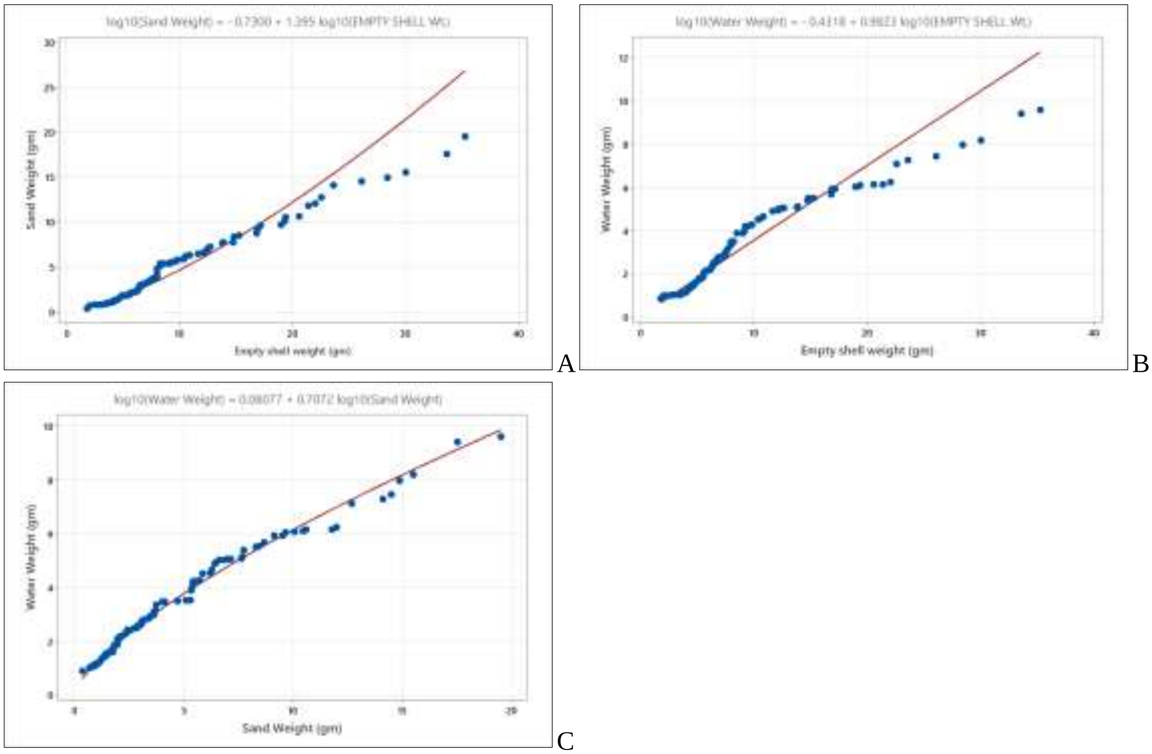

Fig. 4. Fitted line plot of *B. Spirata* relationship between (A) sand weight vs. empty shell weight, water weight vs. empty shell weight (B) and water weight vs. sand weight (C).

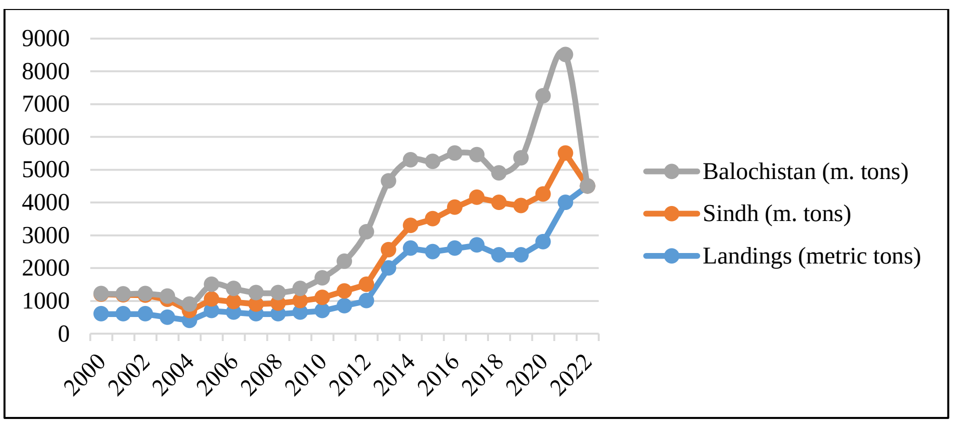

Fig. 5. Landings of *Babylonia spirata* metric tons at coast of Pakistan.

Table 1. Descriptive statistics of morphometric variables of *B. spirata*.

Variable	**N**	**Mean**	**St.Dev**	**Minimum**	**Maximum**
Total Length	146	30.905	8.047	16.160	61.510
Body Length	145	30.510	8.008	16.130	59.790
Height	146	19.444	4.892	4.960	37.830
Width	146	22.892	5.490	7.930	40.340
Apex	146	0.8174	0.3821	0.0700	2.4300
Whorl 4	146	1.4240	0.7869	0.0400	4.3200
Whorl 3	146	2.975	3.178	0.130	18.280
Whorl 2	140	7.057	6.875	1.400	27.790
Whorl 1	109	10.334	7.709	3.040	29.480
Spire Length	146	19.697	9.410	6.080	42.680

Table 2. Regression analysis of growth parameters of *B. spirata*.

Variable	Regression	S	R-sq	R-sq(adj)
Width Vs Total Length	Width = 0.01678 + 0.9009 Total Length	0.0464749	80.35%	80.21%
Height Vs Total Length	Height = - 0.1411 + 0.9586 Total Length	0.0571951	75.35%	75.18%
Width Vs Body Length	Width = 0.1009 + 0.8484 Body Length	0.0514388	75.34%	75.17%
Height Vs Body Length	Height = - 0.04620 + 0.8990 Body Length	0.0628716	69.66%	69.45%
Body Length Vs Total Length	Body Length = - 0.02271 + 1.010 Total Length	0.0195195	96.61%	96.58%
Weight Vs Total Length	Weight = - 2.182 + 2.026 Total Length	0.152705	65.69%	65.45%
Weight Vs Body Length	Weight = - 1.958 + 1.884 Body Length	0.160596	60.71%	60.44%

Table 3. Analysis of variance (ANOVA) comparing morphometric variables.

	Source	DF	SS	MS	F	P
Width Vs Total Length	Regression	1	1.27168	1.27168	588.77	0.000
	Error	144	0.31103	0.00216		
	Total	145	1.58271			
Height Vs Total Length	Regression	1	1.43968	1.43968	440.10	0.000
	Error	144	0.47107	0.00327		
	Total	145	1.91074			
Width Vs Body Length	Regression	1	1.15586	1.15586	436.84	0.000
	Error	143	0.37837	0.00265		
	Total	144	1.53423			
Height Vs Body Length	Regression	1	1.29769	1.29769	328.29	0.000
	Error	143	0.56526	0.00395		
	Total	144	1.86294			
Body Length Vs Total Length	Regression	1	1.55134	1.55134	4071.65	0.000
	Error	143	0.05448	0.00038		
	Total	144	1.60583			
Weight Vs Total Length	Regression	1	6.42858	6.42858	275.68	0.000
	Error	144	3.35792	0.02332		
	Total	145	9.78650			
Weight Vs Body Length	Regression	1	5.69935	5.69935	220.98	0.000
	Error	143	3.68811	0.02579		
	Total	144	9.38746			

Table 4. Descriptive statistics of Gastropod shell morphology and architecture of *B. spirata*.

Variable	N	Mean	Minimum	Maximum
Empty shell weight.	120	9.007	1.862	35.250
Sand Weight	120	4.336	0.376	19.521
Water Weight	120	3.167	0.892	9.598
Spire index	146	0.63898	0.55541	0.92658
Shell width to shell length	146	0.74623	0.39433	1.12059

Table 5. Regression analysis of shell morphology and architecture of *B. spirata*.

Variable	Regression	S	R-sq	R-sq(adj)
Sand Weight vs. Empty shell weight	Sand Weight = - 0.7300 + 1.395 Empty shell weight	0.0682818	96.53%	96.50%
Water Weight vs. empty shell weight	Water Weight = - 0.4318 + 0.9823 Empty shell weight	0.0600146	94.70%	94.65%
Water Weight vs. Sand weight	Water Weight = 0.08077 + 0.7072 Sand Weight	0.0267007	98.95%	98.94%

Analysis of variance ANOVA of Morphometric variables

The analysis of variance ANOVA describe the relationships between morphometric variables in *B. spirata*. The relationship between width and total length is highly significant ($F = 588.77$, $p < 0.001$). The model explains 80.4% of the variance in width ($R^2 = 1.27168 / 1.58271 = 0.804$). This indicates that total length is a strong predictor of width. Total length is a reliable predictor of height, a strong and significant relationship ($F = 440.10$, $p < 0.000$), the model explains 75.4% of the variance in height ($R^2 = 1.43968 / 1.91074$). Body length is a strong predictor of width, a significant relationship ($F = 436.84$, $p < 0.001$), and the model explains 75.3% of the variance in width ($R^2 = 1.15586 / 1.53423$). Body length is a good predictor of height, though the relationship is slightly weaker than for width significant relationship ($F = 328.29$, $p < 0.001$). The model explains 69.7% of the variance in height ($R^2 = 1.29769 / 1.86294$). Body length is almost perfectly predicted by total length, suggesting a nearly linear relationship between these two measures, a powerful relationship ($F = 4071.65$, $p < 0.001$) the model explains 96.6% of the variance in body length ($R^2 = 1.55134 / 1.60583$). Total length is a strong predictor of weight**,** but with slightly lower explanatory power than morphometric dimensions, a significant relationship ($F = 275.68$, $p < 0.001$), the model explains 65.7% of the variance in weight ($R^2 = 6.42858 / 9.78650$). Body length is also a strong predictor of weight, but with slightly less explanatory power than total length, a significant relationship ($F = 220.98$, $p < 0.001$), the model explains 60.7% of the variance in weight ($R^2 = 5.69935 / 9.38746$) (Fig. 3A-3G, Table 3).

Descriptive statistics of Gastropod shell size and architecture

The empty shell weight (N = 120) has a mean of 9.01, ranging from 1.86 to 35.25. Sand weight (N = 120) averages 4.34, with values between 0.38 and 19.52, while water weight has a mean of 3.17 and ranges from 0.89 to 9.60. The spire index (N = 146) has a mean of 0.639, with a minimum of 0.555 and a maximum of 0.927. The shell width to shell length ratio (N = 146) shows a mean of 0.746, varying from 0.394 to 1.121 (Table 4).

Strong linear relationships among shell morphology variables of *B. spirata* was observed: Sand weight strongly related to empty shell weight, described by the equation Sand Weight = −0.7300+1.395 (Empty shell weight*)*, with a high R^2 value of 96.53% (adjusted $R^2 = 96.50$) and a low standard error (S = 0.0683). Water weight increases with empty shell weight (Water Weight = −0.4318 + 0.9823 Empty shell weight), elucidation 94.70% of the variation (adjusted $R^2 = 94.65$; S = 0.0600). The strongest relationship between water weight and sand weight (Water Weight = 0.08077 + 0.7072 Sand Weight), with an R^2 98.95% (adjusted $R^2 = 98.94$; S = 0.0267) (Table 5).

Analysis of variance Gastropod shell size and architecture

ANOVA confirm the significance of regressions, for sand weight versus empty shell weight, the regression sum of squares 15.3048 with an F-value of 3282.60 (P = 0.000). Water weight versus empty shell weight shows a regression sum of squares of 7.5883 and an F-value of 2106.84 (P = 0.000). The relationship between water weight and sand weight the most significant, with a regression sum of squares of 7.92918 and a very high F-value of 11122.02 (P = 0.000), indicating extremely strong associations among these shell architecture variables (Table 6).

Gastropod shell size and architecture

Sand weight vs. empty shell weight showed a significant correlation (r = 0.809, P < 0.001), and water weight vs. empty shell weight showed (r =0.687 moderate to strong positive correlation, P-< 0.001 highly significant. Water weight vs. sand weight showed a (r 0.814, P < 0.001) highly significant (Fig. 4A-4C, Table 7).

Shell Morphology Based on Spire Index (SI) Width-to-Length Ratio (WLR)

Shell Morphology based on Spire Index (SI) = 0.64, range between $0.5 \leq SI < 0.8$ whereas the width to length ratio (WLR) = 0.75, range between $0.7 \leq WLR < 0.9$. The spire index SI value indicates a low to moderately low spire, denotation the shell is not highly elongated but still has a slightly elevated apex. The WLR value of 0.75 points to a broad or inflated shell, which is more globular, rounded in shape rather than narrow, or conical (Table 8).

Trends in *B. spirata* Production and Landings (2000–2022)

Trends in *B. spirata* landings from Sindh and Balochistan during 2000–2022 were measured in metric tons. Total landings were relatively low during 2000–2008, whereas an upward trend occurred after 2009. This increase became more pronounced between 2011 and 2014, followed by a moderated growth rate from 2015 to 2018. During 2019–2022, the data show increased uncertainty; Balochistan documented a sharp peak around 2020–2021, followed by a decline in 2022. Sindh showed a similar but less pronounced pattern, reaching its maximum level around 2021 before declining. In contrast, total landings continued to increase overall, reaching their highest level in 2022 (Fig. 5).

Table 6. Analysis of variance (ANOVA) comparing shell morphology and architecture of *B. spirata*.

Variables	Source	DF	SS	MS	F	P
Sand Weight vs. empty shell weight	Regression	1	15.3048	15.3048	3282.60	0.000
	Error	118	0.5502	0.0047		
	Total	119	15.8550			
Water Weight vs. empty shell weight	Regression	1	7.58830	7.58830	2106.84	0.000
	Error	118	0.42501	0.00360		
	Total	119	8.01331			
Water Weight vs. Sand weight	Regression	1	7.92918	7.92918	11122.02	0.000
	Error	118	0.08413	0.00071		
	Total	119	8.01331			

Table 7. Pairwise Pearson Correlations of shell architecture of *B. spirata*.

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
Sand weight (g)	Empty shell weight (g)	120	0.809	(0.737, 0.863)	0.000
Water weight (g)	Empty shell weight (g)	120	0.687	(0.579, 0.772)	0.000
Water weight (g)	Sand weight (g)	120	0.814	(0.743, 0.867)	0.000

Table 8. *B. spirata* shell morphology based on Spire Index (SI) and Width-to-Length Ratio (WLR)

Spire Index (SI)	Standard Values	Observation	Shell Shape Description	Interpretation
(SI)+(SW/SL)	$0.5 \leq SI < 0.8$	0.64	Low to moderately low spire	Slightly elevated spire
WLR+ (SW/SL)	$0.7 \leq WLR < 0.9$	0.75	SI usually < 0.8 Broad/Inflated	More globular shells with low spires

DISCUSSION

B. spirata found in shallow subtidal zones**,** although it also occurs at greater depths in coastal waters. The habitat consists mainly of soft substrates**,** including sandy, muddy, and mixed sand–mud bottoms and facilitate burrowing and foraging activities. This burrowing behavior reduces exposure to environmental stress and predation, while also influencing shell morphology and overall body form. The morphometric relationships in *B. spirata* collected from the coastal waters of Pakistan demonstrate significant and biologically meaningful trends. Linear regression and ANOVA analyses settled that total length and body length are strong predictors of further morphometric variables, including width, height, and weight. The robust observed relationship was between body length and total length (R^2 = 96.6%), suggesting a stable proportionality and standardized growth pattern across individuals. This finding aligns with previous studies on gastropod morphometry, where body length has been used as a reliable estimator for total size and shell development (Ponder and Lindberg, 2008). Width and height also exhibited strong positive relationships with both total and body lengths (R^2 values ranging from 69% to 80%), highlighting an overall isometric to mildly allometric growth pattern. These finding revealed that as *B. spirata* grows in length, proportional increase in shell breadth and height, reflects a balanced shell development. This type growth pattern of shell is typical in many marine gastropods where environmental and genetic factors contribute to shape variation while maintaining proportional integrity (Vermeij, 2021). Nevertheless, when weight was analysed as a dependent variable, the explanatory power of morphometric predictors decreases slightly (R^2 = 60–66%) that attributed to the differences in age, nutritional status, growth pattern, reproductive stage, and environmental stressors, including temperature, pH, salinity, or substrate type. Similar patterns have been observed in other gastropod studies, where shell weight did not correlate as strongly with size measurements due to intraspecific variability (Ragagnin *et al*., 2018). The spire index (SI = 0.64) and width-to-length ratio (WLR = 0.75) indicate that *B. spirata* has a moderately low spire and a relatively broad, inflated shell morphology. According to Palmer (1981), shell architecture might converse adaptive advantages in soft-bottom habitats, including as improved stability or protection from predators. The broader, globular form could also be advantageous in burrowing or resisting dislodgment in turbulent waters, typical of Pakistan’s coastal zones. Significant correlations were observed among weight-based variables: sand weight vs. empty shell weight (r = 0.809), water weight vs. empty shell weight (r = 0.687), and water weight vs. sand weight (r = 0.814), these all highly significant ($p < 0.001$). These highly significant correlations propose that heavier shells are more probable to retain water and sand. This could be due to the shell architecture that favors the retention of environmental materials or behavioral patterns such as burrowing. Some previous studies have revealed that weightier shells might improve steadiness or camouflage in sediment-rich environments (Trussell, 1997). Additionally, the strongest correlation between water and sand weights recommends that the similar shell features or characteristics might support both types (water and sand) of retention. This could have implications for understanding the ecological role and microhabitat preferences of *B. spirata*. Higher internal volume or aperture width may help in the accumulation of sand and water, thereby linking shell shape to habitat adaptation (Ragagnin *et al*., 2018). The quantitative assessment of shell morphometry, architecture, and spire index variation in intertidal populations of *B. spirata* reveals significant patterns of morphological variability that are likely influenced by both environmental and biological factors. Morphological variation recognized as an adaptive response to environmental condition i.e. wave exposure, substrate type, salinity fluctuations, and food availability (Vermeij, 1973; Chapperon and Seuront, 2011a, b) and high degree of phenotypic plasticity (Trussell, 1997; Hughes and Roberts, 1980). In high-energy intertidal zones, it frequently develops thicker and broader shells that enhance resistance to mechanical stress and predation (Branch and Marsh, 1978). In *B. spirata* compact shells with reduced spire heights are associated with wave-exposed environments, as they minimize the risk of shell breakage and dislodgement (Vermeij, 1973; Palmer, 1990). In contrast, elongated shells with higher spires may occur in more sheltered intertidal habitats where physical stress is reduced and linked to environmental pressures, ontogenetic development, and hydrodynamic constraints (Raup, 1966; Alcaraz *et al*., 2024). Lower spire indices may be advantageous in exposed intertidal conditions by lowering the center of gravity and increasing shell stability (Branch and Marsh, 1978). Environmental cues such as predator presence and hydrodynamic stress are known to induce plastic changes in shell morphology during growth (Palmer, 1990; Trussell, 1997). Additionally, allometric relationships during shell development can further influence shell form and spire proportions (Urdy *et al*., 2010). Wang *et al*., (2025) studied the role of aquaculture in shaping the morphology of *Babylonia areolate* their study revealed significant morphological differences between wild and cultured populations of *B. areolata*. Cultured populations showed more morphological homogeneity, in shell height, shell length, and total weight. In contrast, wild populations showed higher variability in shell thickness and shell aperture width, determined by resource heterogeneity and natural selection pressures in their environment

In conclusion, the morphometric relationships in *B. spirata* bring insights into the growth patterns and shell functional morphology. The strong positive predictive relationships among length-based parameters provide beneficial tools for estimating unmeasured traits, which are valuable in fisheries management, ecological modelling, and conservation strategies. The correlations between shell weight components and retained environmental material further suggest the ecological and functional significance of shell design in relation to habitat use and environmental interaction. Future research combining morphometric, genetic, and environmental data would help distinguish between environmentally induced plasticity and genetically fixed adaptations, providing a more comprehensive understanding of shell variation in this species.

REFERENCES

Alcaraz, G., A. Alvarez-Galicia, M. M Ramírez-Sánchez and L. M. Burciaga (2024). Snail shell shape, force of attachment, and metabolic rate together cope with the intertidal challenge. *Marine Biology*, 171(9): 172.

Bal, D.V. and K. V. Rao (1994). *Marine Fisheries of India*. Tata McGraw-Hill Publishing Company, New Delhi.

Branch, G.M. and A. C. Marsh (1978). Tenacity and shell shape in six *Patella* species: Adaptive features. *Journal of Experimental Marine Biology and Ecology*, 34 (2): 111–130.

Caddy, J. F. (Ed.). (1989). *Marine invertebrate fisheries: their assessment and management*. John Wiley and Sons.

Chaitanawisuti, N. and A. Kritsanapuntu (1998a). Trap fishing for spotted babylon, *Babylonia areolata* Link, 1807 (Gastropoda) in the Eastern Gulf of Thailand. The 8th International Workshop/Congress of the Tropical Marine Mollusc Programme, Prachuab Khirikhan, Thailand, 18–22 August, 1997. Published in Phuket Marine Biological Center Special Publication 18(1): 149–152.

Chaitanawisuti, N. and A. Kritsanapuntu (1998b). Aquaculture potential for juveniles spotted babylon, *Babylonia areolata*, reared under flow-through culture system to marketable size. *International Conference on The Fifth Asian Fisheries Forum, Chiang Mai province, Thailand*, 11–14 November, 1998.

Chapperon, C. and L. Seuront (2011a) Behavioral thermoregulation in a tropical gastropod: links to climate change scenarios. *Global Change Biology*, 17: 1740–1749.

Chapperon, C. and L. Seuront (2011b) Variability in the motion behaviour of intertidal gastropods: ecological and evolutionary perspectives. Jour????

Doustdar, M., S. A. Hashemi and S. H. Hosseinzadeh (2023). Feeding and reproductive biology of Babylonia spirata (Linnaeus, 1758) in the northern Oman sea. *Iranian Journal of Fisheries Sciences*, 22, (2): 450-459

Fatoni, M., D. Pringgenies and A. Djunaedi (2020). Studi perkembangan telur - juvenil keong macan (Babylonia spirata Linnaeus, 1758) dalam Laboratorium (Study on the development of spiral babylonia snail tiger snail juvenile eggs (Babylonia spirata Linnaeus, 1758) in the laboratory). *Jurnal Moluska Indonesia*, 4: 27-37.

Froese, R. (2006). Cube law, condition factor and weight–length relationships: History, meta-analysis and recommendations. *Journal of Applied Ichthyology*, 22 (4): 241–253.

Fraussen, K. and D. Stratmann, (2013). *A Conchological Iconography: The Family Babyloniidae*. Conch Books, Harxheim.96 pp., 48 pls.

Ghani, A., N. Afsar and M. Moazzam, (2018). A checklist of molluscans inhabiting Bandri Beach along the Jiwani coast, Balochistan, Pakistan. *Pak. J. Mar. Sci*., 27(1): 61-71.

HFSP (2012). *Hand book of Fisheries Statistics of Pakistan* (Vol.19, pp.182). Marine Fisheries Department Government of Pakistan. Fish Harbour West Wharf, Karachi.

Hughes, R. N. and D. J. Roberts (1980). Growth and reproductive rates of *Littorina neritoides* (L.) in North Wales. *Journal of the Marine Biological Association of the United Kingdom*, 60(3): 591-599.

Islam, M. R., E. Goberville, A. Saha, S. M. Sharifuzzaman and M. S. Hossain (2025). Seasonal patterns and environmental drivers of gastropod distribution in southeastern Bangladesh. *Marine Environmental Research*, 107593.

Kazmi, Q. B., M. Moazzam and R. Sultana (2018). Marine molluscan fauna of the Pakistani coastal waters. *BCC and T Press, University of Karachi, Pakistan*.

Khan, M.Y. and A. Dastagir (1972). Some marine gastropods from the coast of Pakistan. *Biologia (Pakistan)*, 18: 1–14.

Moazzam, M. and N. Moazzam (2023). Some observations on the biology and fishery of ivory shell (*Babylonia spirata* (Linnaeus, 1758)). *International Journal of Biological Biotechnology*, 20(4): 697-708.

Palmer, A. R. (1981). Do carbonate skeletons limit the rate of body growth?. *Nature*, 292(5819): 150-152.

Palmer, A. R. (1990). Effect of crab effluent and scent of damaged conspecifics on feeding, growth, and shell morphology of the Atlantic dogwhelk *Nucella lapillus* (L.). *Hydrobiologia*, 193(1): 155-182.

Ponder, W.F. and D. R. Lindberg (2008). *Phylogeny and Evolution of the Mollusca*. University of California Press, Berkeley.

Ragagnin, M. N., D. Gorman, I. D. McCarthy, B. S. Sant'Anna, C. C. de Castro and A. Turra (2018). Gastropod shell size and architecture influence the applicability of methods used to estimate internal volume. *Scientific reports*, 8(1): 440. https://doi.org/10.1038/s41598-017-18906-6

Raup, D. M. (1966). Geometric analysis of shell coiling: general problems. *Journal of paleontology*, 1178-1190.

Tan, S. K. and E. Y. Martyn (2013). First record of *Babylonia spirata* (Linnaeus) in Singapore, with notes on congeners in the local seafood trade (Mollusca: Gastropoda: Babyloniidae). *Nature in Singapore*, 6: 191-195.

Trussell, G. C. (1997). Phenotypic plasticity in the foot size of an intertidal snail. *Ecology*, 78 (4): 1033–1048.

Urdy, S., N. Goudemand, H. Bucher and R. Chirat (2010). Allometries and the morphogenesis of the molluscan shell. *Journal of Experimental Zoology Part B*, 314B (5): 280–302.

Vermeij, G. (2021). *A natural history of shells*. P.1-236. Princeton University Press, Princeton.

Vermeij, G. J. (1973). Morphological patterns in high-intertidal gastropods: adaptive strategies and their limitations. *Marine Biology*, 20(4): 319-346.

Wang, H., Z. Chen, Y. Tong, L. Ye and Y. Li (2025). The Role of Aquaculture in Shaping the Morphology of *Babylonia areolata*: A Comparative Study of Cultured and Wild Populations. *Biology*, 14(1): 39. https://doi.org/10.3390/biology14010039