

Original Article

Environmental gradients and physicochemical properties of water as determinants of mangrove gastropod community structure in Sarawak, Borneo

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Abstract: Mangrove ecosystems are highly dynamic ecological boundaries where water physicochemical properties influence benthic community structure, including gastropod assemblages. This study investigated the relationship between environmental gradients and gastropod community structure in a coastal mangrove system in northern Sarawak, Malaysia. Field sampling was conducted from September 2023 to March 2024 across three stations covering downstream to upstream. Gastropods were collected using quadrats during low tide and identified to species level, while in situ and ex situ water parameters, including salinity, pH, temperature, dissolved oxygen (DO), turbidity, conductivity, ammonia, nitrite, nitrate, and phosphate, were measured. Diversity indices, one-way ANOVA, cluster analysis, Principal Component Analysis (PCA), and Canonical Correspondence Analysis (CCA) were used to evaluate spatial variation. A total of eight species from four families were recorded, with the highest species richness and diversity observed at Station 2 ($H' = 1.556$), whereas the upstream Station 3 exhibited the greatest dominance ($D = 0.3211$). Significant spatial differences were detected in the concentrations of temperature, turbidity, DO, ammonia, nitrite, and phosphate, indicating a clear environmental gradient along the river course. PCA and cluster analysis revealed distinct separation of stations, reflecting variation in gastropod community structure. Pearson correlation analysis revealed that pH was significantly and negatively correlated with species dominance; ammonia and nitrite were positively correlated with dominance; conductivity was negatively associated with *Ellobium aurismidae* abundance; and nitrate and salinity were associated with *Cerithidea quoyii* abundance. Although CCA suggested tendencies between species distribution and variables such as salinity, DO, and nutrient concentrations, model significance was not supported by permutation testing. These findings provide baseline information on gastropod diversity and water quality characteristics in Sarawak's mangroves and highlight the influence of spatial environmental gradients on community patterns. The study contributes to understanding ecosystem responses to physicochemical change and supports future biomonitoring and conservation of tropical mangrove habitats.

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Introduction

Mangrove ecosystems occur at the land-sea boundary and act as crucial ecological zones where freshwater, marine, and terrestrial processes converge. They serve as major habitats for a wide range of organisms and provide multiple ecosystem functions, including shoreline protection, carbon sequestration, nutrient cycling, and support for fisheries (Alongi, 2014; Al-Asif et al., 2023). However, their physicochemical

environment is highly dynamic, driven by tidal fluctuations, riverine inputs, salinity gradients, and variable nutrient loads (Rahaman et al., 2013). In particular, water quality parameters such as salinity, pH, dissolved oxygen (DO), and nutrient content reflect this dynamism and help determine habitat suitability for many benthic and epifaunal species (Rehitha et al., 2022). Understanding how these parameters vary spatially and temporally is essential

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for unraveling the mechanisms that shape community structure in mangrove systems. Studies in tropical estuaries show that dissolved inorganic nitrogen moves and changes substantially in waters near mangroves, indicating that nutrient and water flows are closely connected (Jiang et al., 2019; Noriega et al., 2019).

Gastropod mollusks are a prominent faunal group in mangrove forests and play important ecological roles, including detritus processing, grazing on microalgae, and serving as prey for higher trophic levels (Kabir et al., 2014; Idris et al., 2021; Bidat et al., 2023). Mangrove gastropod diversity, abundance, and community composition respond to habitat structure, including root complexity, sediment type, and physicochemical variables (Irma and Sofyatuddin, 2012). For instance, a baseline study of mangrove and gastropod biodiversity in Peninsular Malaysia reported differences in richness between replanted and natural stands, demonstrating the sensitivity of these communities to environmental gradients (Hookham et al., 2014). Despite these understandings, knowledge remains limited regarding how water-quality parameters influence gastropod community structure in mangroves, particularly in Borneo.

Physicochemical water parameters are fundamental to aquatic ecology and are often used as indicators of environmental conditions (Kumar et al., 2022). These parameters are influenced by hydrological processes, organic matter processing, nutrient loading, and microbial biogeochemical cycles (Liu et al., 2024). Fatema et al. (2016) reported that ammoniacal nitrogen concentrations exceeded guideline values in Malaysian mangrove estuaries, indicating changes in ecological conditions. Moreover, interactions among salinity, DO, and pH, along with tidal and seasonal dynamics, have been well documented in mangrove settings, showing that water quality gradients are neither static nor uniform (Nurhidayu and Harun, 2024; Wang et al., 2024). Linking specific water quality parameters to gastropod community structure therefore provides a powerful tool for understanding ecosystem responses to environmental change.

Sarawak in Borneo offers a compelling context for such a study because of its extensive mangrove cover, varied hydrological management, and increasing anthropogenic pressures, including riverine nutrient inputs and land use. While several studies have examined mangrove vegetation, fauna, and sediment characteristics in Malaysia, comparatively few have focused on water-quality physicochemical gradients in relation to gastropod assemblages in Sarawak. Gastropod sensitivity to environmental change can serve as a biological indicator of water-quality status and ecological reliability in mangrove forests (Hamli et al., 2024; Sandaruwan et al., 2024). Consequently, investigating how gradients in water chemistry influence gastropod community structure in Sarawak's mangroves is relevant to both fundamental ecology and applied conservation. Therefore, this study aims to assess the influence of environmental gradients and key physicochemical properties of water on the community structure of mangrove gastropods in Sarawak, Borneo. The results are expected to provide baseline information for monitoring mangrove ecosystems, support understanding of how biotic and abiotic factors are connected in tropical coastal areas, and guide the management of mangrove habitats as the environment changes.

Materials and Methods

Study area: The study was conducted in a coastal mangrove area in northern Sarawak, Malaysia, approximately 30 km southwest of Miri City (Fig. 1). This mangrove system is hydrologically linked to the South China Sea. Three sampling stations were designated along the river course. Station 1 (3°59'26.6"N, 113°43'52.0"E) was positioned near the river mouth, where tidal influence and salinity were highest. Station 2 (3°58'51"N, 113°43'59"E) represented the middle stretch of the river with moderate brackish conditions, while Station 3 (3°59'28.7"N, 113°44'34.9"E) was established further inland at the upstream section, characterized by lower salinity and weaker tidal effects. Field sampling was conducted from September 2023 to March 2024.

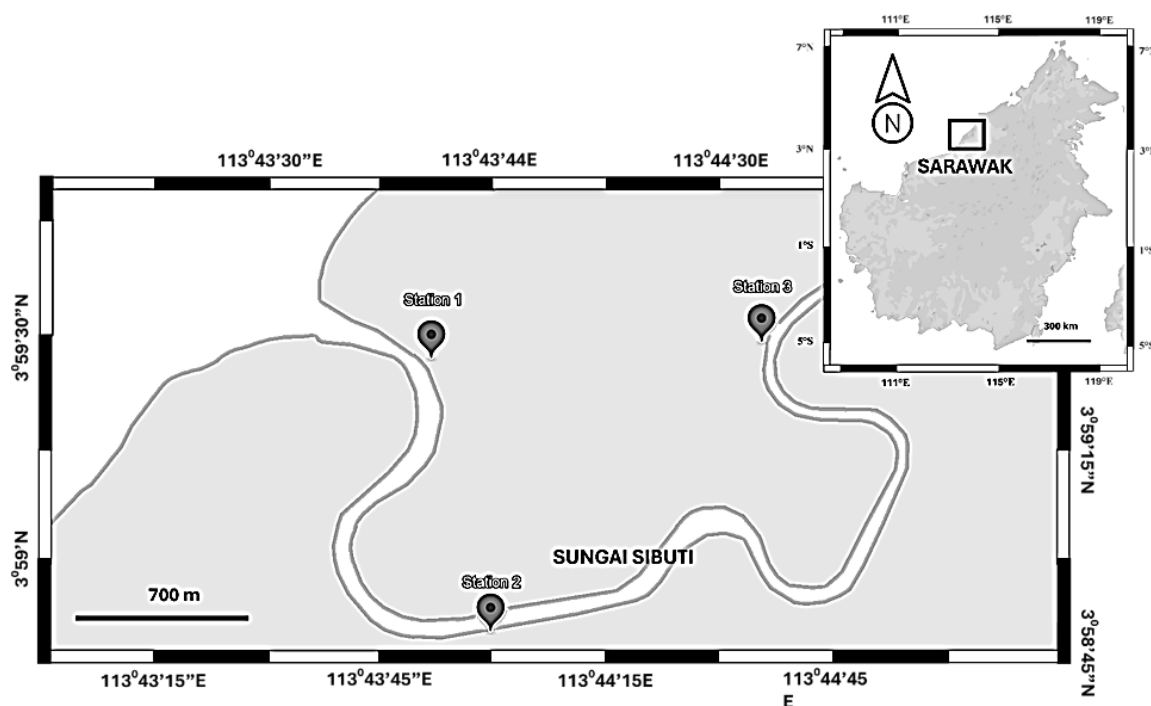


Figure 1. Study location of the gastropod mangrove in Sarawak.

Sampling procedure: At every sampling station, a total of three quadrats (1×1 m) were placed at 10 m intervals along a line parallel to the riverbank. Gastropods found within each quadrat were manually collected during low tide and stored in labeled polyethylene bags indicating the corresponding station details.

Species identification: All collected gastropod specimens were brought to the laboratory at Universiti Putra Malaysia Sarawak (UPMS) for further examination and taxonomic identification. Each specimen was classified to the most specific taxonomic rank possible using diagnostic shell morphology such as aperture configuration, surface sculpture, operculum characteristics, and color pattern, with reference to established identification keys and literature (Reid and Claremont, 2014; Idris et al., 2021; Mustapha et al., 2021; MolluscaBase, 2025).

Environmental parameters: At each sampling site, triplicate in situ water quality parameters were measured, including pH, temperature (°C), conductivity (µS/cm), total dissolved solids (mg/L), salinity (ppt), turbidity (NTU), and dissolved oxygen (mg/L), using a calibrated multi-parameter probe (Model WMS 24 DKK TOA). In addition, ex situ

water quality parameters, including ammonia, nitrate, nitrite, and phosphate (mg/L), were measured in pore water samples. These samples were transported to the laboratory and analyzed in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA, 2005).

Ethical statement: The target organisms of this study were exclusively gastropod mollusks (invertebrates). No experiments on fish or higher vertebrates were conducted; therefore, the journal's framework did not require specific assurance regarding local fish ethics committee guidelines.

Data analysis: Gastropod community structure was quantified using diversity indices, including Margalef's richness (d), Shannon–Wiener diversity index (H'), Simpson's dominance index (D), and Pielou's evenness index (J') (Shannon and Weaver, 1949; Simpson, 1949; Margalef, 1957; Pielou, 1966). One-way Analysis of Variance (ANOVA) was used to test for significant differences in environmental variables among sampling sites, followed by Tukey's post hoc test to identify specific pairwise differences. Multivariate analyses, including cluster analysis using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) with the Bray-Curtis similarity index

Table 1. Occurrence of mangrove gastropod species from different families at three sampling stations.

Family	Species	Station		
		S1	S2	S3
Ellobiidae	<i>Ellobium aurismidae</i> (Linnaeus, 1758)	-	-	+
Littorinidae	<i>Littoraria carinifera</i> (Menke, 1830)	+	+	+
	<i>Littoraria scabra</i> (Linnaeus 1758)	+	+	-
Neritidae	<i>Neripteron cornucopia</i> (W. H. Benson, 1836)	-	+	-
	<i>Neripteron violaceum</i> (Gmelin, 1791)	+	+	+
	<i>Vittina coromandeliana</i> (G.B. Sowerby I, 1836)	+	+	+
Potamididae	<i>Cerithidea charbonnieri</i> (Petit de la Saussaye, 1851)	-	+	+
	<i>Cerithidea quoyii</i> (Hombron & Jacquinot, 1848)	+	+	-

Notes: (+) presence, (-) absence

and Principal Component Analysis (PCA), were performed to assess patterns in community composition along the downstream-to-upstream gradient. Correlations between gastropod species and environmental variables were examined using multivariate ordination techniques, Canonical Correspondence Analysis (CCA), and model significance was evaluated through permutation (Monte Carlo) tests with 999 permutations for the global model, individual axes, and environmental predictors. All analyses were conducted using Paleontological Statistics (PAST) version 4.10.

Results

Distribution and diversity of gastropod species: A total of eight gastropod species representing four families, such as Ellobiidae, Littorinidae, Neritidae, and Potamididae, were recorded across three sampling stations (Table 1). Station 2 (S2) showed the highest species richness, with eight species present, while Station 1 (S1) and Station 3 (S3) recorded five and four species, respectively. Species in the families Littorinidae (*Littoraria carinifera*) and Neritidae (*Neripteron violaceum*, *Vittina coromandeliana*) were widely distributed at all stations. In contrast, species such as *Ellobium aurismidae* and *Cerithidea charbonnieri* were restricted to one and two stations, respectively.

Diversity indices: Analysis of the diversity indices indicated that Station 2 (Table 2) has the highest species richness ($n = 7$; $d = 1.306$) and diversity ($H' = 1.556$). However, Station 2 has the lowest evenness index among the stations. Station 1 had fewer species and individuals ($n = 5$, individuals = 49) but the

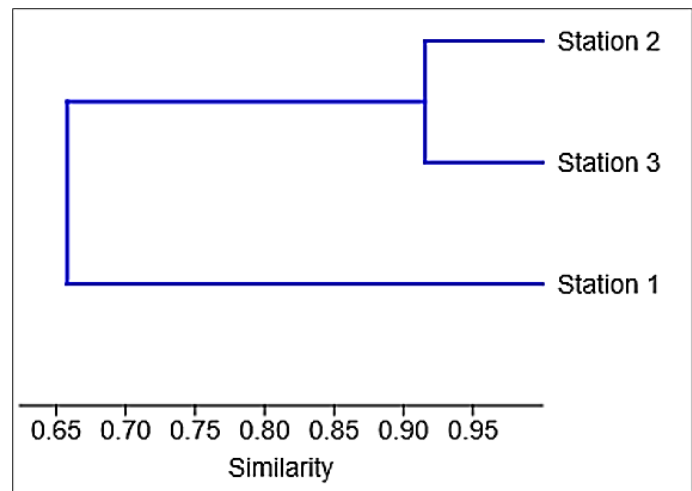


Figure 2. Cluster analysis of sampling stations based on environmental gradients influencing mangrove gastropod community structure.

highest evenness ($J' = 0.9048$). In contrast, Station 3 recorded the greatest number of individuals (116) and higher dominance ($D = 0.3211$). Nevertheless, Station 3 showed the lowest diversity ($H' = 1.362$) and species richness ($n = 5$, $d = 0.8415$).

Cluster analysis: The hierarchical clustering on the gastropod diversity indices showed Station 2 and Station 3 were clustered first at a high similarity level (~ 0.93), indicating very strong resemblance between the two stations in terms of diversity (Fig. 2). Station 1 grouped with Station 2 and Station 3 at a lower similarity level (~ 0.75), reflecting comparatively lower similarity in diversity to the other stations.

Principal component analysis: The PCA biplot revealed clear separation of gastropod diversity among the three stations along the principal components (Fig. 3). Station 1 was positioned at $(-37.5, -0.5)$, showing strong divergence along

Table 2. Community structure indices of mangrove gastropod assemblages at three sampling stations.

Indices	Station 1	Station 2	Station 3
Species Number (<i>n</i>)	5	7	5
Individual Number	49	99	116
Simpson's dominance index (<i>D</i>)	0.2364	0.2602	0.3211
Shannon–Wiener diversity index (<i>H'</i>)	1.497	1.556	1.362
Pielou's evenness index (<i>J'</i>)	0.9048	0.7842	0.8355
Margalef's richness (<i>d</i>)	1.028	1.306	0.8415

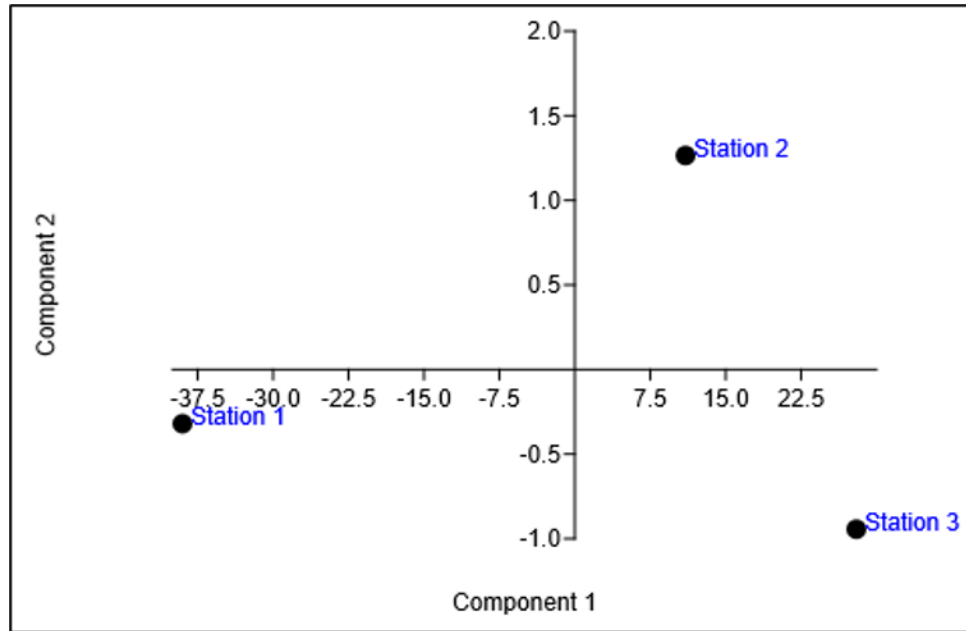


Figure 3. PCA ordination of sampling stations along environmental gradients influencing mangrove gastropod community structure.

Component 1 relative to the other stations. Station 2 was located at (7.5, 1.5), moderately separated from Station 3 (15.0, -0.5) and clearly distinct from Station 1.

One-way ANOVA of environmental variables: The present study of water quality parameters at the three stations is presented in Table 3, indicating no significant differences ($P > 0.05$) were observed in pH (6.29-6.47), salinity (5.8-6.8 PSU), conductivity (1.03-1.18 S/m), and nitrate (0.376-1.094 mg/L). Temperature differed significantly between Stations 3 ($P < 0.05$), while no significant differences were observed at Station 2. Turbidity was significantly higher ($P < 0.05$) at Station 2 than at Stations 1 and 3. Dissolved oxygen (DO) showed significantly higher values ($P < 0.05$) at Station 1 (4.02 mg/L) compared to Station 2 (3.06 mg/L) and Station 3 (2.47 mg/L). Ammonia and nitrite were significantly different ($P < 0.05$), with the highest values at Station 3. Phosphate differed significantly across all stations

($P < 0.001$), with concentrations of 0.214, 0.573, and 0.851 mg/L at Stations 1, 2, and 3, respectively.

Correlation of environmental variables with diversity: Pearson correlation analysis indicated that most environmental variables, such as temperature, turbidity, DO, and phosphate, showed no significant correlation ($P > 0.05$) with biotic variables for mangrove gastropods. However, several strong and significant relationships were identified (Table 4). pH showed a strong negative correlation with Simpson's dominance index (*D*) ($r = -0.99997$, $P = 0.005$). Ammonia ($r = 0.99872$, $P = 0.032$) and nitrite ($r = 0.99909$, $P = 0.027$) were both strongly and positively correlated with dominance. Conductivity exhibited a strong negative correlation with *E. aurismidae* abundance ($r = -0.99863$, $P = 0.033$). Nitrate showed a strong negative correlation with *Cerithidea quoyii* abundance ($r = -0.99954$, $P = 0.019$), while salinity displayed a strong positive correlation with *C. quoyii* abundance ($r = 0.99931$, $P = 0.024$).

Table 3. One-way ANOVA results for water quality parameters measured at different stations within the mangrove area.

Parameters	Station 1 (Mean±std)	Station 2 (Mean±std)	Station 3 (Mean±std)	F value	p
pH	6.47±0.12 ^a	6.42±0.16 ^a	6.29±0.05 ^a	1.764	0.249 ^{ns}
Salinity (PSU)	6.8±1.2 ^a	6.7±1.2 ^a	5.8±0.2 ^a	1.018	0.416 ^{ns}
Temperature (°C)	26.1±0.1 ^a	25.8±0.5 ^{ab}	25.3±0.3 ^b	5.659	0.042*
Turbidity (NTU)	179±66 ^a	817±175 ^b	463±122 ^a	18.48	0.003*
Conductivity (S/m)	1.18±0.18 ^a	1.17±0.18 ^a	1.03±0.03 ^a	0.829	0.481 ^{ns}
DO (mg/L)	4.02±0.32 ^a	3.06±0.25 ^b	2.47±0.4 ^b	17.14	0.003*
Ammonia (mg/L)	0.873±0.153 ^a	1.268±0.25 ^a	2.364±0.504 ^b	15.77	0.004*
Nitrite (mg/L)	0.48±0.26 ^a	0.661±0.161 ^a	1.39±0.37 ^b	9.062	0.015*
Nitrate (mg/L)	0.376±0.23 ^a	0.439±0.227 ^a	1.094±0.547 ^a	3.527	0.097 ^{ns}
Phosphate (mg/L)	0.214±0.083 ^a	0.573±0.081 ^b	0.851±0.062 ^c	53.26	0.000*

Note: Different superscripts between columns indicate significant differences ($P<0.05$). (*) represents a significant difference, while (ns) indicates no significant difference.

Table 4. Pearson correlation coefficients (r) and significance values (P) showing the relationships between environmental variables and biotic responses in the gastropod community.

Environmental Variable	Biotic variable	r - value	p - value
pH	Simpson's dominance index (D)	-0.99997	0.005172
Ammonia	Simpson's dominance index (D)	0.99872	0.032233
Nitrite	Simpson's dominance index (D)	0.99909	0.027135
Conductivity	<i>Ellobium aurismidae</i>	-0.99863	0.033383
Nitrate	<i>Cerithidea qouyui</i>	-99954	0.019415
Salinity	<i>Cerithidea qouyui</i>	0.99931	0.02362

The CCA ordination showed general patterns in gastropod species distribution in relation to environmental gradients (Fig. 4). However, the Monte Carlo permutation test indicated the model was not significant ($P>0.05$); therefore, interpret the observed relationships descriptively. Along Axis 1, variables such as salinity, conductivity, pH, temperature, and DO projected positively, with *Littoraria scabra* and *C. quoyii* positioned toward Station 1, suggesting these species tend to occur under relatively high-salinity conditions. In contrast, nutrients including ammonia, nitrite, nitrate, and phosphate loaded negatively along Axis 1, forming a gradient aligned with Station 3, where *E. aurismidae* occurred. Axis 2 was influenced primarily by turbidity, with *Neripteron cornucopia* located near Station 2.

Discussions

The gastropod assemblages recorded across the three sampling stations demonstrated a clear spatial pattern along the river gradient, reflecting changes in environmental conditions. Station 1, located at the estuary, represents the most marine-influenced

habitat, while Stations 2 and 3, located further upstream, are situated in the upper mangrove region, where freshwater input and nutrient enrichment are more pronounced. Overall species richness was moderate, consistent with tropical mangrove gastropod communities reported in Southeast Asia (Rahmawati et al., 2015; Nugroho et al., 2019; Baharuddin and Satyanarayana, 2024). Widely distributed species such as *L. carinifera*, *N. violaceum*, and *V. coromandeliana* occurred at all stations, supporting previous findings that Littorinidae and Neritidae exhibit broad environmental tolerance and are adaptable in mangrove ecosystems (Iwabuchi and Gosselin, 2020; Mustapha et al., 2021). In contrast, *E. aurismidae* was restricted to Station 3, and *C. charbonnieri* was absent from Station 1, suggesting a preference for less saline, sediment-rich habitats (Mujiono et al., 2025).

Diversity indices showed that Station 2 had the highest species richness and Shannon diversity, consistent with the transitional nature of this zone, which enhances habitat heterogeneity and resource availability and promotes species coexistence (Asadi

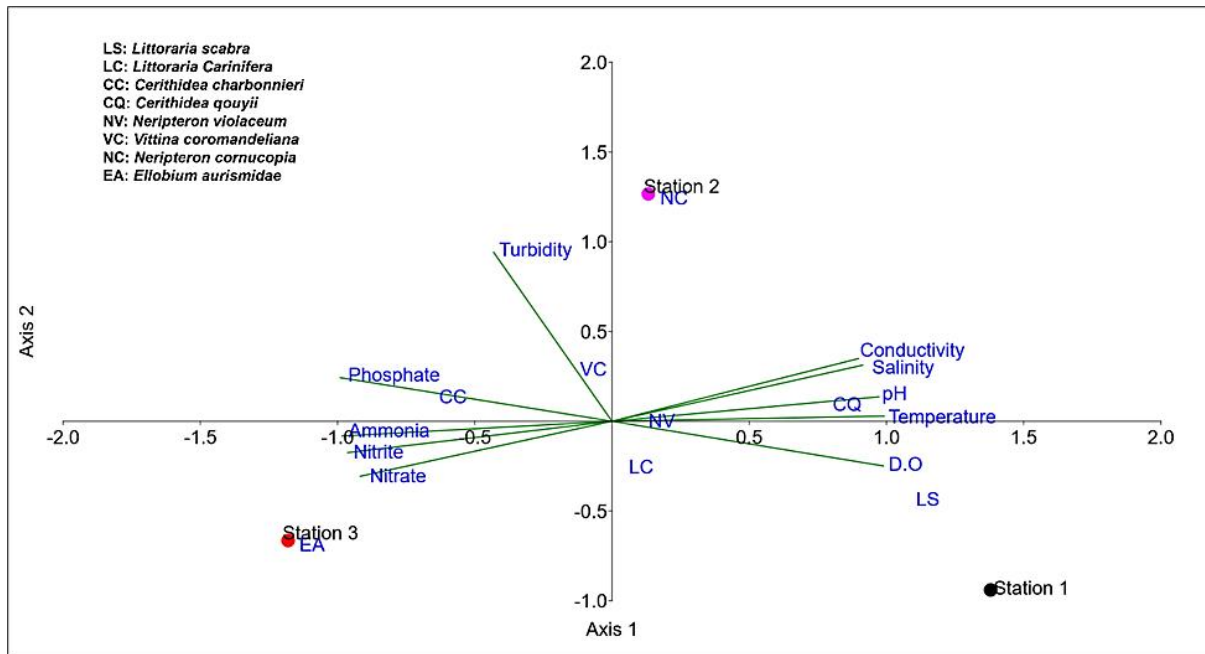


Figure 4. Canonical Correspondence Analysis (CCA) ordination of gastropod species and measured physicochemical parameters of mangrove habitat.

et al., 2025). Station 3, although it had the greatest number of individuals, exhibited lower diversity due to strong species dominance, perhaps related to reduced tidal flushing and higher organic deposition in the upper river, which favor deposit-feeding species adapted to nutrient-rich conditions (Largier, 2023). Station 1 displayed the highest evenness, indicating a relatively balanced community structure under more stable estuarine hydrology (Warna et al., 2025).

Cluster and PCA analyses revealed that Station 1 was structurally distinct from Stations 2 and 3. Station 1's estuarine environment, with relatively higher salinity and DO, supports assemblages typical of marine-fringing mangroves (Ferreira et al., 2024). The closer grouping of Stations 2 and 3 indicates increasing similarity upstream, potentially due to reduced salinity gradients and shared riverine influences. Significant spatial differences in turbidity, ammonia, nitrite, phosphate, and DO reflect these hydrological changes along the river gradient. Higher DO levels at the estuary are associated with tidal mixing, which may benefit species sensitive to hypoxic stress (Duvall et al., 2024). Lower DO in the upper river corresponds with higher organic loads and microbial decomposition (Ferreira et al., 2020). Higher turbidity at Station 2 could enhance periphyton

biomass, providing food for grazing gastropods such as *N. cornucopia* (Tudu et al., 2017; Pacheco et al., 2022).

The weak correlations observed for most environmental variables suggest that mangrove gastropod communities are generally resilient to minor environmental fluctuations, a pattern consistent with the adaptive traits of intertidal mollusks (Amortegui-Torres et al., 2013; Warna et al., 2025). However, the significant correlations detected highlight specific environmental stressors that may influence gastropod community structure. The strong negative correlation between pH and dominance suggests that lower pH may shift competitive balances among species, reducing community unevenness, a relationship also reported in other estuarine ecosystems exposed to acidification (Hossain and Marshall, 2014). In contrast, the positive correlation between dominance and ammonia and nitrite indicates potential nutrient-driven community shifts, in which elevated nitrogen compounds can favor a limited number of tolerant species and reduce diversity (Alongi, 2014; Al-Asif et al., 2023).

Species-specific responses were also evident in *E. aurismidae*, which showed reduced abundance under high conductivity, reflecting sensitivity to

increased ionic stress (Retnaningdyah et al., 2022). Whereas *C. quoyii* exhibited contrasting responses to nitrate and salinity, suggesting ecological flexibility and tolerance to saline conditions but potential negative impacts from nutrient enrichment. Such findings emphasize the importance of physicochemical gradients in regulating gastropod resilience and habitat suitability in mangrove ecosystems, particularly under increasing anthropogenic influence (Magni et al., 2019). Although the CCA model indicates no significant relationships between species and environmental variables, visual trends suggest that salinity and DO may be important in downstream regions, whereas nutrient enrichment and turbidity appear more influential upstream. For instance, the occurrence of *L. scabra* at Station 1 aligns with its tolerance for saline, wave-exposed mangrove zones (David et al., 2021). However, *E. aurismidae* at Station 3 is consistent with adaptation to freshwater-influenced mudflats rich in decaying organic matter (Harzhauser et al., 2023). These exploratory observations indicate that gastropod diversity in this mangrove system is structured along a downstream-to-upstream ecological gradient, influencing community composition and species distribution.

Conclusion

This study provides baseline insights into mangrove gastropod communities and their responses to environmental gradients in a tropical estuarine system in northern Sarawak. Gastropod diversity and dominance patterns varied along the river gradient, reflecting spatial differences in salinity, nutrients, and tidal influence. While most environmental variables showed weak correlations with species abundance, pH, nutrient levels, and salinity were strongly associated with species dominance and distribution, highlighting species-specific sensitivities. These results demonstrate that mangrove gastropods are useful indicators of ecological condition and underscore the importance of maintaining habitat heterogeneity, natural water flow, and nutrient management. Continued monitoring across broader

spatial and temporal scales is recommended to support effective conservation of mangrove biodiversity.

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