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Structure of Macrozoobenthos Community in Mangrove Eco-Tourism Area of Pantai Merdeka Bagan Kuala Tj. Beringin Serdang Bedagai District North Sumatra

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Abstract: The mangrove ecosystem serves as a protector of coastal areas from the onslaught of currents and waves, as a habitat, for foraging, and as a breeding ground for various organisms and others. This research aims to determine the relationship between mangrove vegetation density and macrozoobenthos abundance in the ecotourism area of the Mangrove Forest of Pantai Merdeka Bagan Kuala Tj Beringin Serdang Bedagai. Data collection was conducted using survey methods with quadrat transects for collecting data on mangrove vegetation and macrozoobenthos at three observation stations. Based on the observation results, the composition of mangroves in the ecotourism area consists of Rhizopora sp. (52.90%), Avicennia sp. (23.50%), and Sonneratia sp. (23.50%) with higher mangrove vegetation density (140.100-150.79 ind/ha), thus falling into the good condition criteria. The identification results of macrozoobenthos showed there were 27 species consisting of: 16 species from the class Gastropoda, 2 species from the class Malacostraca, 5 species from the class Bivalvia, 2 species from the class Polychaeta, 1 species from the class Holothuroidea, and 1 species from the class Amphipoda. The abundance of macrozoobenthos in mangrove forests ranges from 85 ind/m2 to 204 ind/m2. The diversity index is moderate to high, and the evenness indicates that the macrozoobenthos community is relatively stable with values between 0.60-0.85. The relationship between mangrove vegetation density and macrozoobenthos abundance is categorized as very strong with a correlation value of 0.92.

Keywords: Community structure; Freedom Beach; Macrozoobenthos; Mangrove density

Introduction

Mangrove forests are a unique type of forest because they develop in coastal areas or around river estuaries, and are influenced by the ebb and flow of sea water with varying levels of salinity. Mangrove plants dominate as they are able to adapt and grow in muddy environments in tidal areas, thus forming a distinctive vegetation ecosystem (Maretik et al., 2022). Mangrove ecosystems are ecosystems located along the coastline and influenced by the tidal movements of the sea (Mattone & Sheaves, 2024; Chaudhuri et al., 2019). These ecosystems play an important role in supporting the life of various living creatures that reside within them. In addition, mangroves serve as a natural protector of the coast from waves and ocean currents, as well as providing habitat, breeding grounds, and foraging areas for various types of organisms (Hemery et al., 2024; Putri & Sadono, 2025). The destruction of mangrove forests, whether caused by human actions or natural disasters, can directly affect the animals that live within them (Arifanti et al., 2025; Yamamoto, 2023). One of these is

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macrozoobenthos, which are small animals that live on the bottom of the water and feed on the remains of fallen leaves, fruits, flowers, and branches of mangroves. Macrozoobenthos play an important role in distributing energy in the ecosystem, from small plants like algae to the large animals that consume them (Benhadji et al., 2025; Oselladore et al., 2022). Macrozoobenthos is one of the biota components that lives in mangrove ecosystems, both within and on the surface of the substrate. As organisms that reside in the mangrove environment, macrozoobenthos contributes to accelerating the process of decomposition and mineralization of organic matter (Cortés-Esquivel et al., 2023). The types of macrozoobenthos commonly found in mangrove areas come from the classes Crustacea, Bivalvia, and Gastropoda (Putri et al., 2015; Kaseng & Suhaeb, 2023). Mangrove vegetation itself grows in coastal areas that are flat with muddy or sandy soil conditions and is unable to thrive in steep coastal regions, with large waves, strong currents, or high fluctuations of tides (Lyddon et al., 2019; Lewis et al., 2019).

According to research by Hasibuan et al. (2021) Lismarita et al. (2022) the macrozoobenthic structure in the mangrove area is influenced by several important factors, such as salinity levels, clay content, temperature, and dissolved oxygen (DO). There is a strong relationship between dissolved oxygen and the level of macrozoobenthic diversity. It was found that the higher the DO levels in the water, the better the water quality tends to be, which ultimately supports the survival of macrozoobenthos. Conversely, low DO levels can negatively affect their presence (Šetlíková et al., 2025; Muntalif et al., 2023). This coastal area also has a mangrove ecosystem that plays an important ecological role, such as protecting the beach from erosion and providing habitat for various coastal fauna. Merdeka Beach is currently continuing to develop as a tourist destination but still faces various challenges, including threats to coastal ecosystems like mangroves caused by human activities.

This study aims to analyze the relationship between mangrove vegetation density and macrozoobenthic abundance in the ecotourism area of Merdeka Beach Mangrove Forest, Bagan Kuala, Tanjung Beringin, Serdang Bedagai. The information is expected to serve as a basis to support conservation efforts and sustainable management of mangrove ecosystems.

Method

This research was conducted in May 2025 and included several stages, such as preparation, selection of observation locations, measurement of environmental parameters of the waters, collection of mangrove vegetation data, as well as data processing and analysis. The research location is in the mangrove ecotourism area of Pantai Merdeka, Bagan Kuala, Tanjung Beringin, Serdang Bedagai District, North Sumatra. Three stations with different levels of mangrove density were designated as data collection locations, namely: Station 1 (restoration area), Station 2 (settlement area), and Station 3 (Ecotourism area).

Tools and Materials

This research used various tools and materials, including GPS (Global Positioning System) to determine the location of the stations and sampling points, a roll meter to measure the length of the transect, and a sewing meter to know the diameter of the mangrove trunks. Macrozoobenthos sampling was carried out using a transect square measuring 1x1 meters. A sieve was used to separate the sediment from the macrozoobenthos, while a shovel was used in the sampling process. Raffia string was used as a boundary for the transect, while stationery and a slate were used to record the observation results. Documentation of the activities was done with a digital camera, and the data was processed using a laptop. Environmental parameters were measured with a thermometer (temperature), refractometer (salinity), DO meter (dissolved oxygen), and pH meter (acidic level).

Research Procedure

This research uses a survey method, which involves direct data collection in the field that includes biological parameters as well as physical and chemical parameters of the water. Biological parameters include measuring mangrove density and collecting macrozoobenthic data, while physical and chemical parameters include measuring temperature, substrate types, salinity, dissolved oxygen (DO), and acidity levels (pH). Subsequent steps include sample identification, followed by data processing and analysis.

Mangrove Vegetation

Vegetation data from mangroves were collected using the quadrat transect method, by stretching a rope perpendicular from the shoreline towards the land, and establishing an observation area of 10 x 10 meters. The types of mangroves present in the plot were observed and recorded as part of the identification process. The measurement process refers to the Decree of the Minister of Environment No. 201 of 2004, which stipulates that at each sampling location, a transect line is created from the sea or river towards the land following the mangrove zoning. Along the transect line, three observation plots are selected with different sizes according to categories: 10x10 meters for trees, 5x5 meters for stakes, and 1x1 meter for seedlings (figure 1). The number of individuals of each mangrove species was recorded in each designated plot, accompanied by measurements of the trunk circumference at breast height (about 1.3 meters above ground level). For mangrove species that have not been identified, complete branch sections with leaves, and flowers or fruits if available, were collected for identification purposes. All plant samples were separated by species, placed in plastic bags, and labeled with relevant information.

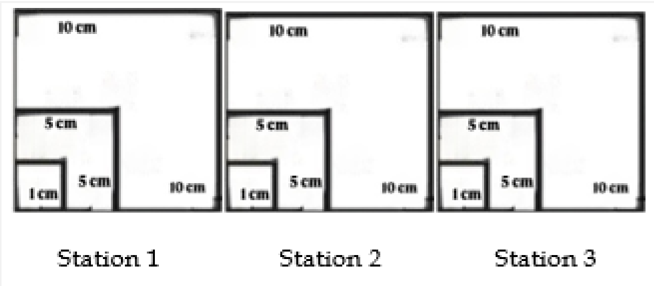

Figure 1. Transect scheme for measuring mangrove vegetation

Macrozoobenthos

The macrozoobenthos collection was conducted at three observation points, each located within a different mangrove transect plot. Each plot consists of three subplots of different sizes: 10 m x 10 m for the tree category, 5 m x 5 m for stakes, and 1 m x 1 m for seedlings. Each plot has three subplots, and in each subplot, a 1 m x 1 m quadrat was used for sampling (Figure 2).

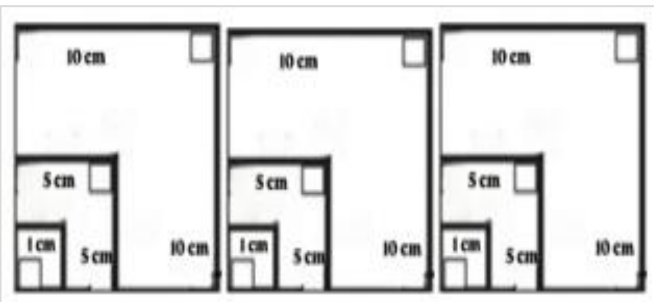

Figure 2. Transect scheme for Macrozoobenthos sampling

Water Quality (Physical and Chemical Parameters)

Physical and chemical parameters are measured using assistive tools. Five observed parameters include temperature, substrate, salinity, dissolved oxygen (DO), and pH. The obtained data is then compared with the standard quality criteria listed in the applicable regulations.

Sample Identification

The macrozoobenthos and mangrove samples that have been collected are stored in labeled ziplock bags, and then identified in the Shafera Enviro Laboratory.

Data Processing

Mangrove Density

The results from the field data will be processed into a percentage value of mangrove density.

$$\mathbf{D} = \frac{Ni}{A} \tag{1}$$

Explanation:
D = Mangrove Density (trees/m^2)
Ni = Number of stands of each type of mangrove
A = Total area of data collection (m^2)

The value of mangrove density can be categorized into 3 categories (Table 1).

Tabel 1. Standard criteria for mangrove density

Criteria	Closing (%)	Density (ind/ha)
Good	Dense ≥75	≥1500
	Currently ≥50-≤75	≥1000-≤1500
	Seldom Rarely ≤50	≤1000

Abundance of Microzoobenthos

The abundance of macrozoobenthos is defined as the number of individuals taken per unit area (m^2).

$$K = \frac{\text{total number of individuals(ind)}}{\text{area of transect sampling(m2)}} \tag{2}$$

Description:
K= Abundance of macrozoobenthos (ind/m^2)

Diversity of Macrozoobenthos

$$H' = -\sum_{i=1}^{s(}\left(\frac{ni}{N}\right)Log2\left(\frac{ni}{N}\right) \tag{3}$$

Explanation:
H' = Diversity Index
ni = Number of individuals of each species
N = Total number of individuals of all species

The values of the macrozoobenthos diversity index obtained from each station are then compared with the classification categories of the diversity index (Table 2).

Table 2. Macrozoobenthos Diversity Index

Diversity(H')	Category
H'<1	Low
H'<1	Medium
H'≥3.00	High

Uniformity of Macrozoobenthos

$$E = \frac{H'}{Log2\ S} \tag{4}$$

Description:
E = Uniformity Index
H′ = Diversity Index
S = Total number of species
0 ≤ E <0.4: low uniformity
0.4 ≤ E < 0.6: moderate uniformity
0.6 ≤ E ≤ 1.0: high uniformity

Macrozoobenthos and Mangrove Vegetation Calculation

To understand the relationship between macrozoobentos and mangrove vegetation, an analysis was conducted using the calculation of the correlation coefficient with the following formula:

Regression Equation:

$$Y = a + bX \quad (5)$$

Description:
Y = Represents the subject of the dependent variable whose value is estimated.
a = The value of Y when X is equal to 0; also called the constant value.
b = The regression coefficient or slope of the line, which describes the magnitude of change in the dependent variable due to changes in the independent variable.
X = The subject of the independent variable that has a certain value.

Calculation of Correlation Test:

$$r_{XY} = \frac{n\sum XY - \sum X \sum Y}{\sqrt{n\sum X^2 - (\sum X)^2}\sqrt{n\sum Y^2 - (\sum Y)^2}} \quad (6)$$

Description:
r = Correlation coefficient between variable x and y, two variables being correlated
X = Mangrove Density
Y = Macrozoobenthos Abundance
N = Number of data

According to Sugiyono (2007), guidelines for interpreting the correlation coefficient include:
0.00 – 0.19 = Very low relationship
0.20 – 0.39 = Low relationship
0.40 – 0.59 = Moderate relationship
0.60 – 0.79 = Strong relationship
0.80 – 1.00 = Very strong relationship.
0.80 – 1.00 = Very strong relationship.

Result and Discussion

Mangrove Vegetation Condition at the Research Location

Samples were taken from three stations, each of which has different regional conditions. Station 1 is located at coordinates 3º29'24'' – 99º15'34'', with a high density of mangrove vegetation, namely 140,100 individuals per hectare, indicating that the mangrove stand at this location is very dense. The sediment texture at this station is classified as clayey silt. This area is still within the tidal zone, and the types of mangroves found include *Rhizophora sp., Avicennia sp.,* and *Sonneratia sp.* Station 2 is located at coordinates 3º30'35'' – 99º13'54''. This area has a medium mangrove density, approximately 1,500 individuals per hectare. The sediment type at this location is classified as clayey silt. The types of mangroves that grow at this station include *Rhizophora sp., Avicennia sp.,* and *Sonneratia sp.* Station 3 is located at coordinates 3º30'28'' – 99º13'54''. This location shows a high density of mangroves, with 150,794 individuals per hectare. The type of sediment in this area falls into the category of dusty clay. The mangrove vegetation growing at this station includes *Rhizophora sp., Sonneratia sp.,* and *Avicennia sp.*

Water Quality

The water quality at the research site was evaluated through measurements of physical and chemical water parameters as well as substrate type identification at three observation points (see Table 3). The temperature recorded in the ecotourism area of Merdeka Beach mangroves ranged from 32.4ºC to 32.8ºC. This temperature range is still within the tolerance limits that support the growth of mangroves, as established by the Minister of Environment (2004) in (Basyuni et al., 2020), stating that the ideal temperature for mangrove ecosystems is between 28–32ºC. The temperature is also suitable for the survival of macrozoobenthos, referring to the seawater quality standards that stipulate the optimal temperature range for marine organism growth is between 28–32ºC (Ding et al., 2022; Lee et al., 2024). The pH values measured at three locations in the study range from 7.2 to 7.6. This range is still appropriate and acceptable for the mangrove ecosystem and macrozoobenthos. This is in accordance with the Decree of the Minister of Environment Number 51 of 2004, which establishes that the optimal pH range for mangrove ecosystems is between 7 and 8.50. The soil in mangrove areas is generally acidic due to high organic material content.

Most aquatic organisms can survive in an environment with a pH between 6 and 9, but if the pH drops below 6, it can negatively affect the survival of biota in those waters (Busch & McElhany, 2016; Gonzalez et al., 2024; Ohnstad et al., 2025). The dissolved oxygen (DO) levels found at the three observation sites ranged from 2 to 2.4 mg/L. Although at a low level, this value is still within the tolerance range that can support macrozoobenthos life, which is between 1–3 mg/L. The low concentration of DO in the research area is likely caused by the high population of organisms, which increases respiratory activity and impacts the decrease of oxygen levels in the water. This statement is in line with the findings of Kendzierska 2024), which explain that oxygen deficiency is a common occurrence, both as a result of natural processes and human activities, and is generally caused by the influx of nutrients from land and the accumulation of large amounts of organic material at the bottom of water bodies. The measured salinity results at three research stations are in the range of 12 to 20%, which still meets the criteria to support macrozoobenthos life based on the quality standards set by the Minister of Environment Decree No. 51 of 2004 with a maximum threshold of 34%. Mangrove ecosystems and macrozoobenthos can generally adapt and thrive within a salinity range of 10 to 30% (Bayudana et al., 2022).

Table 3. Range of Chemical Physical Water Parameter Values at Each Station

Parameter	Unit	Unit test results			Quality standard
		1	2	3	
Temperature	ºC	32.80	32.40	32.40	-
DO	Mg/L	2.40	2	2.10	>5
pH		7.60	7.20	7.02	-
Salinity	%	15	20	12	34

Table 4. Results of Substrate Analysis at the Bottom of the Water in Research Location

Station	Substrate Type	C-Organic Levels	
		%	Criteria
1	Dusty clay	1.23	Low
2	Dusty clay	0.85	Very low
3	Dusty clay	1.27	Low

Source: Technical Guidelines for Soil Fertility Evaluation from PPT Bogor (1995). Criteria for soil chemical properties (Organic C content): > 5.00: Very high; 3.01 – 5.00: High; 2.01 – 3.00: Moderate; 1.00 – 2.00: Low; < 1.00: Very low

The results of the analysis show that the type of substrate of the water area at the three observation stations in the mangrove forest area (stations 1, 2, and 3) is dominated by clayey silt. Among the three locations, there are noticeable differences in substrate values, which affect the density of mangroves at each station. At station 1, the substrate value is recorded at 1.23, accompanied by a high density of mangroves. This indicates that the substrate characteristics at this location sufficiently support optimal mangrove growth. In contrast, station 2 shows the lowest substrate value at 0.85, with only a medium density of mangroves. The low substrate value is suspected to be a constraint in the provision of nutrients and soil structure needed for the development of mangroves. Meanwhile, station 3 with the highest substrate value of 1.27 also shows a high density of mangroves, reinforcing the assumption that substrates with good organic matter content play an important role in supporting the growth of mangrove vegetation. This finding is in line with the opinion of (Windusari et al., 2014), which states that the distribution of mangrove species is influenced by the characteristics of the particle composition of the substrate. Fine-textured substrates generally contain higher amounts of organic matter, allowing for better mangrove growth and supporting increased species diversity. Overall, it can be concluded that the quality of the substrate has a positive relationship with mangrove density, where substrates richer in organic materials tend to support higher mangrove density. Furthermore, good substrates also have the potential to support the abundance of macrozoobenthos because they provide food and suitable habitat structure. In addition, mangrove leaf litter is a primary food source for various macrozoobenthos, reinforcing the conclusion that organic substrate directly affects the abundance of macrozoobenthos (Ananingtyas et al., 2024).

Composition of Mangrove Species

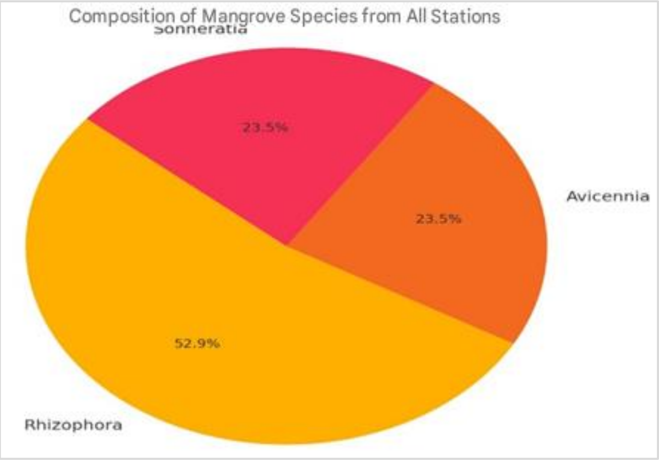

Figure 3. Composition of mangrove species

Based on the results of the analysis of the mangrove species composition conducted at three observation station locations, an overview of the diversity and distribution of mangrove species at each location was obtained (Figure 3). It was found that the species *Rhizophora sp.* dominated, with a total of 45 individuals or about 51.1% of the overall observed mangrove population. This species thrives at all three stations, indicating that environmental conditions, such as muddy substrate, moderate salinity, and areas that are often inundated by tidal water, are very suitable for the growth of *Rhizophora sp.* Meanwhile, the species *Avicennia sp.* and *Sonneratia* each contributed 22.70% (20 individuals). These two species tend to be found in habitats with different characteristics, such as denser substrates or locations closer to river mouths or shorelines. This composition shows that there are variations in ecological conditions at each station, which allows for the simultaneous growth of several different types of mangroves, although *Rhizophora sp*. remains the most adaptive and dominant type. *Rhizophora sp.* is known to have a robust prop root system and high adaptability to anaerobic conditions as well as fluctuating salinity levels, making it very competitive in dominating the middle to back zones of mangrove forests. Its ability for rapid colonization and tolerance to seawater inundation makes this type often replanted in mangrove rehabilitation activities (Carlson et al., 2021).

Mangrove Vegetation Density

The graph in (Figure 4) shows the comparison of the density of three types of mangrove, namely *Rhizophora sp., Avicennia sp.,* and *Sonneratia sp.* across three different plot sizes: Plot 1 (1×1 m), Plot 2 (5×5 m), and Plot 3 (10×10 m). The results indicate that *Rhizophora sp.* dominates the density in all three plots, with values significantly higher than the other two species. The graph shows that *Rhizophora sp.* has the highest density in all plots, but its quantity decreases drastically as the plot size increases. A similar trend is observed for *Avicennia sp.* and *Sonneratia sp.* The decrease in density is due to the effects of plot size. Smaller plots capture many seedlings in a narrow area, while larger plots reflect more uniform vegetation conditions. The dominance of Rhizophora sp. corresponds with its fast-growing and tolerant nature. This finding is also supported by previous research noting that the density of *Rhizophora sp.* in larger plots generally ranges from 2,000 to 4,000 individuals/ha (Sulistiyowati et al., 2025).

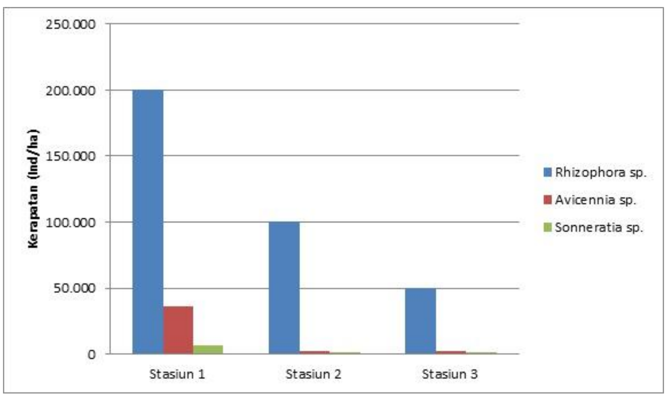

Figure 4. Density of mangrove species at each station

Composition of Macrozoobenthos Types

The identification of macrozoobenthos at the three research stations (Figure 5) shows that the *Gastropoda* class is the most dominant group, with the most commonly found species including *Assiminea sp., Pirenella cingulata, Potamopyrgus sp.,* and *Stenothyra sp.* This dominance reflects that the substrate characteristics and water quality at the research locations are quite ideal for supporting the life of benthic organisms that consume detritus. *Gastropoda* are known to be well-adapted to muddy environments with high organic content, thus their presence is often used as a biological indicator in assessing water quality in estuarine and mangrove forest areas. This is in line with research (Wu et al., 2025), stating that estuarine areas are often characterized by abundant biological resources, such as phytoplankton, algae, zooplankton, and benthic organisms. In addition to *Gastropoda*, several species from the class *Malacostraca* such as *Macrophtalmus sp* and *Uca sp* were also found in moderate numbers. Their presence supports the ecological functions of the benthic community as organic matter decomposers and substrate structure regulators. Other types such as *Cerithium sp, Geloina sp,* and *Acaudina sp* were found in very low numbers, but still contribute to the diversity of the community. This data is consistent with previous research results in tropical coastal areas that show the dominance of *Gastropoda* in the macrozoobenthic community (Ramadhani et al., 2023).

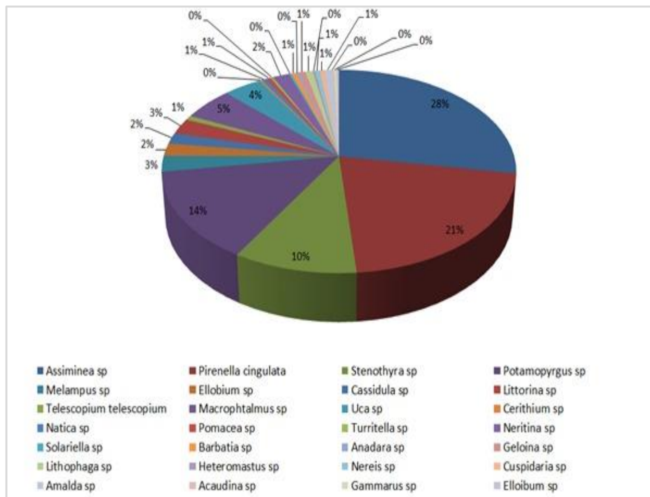

Figure 5. Composition of Macrozoobenthos types

The identification results in (Table 5) show that the macrozoobenthos found at the three research stations consist of 27 species spread across several taxonomic classes, namely *Gastropoda, Bivalvia, Malacostraca, Polychaeta, Amphipoda,* and *Holothuroidea*. From the data above, it can be seen that the class Gastropoda is the most dominant group, especially at Station 1 and Station 3. At Station 1, a total of 56 individuals of *Potamopyrgus sp*, 47 individuals of *Assiminea sp,* and 39 individuals of *Stenothyra sp* were found. This high number indicates that *Gastropoda* dominates the macrozoobenthic community at this station. This reflects the condition of muddy substrates with a relatively high organic matter content, which is an ideal habitat for detritivorous

Gastropoda species. The density of mangrove vegetation can influence the number of *gastropods* found, as this condition is closely related to sediment type, organic matter content, and the intensity of sunlight reaching the substrate surface. These factors directly affect habitat availability and food sources for *gastropods.* This statement is in line with the opinion expressed by (Hajializadeh et al., 2020), that the density of mangroves reflects the high organic matter content that serves as a primary food source for organisms such as *gastropods.* The abundance and presence of gastropods heavily depend on mangrove vegetation as well as the litter produced along the coast of Dompak. Generally, *gastropods* utilize the mangrove ecosystem as a habitat and also carry out their life activities (Purnama et al., 2024; Arceo-Carranza et al., 2024).

Table 5. Composition of types and Quantity of Macrozoobenthos at Each Station

Macrozoobenthic Species	Station			
	1	2	3	Class
Telescopium telescopium	2	1	-	G
Pirenella cingulata	5	2	76	G
Potamopyrgus sp	56	-	-	G
Melampus sp	10	-	-	G
Ellobium sp	5	-	1	G
Cassidula sp	7	-	-	G
Littorina sp	2	5	3	G
Natica sp	2	-	-	G
Pomacea sp	2	-	-	G
Cerithium sp	1	-	-	G
Turritella sp	1	-	-	G
Neritina sp	7	-	-	G
Assiminea sp	47	48	15	G
Stenothyra sp	39	-	-	G
Solariella sp	1	-	-	G
Amalda sp	-	3	-	G
Macrophtalmus sp	2	11	5	M
Uca sp	2	11	1	M
Barbatia sp	2	-	-	B
Anadara sp	1	-	-	B
Geloina sp	3	-	-	B
Lithophaga sp	3	-	-	B
Cuspidaria sp	-	2	-	B
Heteromastus sp	1	-	-	P
Nereis sp	1	1	-	P
Acaudina sp	-	1	1	H
Gammarus sp	-	-	1	A
Amount	202	85	103	

Description: G= Gastropoda; H= Holothuroidea; M= Malacostraca; A= Amphipoda; B= Bivalvia; P= Polychaeta

At Station 2, the macrozoobenthos composition is relatively more balanced with a significant contribution from Assiminea sp (48 individuals) as well as several types from the class *Malacostraca* such as *Macrophtalmus sp* and *Uca sp* (11 individuals each). The presence of this group indicates that the environmental conditions are still quite good, with substrates capable of supporting taxonomic diversity. Conversely, Station 3 shows a very striking dominance by *Pirenella cingulata* (76 individuals), which contributes significantly to the macrozoobenthos composition at that station. The high dominance of this single species may indicate environmental pressure or ecosystem imbalance that leads to a decrease in the diversity of other species. In general, the uneven distribution of macrozoobenthic species among stations can be caused by several factors, such as differences in substrate, water quality, food availability, and anthropogenic influences around the sampling locations. The presence of minor species such as *Gammarus sp, Acaudina sp,* and *Cuspidaria sp* in very small numbers indicates that the habitat can still support diversity, although it may be in less than optimal conditions. This statement is consistent with previous research (Mwakisunga et al., 2020) which states that the distribution of benthic macrofauna species is greatly influenced by sediment grain size and organic carbon content in the sediment.

The Abundance of Macrozoobenthos

The abundance of macrozoobenthos is a measure of the total individuals of all species present in a specific area, and serves as an important indicator for assessing productivity levels and environmental conditions in those waters. Based on the research results, Station 1 showed the highest abundance with a total of 204 ind/m², followed by Station 3 with 100 ind/m2, and Station 2 with 85 ind/m2. At Station 1, the abundance was dominated by the species *Potamopyrgus sp, Assiminea sp, and Stenothyra sp,* indicating that the substrate at this location is rich in organic material and supports a stable benthic community.

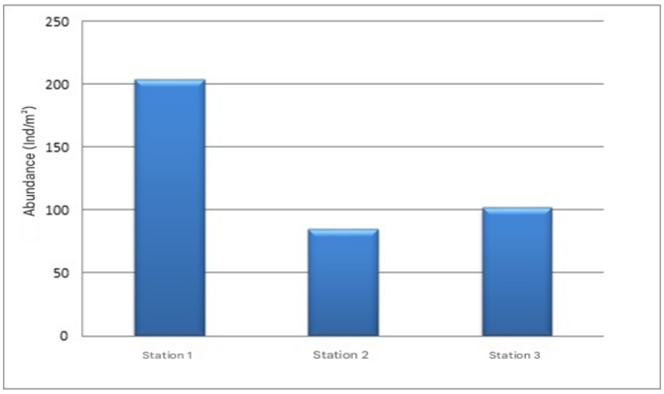

Figure 6. The abundance of Macrozoobenthos

Meanwhile, although the number of individuals at Station 3 is quite high, more than 70% of the population comes from a single species, namely *Pirenella cingulata*, which reflects the dominance of certain species due to ecological pressure or environmental changes. The dominance of one species can lead to a decline in ecosystem functions due to the lack of ecological functional diversity among organisms. As for Station 2, it shows moderate abundance with a relatively even species composition between *Gastropoda* and *Malacostraca,* such as *Assiminea sp, Macrophtalmus sp,* and *Uca sp*. This pattern may indicate dynamic environmental conditions but has not yet experienced heavy pressure. A balanced macrozoobenthic community composition, where individuals are evenly distributed without being dominated by one or two species, indicates a healthy and stable ecosystem. Therefore, the interpretation of abundance data must be viewed comprehensively by considering dominance, diversity, and distribution among species, not just the total number of individuals. According to a Tony et al. (2024), high levels of organic matter in the water contribute to the presence of macrozoobenthos, where an increase in organic matter is generally followed by an increase in the number of macrozoobenthos found.

Index of Macrozoobenthic Diversity

Based on the analysis results, Station 1 showed the highest diversity index of 2.65, followed by Station 2 with a value of 2.36, and Station 3 which had the lowest diversity index of 1.49. According to the diversity index classification, H' values in the range of 1 to 3 are categorized as medium diversity, while values below 1 are categorized as low diversity. Therefore, the macrozoobenthic community at Stations 1 and 2 falls under the medium diversity category, whereas Station 3 has a relatively low diversity level. The high diversity index (H') at Station 1 reflects that the environment there is relatively stable and conducive to the growth of various types of macrozoobenthos. The relatively even distribution of individuals among *Potamopyrgus sp., Assiminea sp., and Stenothyra sp.* indicates the absence of dominance by a single species, which is characteristic of a healthy ecosystem. On the other hand, the low H' value at Station 3 is caused by the significant dominance of *Pirenella cingulata,* which accounts for more than 70% of the total individuals. The dominance of a single species leads to a decrease in the value of biodiversity because the distribution of species becomes unbalanced.

This condition can be a sign of environmental pressure such as changes in water quality, substrate degradation, or disturbances due to human activities. Although the number of individuals at Station 2 is lower, the H' value that is almost the same as Station 1 indicates that the species distribution there is still even and its community remains diverse. Conversely, low species diversity reflects low productivity, which indicates heavy pressure and instability in the ecosystem. This finding is in line with the opinion of Dee et al. (2023) that the decrease in the number of species in an ecosystem is often caused by the dynamics of environmental pressures that occur continuously, coupled with the impacts of various human activities. Mangrove forests located in the tidal zone become the convergence of seawater, brackish water, river flow, and land, thus creating complex environmental conditions. This situation supports the formation of ecosystems with high biodiversity, including various types of plants and animals.

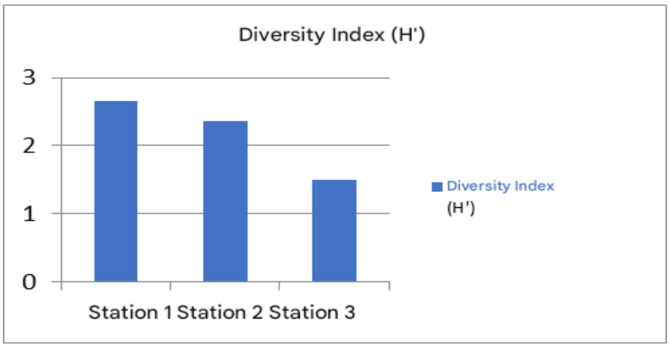

Figure 7. Index of macrozoobenthic diversity

Index of Macrozoobenthic Uniformity

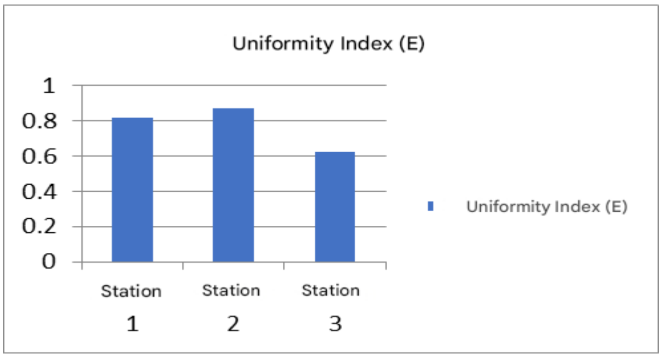

Figure 8. Index of macrozoobenthic uniformity

The results of the uniformity index (E) graph at three stations show differences in the macrozoobenthos uniformity values. Station 1 has an index value of 0.8, indicating that the distribution of individuals among species is fairly even without the dominance of any particular species. Station 2 has the highest value of 0.85, which indicates that the community is in the most stable condition with an almost balanced distribution of individuals. In contrast, Station 3 displays the lowest value of 0.6, indicating the dominance of certain species, which results in a lower level of uniformity compared to the other two stations. In general, the index values at the three stations are still classified as moderate to high, indicating that the macrozoobenthos community in the mangrove ecosystem can be categorized as stable. However, the low value at Station 3 indicates the influence of environmental conditions, such as differences in substrate, variations in the density of mangrove vegetation, and water quality factors that affect the balance of populations among species. This finding is consistent with the research by Kadim et al. (2022), which states that the dominance index value for all stations is less than 0.5, categorized as low. The low dominance index result indicates that macrozoobenthos are in good habitat conditions.

The Relationship of Mangrove Vegetation with Macrozoobenthos

(Figure 9) shows a linear relationship between mangrove vegetation density (stems/m²) and the number of macrozoobenthos (ind/m²). The regression equation obtained from the graph is y = 0.0006x + 49.91 with a coefficient of determination (R^2) of 0.85. This value indicates that approximately 85.61% of the variation in the number of macrozoobenthos can be explained by differences in mangrove vegetation density. This means that there is a very strong relationship between the two, where higher mangrove vegetation density tends to increase the abundance of macrozoobenthos. The regression line in the graph shows a positive relationship trend, where the data points tend to follow the direction of the rising line. This reinforces the understanding that mangrove vegetation plays a vital role in supporting macrozoobenthos life. Mangroves provide complex habitat structures, organic matter from leaf litter, and stable environmental conditions that are crucial for macrozoobenthos to thrive. Although the number of data points in the graph is limited, with only three stations, the visually observed relationship pattern still provides an initial impression that the density of mangrove vegetation affects the community structure of macrozoobenthos in coastal areas.

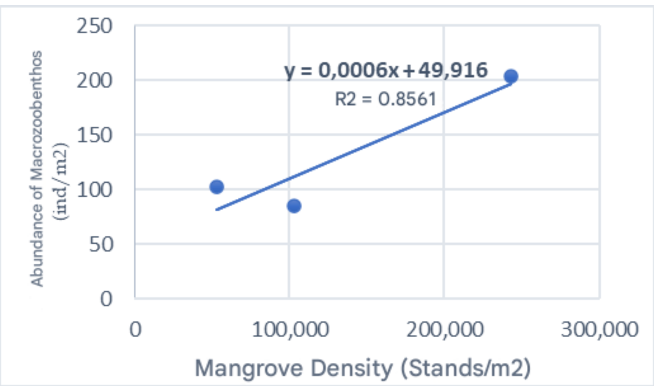

Figure 9. The Relationship of mangrove vegetation with macrozoobenthos

According to research Nihan et al. (2022), the small direct effect of mangrove density on the abundance of macrozoobenthos is supported by various other research findings. For some species of macrozoobenthos, sediment or substrate conditions are the main source of life for macrozoobenthos in the mangrove ecosystem. The roughness of the sediment is a significant determinant of the abundance of macrozoobenthos. The correlation analysis between mangrove vegetation density and macrozoobenthos abundance shows a coefficient value of 0.92, which represents a very strong positive relationship between the two parameters. This means that the denser the mangrove vegetation at a location, the higher the abundance of macrozoobenthos found. The value of 0.00–0.19 falls into the very weak category, 0.20–0.39 weak, 0.40–0.59 moderate, 0.60–0.79 strong, and 0.80–1.000 very strong. Thus, there is a positive linear relationship between mangrove vegetation density and macrozoobenthos abundance, where an increase in mangrove vegetation density contributes to an increase in the number of macrozoobenthos.

Conclusion

Based on research conducted in the Pantai Merdeka Mangrove Forest Ecotourism, Bagan Kuala, Tanjung Beringin, Serdang Bedagai, it concludes that the macrozoobenthos community in the Pantai Merdeka mangrove ecosystem is in fairly good condition. The diversity index (H') at all stations is categorized as moderate to high, indicating that the ecosystem can support the presence of various types of macrozoobenthos. The evenness index (E) also shows a relatively even distribution of individuals, with Station 1 (0.80) and Station 2 (0.85) illustrating a stable community condition, while Station 3 (0.6) indicates the dominance of certain species due to environmental factors. The variation in macrozoobenthos abundance among stations is influenced by differences in substrate, levels of mangrove vegetation density, and water quality conditions. Regression and correlation analysis show a very strong positive linear relationship between the density of mangrove vegetation and the abundance of macrozoobenthos ($R^2 = 0.85$; $r = 0.92$), indicating that as the density of mangrove vegetation increases, the number of macrozoobenthos also increases. This finding emphasizes that mangroves play an important role in providing a complex habitat, supplying organic materials from leaf litter, and maintaining stable environmental conditions. Overall, the low dominance index values (<0.5) at all stations indicate that there are no excessively dominant species, allowing the macrozoobenthos community to remain balanced and reflecting a well-preserved mangrove ecosystem.

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Author Contributions

Y. H. A played a role in the conceptualization, data collection and analysis, as well as manuscript preparation. M. A. H provided supervision, methodological guidance, and input in refining the manuscript.

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Conflicts of Interest

The researchers funded this research independently.

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