



Research Article

Comparison of morphometric traits and condition index of freshwater mussel *Lamellidens marginalis* (Lamarck, 1819) populations across three ecologically distinct habitats of Bangladesh

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ABSTRACT

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Morphological variation is a fundamental component of taxonomic research and provides critical insights into population-level biological and ecological differentiation. The present study investigated inter-population morphological variability in the freshwater mussel *Lamellidens marginalis* collected from three ecologically distinct freshwater habitats from North Central Bangladesh. Specimens (n = 100 per site) were sampled from Darikathal Beel, Trishal, Mymensingh (S₁); the Old Brahmaputra River near the Botanical Garden, Bangladesh Agricultural University, Mymensingh (S₂); and a pond adjacent to Boali Jam-E-Masjid, Tangail (S₃) during December 2023. Twenty-three morphometric, mass-related, and derived ratio parameters were analyzed, including shell dimensions, soft tissue traits and proportional indices. Statistical comparisons revealed significant differences ($p < 0.05$) in 19 of the 23 parameters among at least two populations, indicating pronounced habitat-associated morphological divergence. Shell proportional indices demonstrated clear habitat-specific patterns. The SL/SH ratio indicated greater shell elongation in riverine population compared to the beel population. Conversely, ST/SH and SL/ST ratios suggested that pond-dwelling mussels possessed comparatively rounder and thinner shells than those from beel and riverine habitats. Condition index differed significantly ($p < 0.05$) between riverine and beel populations, reflecting a gradient of habitat suitability ranked as river > pond > beel. Overall, the findings highlight the strong influence of habitat-specific environmental conditions on shell morphology and physiological condition in *L. marginalis*. These results underscore the importance of integrating morphological assessments with molecular genetic analyses to achieve a more robust understanding of population structure and taxonomic resolution of *L. marginalis* across heterogeneous freshwater ecosystems in Bangladesh.

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Introduction

Molluscs represent the second largest phylum within the animal kingdom, following Arthropoda, and display remarkable diversity in terms of morphology, physiology, and ecological adaptation (Bieler and Mikkelsen, 2006; Guan et al., 2025). Within the Mollusca phylum, the class Bivalvia stands out as one of the most ecologically and economically important groups, distinguished by a wide range of variations in shell morphology, body plan, habitat selection, and life-history strategies (Gosling, 2015; Vaughn, 2018). Bivalves inhabit in marine, brackish, and freshwater environments, contributing significantly to ecosystem functionality through their filter-feeding activities (Alleway et al., 2025). Freshwater unionid mussels are stationary benthic organisms that play a crucial role in ecosystem services by filtering out suspended particles,

algae, bacteria, and organic matter from the water column (Islam et al., 2020; Shah et al., 2022; Netti et al., 2025). Through these activities, they enhance water clarity, regulate nutrient cycling, and contribute to overall ecosystem stability (Strayer, 2014; Lopes-Lima et al., 2017). *Lamellidens marginalis* (Lamarck, 1819) is among the most extensively distributed and commercially important freshwater mussel species in South Asia, found in rivers, ponds, beels, haors, and various other inland waterbodies across Bangladesh, India, Nepal, and adjacent countries (Niogee et al., 2019; Haque et al., 2024). The species is employed for human consumption, as well as for poultry and aquaculture feed, lime production, and the freshwater pearl culture (Siddique et al., 2024; Chen et al., 2025). In addition, *L. marginalis* has received scientific attention for its ability to bioaccumulate heavy metals

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and pesticides, making it a suitable bio monitor species for freshwater pollution assessment (Chhandaprajnadarsini et al., 2025).

Morphological characteristics of freshwater mussels are strongly influenced by environmental factors such as hydrodynamic conditions, substrate composition, food availability, and water quality (Sánchez González et al., 2025). Consequently, shell morphometry and derived proportional indices have been widely employed to assess population differentiation, habitat suitability, and adaptive responses in unionid mussels (Sánchez González et al., 2025a). Variations in shell length, height, width, and mass, as well as condition index, reflect both environmental conditions and physiological status of mussel populations (Waliullah et al. 2023; Osei et al., 2026).

Bangladesh possesses exceptionally diverse freshwater habitats, featuring extensive river systems, large wetlands (haors, beels), baors and ponds. In Bangladesh, systematic studies focusing on habitat-specific morphological variations of *L. marginalis* are scarce, despite its ecological and economic importance (Fariha et al., 2025). Understanding morphometric differences among populations inhabiting ecologically distinct freshwater environments is essential for identifying suitable habitats for aquaculture and pearl culture development (Siddique et al., 2024; Nyauchi et al., 2025). Therefore, the present study aims to compare the morphometric traits of *L. marginalis* populations collected from three ecologically distinct freshwater habitats and to evaluate habitat suitability using condition index as an indicator of population health. The findings are expected to provide baseline information supporting sustainable management, domestication, and conservation of this economically valuable freshwater mussel species.

Materials and methods

Sampling sites

Freshwater mussel *Lamellidens marginalis* samples were collected from three ecologically distinct habitats located at Mymensingh and Tangail Districts of Bangladesh. The sampling sites were Darikathal Beel at Trishal, Mymensingh (24.5827°N, 90.3945°E) as Site 1 (S₁), Old Brahmaputra River near Botanical Garden, BAU, Mymensingh (24.7244°N, 90.4416°E) as Site 2 (S₂), and a pond near Boali Jam-E-Masjid, Tangail (24.2483°N, 89.9304°E) as Site 3 (S₃) as shown in Figure 1. A beel (S₁) is a natural saucer-shaped depression of lentic habitat, often acting as a floodplain lake, primarily found in Bangladesh. The Old Brahmaputra River (S₂) is a major distributary in Bangladesh that branches off the main Brahmaputra River (Jamuna)

near Bahadurabad in Jamalpur, flowing southeast past Mymensingh Town before merging with the Meghna River near Bhairab Bazar. The pond (S₃) is a man-made, perennial shallow static waterbody with strong embankments.

Sampling activities

Total 300 samples of *L. marginalis* (100 from each site) were drawn during December 2023. The samples were collected by hand-picking with the help of local people. After collection, samples were placed in a bucket and conveyed to the Aquatic Ecology Laboratory of Bangladesh Agricultural University as soon as possible for further measurement of morphometric traits.

Morphometric measurements

In the lab, at first all the samples were cleaned with running tap water and then shells were opened with the help of a sharp knife very carefully. After opening the shells, wet tissues were removed by the knife and weighed by an electric balance (model no: eki 600-2n). The empty shells were washed, soaked with tissue paper and labeled properly. The shells were dried in sunlight for 48 hours. After sun drying the dry shells were weighed and nine morphometric measurements viz., shell length (SL, mm); shell height (SH, mm); shell thickness (ST, mm); ligament length (LL, mm); distance between adductor muscle scars (DMs, mm); umbo height (UH, mm); shell length between umbo and shell margin (UmSL, mm); and thickness of shell margin (T, mm) were taken with the help of manual compass and mm scale. All morphometric measurements were made following Abbott (1974), Modestin (2017) and Waliullah et al. (2023). Dry shell mass (SM, g) of individual mussel was taken by an electronic balance. In addition to primary morphometric traits, twelve secondary parameters were also established as the ratio of different primary traits viz., SL/SW, ST/SW, SL/ST, SL/UH, SH/UH, ST/UH, SL/WW, SH/WW, ST/WW, SM/WW, LL/DMs and UH/T.

Condition index (CI)

CI is applied in bivalves to indicate the degree of well-being of the animal, reflecting physiological state and environmental conditions. The CI value was determined by calculating the ratio of tissue wet weight (g) to dry shell mass (g), as described by Park et al. (2012).

Statistical analysis

All the morphometric data of the three populations of *L. marginalis* collected from S₁, S₂ and S₃ were computed to make comparisons among them. All data were presented as Mean ± SD. A one-way analysis of variance (ANOVA) was performed followed by Tukey HSD test to evaluate the statistically significant difference at $p < 0.05$ among the populations in respect to each morphometric trait.

Results

Primary morphometric traits

The morphometric measurements of 10 different traits of 3 populations of *Lamellidens marginalis* are presented in Table 1. Morphometric analyses revealed that significant differences exist in most of the traits among the populations ($p < 0.05$) obtained from 3 ecologically distinct habitats. Shell length (SL), shell height (SH), shell thickness (ST), ligament length (LL), distance between adductor muscle scars (DMs), shell length between umbo and shell margin (UmSL) and dry shell mass (SM) were statistically similar ($p > 0.05$) in S_1

and S_2 populations but the traits were significantly higher in S_1 and S_2 populations ($p < 0.05$) when compared with S_3 population. No significant difference ($p > 0.05$) was found in UH among the populations. Significantly higher thickness of shell margin (T) was reported in S_2 population in comparison to other populations but such differences were not found ($p > 0.05$) between S_1 and S_3 populations in case of T. Tissue wet weight (WW) revealed significant differences among all 3 populations ($p < 0.05$) with the chronology as $S_2 > S_1 > S_3$.

Table 1. Comparison of primary morphometric traits of *Lamellidens marginalis* populations (mean \pm SD) obtained from three distinct habitats (S_1 , Darikathal Beel; S_2 , Old Brahmaputra River; S_3 , Pond) from North Central Bangladesh

Traits	S_1	S_2	S_3
	Mean \pm SD	Mean \pm SD	Mean \pm SD
Shell length (SL, mm)	75.46 \pm 3.55 ^a	77.15 \pm 3.32 ^a	62.68 \pm 1.90 ^b
Shell height (SH, mm)	37.40 \pm 2.11 ^a	35.03 \pm 1.46 ^a	29.72 \pm 1.06 ^b
Shell thickness (ST, mm)	23.62 \pm 1.48 ^a	25.11 \pm 1.53 ^a	18.97 \pm 1.26 ^b
Ligament length (LL, mm)	50.03 \pm 2.07 ^a	50.28 \pm 2.29 ^a	39.72 \pm 1.23 ^b
Distance between adductor muscle scars (DMs, mm)	44.63 \pm 2.11 ^a	46.04 \pm 1.92 ^a	36.33 \pm 1.13 ^b
Umbo height (UH, mm)	3.09 \pm 0.29 ^a	3.13 \pm 0.26 ^a	2.81 \pm 0.31 ^a
Shell length between umbo and shell margin (UmSL, mm)	60.24 \pm 2.93 ^a	60.31 \pm 2.15 ^a	52.17 \pm 1.71 ^b
Thickness of shell margin (T, mm)	1.68 \pm 0.19 ^b	2.21 \pm 0.16 ^a	1.42 \pm 0.19 ^b
Dry shell mass (SM, g)	13.69 \pm 3.65 ^a	14.59 \pm 1.98 ^a	8.72 \pm 0.98 ^b
Wet tissue weight (WW, g)	8.22 \pm 0.84 ^b	10.15 \pm 1.05 ^a	6.82 \pm 0.56 ^c

Secondary morphometric traits

The secondary traits calculated from the ratio of different primary traits of respective populations are presented in Figures 2-5.

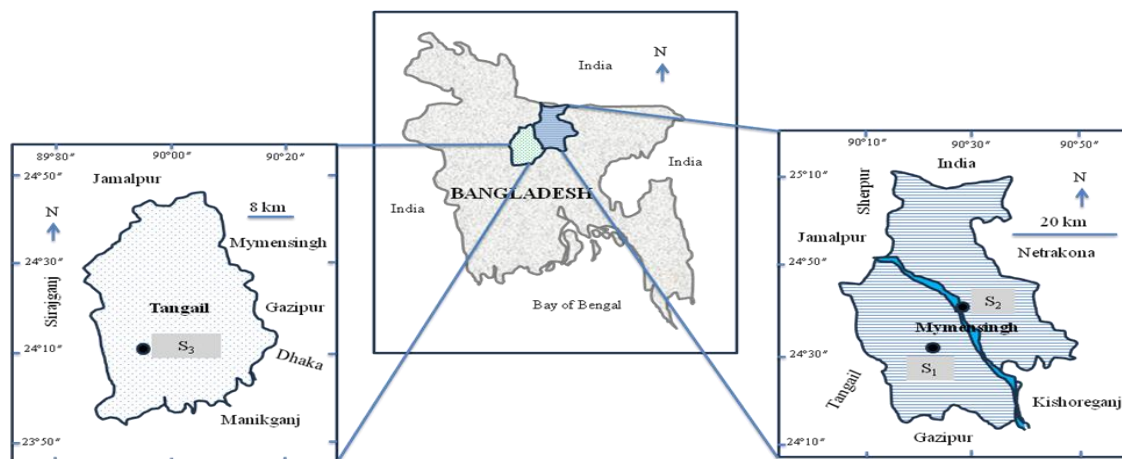


Figure 1: Sampling sites of *Lamellidens marginalis* from Darikathal Beel (S_1), Old Brahmaputra River (S_2) at Mymensingh and a pond (S_3) at Tangail of Bangladesh

Shell length/shell height (SL/SH)

The mean SL/SH ratio were 3.21 ± 0.10 , 3.09 ± 0.09 and 3.31 ± 0.11 for populations of S_1 , S_2 and S_3 , respectively. Significantly higher ($p < 0.05$) SL/SH ratio was found in S_2 population than S_3 population. The ratio indicated that individuals of S_2 population are more elongated than S_3 population. Such differences were not evident

($p > 0.05$) between S_1 and S_2 , and S_1 and S_3 populations (Figure 2).

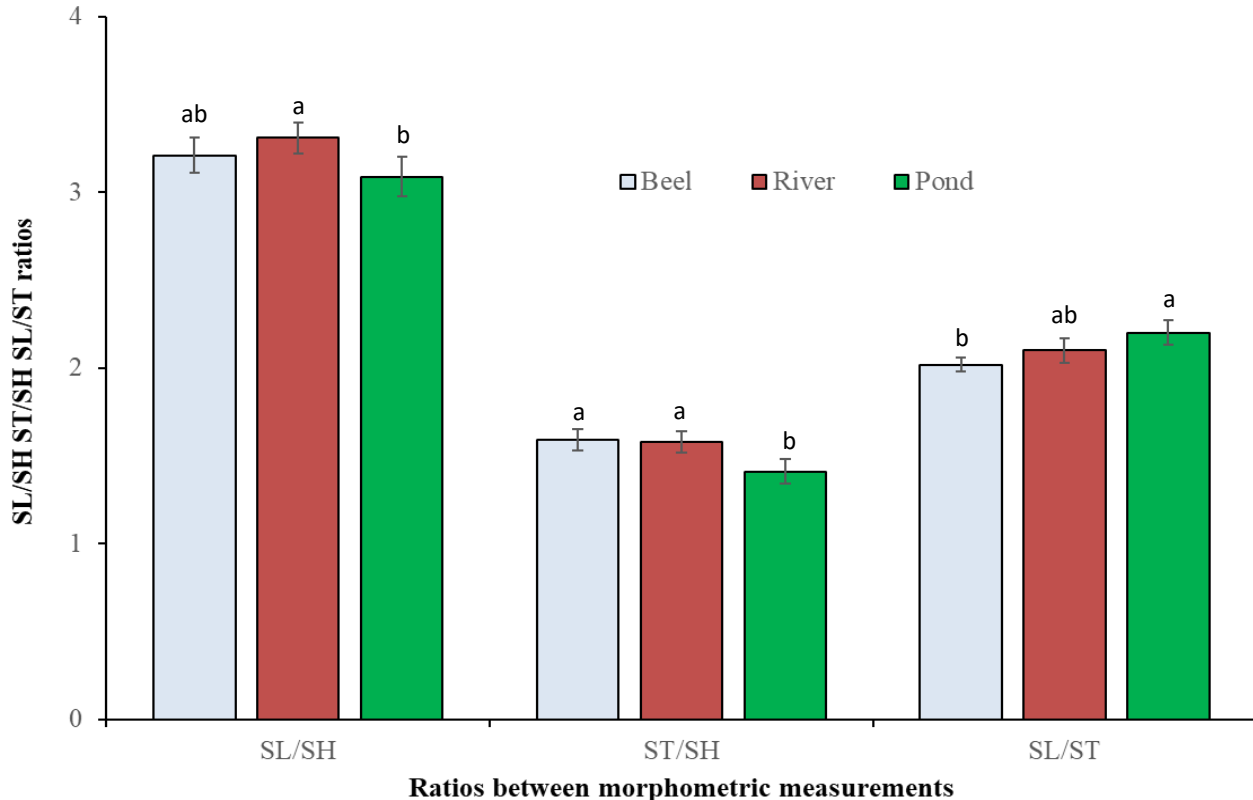


Figure 2: Mean SL/SH, ST/SH and SL/ST of *Lamellidens marginalis* populations (\pm SD) of different habitats; Different letters above the bars indicate significant difference at 5% level of significance; SL, shell length (mm); SH, shell height (mm); ST, shell thickness (mm)

Shell thickness/shell height (ST/SH)

The mean ST/SH ratio of *L. marginalis* samples collected from S₁, S₂ and S₃ populations were 1.59 ± 0.06 , 1.41 ± 0.06 and 1.58 ± 0.07 , respectively. The ST/SH ratio was significantly lower ($p < 0.05$) in individuals of S₃ population than the rest two populations. Such difference was not reported ($p > 0.05$) between populations of S₁ and S₂ (Figure 2). This ratio indicated that the animals of S₃ population are thinner than the rest 2 populations.

Shell length/shell thickness (SL/ST)

The mean SL/ST ratio of *L. marginalis* populations were 2.02 ± 0.04 , 2.20 ± 0.07 and 2.10 ± 0.07 , collected from S₁, S₂ and S₃ populations respectively. The SL/ST ratio was significantly higher ($p < 0.05$) in S₃ population in comparison to S₁ population. This ratio indicated an elongation of shell of S₃ population than S₁ population. Such differences were not existed ($p > 0.05$) between of S₁ and S₂ and S₂ and S₃ populations (Figure 2).

Shell length/umbo height (SL/UH)

The mean SL/UH ratio were 25.27 ± 2.74 , 25.27 ± 2.14 and 23.18 ± 2.09 for S₁, S₂ and S₃ populations, respectively. No statistically significant difference ($p >$

0.05) in SL/UH ratio was found among the 3 populations (Figure 3).

Shell height/umbo height (SH/UH)

The mean SH/UH ratio of *L. marginalis* samples collected from S₁, S₂ and S₃ populations were 7.87 ± 0.82 , 8.16 ± 0.59 and 6.99 ± 0.53 , respectively. The SH/UH ratio was significantly lower ($p < 0.05$) in S₂ population than S₃ population. Such difference was not evident ($p > 0.05$) between the populations of S₁ and S₂, and S₂ and S₃ (Figure 3).

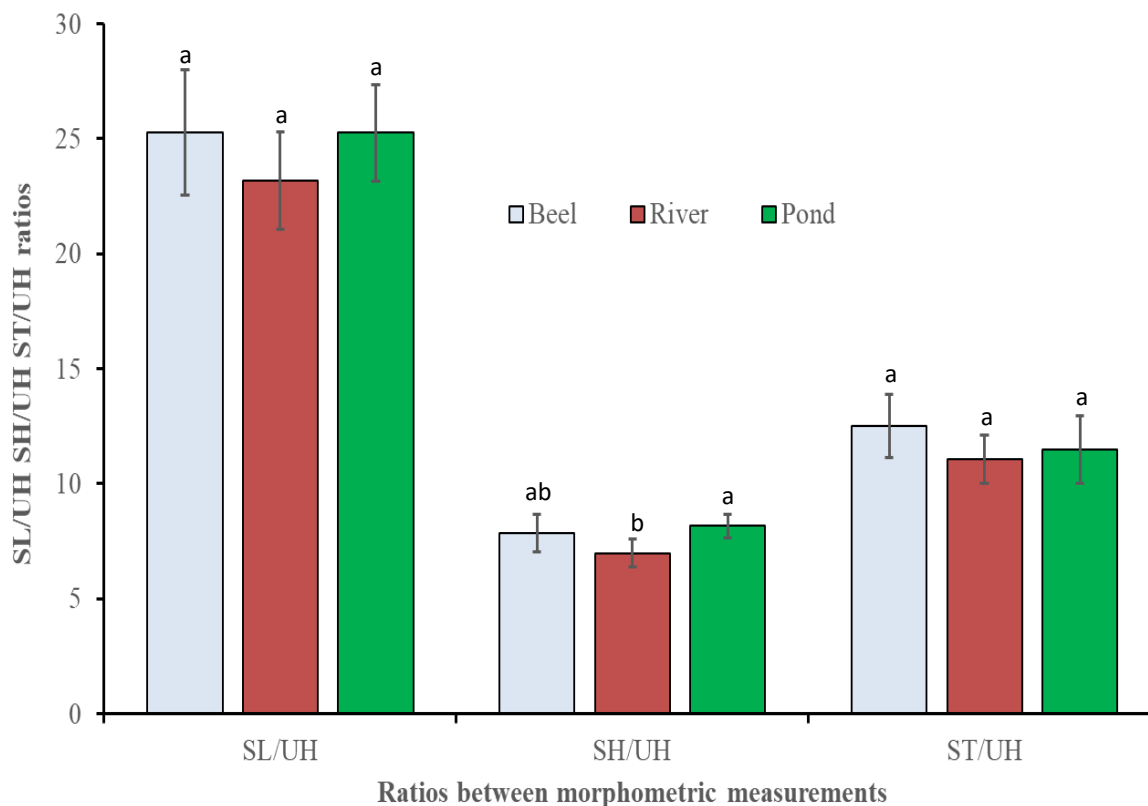


Figure 3: Mean SL/UH, SH/UH and ST/UH of *Lamellidens marginalis* populations (\pm SD) of different habitats; Different letters above the bars indicate significant difference at 5% level of significance; SL, shell length (mm); UH, umbo height (mm); SH, shell height (mm); ST, shell thickness (mm)

Shell thickness/umbo height (ST/UH)

The average ST/UH ratio of S₁ population was 12.53 ± 1.37 . Mean ST/UH ratio of S₂ and S₃ populations were 11.05 ± 1.05 and 11.50 ± 1.46 , respectively. The ST/UH ratio was not significantly different ($p > 0.05$) among the populations (Figure 3).

Shell length/wet tissue weight (SL/WW)

The mean SL/WW ratio of *L. marginalis* populations collected from S₁, S₂ and S₃ were 9.58 ± 0.81 , 9.43 ± 0.82 and 7.79 ± 0.52 , respectively. The SL/WW ratio was significantly higher ($p < 0.05$) in S₁ and S₂ populations than S₃ population. Such difference was not existed ($p > 0.05$) between populations of S₁ and S₂ (Figure 4). This ratio indicated that the edible soft tissue is comparatively lower in S₃ population than the rest 2 populations.

Shell height/wet tissue weight (SH/WW)

The mean SH/WW ratios were 2.99 ± 0.24 , 2.84 ± 0.22 and 2.53 ± 0.17 in S₁, S₂ and S₃ populations, respectively. The SH/WW ratio was significantly higher ($p < 0.05$) in S₁ population than S₃ population. Such differences were

not evident ($p > 0.05$) between populations of S₁ and S₂ and S₂ and S₃ (Figure 4). This ratio implied that the soft tissue content is comparatively higher in S₁ population than S₃ population.

Shell thickness/wet tissue weight (ST/WW)

The mean ST/WW ratio of *L. marginalis* populations collected from S₁, S₂ and S₃ were 4.74 ± 0.37 , 4.50 ± 0.42 and 3.56 ± 0.28 , respectively. The ST/WW ratio was significantly higher ($p < 0.05$) in S₁ and S₂ populations than S₃ population. Such difference was not existed ($p > 0.05$) between populations of S₁ and S₂ (Figure 4). The ratio indicated that the meat content is comparatively higher in S₁ and S₂ populations than S₃ population in relation to ST.

Shell mass/wet tissue weight (SM/WW)

The mean SM/WW ratio of *L. marginalis* populations collected from S₁, S₂ and S₃ were 1.58 ± 0.10 , 1.29 ± 0.13 and 1.45 ± 0.15 , respectively. The SM/WW ratio was significantly higher ($p < 0.05$) in S₁ population than S₂ population. Statistical difference was not noted ($p >$

0.05) between populations of S₁ and S₃, and S₂ and S₃ (Figure 4).

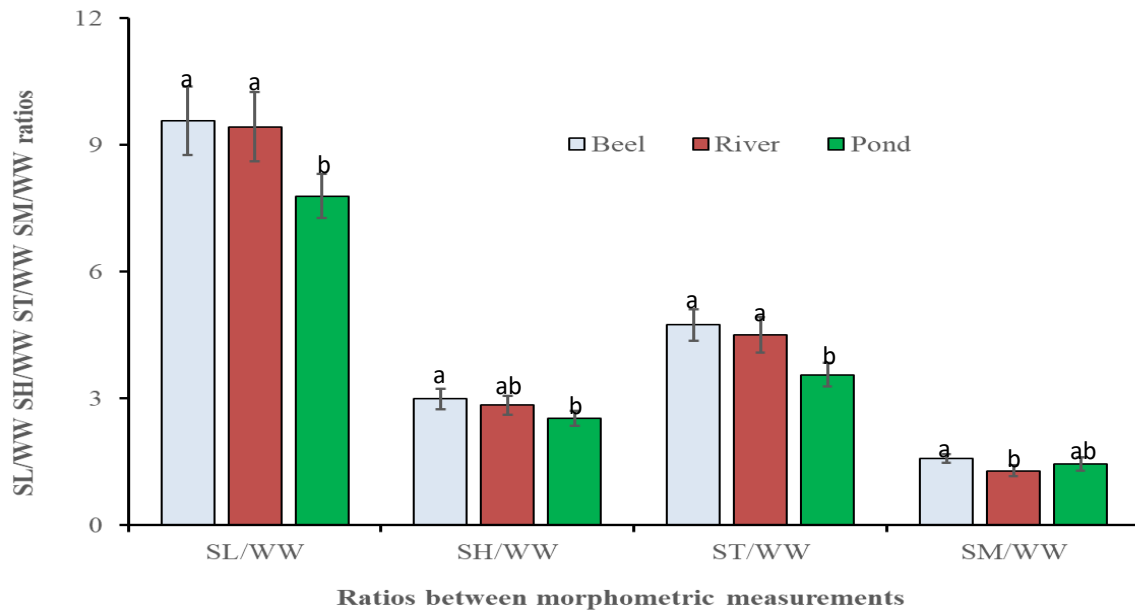


Figure 4: Mean SL/WW, SH/WW, ST/WW and SM/WW of *Lamellidens marginalis* populations (\pm SD) of different habitats; Different letters above the bars indicate significant difference at 5% level of significance; ; SL, shell length (mm); WW, soft tissue wet weight (g); SH, shell height (mm); ST, shell thickness (mm); SM, dry shell mass (g)

Ligament length/distance between adductor muscles scars (LL/DMs)

The mean LL/DMs ratios of S₁, S₂ and S₃ populations were 1.12 ± 0.02 , 1.09 ± 0.02 and 1.09 ± 0.03 , respectively. The LL/DMs ratio did not vary significantly higher ($p > 0.05$) among the populations (Figure 5).

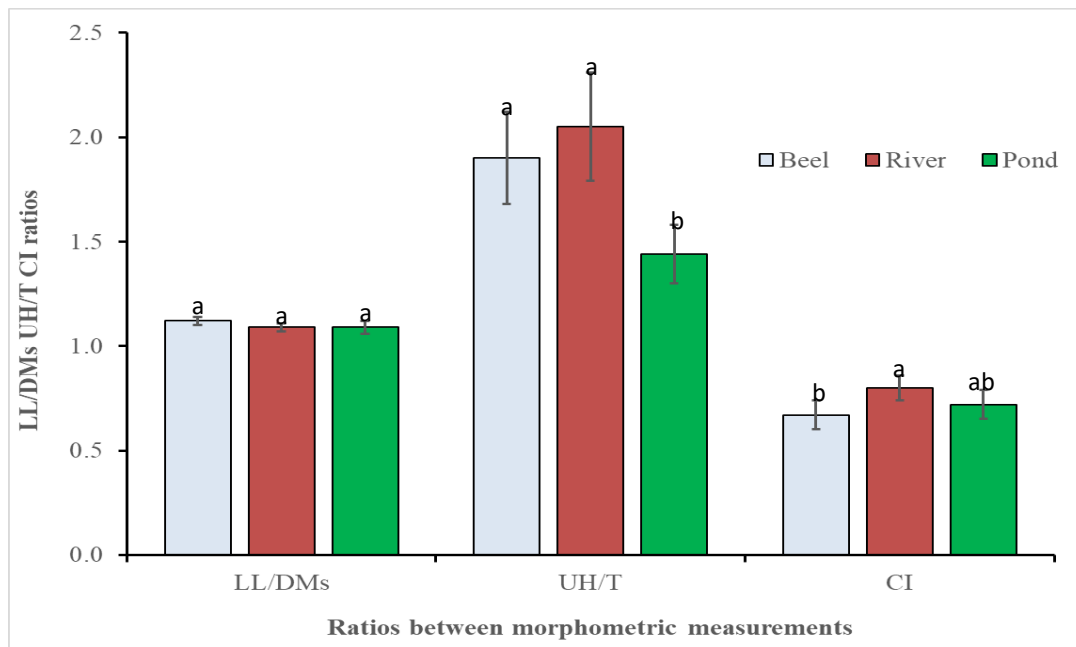


Figure 5: Mean LL/DMs, UH/T and CI of *Lamellidens marginalis* populations (\pm SD) of different habitats; Different letters above the bars indicate significant difference at 5% level of significance; LL, Ligament length (mm); DMs, distance between adductor muscle scars (mm); UH, umbo height (mm); T, thickness of shell margin (mm); CI, condition index.

Umbo height/thickness of shell margin (UH/T)

The mean UH/T ratio of *L. marginalis* populations of S_1 , S_2 and S_3 were 1.90 ± 0.22 , 2.05 ± 0.26 and 1.44 ± 0.14 , respectively. The UH/T ratio was significantly lower ($p < 0.05$) in S_3 population than S_1 and S_2 populations. Statistical difference was not existed ($p > 0.05$) between populations of S_1 and S_2 (Figure 5).

Condition index (CI)

Mean CI of S_1 population was calculated as 0.67 ± 0.07 . For S_2 and S_3 populations the CIs were 0.80 ± 0.06 and 0.72 ± 0.07 , respectively. Significantly higher CI ($p < 0.05$) was reported in S_2 population in relation to S_1 population. Statistical differences were not evident in CIs ($p > 0.05$) between S_1 and S_3 , and S_2 and S_3 (Figure 5).

Discussion

The present study compared the morphological traits and condition index of the freshwater mussel, *Lamellidens marginalis* populations collected from three ecologically distinct freshwater habitats: a natural saucer-shaped depression, beel (S_1); a lotic habitat, river (S_2); and a man-made lentic habitat, pond (S_3). In the present study, 25 out of 27 measured morphometric traits exhibited significant differences ($p < 0.05$) among the three populations, indicating strong habitat-associated morphological plasticity in *L. marginalis*. Key shell dimensions (SL, SH, ST, LL, DMs, UmSL), soft tissue weight (WW), shell mass (SM), and multiple morphometric ratios differed significantly ($p < 0.05$), while umbo height (UH), SL/UH, ST/UH and LL/DMs remained statistically similar ($p > 0.05$). Shell morphological variation among habitats observed in this study is consistent with previous findings in both marine and freshwater bivalves.

Habitat heterogeneity is widely recognized as a major driver of phenotypic variation in aquatic invertebrates, particularly in bivalves, where shell morphology and body condition are closely linked to environmental pressures and resource availability (Hridoy et al., 2025). Morphological differentiation among populations reflects the combined influence of biotic and abiotic interactions acting over time (Teshome et al., 2020; Mukhtar et al., 2025). Previous studies have emphasized that functional phenotypes in bivalves are shaped by habitat-specific factors such as hydrodynamic regime, substrate composition, temperature, food availability, and biological interactions (Renault et al., 2022; AlMealla et al., 2025; Robb, 2025). These factors influence energy allocation patterns, shell deposition, and tissue growth, resulting

in measurable morphometric divergence among populations inhabiting contrasting ecosystems (Gao et al., 2025; Autor et al., 2026). The relative stability of

these latter traits may indicate conservative structural features that are less sensitive to environmental variation, as suggested for other unionid mussels (Dudgeon and Strayer, 2025; Fung, 2025; Hajisafarali et al., 2026). Petracco et al. (2025) demonstrated significant shell shape differentiation in *Donax serra* across geographic regions, attributing variation to temperature and hydrodynamic exposure. Similarly, Qonita et al. (2015) reported habitat-driven variation in umbo height, valve symmetry, and shell elongation in cockles and clams from different sedimentary environments. More recent studies have further emphasized the role of local environmental conditions in driving phenotypic plasticity in bivalve shells, particularly in non-marine systems (Ferreira-Rodríguez et al., 2019; Gomes-dos-Santos et al., 2020; Ramos et al., 2021; Delorme et al., 2024).

The SL/SH, ST/SH and SL/ST indicated that mussels collected from the river (S_2) have elongated and thicker shells than the mussels obtained from the pond (S_3). Although water quality and sediment parameters were not quantified in the present study, the observed morphological trends are consistent with established eco-morphological theories in bivalves. Mussels from lotic habitats often develop more streamlined or elongated shells to cope with current velocity and sediment instability (Haag, 2012; Modestin, 2017). The ratios also reflected that the mussels of the pond (S_3) possessed comparatively rounder and thinner shells than those from the beel (S_1) and river (S_2). Such morphological patterns may reflect reduced hydrodynamic stress and finer sediment composition in lentic environments, which favor lateral shell expansion and increased convexity (Garcia et al., 2012).

Condition index (CI) is widely used as a rapid and cost-effective indicator of physiological status, nutritional condition, and commercial quality in bivalves (Cotou et al., 2024; Yin et al., 2024; Uddin et al., 2024). Because gonads in most bivalves are integrated within the visceral mass, direct estimation of gonadosomatic index is often impractical; consequently, CI serves as a reliable measure reflecting reproductive development and energy reserves (Gosling, 2015; Jolaosho et al., 2023; Kurtay and Lök, 2023; Uddin et al., 2024a). CI has been extensively applied in freshwater and marine bivalve studies to assess seasonal growth patterns, habitat suitability, and environmental stress (Yildiz and Lök, 2005; Niogee et al., 2019; Mia et al., 2024). Significant differences ($p < 0.05$) in CI among the three populations highlight the strong influence of habitat on the physiological condition of *L. marginalis*. The highest CIs were recorded in the riverine population (S_2), followed by the pond (S_3) and beel (S_1) populations. This suggests that the Old Brahmaputra River provides comparatively

favorable conditions for somatic growth and energy accumulation for the population. This could be potentially due to enhanced food availability, continuous water exchange, and reduced organic stress (Hossain et al. 2023). Similar habitat-dependent variations in CIs have been documented for *L. marginalis* and other unionids in South Asian freshwater systems (Salam et al., 2024; Siddique et al., 2020; Hoque et al., 2025). The mean CI values obtained in this study (0.40-0.96) fall within the range reported in previous investigations, confirming the physiological validity of the results. The observed differences further reinforce the notion that habitat quality plays a decisive role in determining growth performance and health status of freshwater mussel populations (Stoeckl et al., 2020). From a management and conservation perspective, these findings underscore the importance of habitat-specific assessments when evaluating the productivity and sustainability of freshwater bivalve resources. Overall, the present study demonstrates pronounced morphological plasticity and habitat-driven variation in condition index of *L. marginalis*, emphasizing the ecological significance of local environmental conditions in shaping phenotypic traits. These results provide valuable baseline information for future studies on population dynamics, conservation planning, and aquaculture potential of freshwater mussels in Bangladesh and similar subtropical regions.

Conclusion

This study uncovered notable morphometric and physiological differences among *Lamellidens marginalis* populations inhabited in three ecologically distinct habitats. The riverine population displayed a more elongated and thicker shell compared to the pond population, while the pond population showed relatively rounder and thinner shells than the other populations. A superior physiological condition of the riverine population was noted over the beel population regarding the condition index. These findings demonstrate that habitat has a profound impact on shell morphology, tissue development, and overall health of *L. marginalis*. However, water quality and sediment data of the habitats could better explain the shell morphological variability of the benthic *L. marginalis*. Such variations specific to habitat offer valuable insights for the sustainable management, conservation, and aquaculture potential of the freshwater bivalve species.

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Author contribution statement

Conceptualization: MMN, MTI, MJU. Developing methods: MMN, MTI, MJU. Data analysis: MMN, SMH. Preparation of figures and tables: MMN, SMH. Conducting the research, data interpretation, writing: MMN, MTI, SMH, MJU.

Statements and Declarations

We have no conflicts of interest to disclose and each author has read the manuscript before submission.

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