

# Growth patterns and morphometric analysis of marketable *Strombus* spp. from Batam, Indonesia

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Manuscript received: 19 June 2025. Revision accepted: 23 September 2025.

**Abstract.** Rahimah I, Bengen DG, Riani E, Windarti, Nurjaya IW, Mahmuda S. 2025. Growth patterns and morphometric analysis of marketable *Strombus* spp. from Batam, Indonesia. *Biodiversitas* 26: 4618-4627. This study investigates morphometric variations and growth patterns of three commercially valuable *Strombus* species from Batam, Indonesia: *Laevistrombus canarium*, *Laevistrombus turturella*, and *Strombus canarium*. A total of 1,786 specimens were collected from Rempang, Galang, and Panjang Islands. Nine morphometric parameters were measured, including Shell Width (SW), Shell Length (SL), Lip Thickness (LT), and Whorl Amount (WA). Statistical analyses, including Principal Component Analysis (PCA) and Pearson correlation, revealed significant interspecific differences, with SW, LT, and WA emerging as the most discriminant traits. *L. canarium* and *L. turturella* showed partial morphological overlap, whereas *S. canarium* exhibited distinct features. Correlation analysis indicated strong positive relationships among SW, BWL, and AL, with *L. canarium* and *L. turturella* showing stronger size-related relationships ( $R^2 = 0.63$ ) than *S. canarium* ( $R^2 = 0.47$ ). Growth analysis confirmed hypoallometric patterns across all species, with b-values of 2.47, 2.65, and 2.20, respectively. Morphological variation was shaped by both intrinsic factors (life stage, gonadal maturity) and extrinsic factors (substrate type, food availability). These findings highlight species-specific adaptations to local benthic habitats and underscore the value of morphometric traits as ecological indicators, underscoring the unique ecological niches of the studied species and their importance for biodiversity conservation. By linking shell morphology to environmental conditions, this study provides a practical basis for monitoring ecosystem health, informing adaptive strategies for sustainable fisheries management and biodiversity conservation in the Indo-Pacific region.

**Keywords:** Growth patterns, hypoallometric growth, morphometric analysis, principal component analysis, *Strombus* species

## INTRODUCTION

The genus *Strombus* is a member of the family Strombidae, comprising sea snails characterized by uniquely shaped shells. The authoritative source on *Strombus* (Abbot 1960) documents more than 50 species within the genus, with 38 discovered in the Indo-Pacific region (Cob et al. 2009; Uneputty et al. 2021). Taxonomic updates have decreased the officially recognized species to approximately 10 to 15 (Latiolais et al. 2006; Machkour-M'Rabet et al. 2021), with many reassigned to other genera such as *Lobatus*, *Eustrombus*, and *Conomurex*. The Neogene Atlas website (neogeneatlas.net), referencing unverified data from the World Register of Marine Species (WoRMS), currently lists 91 extant Strombidae species across 23 genera. Similarly, the Paleobiology Database notes 30 fossil genera and 379 fossil species within the family, but the information remains unverified (National Science Foundation 2025).

*Strombus* species are economically valuable due to their role in fisheries, culinary demand, and ecological importance within seagrass ecosystems (Naung Oo 2018; Supratman and Syamsudin 2019; Viruly et al. 2019; Kobkeatthawin et al. 2021; Tirtama et al. 2024). The species are a crucial element in the food chain of seagrass beds, serving both as predators and prey (Yoswaty and Zulkifli 2016; Hati et al. 2022), as well as possessing a high nutritional value (Đai and Thao 2018; Đai et al. 2018). In addition to its economic significance, it also plays an ecological role by influencing habitat structure and nutrient cycling. A study on benthic communities, including *Strombus*, signifies that benthic organisms can modify the physical characteristics of the substrate, aiding in microhabitat formation and greatly affecting habitat stability and productivity. Furthermore, Cintra (2021) and Setiawan et al. (2023) describe how *Tripneustes gratilla* (Linnaeus, 1758) acts as a bioturbator, enhancing water circulation and nutrient distribution around seagrass roots and within sediments. The role of *Strombus* in

benthic ecosystems is shaped by its interactions with algae, bottom vegetation, and other organisms, working together to sustain ecosystem balance (Arkham et al. 2016).

Environmental stressors such as pollution and land-use change can affect *Strombus* populations and benthic community structure. Studies on mollusk responses to habitat alteration clarify ecosystem dynamics (Siregar et al. 2020). Because of these roles, *Strombus* spp. are effective biodiversity indicators (Riniatsih et al. 2021). Species diversity in marine environments, including *Strombus*, is closely tied to environmental quality and human activity (Salayan et al. 2024). Monitoring mollusk communities in ecologically threatened regions supports biodiversity conservation and resource management (Subhan et al. 2023). As grazers, *Strombus* help regulate algal growth (Cox et al. 2020), provide prey for higher trophic levels, and interact with microbial communities (Johnson et al. 2010). Their sensitivity to environmental change further highlights their ecological relevance (Lambardo et al. 2025).

The Indo-Pacific, particularly Indonesia, hosts a significant diversity of *Strombus* species (Cob et al. 2009). Studies in Indonesian waters showed variations in *Strombus* density, with *Laevistrombus turturella* reaching 9,460 ind/ha in Bangka Belitung (Fifiyanti et al. 2020). *Strombus* sp. in the Riau Archipelago features densities of 0.8 ind/m<sup>2</sup> (*S. canarium*), 0.5 ind/m<sup>2</sup> (*L. turturella*), and 4.3 ind/m<sup>2</sup> (*S. urceus*) (Hati et al. 2022), emphasizing potential population declines (Muzahar et al. 2018; Supratman and Syamsudin 2019; Viruly et al. 2019). Batam Island, surrounded by 371 smaller islands (BPS 2024), is an important fisheries hub. Shellfish, including *Strombus*, are harvested to support tourism and culinary industries. The archipelago's geography offers diverse attractions, placing Batam third nationally in tourism rankings (Nadjmi and Prayitno 2014). The abundance, distinct shell shape, taste, and nutritional value of *Strombus* (Supratman and Syamsudin 2018; Cox et al. 2020; Muzahar and Viruly 2020; Kobkeatthawin et al. 2021; Yu et al. 2023) make it highly sought after by local

fisheries. Increasing tourism and fishing pressures highlight the need for sustainable management (Zhao et al. 2018).

A management approach is needed to maintain the continuous presence of *Strombus* in the wild. Investigations and morphological analyses are essential to develop effective management strategies and conservation plans (Ramses et al. 2023). Therefore, this study aimed to evaluate morphometric variations and growth patterns of *Strombus* species from three islands in Batam using morphometric analysis methods.

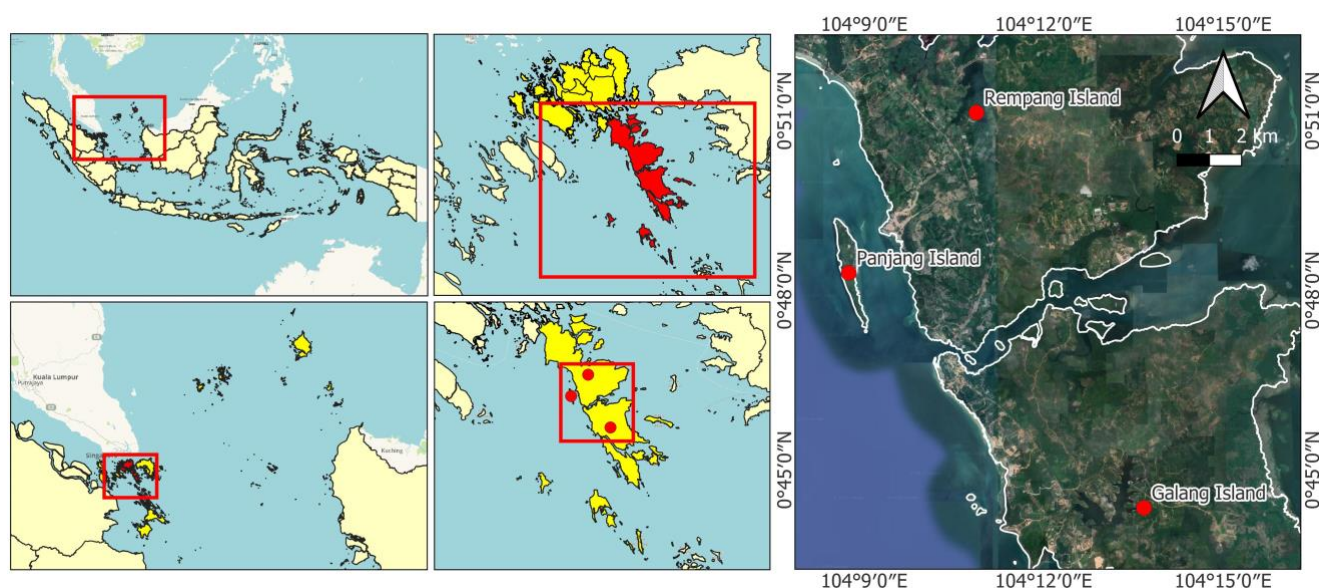
## MATERIALS AND METHODS

### Study area

A total of 1,786 *Strombus* specimens were collected from three islands, namely: Rempang, Galang, and Panjang, Batam, Indonesia. Sampling was conducted monthly from May to October 2024 at fishing locations used by local fishermen in Kampung Cate, Tanjung Banon, and Pantai Melayu. Samples were collected by diving and hand-picking methods during low tide, as detailed in Figure 1.

### Morphological measurement

The morphological identification of *Strombus* was based on the WoRMS database and confirmed through phenotypic comparisons and genetic analysis of five Indonesian *Laevistrombus* species (Muzahar et al. 2018). Nine morphometric characters, namely Shell Width (SW), Shell Depth (SD), Shell Length (SL), Body Whorl Length (BWL), Aperture Length (AL), Lip Thickness (LT), Spire Height (SH), Whorl Amount (WA), and Meat Weight (MW), were measured to the nearest 1.0 mm using calipers. A digital scale determined *Strombus* weight with an accuracy of 0.1 g. The operculum was meticulously taken off and inspected using a light stereomicroscope, as detailed in Figure 2.



**Figure 1.** Map showing the sampling locations on Rempang Island, Panjang Island, and Galang Island in Batam, Indonesia

### Sediment characteristic

Sediment samples were gathered from each observation island and analyzed utilizing the Pipette Fraction Texture Determination Method (van Reeuwijk 2002).

### Data analysis

#### Morphometric differences

Prior to interspecific morphometric comparisons, intraspecific variation across islands (Rempang, Galang, and Panjang) was assessed. Normality of data distribution was first tested using the Shapiro-Wilk test ( $\alpha = 0.05$ ), which indicated that most variables deviated from normality. Homogeneity of variances was evaluated using Levene's test, with some variables showing homogeneity, but the assumption of normality was not fulfilled. Therefore, non-parametric Kruskal-Wallis tests were applied to examine intraspecific differences across islands for each species. As no significant differences were detected ( $p > 0.05$ ), the data were considered morphologically homogeneous within species and subsequently pooled across islands for robust interspecific comparisons.

#### Principal Component Analysis (PCA)

PCA was performed to identify key morphometric traits distinguishing species. Subsequently, the first two principal components, PC1 and PC2, were examined. PCA analysis was conducted using the R programming language, aided by the 'factoextra' package (Kassambara 2025).

#### Pearson correlation analysis

Relationships between morphometric variables were evaluated, and correlation values were presented as a correlation matrix. Darker and lighter colors represented strong and weak correlations, respectively (Pearson 1896).

#### Growth pattern

The relationship between SW and MW was analyzed using the equation  $W = aL^b$ . Based on the variables, MW is meat weight (g), SW is shell width (cm), and  $b$  represents the growth exponent. Growth patterns were categorized as hypoallometric, isometric, or hyperallometric when  $b$  is  $<$ ,  $=$ , and  $>3$ , respectively (Ricker 1973).

### Habitat descriptor

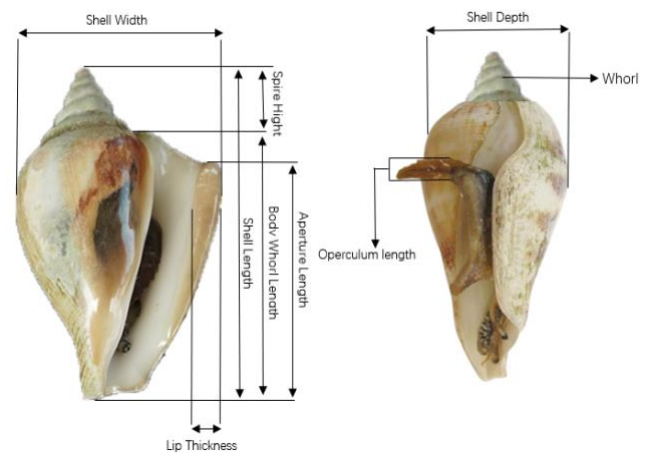
Data were analyzed using descriptive analysis of correlation parameters. This aimed to examine the effect of sediment characteristics on morphological variations.

## RESULTS AND DISCUSSION

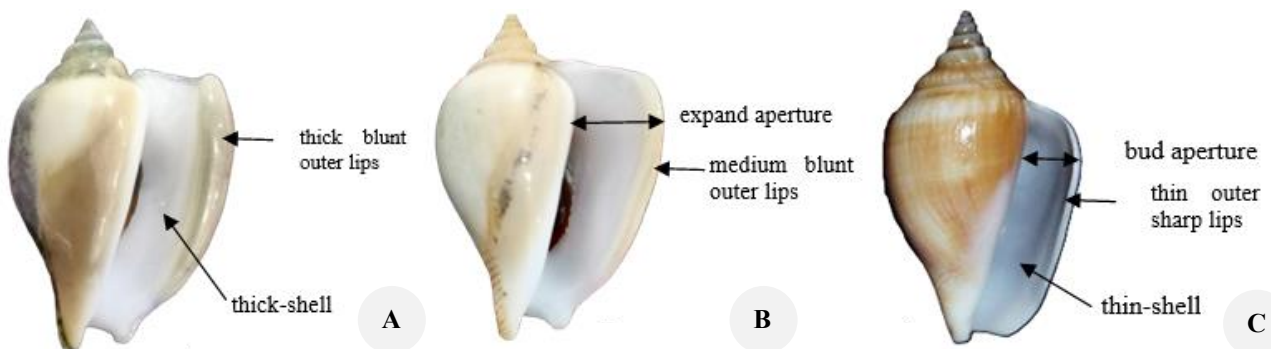
### Species identification and morphometric variations

Morphological characteristics led to the identification of *Strombus* as *Laevistrombus turturella* (Linnaeus, 1758), *L. canarium* (Linnaeus, 1758), and *S. canarium* (Linnaeus, 1758). All three species were observed on each island within the study area, as presented in Figure 3.

This study highlights variations in morphometric and meristic traits, focusing on features such as notching (up/down), posterior shell lip expansion, outer shell lip thickening, and lateral dilation (Muzahar et al. 2018). (Viruly et al. 2019) suggested that *Strombus* from sandy and muddy substrates belonged to the same species despite the morphometric differences (Ramses et al. 2023), further supporting this by stating that differences in shell thickness of *L. canarium* from Bintan waters did not indicate distinct species.



**Figure 2.** Key morphometric parameters of *Strombus* shell. Measurements include SL, SH, AL, BWL, LT, SW, and SD, operculum length, and number of whorls



**Figure 3.** Shell morphology of three Strombidae species: A. *Laevistrombus canarium*: Thick shell, blunt outer lip, B. *Laevistrombus turturella*: Medium shell, expanded aperture, blunt outer lip, C. *Strombus canarium*: Thin shell, narrow aperture, sharp outer lip

*Strombus* species identified were *L. canarium*, *L. turturella*, and *S. canarium*. *L. canarium* and *L. turturella* showed overlapping morphological traits, while *S. canarium* presented distinct characteristics. The three examined Strombidae species exhibit distinct shell morphologies that can be recognized through a combination of quantitative measurements and qualitative diagnostic characters. *L. canarium* is characterized by a relatively thick and heavy shell, a low to moderately elevated spire, and a bluntly expanded outer lip that forms a robust margin around the aperture.

The aperture is moderately wide, providing a clear transition between juvenile elongation and adult shell thickening. In contrast, *L. turturella* displays a medium-thickness shell with a somewhat higher spire compared to *L. canarium*. The outer lip is also blunt but less thickened, while the aperture is distinctly expanded, producing a broader opening that distinguishes it from the other taxa. *S. canarium*, on the other hand, has a markedly thinner and lighter shell with a more pronounced spire. Its aperture is narrow and bud-like, and the outer lip is sharp and thin, lacking the robust thickening observed in *L. canarium*. These qualitative differences complement morphometric analyses by highlighting diagnostic features that are readily identifiable in the field, thus bridging the gap between quantitative shell measurements and practical taxonomic identification.

### Morphometric analysis

Morphometric data were collected from three species of *Strombus* discovered on Rempang, Galang, and Panjang Islands (*L. canarium*,  $n = 623$ ; *L. turturella*,  $n = 835$ ; *S. canarium*,  $n = 328$ ), as detailed in Table 1. *L. canarium* had SW and MW of 23.30-54.00 mm and 2.07-12.60 g, respectively, while *L. turturella* had values of 24.70-58.00 mm and 2.13-13.56 g. The range of SW for *S. canarium* was from 23.70-47.80 mm, where MW ranged from 1.86-11.50 g. The above results are similar to the values reported by previous studies. *Strombus canarium* in Johor Strait, Malaysia, and Bintan Island recorded SW ranges of 29.44-41.90 mm (Cob et al. 2009) and 43.9-56.00 mm, respectively (Yoswaty and Zulkifli 2016). Previous investigations on *L. canarium* reported variations in SW ranging from 38.7 to 47.0 mm, which were consistent with the value observed in this study. For *L. canarium* in Tanjung Pinang, Indonesia, the range was 21.15-49.86 mm, relatively small compared to the result obtained in this study.

The Shapiro-Wilk test for normality ( $\alpha = 0.05$ ) produced p-values of  $<0.05$  for each parameter across all species. This signifies that the data did not follow a normal distribution. The homogeneity of variances among species groups was assessed using Levene's test ( $\alpha = 0.05$ ), which showed homogeneity in some variance comparisons between groups. However, ANOVA could not be performed due to the non-homogeneous distribution of several other variables. Based on the results of these preliminary tests, a non-parametric statistical analysis, the Kruskal-Wallis test, was conducted, as detailed in Table 2. Prior to interspecific comparisons, morphometric data of each species were examined across the three islands. Kruskal-Wallis tests

indicated no significant intraspecific differences between sampling sites for each species, thereby allowing the data to be pooled. This step ensured that the observed differences reflected true interspecific variation rather than geographic effects.

The average variation in nine morphometric variables of *Strombus* showed significant differences ( $p < 0.05$ ), except for BWL ( $p = 0.05054$ ). Variables such as LT and WA presented highly significant differences, with p-values of  $2.20E-16$ , suggesting distinct morphometric variation across species. The LT of *L. canarium*, *L. turturella*, and *S. canarium* were 3.62, 2.66, and 0.69 of the respective SW. Additionally, the WA were 6.15, 6.34, and 6.61 of the respective spire height.

For variables with significant differences, a Dunn's Test was conducted to identify specific species pairs with distinct variations. A Bonferroni correction was applied to the eight significant variables to minimize the risk of Type I errors (false positives), as detailed in Table 3. Variables such as LT and MW showed significant differences across all species pairs. Morphometric analysis revealed that LT and MW were more influential than linear measures such as shell length or width. This reinforces findings on the growth pattern in *Lobatus gigas*, where energy is allocated for SL growth during the juvenile stage, and in adulthood, it is redirected towards lip thickening, somatic tissues, and reproduction (Chan et al. 2013; Tewfik et al. 2019; López-Rojas et al. 2023). This is why SL often reflects overlap between juvenile and adult stages when used as a maturity indicator, making lip thickness a more reliable measure. (Stoner et al. 2012; Foley and Takahashi 2017). The substantial increase in MW reflects energy investment in gonads and reproductive organs, aligning with studies that link reproductive capacity to soft tissue biomass in Caribbean *Strombus* (Tewfik et al. 2019). Biologically, a thickened lip functions not only as a maturity marker but also as protection against predation and mechanical stress, while greater tissue mass reflects a reproductive strategy of producing numerous eggs to offset high larval mortality (Dmitriew and Rowe 2011). These findings are consistent with previous research, where Caribbean *Strombus gigas* consistently used LT as a harvest criterion due to its strong correlation with gonadal maturity (Peel and del Carmen Mandujano 2014; Foley and Takahashi 2017). This study validates that LT and MW are universal indicators of growth patterns, energy allocation, and ecological adaptation in the Strombidae family. Conversely, AL and WA did not show significant differences in all pairwise comparisons.

PCA of morphometric variables resulted in nine principal components explaining 100% of variance (61.6% for PC1, 16.3% for PC2, 7.2% for PC3, 4.4% for PC4, 3.5% for PC5, 2.3% for PC6, 2.1% for PC7, 1.3% for PC8, and 1.1 for PC9), as detailed in Table 4. PC1 and 2 were identified with eigenvalues  $>1$  and a cumulative variance of 77.94%. Table 5 presents factor loading scores for each morphometric variable from PC 1 and PC 2. PCA results showed that SL and BWL contributed most to PC1 (variance = 61.6%), while LT and WA were primary contributors to PC2.

**Table 1.** Mean ( $\pm$ SD) and range of shell morphometric parameters and MW of *Laevistrombus canarium*, *Laevistrombus turturella*, and *Strombus canarium* collected from three sites in the Riau Archipelago

Parameter		<i>Laevistrombus canarium</i>			<i>Laevistrombus turturella</i>			<i>Strombus canarium</i>		
		Galang Island n = 198	Panjang Island n = 213	Rempang Island n = 212	Galang Island n = 321	Panjang Island n = 245	Rempang Island n = 269	Galang Island n = 73	Panjang Island n = 142	Rempang Island n = 113
Shell Width (SW)	Range	29.40-41.20	27.70-54.00	23.30-45.00	24.70-43.80	25.80-44.80	27.00-58.00	28.40-38.90	24.70-46.00	23.70-47.80
	Mean $\pm$ SD	33.83 $\pm$ 2.31	34.79 $\pm$ 3.50	35.81 $\pm$ 4.03	32.95 $\pm$ 2.24	34.39 $\pm$ 3.11	35.40 $\pm$ 4.63	32.76 $\pm$ 1.72	33.70 $\pm$ 3.05	34.59 $\pm$ 4.53
Body Whorl Length (BWL)	Range	31.7-52.50	28.40-57.10	32.60-60.30	21.30-52.20	24.90-56.60	32.50-57.60	37.60-54.40	26.80-53.20	29.70-55.70
	Mean $\pm$ SD	43.10 $\pm$ 3.35	44.25 $\pm$ 4.74	45.89 $\pm$ 5.24	42.29 $\pm$ 2.89	44.01 $\pm$ 3.94	45.57 $\pm$ 5.16	42.59 $\pm$ 2.57	43.52 $\pm$ 4.42	45.30 $\pm$ 5.72
Aperture Length (AL)	Range	34.90- 49.40	32.50-53.50	18.80 -56.70	34.60-50.70	34.00-55.40	30.50-53.80	35.40-51.10	32.10-49.80	29.70-52.70
	Mean $\pm$ SD	40.77 $\pm$ 3.06	41.73 $\pm$ 4.19	42.83 $\pm$ 4.88	40.01 $\pm$ 2.57	41.45 $\pm$ 3.73	42.72 $\pm$ 4.79	40.11 $\pm$ 2.57	40.99 $\pm$ 3.70	42.20 $\pm$ 5.05
Shell Length (SL)	Range	32.20 -66.30	38.30-71.70	39.60-72.70	39.50-67.20	35.30-72.60	41.20-72.40	47.90-65.00	32.10-66.80	44.90-72.00
	Mean $\pm$ SD	53.29 $\pm$ 4.43	53.84 $\pm$ 5.44	55.91 $\pm$ 6.35	52.83 $\pm$ 4.05	54.14 $\pm$ 5.71	56.54 $\pm$ 6.54	54.07 $\pm$ 3.01	54.73 $\pm$ 5.20	58.23 $\pm$ 6.78
Lip Thickness (LT)	Range	1.10-5.70	1.80-6.40	1.70-5.20	0.70-4.90	0.30-4.80	0.60-5.30	0.10-2.00	0.10-1.80	0.10-1.90
	Mean $\pm$ SD	3.61 $\pm$ 0.90	3.79 $\pm$ 0.73	3.46 $\pm$ 0.71	2.77 $\pm$ 0.67	2.64 $\pm$ 0.90	2.55 $\pm$ 0.85	0.82 $\pm$ 0.46	0.65 $\pm$ 0.43	0.67 $\pm$ 0.44
Spire High (SH)	Range	10.00 -17.70	10.00-19.30	9.40-19.10	9.30-19.10	9.30-19.00	9.10-19.60	10.90-16.00	10.40-20.90	10.80-19.50
	Mean $\pm$ SD	13.26 $\pm$ 1.50	13.38 $\pm$ 1.72	13.59 $\pm$ 1.89	13.15 $\pm$ 1.53	13.63 $\pm$ 1.61	14.23 $\pm$ 2.07	13.45 $\pm$ 1.24	14.00 $\pm$ 1.80	14.76 $\pm$ 1.98
Shell Depth (SD)	Range	18.10-31.80	17.40-32.70	18.30-34.10	19.90-37.10	19.80-35.20	19.90-33.50	12.20-31.40	20.90-57.40	20.70-54.40
	Mean $\pm$ SD	24.78 $\pm$ 1.97	25.29 $\pm$ 2.73	26.15 $\pm$ 3.07	24.23 $\pm$ 1.93	25.34 $\pm$ 2.59	25.88 $\pm$ 3.17	24.56 $\pm$ 2.07	25.64 $\pm$ 4.39	26.71 $\pm$ 3.01
Whorl Amount (WA)	Range	5-7	5-8	4-8	4-8	5-8	4-8	6-8	5-7	6-8
	Mean $\pm$ SD	6 $\pm$ 1	6.25 $\pm$ 0.71	6.51 $\pm$ 0.78	6.39 $\pm$ 0.74	6.15 $\pm$ 0.78	6.47 $\pm$ 0.60	6.67 $\pm$ 0.52	6.44 $\pm$ 0.60	6.82 $\pm$ 0.59
Meat Weight (MW)	Range	3.24-8.87	2.49-11.18	2.07-12.60	2.54-11.31	2.14-13.56	2.13-12.21	1.94-7.12	2.49-8.07	1.86-11.50
	Mean $\pm$ SD	4.83 $\pm$ 1.07	5.59 $\pm$ 1.72	5.8 $\pm$ 2.3	4.62 $\pm$ 1.06	5.32 $\pm$ 1.84	5.83 $\pm$ 2.49	4.19 $\pm$ 1.10	4.55 $\pm$ 1.34	5.19 $\pm$ 2.19

**Table 2.** Mean (±SD), Chi-Square values, and p-values of shell morphometric variables and MW among three Strombidae species (*Laevistrombus canarium*, *Laevistrombus turturella*, and *Strombus canarium*)

Morphometric variable	Species (mean±SD)			Chi-square	p-value
	<i>Laevistrombus canarium</i>	<i>Laevistrombus turturella</i>	<i>Strombus canarium</i>		
SW	34.83±3.47	34.16±3.56	33.80±3.42	29.494	3.9 × 10 <sup>-7</sup>
BWL	44.44±4.68	43.89±4.23	43.93±4.33	5.9699	0.05054
AL	41.80±4.21	41.29±3.83	41.21±3.75	8.5891	0.01364
SL	54.37±5.59	54.41±5.45	55.79±5.66	22.582	1.25 × 10 <sup>-5</sup>
LT	3.62±0.79	2.66±0.89	0.69±0.42	1002.2	2.2 × 10 <sup>-16</sup>
SH	13.41±1.72	13.64±1.76	14.14±1.77	35.851	1.64 × 10 <sup>-8</sup>
SD	25.42±2.70	25.07±2.73	25.76±3.59	18.898	7.88 × 10 <sup>-5</sup>
WA	6.15±0.76	6.34±0.73	6.61±0.61	117.49	2.2 × 10 <sup>-16</sup>
MW	5.42±1.82	5.20±1.86	4.69±1.56	35.11	2.38 × 10 <sup>-8</sup>

Note: p<0.05 show significant differences

**Table 3.** Post-hoc pairwise comparison of morphometric parameters among *Laevistrombus canarium*, *Laevistrombus turturella*, and *Strombus canarium*

Variable	Morphometrics	p	Comparison
SW	<i>Laevistrombus canarium</i> vs <i>Laevistrombus turturella</i>	0.000018	Significant
	<i>Laevistrombus canarium</i> vs <i>Strombus canarium</i>	0.000008	Significant
	<i>Laevistrombus turturella</i> vs <i>Strombus canarium</i>	0.632480	Not significant
AL	<i>Laevistrombus canarium</i> vs <i>Laevistrombus turturella</i>	0.0131	Significant
	<i>Laevistrombus canarium</i> vs <i>Strombus canarium</i>	0.1943	Not significant
	<i>Laevistrombus turturella</i> vs <i>Strombus canarium</i>	1.0000	Not significant
SL	<i>Laevistrombus canarium</i> vs <i>Laevistrombus turturella</i>	1.0000	Not significant
	<i>Laevistrombus canarium</i> vs <i>Strombus canarium</i>	0.000053	Significant
	<i>Laevistrombus turturella</i> vs <i>Strombus canarium</i>	0.000035	Significant
LT	<i>Laevistrombus canarium</i> vs <i>Laevistrombus turturella</i>	0.000000	Significant
	<i>Laevistrombus canarium</i> vs <i>Strombus canarium</i>	0.000000	Significant
	<i>Laevistrombus turturella</i> vs <i>Strombus canarium</i>	0.000000	Significant
SH	<i>Laevistrombus canarium</i> vs <i>Laevistrombus turturella</i>	0.0479	Significant (marginal)
	<i>Laevistrombus canarium</i> vs <i>Strombus canarium</i>	8.23 × 10 <sup>-9</sup>	Significant
	<i>Laevistrombus turturella</i> vs <i>Strombus canarium</i>	0.000042	Significant
SD	<i>Laevistrombus canarium</i> vs <i>Laevistrombus turturella</i>	0.0023	Significant
	<i>Laevistrombus canarium</i> vs <i>Strombus canarium</i>	0.9347	Not significant
	<i>Laevistrombus turturella</i> vs <i>Strombus canarium</i>	0.000550	Significant
WA	<i>Laevistrombus canarium</i> vs <i>Laevistrombus turturella</i>	0.1325	Not significant
	<i>Laevistrombus canarium</i> vs <i>Strombus canarium</i>	0.000000	Significant
	<i>Laevistrombus turturella</i> vs <i>Strombus canarium</i>	0.000000	Significant
MW	<i>Laevistrombus canarium</i> vs <i>Laevistrombus turturella</i>	0.0067	Significant
	<i>Laevistrombus canarium</i> vs <i>Strombus canarium</i>	1.03E-08	Significant
	<i>Laevistrombus turturella</i> vs <i>Strombus canarium</i>	0.000664	Significant

Note: p<0.05 show significant differences

Based on the PCA plot in Figure 4, the species were distinguishable, with members of the same genus clustering closely together, reflecting similar characteristics. *L. canarium* and *L. turturella* had a considerable overlap, suggesting they share many morphometric traits identified by the PCA. In contrast, *S. canarium*, represented in green, appeared more distinctly separated from the other two species, particularly along the PC1 axis. This separation signified that *S. canarium* possessed more distinct morphometric characteristics.

**Correlation and growth pattern**

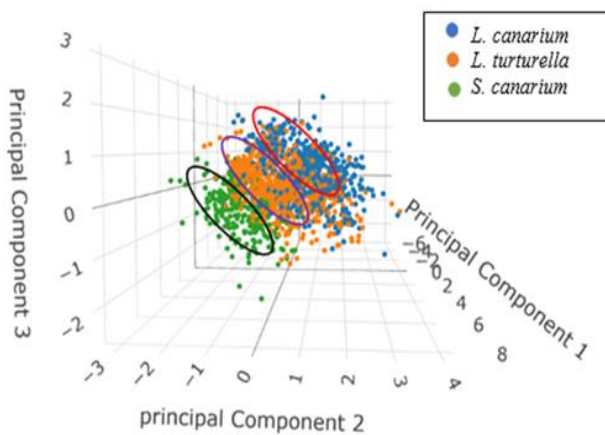
Pearson correlation analysis showed (Figure 5) strong positive relationships between SW and BWL (r = 0.84) as well as AL and BWL (r = 0.88) in *L. canarium* and *L.*

*turturella*. Negative correlations were observed between LT and SH (-0.25).

In general, the variables SW, BWL, and AL in *S. canarium* had strong positive correlations with other variables. This is evident in the correlations between SW and BWL (0.74), AL and BWL (0.82), SL and WA (0.72), as well as SW and MW (0.75), while SH and WA showed a moderate correlation (0.58). LT tended to have negative correlations with several variables, such as SL, SH, and MW. Negative correlation values are observed between SL and LT (-0.26), AL and SL (-0.22), LT and SH (-0.13), LT and SD (-0.08), as well as LT and MW (-0.14). Variables with weak or almost no correlation were observed between SW and SL (0.09) as well as LT and BWL (-0.18). Finally, MW showed low correlations with most variables, except for SW (0.75) and WA (0.37).

The relationship between SL and SW is crucial for analyzing the growth rate of *Strombus* species. The parameter b reflected both growth conditions and the type of species, primarily influenced by environmental factors and food availability. Furthermore, the relationships between SL and SW were highly significant for three species of *Strombus* ( $p < 0.05$ ), as detailed in Figure 6 and Table 6. The coefficient of determination ( $R^2 = 0.63$ ) in *L. canarium* and *L. turturella* signified a strong relationship. In contrast, the  $R^2$  value for *S. canarium* (0.47) suggested a moderate relationship between the variables, reflecting a moderate predictive strength.

Growth pattern analysis confirmed hypoallometric growth in all species, with b-values of 2.47, 2.65, and 2.20 for *L. canarium*, *L. turturella*, and *S. canarium*. These results suggested that SL increased at a faster rate than the weight, influenced by environmental conditions, habitat, and feeding availability.



**Figure 4.** Three-dimensional Principal Component Analysis (PCA) plot based on morphometric parameters of three Strombidae species. The first three principal components (PC1, PC2, PC3) explain 85.15% of the total variance (PC1 = 61.63%, PC2 = 16.31%, PC3 = 7.20%). Blue points represent *Laevistrombus canarium*, orange points *Laevistrombus turturella*, and green points *Strombus canarium*. Ellipses indicate the clustering tendency of each species, showing partial overlap but clear separation along PC1 and PC2 axes

**Table 4.** Eigenvalues, percentage of variance, and cumulative variance explained by principal components from PCA of morphometric data across three *Strombus* species

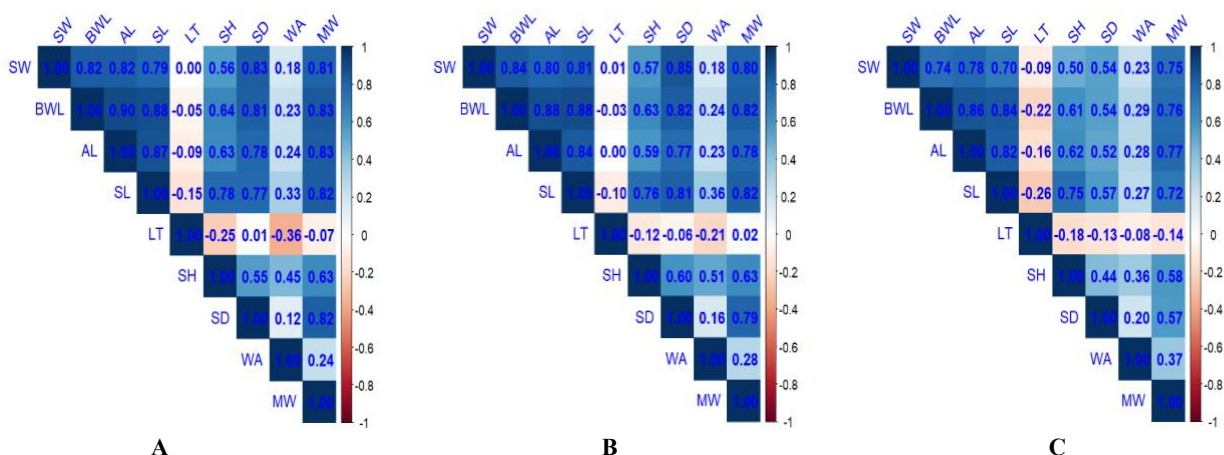
Factor	Eigenvalues	Variance (%)	Cumulative variance (%)
PC1	5.5468824	0.6163	61.63
PC2	1.4680574	0.1631	77.94
PC3	0.6483588	0.07204	85.148
PC4	0.3989252	0.04433	89.580
PC5	0.3175082	0.03528	93.108
PC6	0.2100709	0.02334	95.442
PC7	0.1906671	0.02119	97.561
PC8	0.1185298	0.01317	98.878
PC9	0.1010002	0.01122	100

**Table 5.** Factor loadings on PC1 and PC2 based on morphometric measurements

Variables	Factor Loading	
	PC1	PC2
SW	0.37371071	0.18957102
BWL	<b>0.39417612</b>	0.09774420
AL	0.38770758	0.10223363
SL	<b>0.39774085</b>	-0.07885410
LT	-0.03223781	<b>0.67429942</b>
SH	0.32301089	-0.29668699
SD	0.35576151	0.09920669
A	0.14863766	<b>-0.60376737</b>
MW	0.37738020	0.14408098

**Table 6.** Regression coefficients (a, b) and growth type for *Laevistrombus canarium*, *Laevistrombus turturella*, and *Strombus canarium*

Species	n	Regression parameter		$r^2$	Growth pattern
		a	b		
<i>Laevistrombus canarium</i>	623	0.0003	2.47	0.63	Hypoallometric
<i>Laevistrombus turturella</i>	835	0.0001	2.65	0.63	Hypoallometric
<i>Strombus canarium</i>	328	0.0007	2.20	0.47	Hypoallometric



**Figure 5.** Heatmap of morphometric relationships in: A. *Laevistrombus canarium*, B. *Laevistrombus turturella*, C. *Strombus canarium*

**Relationship between sediment type and morphometric variation**

Table 7 shows the results of the sediment fraction analysis. The three locations primarily featured a sand substrate, except for Rempang Island, which was mostly composed of clay. On Rempang Island, the clay was slightly more prominent than the dust and sand substrates. The differences between sand and clay were primarily influenced by physical characteristics, ecological functions, and the geological processes behind their formation. Sand, which is characterized by larger particle sizes, is compared to clay substrates with finer particles (Syahputri et al. 2023). The elevated clay fraction percentage on Rempang Island is believed to result from nutrient contributions from the mainland (Batam Island), which is a hub of concentrated human activity. In contrast, Rempang and Galang Islands are located further away from Batam Island and do not benefit from direct nutrient input.

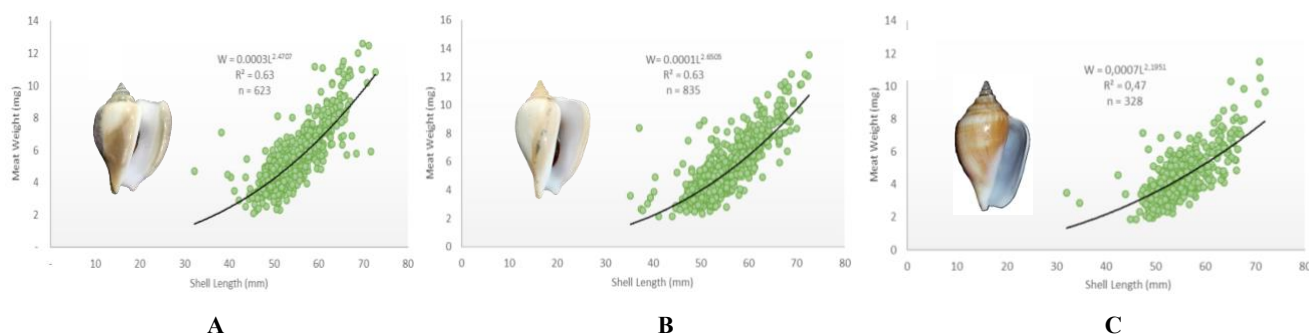
Morphometric parameters, namely SL and LT, used to assess the relationship with sediment type, showed varying patterns. The correlation analysis of specimens from clay substrates (Figure 7.A) featured a very strong negative relationship between the parameters ( $r = -0.99$ ). This suggests

that as SL increases, LT tends to decrease. The result was supported by the scatter plot visualization, where a consistent decline in LT with increasing SL was observed. This may show a morphological response to the finer texture of clay sediment or reflect growth strategy shaped by the relatively stable and compact nature of the substrate.

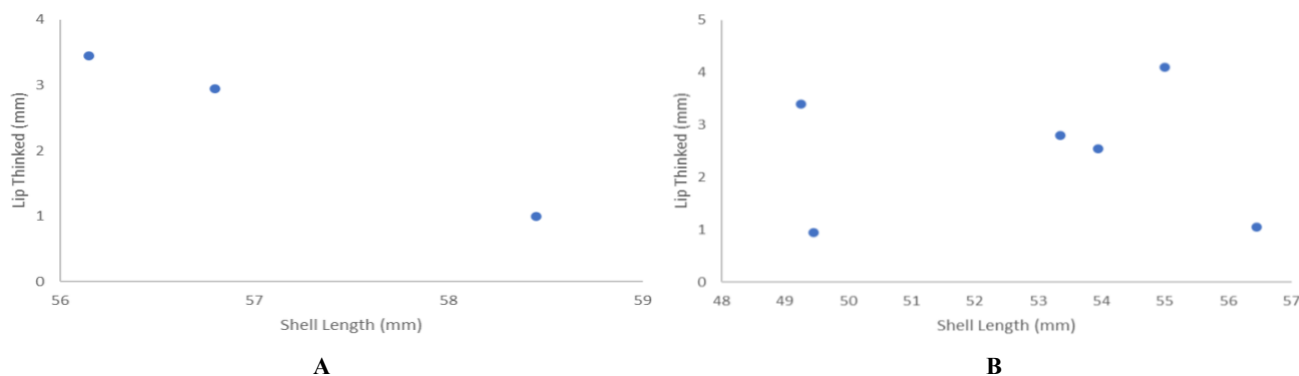
Specimens from sand substrates (Figure 7.B) produced a correlation coefficient of  $r = 0.02$ , indicating no linear relationship between SL and LT. Data points in the corresponding scatter plot were dispersed randomly without any clear trend. This implied that in sandy environments, the two morphometric parameters were not strongly associated and were possibly influenced by other factors such as genetic variation, age, or specific microhabitat conditions.

**Table 7.** Sediment fraction composition

Island	Sediment fraction (%)			Amount	Sediment type
	Sand	Dust	Clay		
Rempang	29.8	30.1	40.1	100%	Clay
Galang	97.5	2.1	0.4		Sand
Panjang	88.6	5.3	6.1		Sand



**Figure 6.** Length-weight relationship for: A. *Laevistrombus canarium*, B. *Laevistrombus turturella*, and C. *Strombus canarium*



**Figure 7.** Scatter plots showing the relationship between shell length and lip thickness of Strombidae species in different sediment types: A. In a clay substrate, and B. In a sand substrate

In conclusion, this study provides a comprehensive assessment of the morphometric characteristics and growth dynamics of three *Strombus* species (*L. canarium*, *L. turturella*, and *S. canarium*) in Batam, Indonesia, revealing significant morphological differences, particularly in shell width, lip thickness, and whorl angle, with growth analyses consistently indicating hypoallometric development. Environmental factors, especially benthic habitat conditions, strongly influenced the observed morphometric variation, underscoring the need for conservation strategies that protect sediment characteristics essential for maintaining species integrity and mitigating the impacts of environmental degradation and overexploitation. By linking morphometric traits to habitat conditions, the study highlights the dual ecological role of shell morphology as an adaptive response and a diagnostic feature for conservation planning. PCA further identified key traits such as shell length and lip thickness as reliable species markers, and the consistent growth patterns emphasize the value of morphometric traits as indicators for biodiversity monitoring, ecosystem health assessment, and sustainable fisheries management.

#### ACKNOWLEDGEMENTS

The authors are grateful to the Indonesian Education Scholarship (BPI), the Center for Higher Education Funding and Assessment (PPAPT), and the Indonesia Endowment Fund for Education (LPDP) for the support in funding academic endeavors and enabling the study process. The authors are also thankful to the Fisheries Biology Laboratory, Universitas Riau, for analytical support.

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