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Comprehensive assessment of *Terebralia palustris* populations in the Sayeung Calang River ecosystem, Aceh Jaya, Indonesia

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Abstract. *Isma MF, Prayitno SB, Haeruddin, Muskananfola MR. 2025. Comprehensive assessment of* Terebralia palustris *populations in the Sayeung Calang River ecosystem. Biodiversitas 26: 62-72. Terebralia palustris* (Linnaeus, 1767) a mangrove-dwelling gastropod, has a vast Indo-Pacific distribution spanning over 10,000 kilometers across diverse ecoregions. This study aimed to analyze population ecology and health conditions of *T. palustris.* Samples were collected from three sections of the Sayeung Calang River, Indonesia, using a 50 m line transect with 10 × 10 m plots and 1 × 1 m subplots. Density showed no significant variation ($p > 0.05$) with even distribution (<1). SL and SW morphometrics differed significantly ($p < 0.05$). Other morphometrics (SP, BWL, AW, AL, BW) showed no significant variation. The highest morphometric variation coefficient exceeded 40% (AW/SL). ST1 - ST2 and ST3 differentiation was primarily driven by SW/SL (34.31%), while ST1-ST4 and ST2 and ST3-ST4 differentiation was primarily driven by BW/SL (38.52 and 39.17%, respectively). PCA analysis identified SW/SL and SP/SL as the main morphometric characters ($r = 0.44$). Discriminant analysis indicated that AW/SL, AL/SL, SP/SL, and BWL/SL were most differentiated between sections. *T. palustris* exhibited an unimodal age distribution, suggesting disrupted health and severe competition, resulting in low adaptation (diversity coefficient: 20.44-38.04%). In conclusion, *T. palustris* in the area demonstrates distinct morphometric adaptations and distribution patterns, likely influenced by environmental conditions. Limited growth and adaptation capacity may result from intraspecific competition and habitat variability.

Keywords: Density, demography, distribution, health, morphometrics

INTRODUCTION

Estuarine ecosystems are among the most productive and biodiverse ecosystems in the world (Kennish 2002; Hasan et al. 2022; Hasan et al. 2023), mangrove forests are the forests with the greatest productivity in the world (Kathiresan and Bingham 2001; Setyawan and Winarno 2006a; Setyawan and Winarno 2006b) mangroves are inhabited by a variety of biota (Chen et al. 2007; Maia and Continho 2013). One group of animals that live in mangrove ecosystems is gastropoda, mangrove gastropods play an important role in ecosystems as benthic deposit feeders (Raw et al. 2017a). *Terebralia palustris* (Linnaeus, 1767) is a gastropod belonging to the family Potamididae (Raw et al. 2017a; Ratsimbazafy and Kochzius 2018; Thangaraj et al. 2020; Hamamoto et al. 2024) with shell length reaches 160 mm (Fratini et al. 2004), making it the first large-bodied member of the genus *Terebralia* (Hamamoto et al. 2024). It is native to and populates densely in mangrove forests (Raw et al. 2017b; Ginantra et al. 2020; Muskananfola et al. 2020; Fujita 2022; Müller García and Nebelsick 2024; Hamamoto et al. 2024). It has a wide distribution across the Indo-Pacific, East Africa, and West Pacific, spanning approximately 10,000 km longitudinally across various ecoregions (Houbrick 1991; Cannicci et al. 2008; Hamamoto et al. 2024; GBIF 2024). *T. palustris* using its muscular foot crawls on the forest floor (Fratini et al. 2001; Fratini et al. 2004; Pape et al. 2008; Hinokidani and Nakanishi 2019; Cañada et al. 2021), eats organic matter from shed leaves (Shah and Mohan 2020; Cañada 2020; Hamamoto et al. 2024) (for adults), and eats the remains of dead living things (detrivores, for juveniles) (Fratini et al. 2004). *Terebralia palustris* as a detritivore is important for the ecosystem as it accelerates the decomposition of organic waste and recycle the nutrients that can be utilized by the mangrove and other organisms, supporting the productivity and health (Patria and Putri 2017) and therefore, is frequently used as a bioindicator in assessing the health of mangrove ecosystems (Hamamoto et al. 2024). Juveniles prefer low intertidal habitats (Kihia et al. 2015; Peer et al. 2018) where adults typically inhabit higher intertidal areas (Fratini et al. 2004; Sandaruwan et al. 2024). In Indonesia, *T. palustris* can be found in the mangrove forests of Aceh Province, including those surrounding the Sayeung Calang River in Aceh Jaya District. The banks of this river are dominated by mature mangrove trees.

The 2004 Aceh Tsunami severely impacted the Sayeung Calang River, damaging many mangroves and causing large logs from wide-diameter trees to fall (Bayas et al. 2011). However, *T. palustris* populations are still observed in the area (Fitriani 2022). The river is approximately 5 km long and 33 m wide. Mangrove cover is less dense in the initial 0-200 m section compared to the rest of the river. Most of the species are *Rhizophora*, mainly *Rhizophora apiculata* Blume. Other true mangroves that grow in groups such as *Avicennia* and *Bruguier* also found in this area, primarily replanted (reforestation) by the local community after being inaugurated as an ecotourism area; for education, research, and tourism. The Sayeung Calang River's mangrove area, retain sand and mud mixed with the water, is the natural habitat of estuarine crocodiles as well as bits of mollusk shells from bivalves and gastropods (Nurcholisudin 2024). The proximity of the Indian Ocean influences water clarity and results in a dominance of sand visible within 0-2 km from the ST1 mouth, while on the contrary, land affects the ST4 section, which is shown by a high level of turbidity and dominance of mud.

Understanding the condition of species in the area, especially invertebrates, is critical for developing effective management and conservation plans (Islamy and Hasan 2020; Isroni et al. 2023; Hamamoto et al. 2024). Marine invertebrates, including *T. palustris*, play a crucial role in the food web and coastal ecosystem, and they also represent a valuable economic resources (Sole et al. 2023). According to Waykar and Deshmukh (2012), the existence of the gastropod community is significantly influenced by many environmental factors, such as river flow that affects the morphology and population distribution (Kobayashi and Iwasaki 2002). Furthermore, salinity, temperature, food availability, and existence of predators can influence the gradation distribution of gastropods from ST1 to ST4 or vice versa. Currently, there is little research on the bioecology of gastropods on the shore of Aceh Province, particularly for *T. palustris*. Previous study by Saleky et al. (2023) conducted on the bioecology of *T. palustris* on Papua Island done in the intertidal area directly facing the ocean, whereas the analysis included the density, relationship between body length and weight, quality, and environmental characteristics as determining factors of *T. palustris* distribution and density. Similar studies focusing on river banks have not yet been conducted in Aceh, Indonesia. Therefore, this study is critical for examining the density, distribution, morphometric variability, demographic structure, and health conditions of *T. palustris* habitating in river in Aceh Province, Indonesia.

MATERIALS AND METHODS

Study area

The study was conducted in January 2024 in the Sayeung Calang River, Aceh Jaya, Indonesia, and included four (4) observation sites (Figure 1 and Table 1). Station 1 is ST1; Stations 2 and 3 are ST2 and ST3; and Station 4 is ST4.

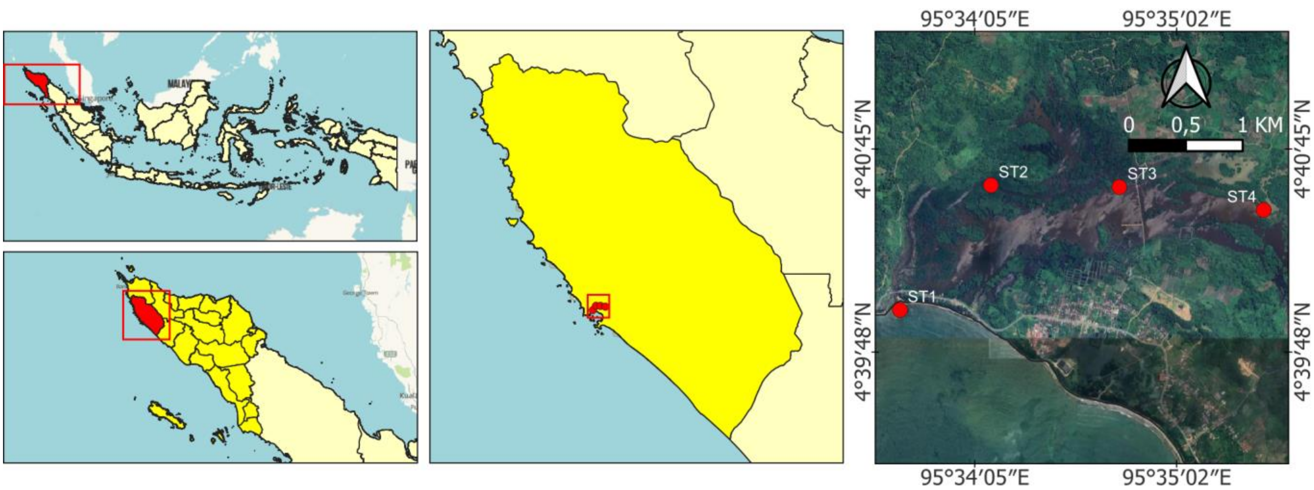

Figure 1. Research location map in Sayeung Calang River, Aceh Jaya, Aceh, Indonesia

Table 1. Coordinates of *Terebralia palustris* gastropod research in the Sayeung Calang River

Station	Location	Coordinate	Site description
1	0 m (downstream)	4°39’59.51”N 95°33’43.50”E	Station 1: Located close to the coastline, adjacent to the Indian Ocean, this location is in a mangrove area not far from the sea. The access is close to the residential area and also not far from the mangrove ecotourism area.
2	±1,700 m from downstream	4°40’35.10”N 95°34’09.47”E	Station 2: Located further from the coastline, following the flow of the Sayeung Calang River. Surrounded by mangrove areas. Located further from settlements which show the condition of the mangroves that are still natural.
3	±3,100 m from downstream	4°40’34.60”N 95°34’46.14”E	Station 3: Located further from Station 1 and 2, still along the Sayeung Calang River. This location is also surrounded by a large and natural mangrove area.
4	±5,000 m from downstream	4°40’28.04”N 95°35’27.31"E	Station 4: Located at the end of the river and still following the flow of the Sayeung Calang River. This location is a more Station 4 part of the Station 1 and is still in the mangrove ecosystem but less than Stations 2 and 3. The distance from the settlement is further than the previous location, this location is not far from the plantations of the Lhok Buya Village community.

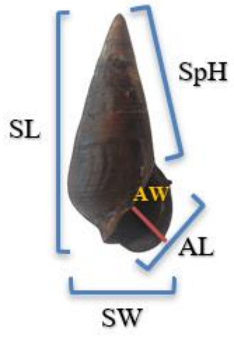

Figure 2. Dimensions of *Terebralia palustris* (Linnaeus, 1767) snail size

Figure 3. *Terebralia palustris* (Linnaeus, 1767) in the mangrove ecosystem of the Sayeung Calang River, Aceh Jaya, Indonesia

Sampling

Gastropods *T. palustris* were hand-collected using a purposive sampling method at the lowest tide. *Terebralia palustris* was taken by transect line method; drawing a 50 m long line transect and making plots of 10 × 10 m, then each plot was made into subplots of 1 × 1 m with 5 replications (top left, top right, ST2 and ST3, bottom left and bottom right). *Terebralia palustris* was put into a polyethylene plastic bag and given 70% alcohol to store, following the sampling method described by Syahrial et al. (2023).

Data analysis

Density of *T. palustris* was calculated using methods described in Odum (1971), Southwood (1978), and Brower and Zar (1984). The distribution of *T. palustris* was determined using the Morisita (1959) index, while the morphometric measurements for its variability refer to Samsi et al. (2019). Seven morphometric characters of *T. palustris* have been determined using a measuring tool, the Monotaro Digital Caliper (accuracy level 0.01 mm); then weighed using a Toledo AB-204 analytical scale (accuracy level 0.01 g).

Morphometric measurements were standardized (Figure 2). The length of the Shell (SL), Spire Height (SpH), Shell Width (SW), Aperture Length (AL), and Wide Aperture (AW) (Eddiwan et al. 2017; Haumahu and Uneputty 2018).

Demographic structure was determined using the methodology described by Isma et al. (2021). Body length data were analyzed using the FISAT II v1.2.2 program.

Statistical analysis

The health of gastropod *T. palustris* in Sayeung Calang River was examined using the Lugo (1978) equation, which is based on the distribution of morphometric values in the log-normal distribution graph. To assess the competition and adaptation of *T. palustris* population based on morphometric data, a study was conducted using the Coefficient of Diversity (CV) and an equation based on Walpole (1995). ANOVA statistics were used, followed by Tukey HSD and Duncan multirange tests, to determine the comparison in each part of the Sayeung Calang River, as well as the similarity of each morphometric between observation stations (intra population) and river sections (spatial population). If the morphometric data did not meet the assumption of normality (tested using the Kolmogorov-Smirnov test with Lilliefors correction, according to Zar (2009), a non-parametric one-way PERMANOVA multivariate test based on the Bray-Curtis Similarity Index was used (Anderson 2001).

Multivariate statistics were also used to examine the variability of morphometric properties of *T. palustris* in the Sayeung Calang River between river sections, including Principal Component Analysis (PCA), discriminant analysis, and Similarity of Percentage (SIMPER). To assess the grouping of morphometric variability of *T. palustris* between river sections, multivariate Cluster Analysis (CA) was used (Hermida et al. 2005; Vatandoust et al. 2014; Gupta et al. 2018). The SPSS v24 program was used to perform ANOVA analysis on the Tukey HSD and Duncan multirange tests, as well as multivariate discriminant and CA. Meanwhile, the PAST 3 program was used to conduct multivariate PERMANOVA, PCA, and SIMPER analyses.

RESULTS AND DISCUSSION

Specimen identification

Terebralia palustris is a species of gastropod commonly found in Sayeung Calang River mangrove ecosystems (Figure 3). This species is easily recognized by its elongated cone-shaped shell with a rough texture. The color varies from brown to gray, the shell has a clearly visible spiral pattern. This gastropod belongs to the Potamididae family which lives on mangrove substrates and functions to maintain the health of mangroves. *T. Palustris* lives in groups in mangrove ecosystems. One of its habitats is the Sayeung Calang River mangrove ecosystem in Aceh Jaya.

Density

The density of *T. palustris* in the Sayeung Calang River was consistent across observation locations, ranging from 17 to 22 individuals per square meter (ind/m^2) (Table 2). The density of *T. palustris* showed little variation between river sections, with a range of 18-22 individuals per square meter (ind/m^2). The highest density was found in the ST1 (22 ± 3.51 ind/m^2 and a coefficient of variation of 15.72%), while the lowest was found in the ST4 (18 ± 3.06 ind/m^2 and a coefficient of variation of 16.66%) (Table 2). This suggests an inverse relationship between distance from the river mouth and *T. palustris* density. This is likely attributed to the interaction between salinity and temperature. Freshwater influx from groundwater seepage in the ST4 area may contribute to lower gastropod abundance in areas with high mud content. The low abundance may also be influenced by warmer water temperatures (35°C) in the ST4 compared to the cooler temperatures (29°C) in the sandy ST1. This temperature difference likely arises from the fact that mud has smaller particle sizes than sand, leading to better heat retention. According to Crowe and McMahon (1997), marine mollusk biota are highly susceptible to ambient salinity and temperature.

Furthermore, low *T. palustris* abundance in the ST4 may be attributed to limited food availability and predation pressure. According to Pape et al. (2008), the aqueous substrate with mud proportion has fewer food options for *T. palustris*. Additionally, heavy predation by the mangrove crab *Scylla serrata* (Forskål, 1775), which thrives in shallow, muddy waters, may significantly impact gastropod abundance (Hill 1976; Pape et al. 2008; Hewitt et al. 2023). ANOVA analysis revealed no significant differences in *T. palustris* density among different locations ($p > 0.05$) (Table 3). This finding was supported by the Duncan's multiple range test (Table 2), indicating no significant differences in density between the ST1, ST2 and ST3, and ST4 sections of the Sayeung Calang River.

Distribution

Terebralia palustris populations exhibited an even distribution in the Sayeung Calang River, as indicated by Morisita index values below one. Morisita index values, reflecting the distribution of *T. palustris* in the Sayeung Calang River, ranged from 0.04 to 0.07. Station 3 exhibited the highest Morisita index value (0.07 ± 0.05) with a coefficient of variation of 66.03%, where stations 1 and 2 exhibited similarly low Morisita index values (0.04 ± 0.02) but showed differing coefficients of variation (57.04% for station 1 and 46.95% for station 2), as presented in Table 2. Furthermore, Table 2 shows that the Morisita index values between different locations were similar (mean = 0.01), with a lower standard deviation (0.002) in the ST1 compared to the ST2 and ST3, and ST4 sections (0.003). The coefficient of variation of the Morisita index differed among river sections: 29.26% in the ST1, 32.24% in the ST2 and ST3, and 31.33% in the ST4. Accordingly, the lower coefficient of variation in the ST1 section suggests a more stable distribution of *T. palustris* compared to the ST2 and ST3, and ST4 sections. This finding is supported by ANOVA analysis of the Morisita index, which showed no significant differences among river sections ($p > 0.05$) (Table 4). Similarly, Duncan's multiple range test (Table 2) supported the even distribution of *T. palustris* along the river flow, suggesting high adaptability to environmental conditions and minimal inter-individual competition.

Morphometric variability

Terebralia palustris in the Sayeung Calang River has a body length ranging from 86.86 to 92.89 mm (Table 2), implying that most of the findings are adults. According to Soemodihardjo and Kastoro (1977) and Fratini et al. (2004), adults *T. palustris* have body length of > 50 mm or 5 cm, whereas juveniles have a body length < 50 mm. In another study, Saleky et al. (2023) reported smaller adult gastropod body lengths (49.00-64.00 mm) compared to those observed in this study (86.86-92.89 mm). Samsi et al. (2019) report adults *T. palustris* have body lengths ranging from 80.00-92.00 mm.

Gastropod shell size can be significantly influenced by various factors, including limited food availability, competition, and environmental pollution, which can stress individuals and hinder growth (Alka et al. 2020). According to Mead (1961) and Raut and Ghose (1984), significant climate change can induce hibernation in gastropods, particularly during periods of low temperature and humidity. Prolonged hibernation can lead to physiological changes and negatively impact gastropod growth (Vinci et al. 1998). ANOVA analysis of the three river sections revealed significant differences in SL and SW ($p < 0.05$) but not in SP, BWL, AW, AL, and BW ($p > 0.05$) (Table 5). Duncan's multiple range test indicated that BWL, AW, AL, and BW exhibited high similarity across all three river sections. SL showed high similarity between the ST1 and ST2 and ST3 sections, while SW showed high similarity between the ST2 and ST3, and ST4 sections. No significant differences were observed in SP among the sections (Table 2).

Among the morphometric ratios, SP/SL exhibited the lowest value at Station 2 (61.70 ± 7.34, CV = 11.89%) and the highest at Station 1 (63.95 ± 6.74, CV = 10.54%). For BWL/SL, the lowest value was observed at station 1 (36.05 ± 6.74, CV = 18.69%) and the highest at station 2 (38.30 ± 7.34, CV = 19.15%). Regarding SW/SL, the lowest value was recorded at station 3 (30.44 ± 7.86, CV = 25.82%) and the highest at station 1 (38.08 ± 8.18, CV = 21.47%). Finally, for BW/SL, the lowest value was observed at station 1 (33.36 ± 5.96, CV = 17.87%) and the highest at station 4 (40.78 ± 11.59, CV = 28.42%) (Table 2).

Table 2 further indicates that the AW/SL morphometric ratio of *T. palustris* in the Sayeung Calang River exhibited a coefficient of variation exceeding 40% at stations 1 (46.97%), 2 (47.12%), and 4 (62.01%). Additionally, Table 2 reveals that at station 2, three morphometric ratios (excluding SP/SL, SW/SL, and BW/SL) exhibited relatively high values compared to SL. Conversely, at station 3, three morphometric ratios (excluding SP/SL, BWL/SL, and BW/SL) exhibited relatively low values compared to SL. ANOVA analysis of the three river sections revealed significant differences in SW/SL and BW/SL ($p < 0.05$) but not in SP/SL, BWL/SL, AW/SL, and AL/SL (Table 6). Duncan's multiple range test indicated that SP/SL, BWL/SL, AW/SL, and AL/SL exhibited high similarity across all three river sections. SW/SL showed high similarity between the ST2 and ST3, and ST4 sections, while BW/SL exhibited significant differences among the sections (Table 2).

Table 2. Density and Morisita index of gastropod *Terebralia palustris* in the Sayeung Calang River, Aceh Jaya, Indonesia

Parameter	Based on the observation station				Based on the river section		
	Station 1	**Station 2**	**Station 3**	**Station 4**	**ST1**	**ST2 and ST3**	**ST4**
DS (ind/m^2)	22±5.81(26.04)^{b}	22±4.23(19.21)^{b}	17±3.20(19.38)^{a}	18±3.74(20.31)^{a}	22±3.51(15.72)^{a}	19±3.37(17.59)^{a}	18±3.06(16.66)^{a}
MI	0.04±0.02(57.04)^{a}	0.04±0.02(46.95)^{a}	0.07±0.05(66.03)^{b}	0.06±0.03(57.06)^{ab}	0.01±0.002(29.26)^{a}	0.01±0.003(32.24)^{a}	0.01±0.003(31.33)^{a}
SL (mm)	92.89±12.23(13.17)^{c}	90.00±12.46(13.85)^{b}	91.74±13.56(14.79)^{bc}	86.86±15.46(17.80)^{a}	92.89±2.20(2.37)^{b}	90.90±1.83(2.01)^{b}	86.98±1.87(2.15)^{a}
SP (mm)	59.66±11.16(18.70)^{b}	55.92±11.86(21.21)^{a}	58.70±12.17(20.73)^{b}	54.53±14.46(26.52)^{a}	59.56±1.22(2.04)^{b}	57.36±2.44(4.25)^{ab}	54.67±1.87(3.43)^{a}
BWL (mm)	33.23±6.15(18.50)^{ab}	34.08±6.12(17.97)^{b}	33.04±6.73(20.36)^{ab}	32.33±7.97(24.66)^{a}	33.33±1.89(5.66)^{a}	33.54±1.24(3.69)^{a}	32.31±0.31(0.96)^{a}
SW (mm)	35.45±9.63(27.17)^{c}	32.92±8.23(24.98)^{b}	28.25±9.15(32.40)^{a}	26.98±11.57(42.89)^{a}	35.47±0.91(2.57)^{b}	30.58±2.98(9.74)^{a}	26.82±0.25(0.95)^{a}
AW (mm)	1.92±0.89(46.17)^{c}	2.20±0.95(43.11)^{b}	1.35±0.39(28.48)^{a}	1.46±0.93(63.71)^{a}	1.93±0.41(21.29)^{a}	1.78±0.55(30.86)^{a}	1.45±0.14(9.54)^{a}
AL (mm)	2.08±0.59(28.40)^{a}	2.36±0.63(26.79)^{b}	2.00±0.53(26.39)^{a}	1.98±0.60(30.34)^{a}	2.09±0.18(8.66)^{a}	2.18±0.24(11.20)^{a}	1.98±0.09(4.58)^{a}
BW (gr)	30.79±5.50(17.87)^{a}	31.11±8.54(27.46)^{a}	36.20±10.07(27.81)^{b}	35.08±10.40(29.63)^{b}	30.77±1.29(4.20)^{a}	33.63±3.05(9.07)^{a}	35.22±2.34(6.64)^{a}
SP/SL	63.95±6.74(10.54)^{b}	61.70±7.34(11.89)^{a}	63.61±7.20(11.33)^{b}	62.15±9.33(15.01)^{a}	63.82±1.70(2.66)^{a}	62.69±1.79(2.86)^{a}	62.24±1.02(1.64)^{a}
BWL/SL	36.05±6.74(18.69)^{a}	38.30±7.34(19.15)^{b}	36.39±7.20(19.80)^{a}	37.85±9.33(24.66)^{b}	36.18±1.70(4.69)^{a}	37.31±1.79(4.81)^{a}	37.76±1.02(2.70)^{a}
SW/SL	38.08±8.18(21.47)^{c}	36.41±7.44(20.44)^{b}	30.44±7.86(25.82)^{a}	30.72±11.69(38.04)^{a}	38.07±0.30(0.80)^{b}	33.41±3.45(10.32)^{a}	30.70±0.89(2.91)^{a}
AW/SL	2.09±0.98(46.97)^{c}	2.47±1.16(47.12)^{d}	1.47±0.38(25.67)^{a}	1.73±1.07(62.01)^{b}	2.10±0.41(19.33)^{a}	1.97±0.63(31.88)^{a}	1.71±0.17(9.73)^{a}
AL/SL	2.26±0.67(29.63)^{ab}	2.68±0.85(31.73)^{c}	2.19±0.56(25.81)^{a}	2.34±0.87(37.30)^{b}	2.27±0.23(10.18)^{a}	2.44±0.30(12.13)^{a}	2.35±0.08(3.42)^{a}
BW/SL	33.36±5.96(17.87)^{a}	34.95±10.74(30.73)^{b}	39.11±8.20(20.97)^{c}	40.78±11.59(28.42)^{d}	33.37±0.98(2.94)^{a}	36.98±2.75(7.43)^{ab}	40.92±3.40(8.32)^{b}

Note: DS: Density; MI: Morisita Index; SL: Shell Length; SP: Spire; BWL: Body Whorl Length; SW: Shell Width; AW: Anterior Width; AL: Aperture Length; BW: Body Weight

Table 3. Analysis of variance of *Terebralia palustris* gastropod density in Sayeung Calang River, Aceh Jaya, Indonesia based on river part

Location	ST1	ST2 and ST3	ST4
ST1	-		
ST2 and ST3	0.409	-	
ST4	0.350	0.934	-

Table 4. Analysis of variance of Morisita index of *Terebralia palustris* gastropod in Sayeung Calang River, Aceh Jaya, Indonesia based on river part

Location	ST1	ST2 and ST3	ST4
ST1	-		
ST2 and ST3	0.455	-	
ST4	0.316	0.856	-

Table 5. Analysis of variance of morphometric of *Terebralia palustris* gastropod in Sayeung Calang River, Aceh Jaya, Indonesia based on river part

Location	ST1	ST2 and ST3	ST4
SL morphometrics			
ST1	-		
ST2 and ST3	0.354	-	
ST4	0.011	0.044	-
SP morphometrics			
ST1	-		
ST2 and ST3	0.345	-	
ST4	0.046	0.220	-
BWL morphometrics			
ST1	-		
ST2 and ST3	0.972	-	
ST4	0.611	0.404	-
SW morphometrics			
ST1	-		
ST2 and ST3	0.033	-	
ST4	0.003	0.099	-
AW morphometrics			
ST1	-		
ST2 and ST3	0.892	-	
ST4	0.437	0.580	-
AL morphometrics			
ST1	-		
ST2 and ST3	0.800	-	
ST4	0.814	0.401	-
BW morphometrics			
ST1	-		
ST2 and ST3	0.312	-	
ST4	0.146	0.676	-

Table 6. Analysis of variance of the morphometric ratio of gastropod *Terebralia palustris* to SL in Sayeung Calang River, Aceh Jaya, Indonesia based on the river part

Location	ST1	ST2 and ST3	ST4
SP/SL morphometric ratio			
ST1	-		
ST2 and ST3	0.611	-	
ST4	0.490	0.918	-
BWL/SL morphometric ratio			
ST1	-		
ST2 and ST3	0.611	-	
ST4	0.490	0.918	-
SW/SL morphometric ratio			
ST1	-		
ST2 and ST3	0.076	-	
ST4	0.018	0.348	-
AW/SL morphometric ratio			
ST1	-		
ST2 and ST3	0.935	-	
ST4	0.648	0.769	-
AL/SL morphometric ratio			
ST1	-		
ST2 and ST3	0.618	-	
ST4	0.920	0.869	-
BW/SL morphometric ratio			
ST1	-		
ST2 and ST3	0.186	-	
ST4	0.017	0.143	-

SIMPER analysis of the morphometric ratios relative to SL revealed that SW/SL was the primary differentiating factor between the ST1 and ST2 and ST3 sections (34.31%), while BW/SL was the primary differentiating factor between the ST1 and ST4 sections (38.52%) (Table 7). Similarly, between the ST2 and ST3, and ST4 sections, BW/SL was the primary differentiating factor (39.17%) (Table 7). Furthermore, Table 7 shows that AW/SL and AL/SL had minimal differentiating contributions (below 10%) between all section pairs: ST1 - ST2 and ST3 (4.26%), ST1 - ST4 (2.29%), and ST2 and ST3 - ST4 (0.97%).

ANOVA results for the SW/SL ratio showed significant differences among river sections ($p < 0.05$) (Table 6), indicating significant variation in SW/SL ratios across the three sections. However, no significant differences were found in SW/SL ratios between the ST1 and ST2 and ST3 sections or between the ST2 and ST3, and ST4 sections ($p > 0.05$). Similarly, ANOVA analysis revealed no significant differences in BW/SL ratios among river sections ($p > 0.05$) (Table 6). However, a significant difference in BW/SL ratio was observed between the ST1 and ST4 sections ($p < 0.05$) (Table 6), indicating a distinct difference between these two sections.

Principal Component Analysis (PCA) revealed that two principal components explained the total variation in morphometric ratios relative to SL in *T. palustris* across the three river sections: PC1 (86.74%) and PC2 (13.26%) (Table 8). PC1 primarily reflected variation in SW/SL and SP/SL (both $r = 0.44$), while PC2 primarily reflected variation in AL/SL ($r = 0.87$) and AW/SL ($r = 0.42$). Figure 4 shows that the ST1 section is positioned closer to the center of the PC1 axis, suggesting that SW/SL values tend to be higher in the ST1 section compared to the ST2 and ST3, and ST4 sections. Similarly, the positioning of the ST1 section closer to the center of the PC1 axis suggests that SP/SL values tend to be higher in the ST1 section compared to the ST2 and ST3 and/or ST4 sections. These higher SW/SL and SP/SL ratios observed in the ST1 section may be attributed to predator avoidance strategies.

Gastropods, including *T. palustris*, are known to exhibit defensive adaptations such as shell widening and spire elevation in response to predation pressure (Boulding 1984; Hoverman et al. 2014). Given the higher predator abundance typically observed in ST1 areas (Whitfield 2020; Jones et al. 2021; Mosman et al. 2023), these morphological adaptations may be more pronounced in this section.

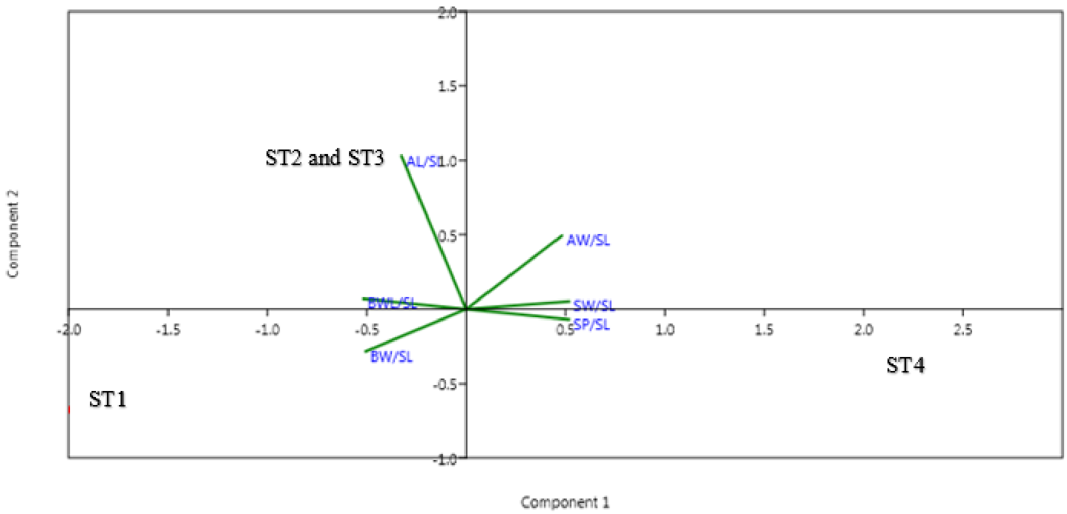

Figure 4. PCA analysis showing the differentiation of gastropods *Terebralia palustris* between parts in the Sayeung Calang River, Aceh Jaya, Indonesia; ST1, ST2 and ST3, and ST4

Table 7. SIMPER analysis of morphometric differences resulting from SL transformation of the gastropod *Terebralia palustris* in the Sayeung Calang River part, Aceh Jaya, Indonesia

Character	ST1 vs ST2 and ST3		ST1 vs ST4		ST2 and ST3 vs ST4	
	Dissimilarity (%)	Contribution (%)	Dissimilarity (%)	Contribution (%)	Dissimilarity (%)	Contribution (%)
SW/SL	1.33	34.31	2.10	37.72	0.96	28.66
BW/SL	1.12	28.95	2.14	38.52	1.31	39.17
SP/SL	0.59	15.10	0.57	10.25	0.43	12.82
BWL/SL	0.59	15.10	0.57	10.25	0.43	12.82
AW/SL	0.17	4.26	0.13	2.29	0.14	4.29
AL/SL	0.09	2.28	0.05	0.97	0.08	2.24

Table 8. Summary of principal component analysis results and correlation coefficient values between the PC components of the morphometric ratio and the SL of the gastropod *Terebralia palustris* between Sayeung Calang River parts, Aceh Jaya, Indonesia

Principal component	Eigenvalue	%Variance
1	5.20	86.74
2	0.80	13.26
Character	**PC1**	**PC2**
SW/SL	0.4380	0.0441
SP/SL	0.4377	-0.0589
BWL/SL	-0.4377	0.0589
BW/SL	-0.4281	-0.2405
AW/SL	0.4069	0.4170
AL/SL	-0.2758	0.8714

A one-way PERMANOVA analysis using the Bray-Curtis similarity index revealed significant differences in morphometric ratios relative to SL among the three river sections of *T. palustris* in the Sayeung Calang River (9,999 permutations, $F = 4.586$, $p = 0.0095$). This analysis was conducted because the data were found to be non-normally distributed ($p < 0.05$) and exhibited significant heteroscedasticity. Discriminant analysis, conducted to further investigate differences in morphometric ratios relative to SL in *T. palustris*, identified only one discriminant function, which included a single character: BW/SL (Table 9). The average BW/SL ratio data indicated that *T. palustris* individuals with heavier body weights were found further ST1. This observation is supported by the lower density of *T. palustris* observed in the ST4 section (Table 2), which may be indicative of reduced competition for resources (e.g., food, space, mates) in this area. Furthermore, Table 9 also shows that the morphometric ratio character of SL gastropod *T. palustris* between river parts is distinguished by AW/SL, AL/SL, SP/SL, and BWL/SL; then the results of the centroid discriminant function of the morphometric ratio to SL gastropod *T. palustris* in the Sayeung Calang River used as its variable show that the ratio of AW/SL, AL/SL, SP/SL and BWL/SL in the ST1 has a difference with the ST2 and ST3, and ST4 parts (Figure 5) where the ratio of AW/SL, AL/SL, SP/SL, and BWL/SL in the ST1 is separated independently in the cluster tree while the ST2 and ST3, and ST4 parts are in one branch in the cluster tree.

Demographic structure

Demographic analysis of *T. palustris* populations in the Sayeung Calang River revealed an unimodal distribution based on the Bhattacharya method, suggesting the presence of a single age group (Figure 6). However, the abundance distribution indicated the presence of two age groups (Table 10). Stations 2 and 3 exclusively comprised adult individuals, while Stations 1 and 4 exhibited a mixed population with both juveniles (approximately 0.30 and 0.36%, respectively) and adults. This suggests that Stations 1 and 4 may support more diverse *T. palustris* population growth compared to Stations 2 and 3. Furthermore, the presence of both juveniles and adults at Stations 1 and 4 indicates that these locations may be more suitable for the growth and development of *T. palustris* within the Sayeung Calang River. Body length measurements of *T. palustris* ranged from 45 to 156 mm at Station 1, with a modal class around 94.60 mm. At Station 2, the range was 56 to 140 mm with a modal class around 95.80 mm. At Station 3, the range was 53 to 149 mm with a modal class around 93.40 mm. Finally, at Station 4, the body length ranged from 47 to 142 mm with a modal class around 89.80 mm.

Analysis of morphometric value distribution on a log-normal graph (Figure 7) suggests that *T. palustris* population in the Sayeung Calang River exhibits poor health, characterized by two distinct and disconnected linear lines. This finding underscores the potential long-term impacts of increasing coastal populations on ecosystem balance and its biota (Callaway and Zedler 2004). These impacts include irreversible habitat destruction, material release, and disruptions to ecological processes, such as the introduction of top predators, which can induce stress disorders in prey species (Lee 2016). As highlighted by Mwaguni and Munga (1997), rapid population growth, increased urbanization, industrial expansion, and the exploitation of natural resources contribute significantly to the degradation of coastal ecosystems through increased pressure on the biological community.

Table 9. Summary of the results of the discriminant analysis of the morphometric ratio against the SL of the gastropod *Terebralia palustris* between parts of the Sayeung Calang River, Aceh Jaya, Indonesia

Function	Eigen-values	% of Variance	Cumulative %	Canonical Correlation
1	1.36	100.00	100.00	0.76

Variable	Wilks' Lambda	*F*-value	*p*-level
AW/SL	0.912	0.437	0.659
AL/SL	0.903	0.482	0.633
SP/SL	0.855	0.765	0.493
BWl/SL	0.855	0.765	0.493

Table 10. Distribution of abundance of gastropods *Terebralia palustris* in the Sayeung Calang River, Aceh Jaya, Indonesia based on age groups at four observation stations

Age group	Station (ind)				Total (ind)
	1	2	3	4	
Juvenil (< 50 mm)	1	0	0	1	2
Adult (> 50 mm)	334	330	248	275	1,187
Total (ind)	335	330	248	276	1,189

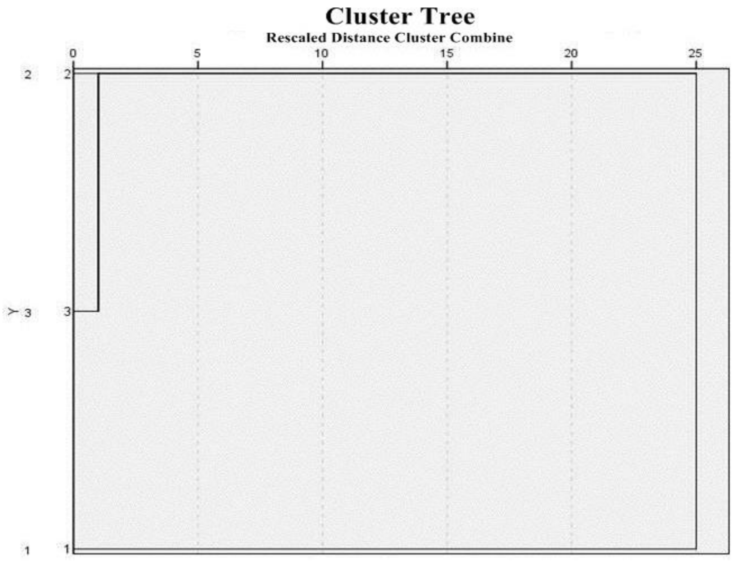

Figure 5. Dendrogram of morphometric ratio to SL of gastropod *Terebralia palustris* between parts of the Sayeung Calang River, Aceh Jaya, Indonesia using the centroid discriminant function as its variable. 1 = ST1; 2 = ST2; ST3; 4 = ST4

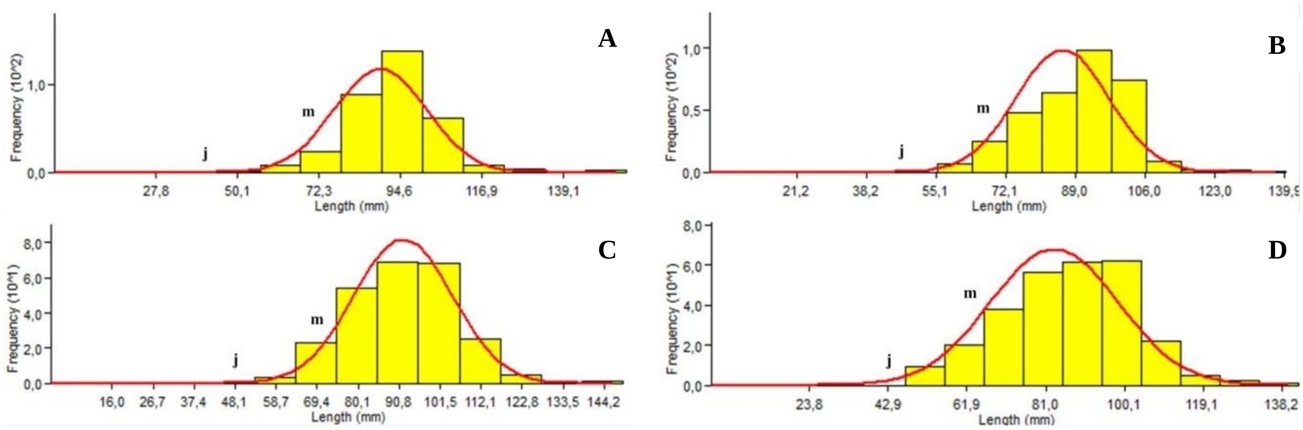

Figure 6. Frequency distribution of body length of gastropod *Terebralia palustris* in Sayeung Calang River, Aceh Jaya, Indonesia according to Bhattacharya method. A. Station 1; B. Station 2; C. Station 3; D. Station 4. j: Juvenile; m: Mature

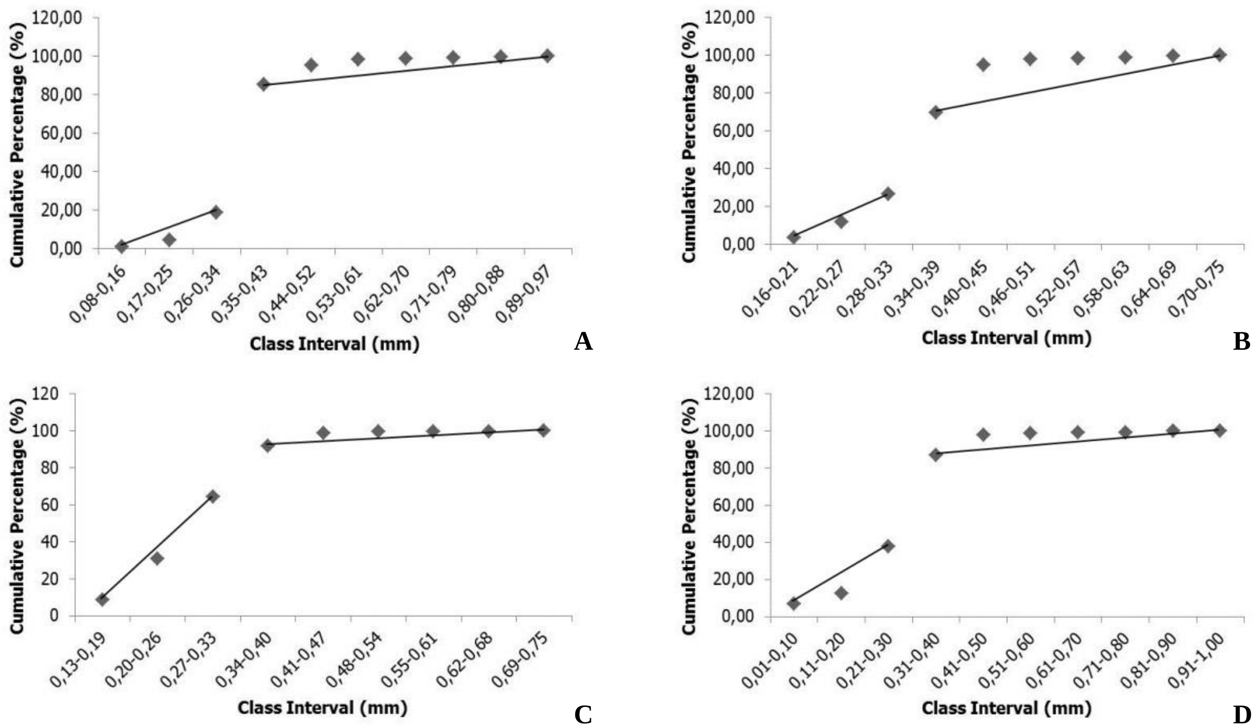

Figure 7. Distribution of morphometric values in the log-normal distribution graph depicting the health condition of *Terebralia palustris* gastropods in the Sayeung Calang River, Aceh Jaya, Indonesia. A. Station 1; B. Station 2; C. Station 3; D. Station 4

Health conditions

The findings of the diversity coefficient calculation suggest that the gastropod population of *T. palustris* in the Sayeung Calang River exhibits a clustered distribution, indicative of increased intraspecific competition and potentially lower adaptive capacity (Figure 8). The diversity coefficient values ranged from 20.44 to 38.04%. As highlighted by Baconnier et al. (1993), all species interact within and between populations, competing for resources such as food, mates, and space through various mechanisms including predation, parasitism, commensalism, mutualism, and amensalism.

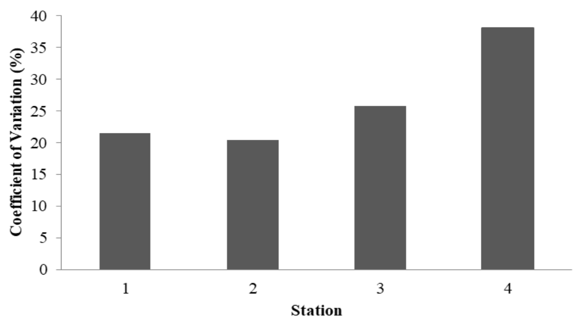

Figure 8. Individual competition and adaptability of the gastropod population of *Terebralia palustris* in the Sayeung Calang River, Aceh Jaya, Indonesia using the coefficient of diversity

In conclusion, the study of *T. palustris* in the Sayeung Calang River revealed a relatively consistent population density across the river, with slightly higher densities observed ST1. This distribution pattern was influenced by environmental factors such as salinity, substrate composition, and predation. The Morisita index and statistical analyses indicated a relatively uniform and stable distribution, suggesting the species' adaptability and minimal intraspecies competition. Morphometric analysis revealed that the population primarily consisted of healthy adults, with variations in shell and body dimensions likely influenced by environmental gradients. ST1 populations exhibited heavier body weights relative to shell length, potentially reflecting reduced resource competition. While juveniles were observed at some locations, indicating potential for population growth, overall age diversity was limited, suggesting potential population stress. These findings highlight that *T. palustris* is a resilient species but faces ecological pressures from habitat disturbances and anthropogenic impacts. This study emphasizes the need for sustainable conservation measures to mitigate these stressors, support population health, and maintain the ecological balance of the Sayeung Calang River ecosystem.

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