The relationship and influence of mangrove density on density and diversity of macrobenthos in the mangrove ecosystems of Makassar City, Indonesia

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Abstract. Mangrove ecosystems provide essential ecological services and support diverse benthic organisms, including macrobenthos, which serve as bioindicators of environmental stability. Understanding how mangrove structural attributes influence macrobenthic communities is crucial for effective coastal ecosystem management. This study aims to examine the relationship and influence of mangrove density on the density and diversity of macrobenthos in the mangrove ecosystems of Makassar City, Indonesia. Field data were collected across fifteen sampling stations representing different ecological settings. Mangrove density was measured using plot-based line transect methods, while macrobenthos were sampled using quadrat excavation and identified to the species level. Correlation and linear regression analyses were conducted to assess the statistical relationships between mangrove density and both macrobenthos density and diversity. The results revealed a strong, statistically significant positive correlation between mangrove density and macrobenthos density ($r = 0.754$, $R^2 = 0.569$, $p>0.05$), indicating that denser mangrove stands tend to support more abundant benthic communities. In contrast, the relationship between mangrove density and macrobenthos diversity was weaker ($r = 0.459$, $R^2 = 0.2092$, $p>0.05$), suggesting that diversity patterns are shaped by multiple environmental and ecological drivers beyond vegetation density alone. These findings highlight mangrove stand density as an important structural factor influencing macrobenthos density, while emphasizing the need to account for broader environmental variables when assessing diversity. Further research should integrate multivariate ecological parameters and long-term monitoring to guide effective conservation strategies.

Keywords: Mangrove density, macrobenthos diversity, coastal ecosystems, mangrove, benthic communities

1. Introduction

Mangrove ecosystems, located in intertidal zones, form a critical interface between marine and terrestrial systems, delivering essential ecosystem services such as coastal protection, carbon sequestration, and habitat provision for diverse species (Cannicci et al., 2021; Meijer et al., 2021). Mangroves are plants that are well adapted to grow even in salty waters and even in anoxic environments or environments where there is no oxygen content at all

(Rahim et al., 2017). Nonetheless, their distribution is not ubiquitous across all coastal regions. Successful mangrove establishment depends on specific ecological condition, including protected and relatively calm coastal conditions and the presence of sediment from river mouths (Arfan et al., 2019). Mangrove ecosystem is habitat for fish, shrimp, various bird species, which utilize mangrove for foraging, spawning, breeding, nesting, and roosting (Alongi, 2014; Chen et al., 2018; Murdiyarso et al., 2015). Mangroves ecologically can mitigate climate change, reduce wave energy (Meijer et al., 2021; Nozarpour et al., 2023).

Among the organisms supported by mangrove systems, macrobenthos is particularly significant. These organisms, inhabiting the sediment surface and substrate layers, act as bioindicators of ecological stability due to their sensitivity to environmental changes (Almaniar et al., 2021; Bo et al., 2020; Matin et al., 2018; Rizal et al., 2018; Zhang et al., 2019). Furthermore, macrobenthos contribute to ecosystem balance as detritivores and filter-feeders (Zabbey & Uyi 2014; Chen et al., 2017). Empirical evidence further underscore that macrobenthos diversity is positively correlated with mangrove age, density, and structural complexity, highlighting the importance of mangrove conservation for biodiversity preservation (Chen et al., 2023; Wang et al., 2021).

Macrobenthos abundance can be influenced by several factors, including mangrove stand age (Wang et al., 2021), changes in vegetation (Pan et al., 2021), and mangrove density (Arfan et al., 2023). Furthermore, according to Chen et al. (2023), as mangroves age, they accumulate more organic matter and nutrients, boosting primary productivity and macrobenthos diversity. In addition, at intermediate mangrove tree density levels, there is an optimal balance that supports the existence of a diverse and dense macrobenthos community (Pan et al., 2021). Macrobenthos density in mangrove ecosystems is also influenced by various environmental factors, such as salinity, organic matter content (leaf and twig litter), sediment characteristics, and nutrient availability (Pawar, 2015).

While previous studies have acknowledge the ecological role of mangrove vegetation in supporting macrobenthos communities, most have examined this relationship at a broader level considering general structural attributes such as species composition, canopy cover, or age of mangrove stands. However, few have expilicity isolated and statistically quantified the role of mangrove density as an independent ecological variable influencing both the density and diversity of macrobenthos, particularly within the context of Indonesian coastal ecosystems. This study advances the literature by conducting a quantitative analysis, utilizing correlation and regression models, to determine how variation in tree density within mangrove stands specifically affect macrobenthic community structure.

The contribution of this research lies in its contextual and applied focus rather than methodological novelty. Unlike previous studies predominantly in relatively undisturbed ecosystems, this study isolates mangrove density alone as a predictor in urban coastal vulnerable to pressures such as tourism, settlements, and pollution. By concentrating on Makassar City's mangrove ecosystems, which represent a dynamic interface between natural regeneration and anthropogenic disturbance, this research offers context-specific empirical evidence to clarify the extent to which mangrove density alone drives benthic ecological patterns in tropical coastal settings.

This study aims to investigate the intricate relationships between mangrove density and the density and diversity of macrobenthos within the mangrove ecosystems of Makassar City, Indonesia. By focusing on density as a measurable ecological parameter, the research provides a more nuanced understanding of how structural variation in mangrove habitats influences benthic community composition. The findings are expected to contribute to the development of evidence-based conservation and management strategies, particularly in urban and peri-urban coastal zones where mangrove ecosystems are increasingly threatened by anthropogenic disturbance and environmental degradation.

2. Methods

2.1. Study area

This study was conducted in the mangrove ecosystem of Makassar City, South Sulawesi Province, Indonesia (Figure 1). This region features a tropical climate with an average 28.8-30.0°C temperature, 75%-87% humidity, and 43-1195 mm annual rainfall (BPS of Makassar City, 2022). The research area is the mangrove ecosystem in Makassar City, Indonesia, covering Untia, Lakkang Delta, and Lantebung.

The study was conducted across three distinct locations within the mangrove ecosystems of Makassar City, each representing different environmental conditions: the Mangrove Restoration Center in Untia, the Lakkang River Delta residential area, and the Mangrove Ecotourism Area in Lantebung. The Untia site functions as a focal point for mangrove rehabilitation. This area is relatively insulated from intensive human disturbance and serves as a controlled environment to observe macrobenthos responses under managed ecological conditions. In contrast, the Lakkang Delta represents a densely inhabited riparian settlement where human activities, such as domestic waste discharge, small-scale agriculture, and river transportation, have a direct influence on mangrove health and water quality. Meanwhile, the Lantebung Ecotourism Area illustrates a hybrid landscape

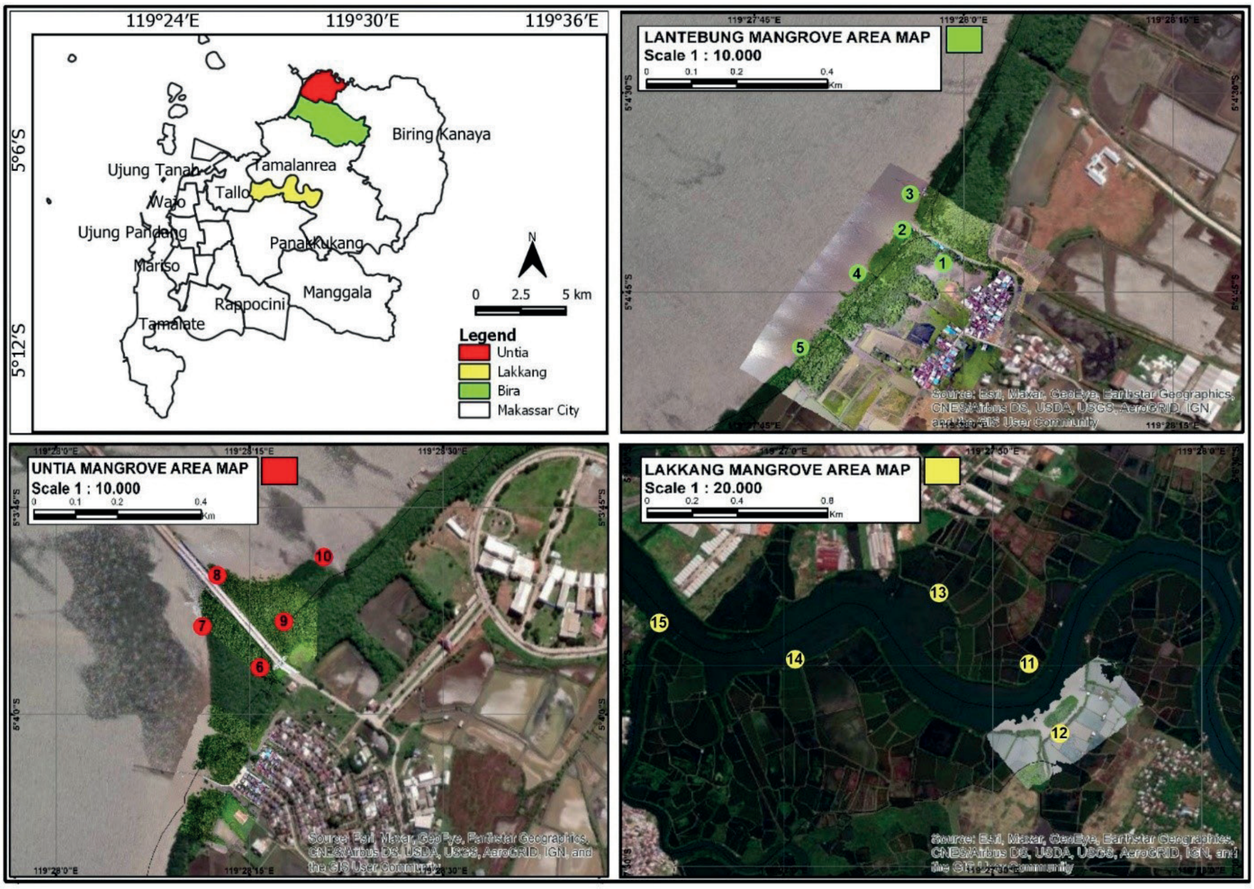

Figure 1. Map of mangrove areas in Makassar City, Indonesia

where conservation, tourism, and community engagement intersect. While it retains relatively intact mangrove stands, the development of infrastructure such as bridge and visitor facilities introduces localized environmental pressures. Each station thus offers a unique ecological setting for evaluating the role of mangrove density on macrobenthos.

2.2. Data and Analysis

Data collection was conducted through field observation. Identification and recording of the number of mangroves at each station based on the type of mangrove. Mangrove density was calculated using the following formula (Cooray et al., 2021; Xiong et al., 2018):

Tree density (tree/ha) = Number of trees (tree) / Area (ha)

Classification of mangrove density based on Hilmi et al., (2021) who measured the density of trees > 4 cm in diameter using the line transect method with a sampling plot measuring 10 m x 10 m. This means that researchers use a line as an observation path and divided the line into 10 x 10 m plots to count the number of trees in each plot. A total of 15 plots were surveyed, and counts from these plots were averaged and then multiplied by a conversion factor (10,000 divided by the plot area) to obtain the tree density per hectare (trees/ha).

The macrobenthos sampling was conducted at multiple stations within the mangrove ecosystems of Makassar City to ensure adequate representation. Macrobenthos sampling was carried out directly in the mangrove ecosystem. Then, the samples were photographed and videotaped. Based on the photos and videos, the samples were identified. After that it is returned to its habitat. Sampling was conducted on three days at each location. Observation and measurements at each station were conducted at low tide to allow easy access to the substrate and minimize hydrodynamic disturbances. A standardized quadrat sampling was employed, whereby 1 m² quadrats were systematically placed at each station. Within each quadrat, we excavated sediment up to a depth of approximately 10–15 cm to capture benthic organisms living within or on the substrate. To collect samples consistently, we used hand sieves with mesh sizes of 1 mm, allowing sediment to filter out while retaining larger macrobenthic organisms.

Each specimen was photographed and recorded on video to document morphological characteristics for taxonomic identification. Identification was conducted based on visual documentation, after which the organisms were returned to their natural habitat to minimize ecological disruption. For each station, the number of individuals per species was recorded and used to determine macrobenthos density, expressed as individuals per square meter. A diversity metrics, the Shannon-Wiener Diversity Index (H'), was then applied to assess community structure. Macrobenthos density was computed using the following formula (Almaniar et al., 2021):

$$D = \frac{ni1}{A} + \frac{ni2}{A} + \frac{ni3}{A} + \cdots \frac{nin}{A}$$

where, D is macrobenthos density (ind m-²); *ni* is number of individuals for each species; 1 2 3 is stations; A is area (m^2). The Shannon-Wiener Diversity index (Shannon Wiener 1949):

$$H' = - \sum (ni/N) \ln (ni/N)$$

where, H' is macrobenthos diversity; *ni* = number of individuals of species i; N = total individuals per station.

Species richness was determined as the total number of macrobenthos species identified at each sampling station, while species evenness was evaluated using Pielou's Evenness Index (J'), calculated as (Beisel et al., 2003):

$$J' = \frac{H'}{\ln(S)}$$

where H' is the Shannon-Wiener Diversity Index and S is the total number of species (richness) at the station. These metrics were used in a descriptive manner to complement the interpretation of diversity patterns observed in different mangrove density conditions. While the primary statistical analyses focused on the relationships between mangrove density and macrobenthos density and overall diversity (H'), references to richness and evenness were included to provide additional ecological context.

Correlation analysis is utilized to identify the relation among mangrove density with density and diversity of macrobenthos. Meanwhile, regression analysis is employed to assess the effect of mangrove density on the density and diversity of macrobenthos. Through correlation analysis, researchers can identify the strength of the relationship between these two variables, providing insight into whether increases or decreases in mangrove density are associated with changes in macrobenthos density and diversity. On the other hand, regression analysis allows researchers to evaluate the direct impact of mangrove density on macrobenthos, considering other potential influencing variables (Arfan et al., 2024). Thus, these two analytical methods complement each other in uncovering the ecological dynamics among mangrove density and macrobenthos communities. To ensure the accuracy and reliability of statistical interpretations, all correlation and regression analyses in this study were conducted using IBM SPSS Statistics software.

3. Result and Discussion

3.1. Result

The results of mangrove identification of the number of mangrove trees at each observation point are presented sequentially in Table 1, while the identification of the number of macrobenthos organisms is presented in Table 2, and analysis of mangrove density, density and diversity of macrobenthos is presented in Table 3

Graph of mangrove density, density and diversity of macrobenthos in the mangrove ecosystem of Makassar City is presented in Figure 2.

Table 1. Number of mangrove trees found in Makassar City, Indonesia

Location	Species Mangrove (ind)							Total
	Rm	*Ra*	*Am*	*Aa*	*Sa*	*Nf*	*Bg*	
1	98	22	33	22	6	0	1	182
2	88	33	22	13	0	0	0	156
3	45	22	31	8	0	0	1	107
4	78	21	19	9	2	0	2	131
5	96	42	35	4	3	0	3	183
6	7	1	123	6	0	0	0	137
7	5	2	98	20	1	0	0	126
8	2	2	87	13	0	0	1	105
9	2	3	75	21	1	0	0	102
10	12	2	89	15	2	1	0	121
11	3	2	3	4	0	5	3	20
12	3	2	2	5	0	8	1	21
13	1	2	2	0	0	12	2	19
14	2	1	1	2	1	55	2	64
15	2	2	0	0	2	60	2	68
Total	444	159	620	142	18	141	18	1542

Rm=*Rhizophora mucronata*; Ra=*Rhizophora apiculata*; Am=*Aveciina Marina*; Am=*Avicennia alba*; Sa=*Sonneratia alba*; Nf=*Nypa fruticans*; Bg=*Bruguiera gymnorrhiza*

Table 2. Number of macrobenthos organisms found in the mangrove ecosystem of Makassar City, Indonesia

Location	*Pil*	*Lit*	*Nat*	*Ter*	Mel	Cer	Cre	Tel	Crep	Ses	Uca	Ner	Sac	Scy	Met	Total
1	16	36	6	34	18	7	5	10	6	45	65	3	0	2	13	266
2	12	2	3	5	8	2	5	14	6	24	55	3	3	23	23	188
3	4	4	0	0	3	7	0	5	5	10	34	0	0	4	12	88
4	5	0	0	4	6	6	4	7	0	17	4	4	0	6	5	68
5	33	15	8	6	12	4	6	5	32	55	88	6	3	2	18	293
6	2	2	0	6	12	0	0	12	3	10	22	2	0	0	13	84
7	0	6	5	2	16	6	3	15	4	10	21	3	1	0	3	95
8	4	2	5	4	6	7	7	18	4	8	13	2	1	0	7	88
9	6	3	0	8	5	3	3	0	0	12	13	3	0	2	18	76
10	6	2	4	7	7	3	7	0	6	7	12	4	4	0	8	77
11	3	4	2	8	8	3	4	2	5	7	7	4	2	0	9	68
12	4	4	3	3	0	4	3	0	4	8	9	3	3	2	2	52
13	6	3	2	3	0	5	3	6	3	2	11	0	2	0	2	48
14	1	2	8	3	0	5	2	0	8	8	10	2	5	0	12	66
15	2	1	3	6	6	4	5	6	3	5	10	0	20	1	7	79
Total	104	86	49	99	107	66	57	100	89	228	374	39	44	42	152	1637

Pil=*Pilsbryooncha exilis*; Lit=*Littoria* sp.; Nat=*Natica* sp.; Ter=*Terebia* sp.; Mel=*Melanoides* sp.; Cer=*Cerithidea quadrata*; Cre=*Crepidula convexa*; Tell=*Telescopium mauritsi*; Crep=*Crepidula convexa*; Ses=*Sesarma* sp.; Uca=*Uca* sp.; Ner=*Nerita* sp.; Sac=*Saccostrea* sp.; Scy=*Scylla serrate*; Met=*Metaplax* sp.

Table 3. Mangrove density, macrobenthos density, and macrobenthos diversity in the mangrove ecosystem of Makassar City, Indonesia

Station	Mangrove Density (ind/100m^2)	Macrobenthos Density (ind/100m^2)	Macrobenthos Diversity
1	1.82	2.66	2.99
2	1.56	1.88	2.83
3	1.07	0.88	1.96
4	1.31	0.68	2.30
5	1.83	2.93	3.13
6	1.37	0.84	1.78
7	1.26	0.95	2.63
8	1.05	0.88	2.60
9	1.02	0.76	2.05
10	1.21	0.77	2.45
11	0.2	0.68	2.28
12	0.21	0.52	2.62
13	0.19	0.48	1.95
14	0.64	0.66	2.61
15	0.68	0.79	2.15

(a)
(b)

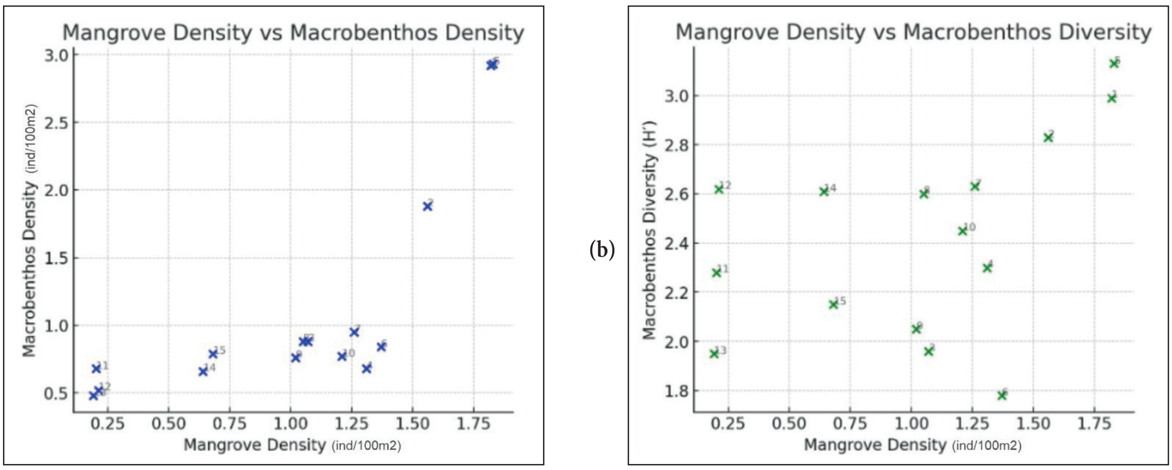

Figure 2. Scatter plot mangrove and macrobenthos in the mangrove ecosystem of Makassar city, Indonesia (a) Mangrove density vs macrobenthos density (b) Mangrove density vs macrobenthos diversity

Regression relationships between mangrove density and macrobenthos density showed in Figure 3.

Regression relationships between mangrove density and macrobenthos diversity showed in Figure 4.

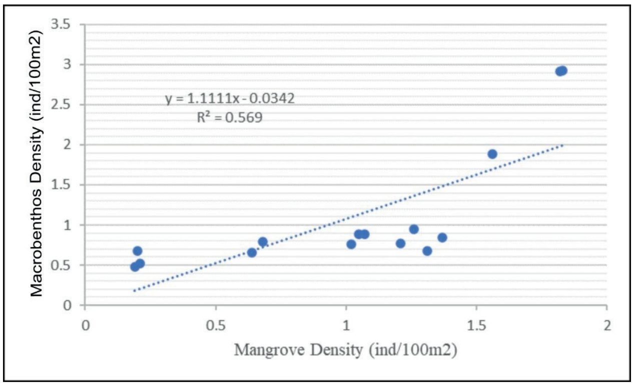

Figure 3. The effect of mangrove density and macrobenthos density

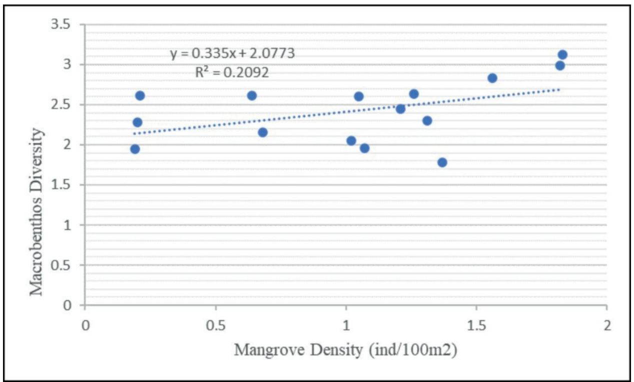

Figure 4. Graph of the effect of mangrove density and macrobenthos diversity

3.2. Mangrove and Macrobenthos Ecosystem Conditions

The mangrove ecosystems of Makassar City exhibit considerable heterogeneity in species composition and stand density, which in turn shape the structural and functional characteristics of associated macrobenthic communities. A total of seven mangrove species were identified across the study sites, with *Rhizophora mucronata*, *Avicennia marina*, and *Nypa fruticans* being the most dominant (Table 1). These species are unevenly distributed across coastal, estuarine, and riparian zones, reflecting variations in geomorphological setting and anthropogenic influence. For instance, *Rhizophora mucronata* predominates in the Lantebung ecotourism area, while *Avicennia marina* is more prevalent near the harbor zone in Untia, and *Nypa fruticans* is common in inland riparian areas such as the Lakkang Delta. Mangrove stand density ranged from 0.19 to 1.83 individuals per square meter, with Station 5 recording the highest density (Figure 2). These variations provide a natural gradient to examine how structural attributes of mangroves may influence benthic ecological patterns. Higher density areas tend to exhibit more complex root systems and greater detrital input, thereby enhancing habitat suitability for a wide range of macrobenthic organisms.

Macrobenthos communities sampled across the 15 stations comprised 15 species (Table 2), including gastropods (*Telescopium mauritsi*, *Cerithidea quadrata*), bivalves (*Saccostrea* sp.), and crustaceans (*Uca* sp., *Sesarma* sp., *Scylla serrata*). Species composition varied significantly across locations, influenced by both environmental parameters and mangrove characteristics. Areas with higher mangrove density generally exhibited greater species evenness and richness, which may be attributed to more stable microhabitats, higher organic matter availability, and greater protection from predation and physical disturbance. Conversely, sites with sparse mangrove cover tended to support less diverse and more unevenly distributed macrobenthic populations, likely due to the limited structural complexity and reduced resource input.

Table 3 reinforce that stations with higher mangrove density typically supported higher macrobenthos density. For instance, Station 1 (1.82 ind/100m^2) and Station 5 (1.83 ind/100m^2)) both recorded the highest macrobenthos densities (2.92 and 2.93 ind/100m^2, respectively). However, the relationship was not entirely consistent. Station 2, despite its relatively high mangrove density (1.56 ind/100m^2), supported only moderate macrobenthos density (1.88 ind/100m^2), indicating that additional ecological or anthropogenic factors may be at play.

Patterns of macrobenthos diversity (H′) displayed similar but more complex trends. Diversity was highest at Station 5 (H′ = 3.13) and Station 1 (H′ = 2.99), corresponding with high mangrove density. Yet, notable exceptions emerged. Station 12, for example, had one of the lowest mangrove densities (0.21 ind/100m^2) but recorded a relatively high diversity value (H′ = 2.62). This anomaly suggests that other factors (such as sediment quality, organic matter distribution, or reduced anthropogenic disturbance) can compensate for low vegetation density in supporting benthic diversity.

The scatterplot analysis further illustrates these dynamics. Figure 2a, depicting the relationship between mangrove density and macrobenthos density, reveals a clear positive trend, with data points clustering upward as mangrove density increases. However, deviations such as the case of Station 2 highlight the role of site-specific substrate conditions and anthropogenic pressures in moderating the relationship. Figure 2b, showing the relationship between mangrove density and macrobenthos diversity, exhibits a weaker positive pattern. While stations with high mangrove density generally supported higher diversity, exceptions such as Station 12 demonstrate that diversity is also influenced by factors including microhabitat heterogeneity, water quality, detrital availability, and disturbance regimes.

This spatial variation underscores the ecological interdependence between mangrove vegetation and macrobenthic assemblages. Dense mangrove stands function not only as physical habitat but also as ecological engineers that regulate sediment composition, hydrodynamics, and nutrient cycling, factors critical for sustaining benthic biodiversity (Kristensen et al., 2008; Primavera et al., 2019). Furthermore, in urban and peri-urban settings like Makassar, where mangrove ecosystems face increasing anthropogenic pressures, understanding the localized ecosystem conditions is essential for designing effective conservation and restoration interventions. The observed correlation between mangrove structure and macrobenthos distribution affirms the importance of maintaining both species diversity and structural integrity of mangrove forests to ensure the resilience of coastal benthic ecosystems.

3.3. Effect of Mangrove Density on Macrobenthos Density

The statistical analysis of the relationship between mangrove density and macrobenthos density reveals a strong and statistically siginifikan positive correlation, with a Pearson correlation coefficient of r = 0.754 and a coefficient of determination R^2 = 0.569 (Figure 3). This indicates that approximately 56.9% of the variability in macrobenthos density across sampling sites can be explained by variations in mangrove density, leaving 43.1% influenced by other factors. The associated p-value = 0.0012 (< 0.05) confirms that this relationship is unlikely to have arisen by chance, despite the modest sample size. The regression equation y=1.1111x–0.0342y = 1.1111x - 0.0342y=1.1111x–0.0342. where y is the macrobenthos density (ind/100m²) and x is the mangrove density (ind/100m²). This implies that for every unit increase in mangrove density, the predicted macrobenthos density increases by approximately 1.11 individuals m^{-2}. This finding supports the ecological premise that denser mangrove stands provide more favorable conditions for macrobenthic communities through increased habitat complexity, organic matter availability, and environmental buffering.

These findings align with previous research demonstrating that mangrove structural attributes, particularly stem density, enhance the carrying capacity for benthic organisms by providing diverse microhabitats and stable substrates (Yang et al., 2022). Denser root networks reduce sediment erosion and trap organic detritus, which serves as a vital food source for detritivorous and filter-feeding macrobenthos (Arfan et al., 2024). In addition, dense mangrove zones often exhibit lower hydrodynamic energy, which minimizes physical disturbance and allows more stable settlement conditions for benthic fauna.

However, the proportion of unexplained variation indicates that additional biophysical and anthropogenic factors. These may include sediment grain size, water salinity, nutrient concentration, seasonal changes, and pollution levels, variables that were not the primary focus of this study but are known to influence benthic population dynamics (Hamli et al., 2023; Pawar, 2015). Moreover, localized disturbances, particularly in urbanized areas, may introduce confounding effects that obscure otherwise strong ecological relationships. Moreover, differences in site histories, such as restoration efforts or prior degradation, could shape community composition independently of current mangrove density. For instance, artificially planted mangrove stands may not yet support the same level of ecosystem complexity or organic matter as mature, naturally regenerating forests, which can affect the macrobenthic colonization process (Bayudana et al., 2022; Guo et al., 2024).

Overall, the evidence indicates a robust and statistically significant ecological linkage between mangrove density and macrobenthos density, further studies with larger datasets and additional environmental parameters are necessary to validate and refine this relationship. Nonetheless, the current evidence underscores the potential of mangrove density as a key ecological indicator for assessing and managing benthic biodiversity in tropical coastal systems.

3.4. Effect of Mangrove Density on Macrobenthos Diversity

The analysis of the relationship between mangrove density and macrobenthos diversity reveals a moderate positive correlation, with a Pearson correlation coefficient of r = 0.459 and a coefficient of determination R^2 = 0.2092 (Figure 4). This indicates that approximately 20.92% of the variation in macrobenthos diversity across sampling sites can be attributed to differences in mangrove density, while the remaining 79.1% is explained by other environmental factors. Despite the presence of this trend, the correlation was not statistically significant (P > 0.05), suggesting that mangrove density alone may not be a strong or sufficient predictor of macrobenthos diversity in the study area.

The regression equation y = 0.335x + 2.0773 suggests that an incremental increase in mangrove density corresponds to a modest increase in the Shannon-Wiener diversity index. However, the relatively low R^2 value reflects the complexity of factors that govern benthic diversity, implying that macrobenthic community structure is shaped by multifactorial influences beyond vegetation density. These may include sediment heterogeneity, oxygen availability, microhabitat variation, resource distribution, and interspecific interactions, all of which interact in non-linear ways within tropical estuarine systems.

Diversity indices are inherently sensitive to both species richness and evenness. In ecological terms, even small changes in environmental heterogeneity can influence species coexistence and dominance hierarchies (Chen et al., 2023). As such, while mangrove density can enhance habitat structure, it may not always translate directly into higher diversity if other ecological conditions, such as pollution levels, nutrient availability, or hydrological fluctuations, constrain niche differentiation. Particularly in disturbed or transitional environments, localized stressors can override the potential benefits of increased structural complexity.

Moreover, temporal dynamics may influence diversity outcomes. Given that macrobenthic communities exhibit seasonal shifts in recruitment and mortality, a single temporal snapshot may not fully capture the diversity trends associated with vegetation structure. Previous studies have highlighted that macrobenthic diversity is often more responsive to longer-term habitat stability and organic matter accumulation than to stand density alone (Pan et al., 2021; Wang et al., 2021).

These results, while not statistically conclusive, underscore the partial role of mangrove density in shaping macrobenthic diversity and highlight the need for a more integrative approach in assessing benthic ecosystem health. Future research should incorporate longitudinal sampling and multivariate modeling to disentangle the relative contributions of biotic and abiotic drivers. Understanding these interactions is crucial for designing adaptive management strategies that aim to preserve biodiversity in rapidly changing coastal environments, especially in urban and peri-urban mangrove landscapes where ecological resilience is increasingly tested.

4. Conclusion

This study provides empirical evidence of the ecological relationship between mangrove density and the structure of macrobenthic communities in the mangrove ecosystems of Makassar City, Indonesia. Mangrove density exhibited a strong, statistically significant positive relationship with macrobenthos density, explaining more than half of its spatial variability. In contrast, the relationship between mangrove density and macrobenthos diversity was weaker and not statistically significant, underscoring that diversity patterns are influenced by a broader suite of ecological drivers. By quantitatively isolating mangrove density as an independent ecological variable, this research addresses a gap in tropical benthic ecology and emphasizes the importance of mangrove stand quality in biodiversity assessments.

This study was constrained by its limited spatial and temporal scope, focusing on 15 sampling stations within a single urban mangrove system. Seasonal dynamics, historical site conditions, and additional abiotic variables such as sediment grain size, organic matter content, nutrient levels, and water quality were not incorporated into the statistical models, potentially limiting explanatory power. Future research should employ long-term, seasonal monitoring across multiple mangrove systems with varying disturbance histories and integrate multivariate environmental analyses to disentangle the relative contributions of biotic and abiotic factors. Expanding the spatial coverage to include rural and pristine sites will also help establish ecological baselines, improve predictive models, and inform adaptive coastal management strategies.

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Author contribution

Conceptualization: Arfan A., Ilyas M., and Sanusi W.; methodology: Arfan A. and Ilyas M.; formal analysis: Arfan A., Sanusi W., and Rakib M.; field survey: Arfan A., Sanusi W., Rakib M., and Sukri I.; writing – original draft preparation: Arfan A., Sanusi W., and Sukri I.; writing – review and editing: Arfan A., and Sukri I.; revision: Arfan A. and Sukri I. All authors read and approved the final manuscript.

Conflicts of Interest:

The authors declare no conflict of interest.

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