



Temporal patterns in shell allometric dynamics and condition index of *Modiolus metcalfei* (Hanley, 1843) in Vellar Estuary, Tamil Nadu, India

Subramaniyan Anbuselvan • Vengatesan Sanjaikumar • Gothandapani Jana • Surendrakumar Nabisha • Anandanatesan Arundathy • Muthusamy Thangaraj

Centre of Advanced Study in Marine Biology, Faculty of Marine Sciences, Annamalai University, Parangipettai 608 502, Tamil Nadu, India

Correspondence

Muthusamy Thangaraj; Centre of Advanced Study in Marine Biology, Faculty of Marine Sciences, Annamalai University, Parangipettai 608 502, Tamil Nadu, India

 coralholders@gmail.com

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Abstract

The present study investigates the seasonal variation in length–weight relationships (LWRs) and condition factors of the brown mussel, *Modiolus metcalfei* (Hanley, 1843) in the Vellar Estuary of Tamil Nadu, India. Mussels were collected fortnightly during August 2024 – July 2025. The LWRs were analyzed using both non-linear and linear allometry models, and condition status was assessed using Fulton's condition factor (K) and relative condition factor (K_r). The results revealed a consistent negative allometry growth pattern ($b < 3$) across all seasons, with b -values ranging from 2.34 (pre-monsoon) to 2.73 (post-monsoon). The coefficient of determination (r^2) ranged from 0.8832 to 0.9114, indicating a strong correlation between length and weight. Seasonal variation was also observed in condition factors, with the higher K value was recorded during monsoon and significantly higher K_r was observed during post-monsoon period. These findings suggest that the growth and physiological condition of *M. metcalfei* are significantly influenced by environmental fluctuations such as salinity, temperature, dissolved oxygen, and food availability. This study provides essential baseline data for understanding the population dynamics and ecological adaptations of *M. metcalfei* in the Vellar estuarine habitat.

Keywords: allometry; condition factor; length–weight relationship; *Modiolus metcalfei*; seasonal variation; Vellar Estuary

1 | INTRODUCTION

Modiolus metcalfei (Hanley, 1843), commonly known as the brown mussel, is an infaunal bivalve of the mangrove ecosystems in Southeast Asia. It attaches to mangrove roots in intertidal mudflats and forms dense beds using byssal threads (Morton 1977; Tumanda *et al.* 1997). Juvenile exhibit streamlined shells for efficient burrowing, while adults develop deeper burrows with reduced mobil-

ity due to changes in shell morphology (Pohlo 1964). As sentinel species, mussels are widely used in biomonitoring programs to assess environmental pollution (Diouf *et al.* 2020).

Length-weight relationships (LWR) and condition factors are key tools in fisheries science for assessing growth, health, and population dynamics (Park and Oh 2002; Froese 2006). LWRs also enable conversions be-

tween length and weight, facilitate stock assessments, and allow comparisons across populations and habitats (Anderson and Gutreuter 1983; Pauly 1993). The concept of allometry was first introduced by Huxley and Tessier (1936) to describe the relationship between body dimensions. In molluscs, shell growth patterns reflect both intrinsic factors and environmental influences such as salinity, sediment type, wave action, and depth (Wilbur and Owen 1964; Costa *et al.* 2008; Noor *et al.* 2021). While traditional morphometrics can be size-dependent and autocorrelated (Zelditch *et al.* 2012), allometry analysis offers better insights into organismal form and ecological adaptation. Various allometry relationships studies have been conducted in bivalves to assess their growth pattern (Gaspar *et al.* 2001; Tenjing *et al.* 2013; Thomas 2013; Nagvenkar *et al.* 2014; Bahtiar and Findra 2025). Relative condition factor (K_n) and Fulton's condition factor (K) were used in previous studies to estimate the organismal well-being and it can vary with season, sex, and physiological state (Watanabe and Katayama 2010; Sundaram *et al.* 2011; Isnard *et al.* 2015).

Despite the ecological importance of *M. metcalfei* in the Vellar Estuary, existing studies have mainly focused on species diversity, with limited data on growth patterns. This study aims to assess the seasonal shell allometry and length-weight relationships in *M. metcalfei* in the Vellar Estuary habitat.

2 | METHODOLOGY

2.1 Study area

The Vellar Estuary is located on the southeast coast of India and is classified as a "true estuary," characterized by an open estuarine mouth throughout the year. Based on salinity gradients, the estuary has been categorized into marine, gradient, tidal, and freshwater zones (Ramamurthy 1954). The estuarine system is influenced by semi-diurnal tides, with maximum tidal amplitude of approximately 1 m. The depth of the estuary ranges between 2.3 and 5.0 m. The interaction between neritic waters and estuarine conditions facilitates the exchange of both biotic and abiotic components, with tidal influence extending up to 16 km upstream. The system experiences seasonal variations in chlorinity and freshwater inflow, which influence the cycling of elements within the estuarine and adjacent coastal systems (Natarajan *et al.* 1979). Environmental parameters in the Vellar Estuary vary with three main seasons: pre-monsoon (May–August), monsoon (September–December), and post-monsoon (January–April).

2.2 Sample collection

Specimens of *M. metcalfei* were collected fortnightly from August 2024 to July 2025. The study was conducted within a defined oyster-bed area of approximately 790 m²

in the (Figure 1) Vellar Estuary (11°29'25"N, 79°45'60"E). During each sampling event, three 2 m² quadrats were randomly positioned within the oyster bed area. The quadrat positions were randomly changed during each sampling event rather than repeatedly sampling the same locations. To minimize depth related variability, sampling was conducted at an approximately uniform depth of 30 cm. Sampling effort was standardized throughout the study by maintaining the same sampling frequency, number and size of quadrats, total sampled area per event, sampling depth, and collection procedure during each sampling. Mussels associated with edible oyster beds were carefully detached and rinsed with estuarine water to remove sediment and debris. Morphometric measurements were recorded for each individual mussel, including shell length (SL), shell width (SW), and shell height (SH), using a digital Vernier caliper with a precision of 0.02 mm. Shell weight (SWt) was measured using a digital balance with 0.01 g accuracy. During the study period, environmental parameters in the estuary water were monitored and recorded as given in Table 1.

TABLE 1 Water quality parameters in Vellar Estuary during the study period (values in the column sharing common superscript is not significantly different at $p = 0.05$ level).

Season	Temperature (°C)	Salinity (ppt)	pH	DO (mg/L)
Pre monsoon	29.7± 2.5 ^a	30.3± 3.5 ^a	7.5± 0.5 ^a	4.81± 0.53 ^a
Monsoon	26.5± 2.3 ^b	22.1± 12.2 ^b	7.9± 0.3 ^a	5.85± 0.64 ^a
Post monsoon	27.8± 2.1 ^b	24.3± 5.7 ^b	7.6± 0.2 ^a	5.14± 0.71 ^a

2.3 Data analysis

The length–weight relationship (LWR) was assessed using the following non-linear equation:

$$W = a L^b$$

where W is the total weight (g), L is the shell length (mm), a is the intercept (initial growth coefficient), and b is the slope or growth exponent (Ramesha and Seetharamiah 2009; López *et al.* 2018; Nahar *et al.* 2019; Petetta *et al.* 2019; Bouzaidi *et al.* 2021). The equation was log-transformed and analyzed using the Linear Allometric Model (LAM):

$$\log W = \log a + b \log L$$

The b value indicates the nature of growth: $b = 3$ imply isometry growth, $b > 3$ indicates positive allometry growth, and $b < 3$ suggests negative allometry growth. All the shell morphometric data of the three seasons were analyzed using univariate analysis of variance (ANOVA), with Tukey HSD (for unequal N) post-hoc comparison tests to investigate significant shell morphometric differ-

ences. Tests were considered significant at $p < 0.05$.

The condition of the mussels was evaluated using Fulton's condition factor (K) and the relative condition factor (K_n), both of which serve as indicators of physiological well-being and environmental suitability (Simon and Mazlan 2008; Isnard et al. 2015; Hashim et al. 2017). These were calculated using the following equations:

Fulton's Condition Factor (K): $K = 1000 W / L^3$

Relative Condition Factor (K_n): $K_n = W / a L^b$
where W is the total body weight (g) and L is the shell length (mm). Higher values of K and K_n indicate better nutritional status and overall condition. Seasonal differences in Fulton's condition factor (K) and relative condition factor (K_n) were also evaluated among the three seasons. Statistical significance was assessed at $p < 0.05$.

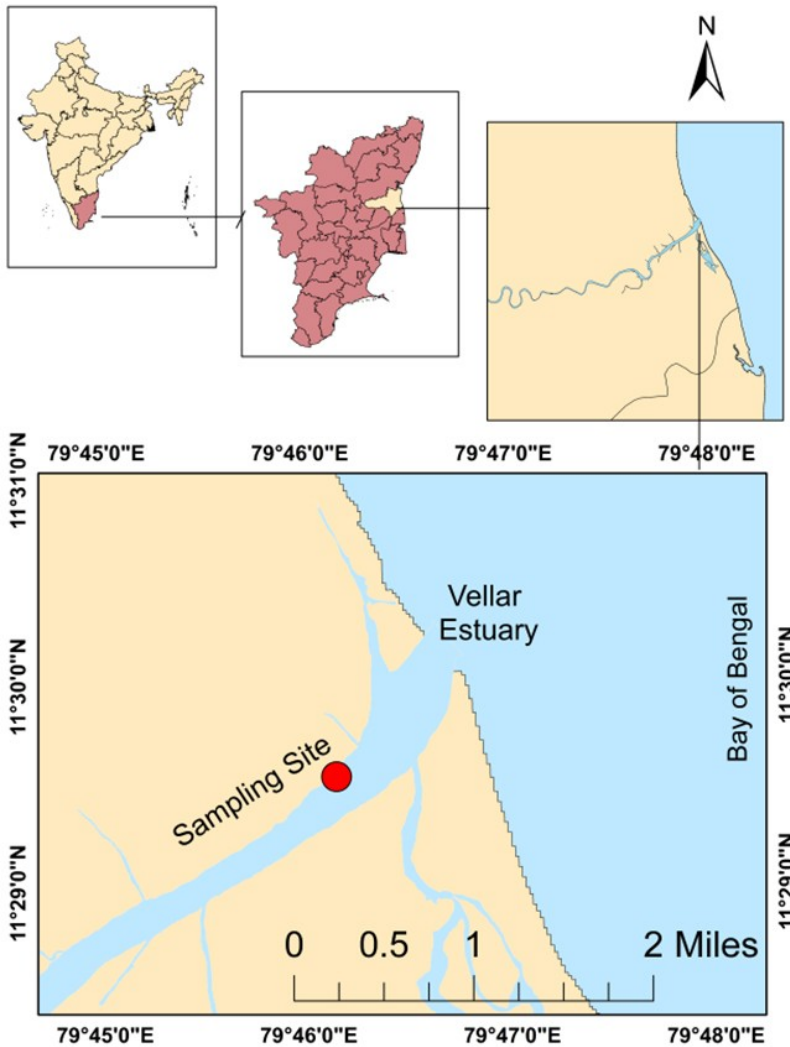


FIGURE 1 Map showing the *Modiolus metcalfei* sampling site in the Vellar Estuary, Tamil Nadu, India.

3 | RESULTS

3.1 Shell morphometry

The shell morphometric variables (total length, weight, total height, and total width) were measured in 2,531 individuals during the study period, comprising 887 individuals in the pre-monsoon, 520 in the monsoon, and 1,124 in the post-monsoon season. The detailed descriptions of shell morphometry in different seasons are given in Table 2. Total Length ranged from 2.30 to 38.10 mm across all seasons. The mean total length was highest in the pre-monsoon (20.76 ± 6.78 mm), followed closely by

the post-monsoon (20.59 ± 7.08 mm), and lowest during the monsoon (20.47 ± 6.61 mm). Body weight varied between 0.009 g and 6.543 g. The highest mean body weight was recorded during the monsoon (1.44 ± 1.05 g), while the post-monsoon showed a slightly lower value (1.33 ± 1.00 g). A significant difference was observed only between the post-monsoon and the other two seasons. Total height showed notable seasonal differences, with the highest mean height during the pre-monsoon (10.02 ± 3.13 mm), and the lowest during the monsoon (8.15 ± 2.43 mm). Total width showed a contrasting pat-

tern, with the monsoon exhibiting the highest mean width (10.38 ± 3.01 mm), while the pre-monsoon showed the lowest value (8.35 ± 2.72 mm).

The smallest (2.3 mm) and largest total length (38.1 mm) animals were observed in pre monsoon season. The maximum (6.534 g) and minimum body weight (0.009 g) animals were observed in post monsoon. Maximum height (20.1 mm) was observed in post monsoon, while minimum (1 mm) was in pre monsoon. The animals which are having maximum (17.8 mm) and minimum shell width (1.8 mm) were observed in post monsoon season.

3.2 Allometry growth

The length–weight and other morphometric relationships

of *M. metcalfei* collected from the Vellar Estuary exhibited consistent negative allometry growth across all seasons, as indicated by b values significantly less than 3 ($p < 0.05$). A summary of the regression parameters and the nature of allometry are provided in Table 3. In the length–weight relationship, the growth exponent (b) ranged from 2.3479 (pre-monsoon) to 2.7328 (post-monsoon). The highest coefficient of determination ($r^2 = 0.9114$) was observed during the monsoon season, suggesting a stronger fit between shell length and weight in that period. Despite seasonal variations, all three b values were < 3 , indicating negative allometry growth, where length increases at a faster rate than weight.

TABLE 2 ANOVA result of morphometric variables in *Modiolus metcalfei* at Vellar Estuary (values in the row sharing common superscript is not significantly different at $p = 0.05$ level).

Parameter	Central tendency and data range	Pre monsoon	Monsoon	Post monsoon
Total length (mm)	Mean $\pm$ SD	20.76 ± 6.78^a	20.47 ± 6.61^b	20.59 ± 7.08^c
	Range (min–max)	2.30–38.10	5.30–36.80	3.70–37.10
Body weight (g)	Mean $\pm$ SD	1.43 ± 1.10^a	1.44 ± 1.05^a	1.33 ± 1.00^b
	Range (min–max)	0.025–6.020	0.019–4.923	0.009–6.543
Total height (mm)	Mean $\pm$ SD	10.02 ± 3.13^a	8.15 ± 2.43^b	8.78 ± 2.97^c
	Range (min–max)	1.00–18.40	1.30–15.50	1.50–20.10
Total width (mm)	Mean $\pm$ SD	8.35 ± 2.72^a	10.38 ± 3.01^b	9.61 ± 3.29^c
	Range (min–max)	2.30–15.70	3.30–17.50	1.80–17.80

TABLE 3 Descriptive statistics and allometric relationships in *Modiolus metcalfei* at Vellar Estuary in different seasons.

Relationship	Season	n	a	SE of a	b	SE of b	r^2	Allometry (t-test)
Length – weight	Pre monsoon	887	0.0009	0.1939	2.3479	0.0431	0.8832	A-
	Monsoon	520	0.0007	0.1087	2.4343	0.0313	0.9114	A-
	Post monsoon	1124	0.0002	0.1200	2.7328	0.0205	0.9004	A-
Length – width	Pre monsoon	887	0.5993	0.0715	0.8662	0.0159	0.8168	A-
	Monsoon	520	0.9073	0.0594	0.8081	0.0166	0.8506	A-
	Post monsoon	1124	0.5734	0.0630	0.9306	0.0107	0.8465	A-
Length – height	Pre monsoon	887	0.8982	0.0719	0.7932	0.0160	0.7531	A-
	Monsoon	520	0.6799	0.0614	0.8233	0.0172	0.8363	A-
	Post monsoon	1124	0.5475	0.0658	0.9162	0.0112	0.7999	A-
Height – weight	Pre monsoon	887	0.0047	0.1827	2.3716	0.0441	0.6625	A-
	Monsoon	520	0.0037	0.1096	2.7482	0.0337	0.8235	A-
	Post monsoon	1124	0.0033	0.1833	2.6425	0.0315	0.6664	A-
Width – weight	Pre monsoon	887	0.0062	0.1517	2.458	0.0350	0.7870	A-
	Monsoon	520	0.0017	0.1218	2.7811	0.0383	0.8211	A-
	Post monsoon	1124	0.0029	0.1910	2.6047	0.0326	0.7232	A-
Width – height	Pre monsoon	887	1.9253	0.0669	0.7734	0.0154	0.6236	A-
	Monsoon	520	0.9427	0.0620	0.9195	0.0195	0.7555	A-
	Post monsoon	1124	1.4461	0.1047	0.7912	0.0178	0.5487	A-

For the length–width relationship, b values ranged from 0.8081 (monsoon) to 0.9306 (post-monsoon), all indicative of negative allometry. The highest r^2 value was

also observed during the monsoon (0.8506), suggesting consistent proportional growth in shell width with respect to length. Similarly, the length–height relationship

showed b values between 0.7932 and 0.9162 across seasons, with moderate to strong correlations (r^2 values ranging from 0.7531 to 0.8363). Again, allometric growth remained negative. In the height–weight relationship, the b exponent reached its highest during the monsoon (2.7482), followed by post-monsoon (2.6425) and pre-monsoon (2.3716). These results reinforce the trend of negative allometry, with monsoon samples showing a comparatively stronger correlation ($r^2 = 0.8235$).

3.3 Size frequency distribution

The length-frequency distribution of the species showed marked seasonal variations (Figure 2). Individuals ranging from 21.0 mm to 25.9 mm were most dominant in all three seasons, with the highest number recorded during the post-monsoon ($n = 297$), followed by pre-monsoon (n

$= 215$) and monsoon ($n = 120$). The post-monsoon season exhibited the greatest abundance across almost all size classes, particularly in the 6–30.9 mm range, indicating enhanced growth and recruitment during this period. A steady increase in frequency was observed from the 6.0–10.9 mm to 26.0–30.9 mm size classes during all seasons, after which the number declined in the higher length classes. The smallest size class (1.0–5.9 mm) was least represented in all seasons, indicating limited early juvenile presence or sampling bias towards larger individuals. The presence of larger individuals (above 31.0 mm) was minimal in all seasons, and completely absent in the post-monsoon beyond 36 mm, suggesting either natural mortality, or seasonal variation in the occurrence of large-sized individuals.

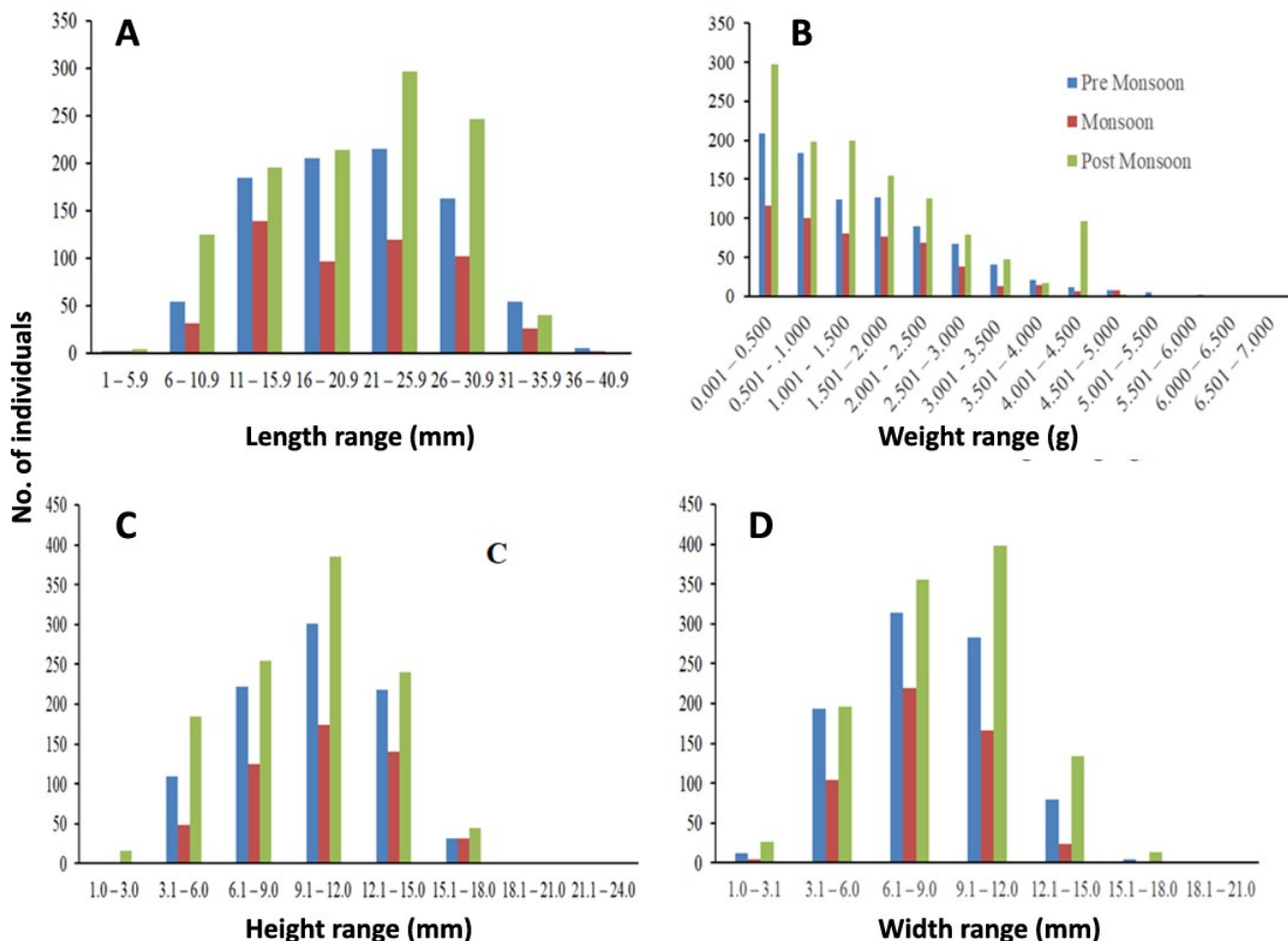


FIGURE 2 Temporal variation of (A) length, (B) weight, (C) height and (D) width frequency of *Modiolus metcalfei* in the Vellar Estuary during the study period.

3.4 Condition index

Fulton's condition factor (K) of *M. metcalfei* was ranged from 0.0061 to 0.0224 during monsoon season. The K

value was significantly varied between the three seasons at $p = 0.05$ level. The relative condition factor (K_r) was ranged from 0.3738 to 1.6428 during pre-monsoon sea-

son. The K_n values of monsoon and post monsoon were not significantly different at $p = 0.05$ level (Figure 3).

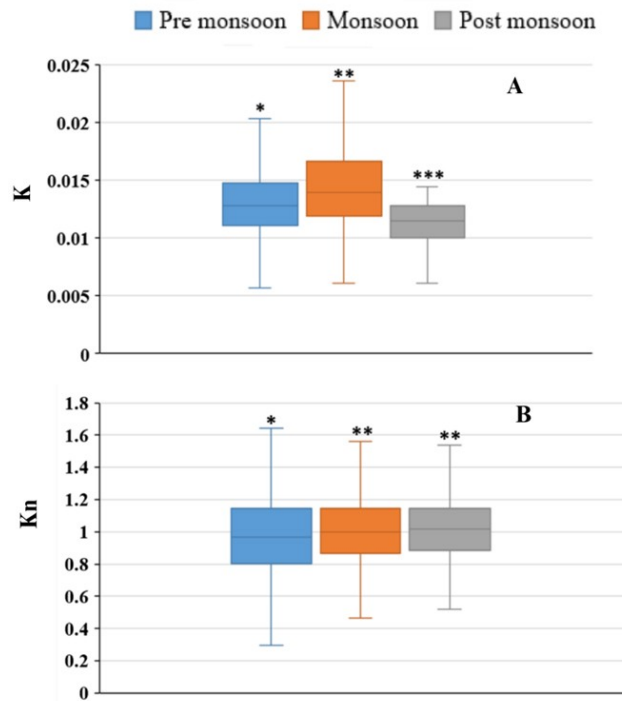


FIGURE 3 (A). Box-plots of Fulton's condition factor (K). (B). Relative condition factor (K_n) of *Modiolus metcalfei* in the Vellar Estuary (Line = median, box = 25th and 75th percentile, whiskers = 10th and 90th percentile, Bars showing similar symbol are not significantly different at $p = 0.05$ level).

4 | DISCUSSION

The allometry relationships analysed in this study aimed to evaluate the growth patterns of *M. metcalfei* in the Vellar Estuary. Growth patterns were assessed through the dispersion trends in morphometric data, particularly the relationship between shell length and body weight. Parameters such as the length–weight regression coefficient (b) and the coefficient of determination (r^2) were estimated using the power regression model, which was log-transformed to a linear form (Thomas 2013). The main objective was to determine whether the species exhibited isometry or allometry growth, based on the b -value obtained from the equation. According to Froese (2006), the b -value for most fish and shellfish typically lies between 2.5 and 3.5. However, Jisr et al. (2018) reported that b -values in several bivalve species can range from 0.823 to 3.016, with r^2 values between 0.051 and 0.898, indicating a variable but often strong relationship between length and weight.

In the present study, the b -values for the length–weight relationship in *M. metcalfei* ranged from 2.34 (pre-

monsoon) to 2.73 (post-monsoon), all below the isometry threshold of 3.0, thereby indicating a negative allometry growth pattern. These findings are consistent with those reported by Hariyadi et al. (2023) for the clam *Potamocorbula faba* from Permisan Bay, Indonesia, where b -values ranged from 2.15 to 2.52. The observed growth pattern suggests that shell length increases more rapidly than body weight, resulting in an unbalanced growth trend. Similar results were observed in *Corbula gibba* in Tripoli, Lebanon, with a b -value of 2.96 (Jisr et al. 2018), indicating negative allometry, whereas *C. gibba* in the North Sea exhibited positive allometry ($b = 3.28$; Robinson et al. 2010). Likewise, Thomas (2013) reported a positive allometry in the short-neck clam *Paphia malabarica* from the Dharmadom estuary, Kerala, and Nagvenkar et al. (2014) found year-round positive allometric growth in the same species from the Nerul estuary, Goa. Petetta et al. (2019) also documented a positive allometric growth pattern ($b = 3.28$) in *Ensis minor* in the Italian coast (Table 4). The variability in b -values among species and regions is often attributed to several factors, including environmental conditions, habitat quality, food availability, reproductive status, and sampling period (Froese 2006; Abelha and Goulart 2008; Isnard et al. 2015). Additionally, b -values may reflect gonadal development and maturation processes in bivalves (Galvão et al. 2015; Hemachandra et al. 2017). In the current study, the highest b -value (2.73) was observed during the post-monsoon season, while the lowest (2.34) occurred in the pre-monsoon. This seasonal variation may be influenced by environmental factors such as food availability, temperature, salinity, pH, and dissolved oxygen. Patimar et al. (2009) noted that site-specific and seasonal characteristics can lead to significant differences in growth responses among populations. The r^2 values in the present study ranged from 0.8832 to 0.9114, with the highest correlation observed during the monsoon season, indicating a strong relationship between length and weight in *M. metcalfei*. This supports the use of length–weight relationships as reliable indicators of growth dynamics and population structure in estuarine bivalve like *M. metcalfei*.

The condition status of *M. metcalfei* was further assessed using Fulton's condition factor (K) and the relative condition factor (K_n), both of which provide insight into the health, reproductive condition, and nutritional status of the species (Froese 2006; Sundaram et al. 2011). In the present study, the K_n values ranged from 0.3738 to 1.6428 (pre-monsoon), while K values ranged from 0.0061 to 0.0224 (monsoon season). These values are comparable to those reported by Hariyadi et al. (2023) in *P. faba*, where K ranged from 0.0631 to 0.2787 and K_n from 0.9364 to 1.0506. In our study, the highest median K was observed during the monsoon season, while the lowest was recorded in the pot-monsoon. Conversely, the highest median K_n occurred during the post-monsoon season,

suggesting an improvement in physiological condition during this period. Seasonal differences in condition factors may be attributed to environmental variation, reproductive activity, or fluctuations in food resources. Şaşı (2008) and Ndome *et al.* (2012) also enlightened that condition factors can be influenced by age, sex, maturity, stress, and habitat quality. Moreover, phenotypic plasticity

in shell morphology may affect tissue allocation and influence the length weight ratio (Turra *et al.* 2018). In suboptimal environments, reduced food intake or environmental stressors may compromise energy acquisition and allocation, ultimately impacting growth and condition.

TABLE 4 Comparative analysis of length–weight relationship (*b*-value) and growth pattern in different bivalve species from various geographic locations.

Species	<i>b</i> -value	Growth type	Location	Reference
<i>Modiolus metcalfei</i>	2.34–2.73	A-	Vellar Estuary, India	Present study
<i>Potamocorbula faba</i>	2.15–2.52	A-	Permisan Bay, Indonesia	Hariyadi <i>et al.</i> (2023)
<i>Corbula gibba</i>	2.96	A-	Tripoli, Lebanon	Jisir <i>et al.</i> (2018)
<i>Corbula gibba</i>	3.28	A+	North Sea	Robinson <i>et al.</i> (2010)
<i>Paphia malabarica</i>	3.10–3.40	A+	Nerul Estuary, Goa, India	Nagvenkar <i>et al.</i> (2014)
<i>Paphia malabarica</i>	3.23	A+	Dharmadom Estuary, Kerala, India	Thomas (2013)
<i>Ensis minor</i>	3.28	A+	Northern Adriatic & Tyrrhenian Sea, Italy	Petetta <i>et al.</i> (2019)
<i>Perna viridis</i>	2.67	A-	Versova creek, Mumbai, India	Sundaram <i>et al.</i> (2011)
<i>Chamelea gallina</i>	2.37	A-	Black Sea	Kasapoglu and Duzgunes (2013)
<i>Donax trunculus</i>	2.69	A-	West Marmara Sea	Çolakoğlu (2014)
<i>Donax semistriatus</i>	2.44	A-	Gulf of Tunis	Charef <i>et al.</i> (2012)
<i>Mactra stultorum</i>	2.20	A-	Gulf of Tunis	Charef <i>et al.</i> (2012)
<i>Solen marginatus</i>	2.96	A-	Galicia, NW Spain	DaCosta and Martínez-Patiño (2009)
<i>Dosinia lupinus</i>	3.19	A+	North Sea	Robinson <i>et al.</i> (2010)
<i>Peronidia albicans</i>	3.07	I	Algarve Coast, Southern Portugal	Vasconcelos <i>et al.</i> (2018)
<i>Peronaea planata</i>	0.83	A-	Gulf of Tunis	Charef <i>et al.</i> (2012)
<i>Anodontia edentula</i>	3.70	A+	Barangay, Nabago, Philippines	Degamon <i>et al.</i> (2023)
<i>Saccostrea cucullata</i>	2.61	A-	Barangay, Nabago, Philippines	Degamon <i>et al.</i> (2023)
<i>Perna perna</i>	2.44	A-	Mamelles coast, Dakar, Senegal	Diouf <i>et al.</i> (2020)
<i>Etheria elliptica</i>	4.63–5.56	A+	Ogbese River, Nigeria	Oyewole <i>et al.</i> (2013)
<i>Parreysia favidens</i>	3.06	I	Seeta river in the Western Ghats, India	Ramesha and Sophia (2015)

A- = negative allometry; A+ = positive allometry; I = isometry

5 | CONCLUSIONS

In Vellar Estuary the availability of the brown mussel, *M. metcalfei* throughout the year indicates their tolerance to various environmental conditions and adaptability to different season. The observed season wise growth patterns and condition indices may be associated with changes in environmental conditions and food availability. Results of the present study give an overall idea about the relative growth of body parts of *M. metcalfei*. These variations reflect the dynamic estuarine environment and highlight the importance of seasonal monitoring for understanding population health and ecological responses. This study enhances our understanding of the growth biology of *M. metcalfei* and provides valuable baseline data for future ecological and conservation studies. The morphometric patterns and condition indices presented here can be instrumental in assessing the species' adaptive strategies,

reproductive potential, and responses to environmental stressors in estuarine ecosystems. Further long-term ecological studies should also be undertaken to carefully monitor the shellfish exploitation in this region.

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ETHICAL APPROVAL

All applicable international, national and/or institutional guidelines for the care and use of animals were followed in this study.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

Subramaniyan Anbuselvan: Formal analysis, Investigation, Writing – original draft preparation; Vengatesan Sanjaikumar: Investigation; Gothandapani Jana: Investigation; Surendrakumar Nabisha: Data curation; Anandanatesan Arundathy: Investigation, Muthusamy Thangaraj: Conceptualization, Formal analysis, Supervision, Writing – review & editing.

AI-USE STATEMENT

No AI was used to write or analyse the data during the preparation of this manuscript.

DATA AVAILABILITY STATEMENT

The data of this study are available on a reasonable request from the corresponding author.

REFERENCES

- Abelha MCF, Goulart E (2008) [Population structure, condition factor and reproductive period of *Astyanax paranae* \(Eigenmann, 1914\) \(Osteichthyes: Characidae\) in a small and old Brazilian reservoir](#). Brazilian Archives of Biology and Technology 51(3): 503–512.
- Anderson RO, Gutreuter SJ (1983) Length, weight and associated structural indices. In: Fisheries techniques (pp. 283–300). American Fisheries Society.
- Bahtia MN, Findra (2025) [Population dynamics of horse mussels *Modiolus modulaides* \(Röding, 1798\) in Kendari Bay, Southeast Sulawesi, Indonesia](#). International Journal of Aquatic Biology 13(2): 153–161.
- Bouzaidi H, Maatouk M, El Moumni B, Haroufi O, Saber MA, ... Daoudi M (2021) [Population structure, age and growth of *Callista chione* \(Bivalvia: Veneridae\) in Martil Coast of the western Mediterranean](#). Regional Studies in Marine Science 48: 101996.
- Charef A, Langar NZ, Gharsallah IH (2012) [Stock size assessment and spatial distribution of bivalve species in the Gulf of Tunis](#). Journal of the Marine Biological Association of the United Kingdom 92(1): 179–186.
- Çolakoglu S (2014) [Population structure, growth and production of the wedge clam *Donax trunculus* \(Bivalvia, Donacidae\) in the West Marmara Sea, Turkey](#). Turkish Journal of Fisheries and Aquatic Sciences 14: 221–230.
- Costa C, Aguzzi J, Menesatti P, Antonucci F, Rimatori V, Mattoccia M (2008) [Shape analysis of different populations of clams in relation to their geographical structure](#). Journal of Zoology 276(1): 71–80.
- Degamon LS, Eviota MP, Hugo RL, Bertulfo RE, Odojan MM, ... Cuadrado JT (2023) [Length–weight relationship of bivalves and gastropods from mangrove forest of Brgy. Nabago, Surigao City, Philippines](#). IOP Conference Series: Earth and Environmental Science 1250: 012003.
- Diouf A, Fall J, Loum A, Faye A, Diago M, Diouf M (2020) [Morphometric and length–weight relationships of the mussel *Perna perna* from the Mamelles coast, Dakar, Senegal](#). International Journal of Fisheries and Aquatic Studies 8(3): 106–114.
- Froese R (2006) [Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations](#). Journal of Applied Ichthyology 22: 241–253.
- Galvao P, Longo R, Torres JPM, Malm O (2015) [Estimating the potential production of the brown mussel *Perna perna* \(Linnaeus, 1758\) reared in three tropical bays by different methods of condition indices](#). Journal of Marine Sciences 2015: 1–11.
- Gaspar MB, Santos MN, Vasconcelos P (2001) [Weight–length relationships of 25 bivalve species \(Mollusca: Bivalvia\) from the Algarve coast \(southern Portugal\)](#). Journal of the Marine Biological Association of the United Kingdom 81(5): 805–807.
- Hariyadi H, Winaya A, Zainuri M, Afiati N, Sya'rani L, Anne O (2023) [The length–weight relationships and condition factors of *Potamocorbula faba* Hinds, 1843 in the Permisian Bay, East Java, Indonesia](#). In: E3S Web of Conferences (pp 00015). EDP Sciences.
- Hashim M, Abidin DAZ, Das SK, Mazlan AG (2017) Length–weight relationship, condition factor and TROPH of *Scatophagus argus* in Malaysian coastal waters. AACL Bioflux 10(2): 297–307.
- Hemachandra TSY, Tenjing SY, Thippeswamy S (2017) [Population dynamics of the Asian green mussel *Perna viridis* \(L.\) from St. Mary's Islands off Malpe, India](#). Indian Journal of Geo-Marine Sciences 46(8): 1659–1666.
- Huxley JS, Teissier G (1936) [Terminology of relative growth](#). Nature 137(3471): 780–781.
- Isnard E, Tournois J, McKenzie DJ, Ferraton F, Bodin N, ... Darnaude AM (2015) [Getting a good start in life? A comparative analysis of the quality of lagoons as juvenile habitats for the gilthead seabream *Sparus aurata* in the Gulf of Lions](#). Estuaries and Coasts 38(6): 1937–1950.
- Jisr N, Younes G, Sukhn C, El-Dakdouki MH (2018) [Length–weight relationships and relative condition factor of fish inhabiting the marine area of the eastern Mediterranean city, Tripoli–Lebanon](#). Egyptian Journal of Aquatic Research 44: 299–305.
- Kasapoglu N, Duzgunes E (2013) [Length–weight relationships of marine species caught by five gears from the Black Sea](#). Mediterranean Marine Science 15: 95–100.
- López-Rocha JA, Fernández-Rivera Melo FJ, Gastélum-Nava E, Larios-Castro E, Romo-Piñera A (2018) [Morphometric relationship, growth parameters, and natural mortality as estimated primary inputs for fishery management in new fishing areas for bivalve](#)

- molluscs (Bivalvia: Veneridae). Journal of Shellfish Research 37(3): 591–600.
- Morton B (1977) The biology and functional morphology of *Modiolus metcalfei* (Bivalvia, Mytilacea) from the Singapore mangrove. Malacologia 16: 501–517.
- Nagvenkar SS, Ansari ZA, Jagtap TG (2014) Population density, biomass and allometric relationship of shortneck clam *Paphia malabarica* (Chemnitz, 1782) from estuarine regions of Goa, west coast of India. Indian Journal of Fisheries 61(4): 18–23.
- Nahar D, Islam MS, Islam MA, Jasmine S, Mondol MTA (2019) Growth pattern of freshwater bivalve mollusk *Lamellidens marginalis* (Lamarck, 1819) from the northwest Bangladesh. Journal of Bio-Science 27: 121–132.
- Natarajan P, Devadoss P, Muniyandi K (1979) Fisheries of Vellar estuary, Portonovo. Indian Journal of Fisheries 26: 201–206.
- Ndome CB, Eteng AO, Ekanem AP (2012) Length-weight relationship and condition factor of the smooth mouth marine catfish (*Carlarius heudelotii*) in the Gulf of Guinea, Niger Delta, Nigeria. AACL Bioflux 5(3): 163–167.
- Noor AR, Shakil A, Hoque NF, Rahman MM, Akter S, ... Rahman MJ (2021) Effect of eco-physiological factors on biometric traits of green mussel *Perna viridis* cultured in the southeast coast of the Bay of Bengal, Bangladesh. Aquaculture Reports 19: 100562.
- Oyewole OO, Aboderin OO, Aluko OJ, Adeyemo JO (2013) Length-weight relationship of freshwater mussel (*Etheria elliptica*) from River Ogbese, Nigeria. Nigerian Journal of Fisheries 10(1–2): 627–630.
- Park KY, Oh CW (2002) Length-weight relationships of bivalves from coastal waters of Korea. Naga, The ICLARM Quarterly 25(1): 21–22.
- Patimar R, Yousefi M, Hoseini SM (2009) Age, growth and reproduction of the sand smelt *Atherina boyeri* Risso, 1810 in the Gomishan wetland – southeast Caspian Sea. Journal of Fish Biology 81(4): 457–462.
- Pauly D (1993) Editorial. Fishbyte section. Naga, ICLARM Quarterly 16(2–3): 26.
- Petetta A, Bargione G, Vasapollo C, Virgili M, Lucchetti A (2019) Length–weight relationships of bivalve species in Italian razor clam *Ensis minor* (Chenu, 1843) (Mollusca: Bivalvia) fishery. The European Zoological Journal 86(1): 363–369.
- Pohlo RH (1964) Ontogenic changes of form and mode of life in *Tresus nutalli* (Bivalvia: Mactridae). Malacologia 1: 321–330.
- Ramamurthy A (1954) A preliminary study of the hydrology and fauna of Vellar estuary (South Arcot District). In: Proceedings of the Indo-Pacific Fishery Council Symposium 9p.
- Ramesha M, Seetharamaiah T (2009) Allometry and condition index in the freshwater bivalve *Parreysia cor-rugata* (Muller) from river Kempuhole, India. Asian Fisheries Science 22: 203–214.
- Robinson LA, Greenstreet SPR, Reiss H, Callaway R, Craeymeersch J, ... Lancaster J (2010) Length–weight relationships of 216 North Sea benthic invertebrates and fish. Journal of the Marine Biological Association of the United Kingdom 90(1): 95–104.
- Sasi H (2008) The length and weight relations of some reproduction characteristics of Prussian carp, *Carassius gibelio* (Bloch, 1782) in the South Aegean Region (Aydın-Turkey). Turkish Journal of Fisheries and Aquatic Sciences 8: 87–92.
- Simon KD, Mazlan AG (2008) Length-weight and length-length relationships of archer and puffer fish species. The Open Fish Science Journal 1: 19–22.
- Sundaram S, Josekutty CJ, Chavan BB (2011) Length-weight relationship of green mussel *Perna viridis* (Linnaeus, 1758) from Versova creek, Mumbai. Marine Fisheries Information Service 207: 33–34.
- Tenjing SY, Thippeswamy S, Krishna MP, Narasimhaiah N, Vineet KK (2013) Biometric relationship of the eared horse mussel *Modiolus auriculatus* (Krauss, 1848) (Bivalvia: Mytilidae) collected from Byndoor, Karnataka, India. Advanced BioTech 13(3): 5–10.
- Thomas S (2013) Allometric relationships of short neck clam *Paphia malabarica* from Dharmadom estuary, Kerala. Journal of the Marine Biological Association of India 55(1): 50–54.
- Tumanda Jr, MI, Yap HT, McManus LT, Ingles JA, López MG (1997) Growth, mortality and recruitment pattern of the brown mussel, *Modiolus metcalfei* (Bivalvia: Mytilacea), in Panguil Bay, Southern Philippines. Aquaculture 154(3–4): 233–245.
- Turra A, Corte GN, Amaral ACZ, Yokoyama LQ, Denadai MR (2018) Non-linear curve adjustments widen biological interpretation of relative growth analyses of the clam *Tivela mactroides* (Bivalvia: Veneridae). PeerJ 6: e5070.
- Vasconcelos P, Moura P, Pereira F, Pereira A, Gaspar M (2018) Morphometric relationships and relative growth of 20 uncommon bivalve species from the Algarve coast (Southern Portugal). Journal of the Marine Biological Association of the United Kingdom 98(3): 463–474.
- Watanabe S, Katayama, S (2010) Relationships among shell shape, shell growth rate, and nutritional condition in the Manila clam (*Ruditapes philippinarum*) in Japan. Journal of Shellfish Research 29(2): 353–359.
- Wilbur KM, Owen G (1964) Growth (pp. 211–242). In: Wilbur KM, Yonge CM (Eds) Physiology of mollusca, volume 1. Academic Press.
- Zelditch ML, Swiderski DL, Sheets HD, Fink WL (2012) Geometric morphometrics for biologists: a primer. Elsevier Academic Press, London, UK.



S Anbuselvan  <https://orcid.org/0009-0001-1137-7546>
V Sanjaikumar  <https://orcid.org/0009-0008-9440-1708>
G Jana  <https://orcid.org/0009-0005-3286-7711>
S Nabisha  <https://orcid.org/0009-0007-6222-8050>
A Arundathy  <https://orcid.org/0009-0008-0665-1038>
M Thangaraj  <https://orcid.org/0000-0002-1559-584X>