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The effect of stranded marine debris on the mangrove ecosystem in the coastal area of Liquiça Municipality of Timor-Leste

Dampak sampah laut yang terdampar di ekosistem mangrove di wilayah pesisir Liquiça, Timor-Leste

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Abstract.
This study aims to determine the types, abundance and composition of the stranded marine debris and its impact on the mangrove ecosystem in Liquiça Municipality, Timor-Leste. Data were collected from 6 September 2024 to 30 October 2024 at three stations using surveys and direct field observations. Analysis was conducted both quantitatively and qualitatively. Seven types of debris were identified : plastic, metal, glass, rubber, fabric, organic and other inorganic waste. Plastic was the most dominant at all stations, Station 1 recorded the highest debris abundance at 1.62 items/m^2, with plastic waste also dominating by category at Stations 1 and 3 (155 items/m^2 and 137 items/m^2). Station 1 also had the heaviest debris weight at 4,339 g/m^2 and the largest volume at 235 cm^3/m^2. The findings indicate that stranded marine debris does have a negative impact on the mangrove ecosystem, significant negative correlation between the weight of marine debris and macrozoobenthos. However no correlation between debris and mangrove's seedlings was found.

Keywords: marine debris, mangrove, macrozoobenthos, coastal area, Liquiça Municipality

Abstrak.
Penelitian ini bertujuan untuk menentukan jenis, kelimpahan, dan komposisi sampah laut terdampar serta dampaknya terhadap ekosistem mangrove di Liquiça, Timor-Leste. Pengumpulan data dilakukan pada 6 September 2024 hingga 30 Oktober 2024 dengan menerapkan teknik survei dan observasi lapangan langsung di tiga stasiun. Data dianalisis secara kuantitatif dan kualitatif. Tujuh jenis sampah ditemukan di lokasi penelitian, yaitu plastik, logam, kaca, karet, kain, sampah organik dan sampah anorganik lainnya. Sampah Plastik adalah yang paling dominan di semua stasiun. Stasiun 1 mencatat kelimpahan sampah tertinggi pada 1,62 item/m^2, dengan sampah plastik juga mendominasi berdasarkan kategori di stasiun 1 dan 3 (155 dan 137 item/m^2). Stasiun 1 juga memiliki berat sampah terberat pada 4.339 g/m^2 dan volume terbesar pada 235 cm^3/m^2. Hasil penelitian menunjukkan bahwa sampah laut yang terdampar memberikan dampak negatif terhadap ekosistem mangrove, karena ditemukan korelasi negatif yang jelas dan signifikan antara berat sampah laut dengan makrozoobentos. Namun tidak ditemukan korelasi antara sampah dengan bibit mangrove.

Kata kunci: sampah laut, mangrove, makrozoobentos, wilayah pesisir, Liquiça

1. INTRODUCTION

Coastal area are dynamic interface zones characterized by the continuous interaction and evolving balance between land, water and atmosphere that driven by both natural process and anthropogenic activities (Beatley *et al.* 2002). These zones also define as the transitional area between land and sea, encompassing the coastal environment, adjacent hinterland and coastal waters (Setyawan *et al.* 2016). While it holds high importance for life because its wealth of natural resources, this area is also heavily influenced by land-derived factors such as runoff and sedimentation, as well as

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marine influences like tides and water quality (Wibisono 2011). These complex factors result in problems such as pollution and waste impacts on coastal ecosystems and large part of marine debris is entering the sea via rivers (Zamdial *et al.* 2017).

Debris is also characterized as solid waste material that comes from human activity and is no longer needed (Wijayanti *et al.* 2023). Waste from the water and land such as plastic waste is one of the problems faced by the whole world today, including Timor-Leste (Gusti *et al*. 2023). Timor-Leste is one of the Small Island Developing States (SIDS) that is most affected by the negative effects of plastic waste on the environment, human rights, and human health (Lachmann *et al.* 2017).

An estimated 56.6 tons of unmanaged waste is released daily and is believed to enter the marine environment in Timor-Leste through indiscriminate and unregulated dumping. In 2010, around 20,690 tons of plastic waste was dumped into the waters and its impacts on marine and coastal biodiversity have not been fully documented due to lack of management (Jambeck *et al.* 2015). Poor waste management will result serious issues such as water pollution, flooding during the rainy season, and fires in the dry season (Harefa and Pharmawati 2022) that can happen in Liquiça if the attention is not taken from now.

Liquiça is one of the Municipalities in Timor-Leste that has a coastline in Regency of Bazartete and located near Dili the city of Timor-Leste, the mangrove area is densely settled and contains a variety of both inorganic and organic waste (Paulus *et al.* 2020). This pollution not only harms marine life but also leads bioaccumulating of toxic substances in the food chain, furthermore the issue becomes more complicated with persistent plastic waste (Priatna *et al.* 2024). Due to the problems caused by marine pollution on coastal ecosystems at the research location, this study seeks to evaluate the condition of stranded marine waste and its effects on mangrove ecosystems. Specifically, this study aimed to assess the quality of the mangrove community structure and the presence of macrozoobenthos in relation to marine debris.

2. METHODOLOGY

2.1. Location and time of study

This research was conducted from September to October 2024 in the mangrove ecosystem of Regency Bazartete, Liquiça Municipality, Timor-Leste. The sampling area consisted of three stations, namely in the villages of Tibar, Ulmera and Motaikun

(**Figure 1**). The selection of the sampling location considered the presence of coastal mangroves, settlements and piles furthermore, the Liquiça Municipality is a place for garbage disposal from all Municipalities in Timor-Leste.

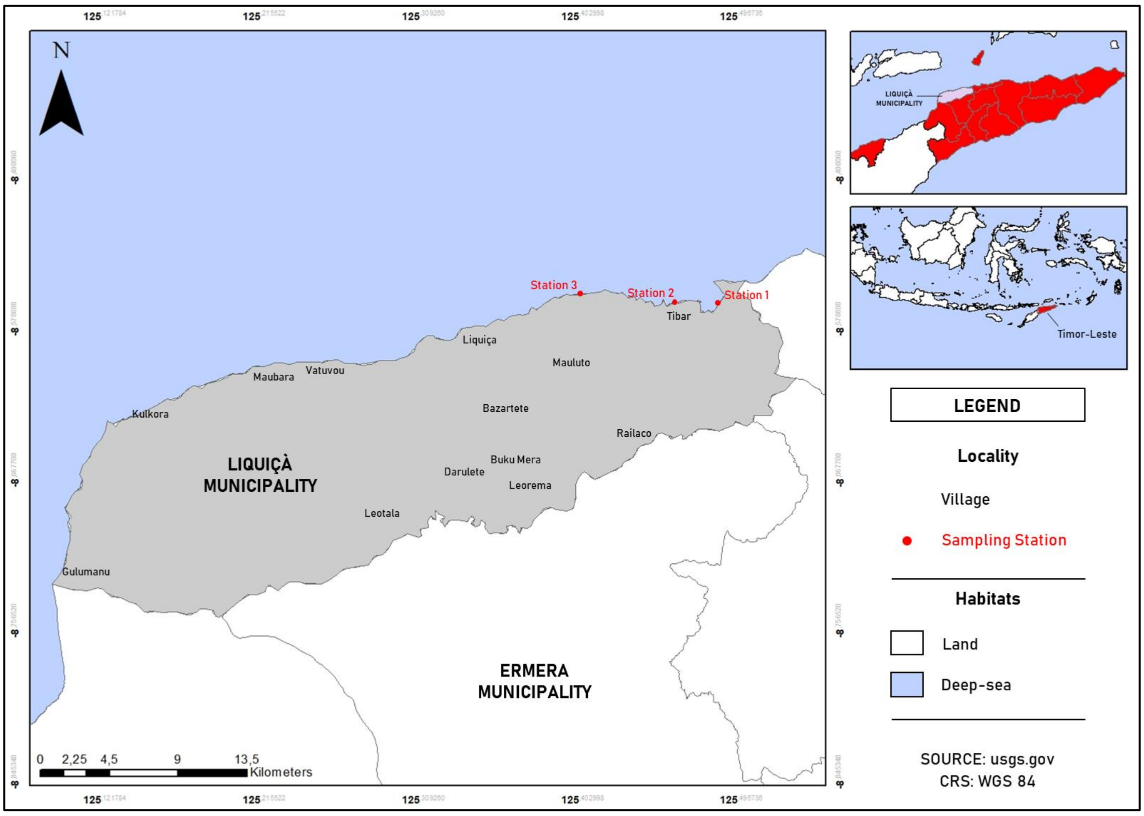

Figure 1. Map of research location and sampling sites in mangrove forests in Bazartete, Liquiça Municipality of Timor-Leste.

2.2. Data collection

Marine debris sampling at observation points and additional measurements were carried out at three stations where Station 1 is in Tibar Village, Station 2 is in Ulmera Village, and Station 3 is in Motaikun Village. The sampling method applied in the mangrove area used the line transect method. Marine debris that has settled was collected, put into sacks/plastic, dried and sorted, and the type, weight and number of marine debris was recorded (Eriksson *et al.* 2013). In addition, direct observations were also carried out in the field. The length of the transect line around it depended on the distribution of waste in the area where there are mangroves. Waste distribution was observed by marking 5 quadrat transect plots at each station with a size of 5 x 5 meters, while for biological sampling of mangroves 5 plots were made with a size of 10 x 10 meters (**Figure 2)**.

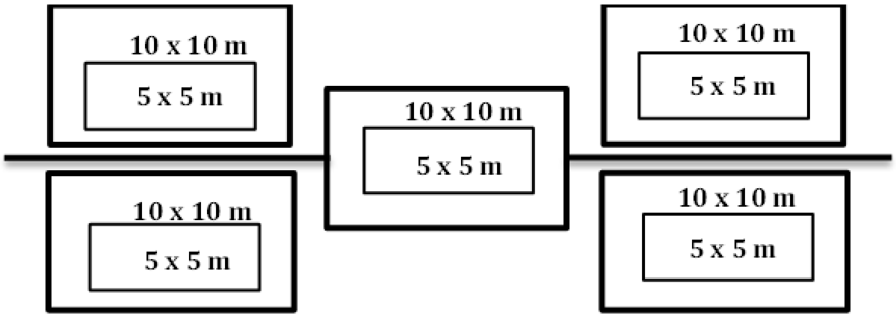

Figure 2. Sketch of quadrat transect plot in marine debris and mangrove data collection.

Sampling of macrozoobenthos epifauna in the mangrove area was carried out using line transects on marine debris transect plots with subplots, where each transect plot was divided into 5 parts, namely subplots, each of which has size of 1 x 1 m which can be seen in **Figure 3** (Bai'Un 2021). Macrozoobenthos was sample from each subplot using a shovel to a depth of 20 cm once for each plot. Macrozoobenthos that had been filtered were placed in clean clear plastic bag and then taken to be identified according to their type.

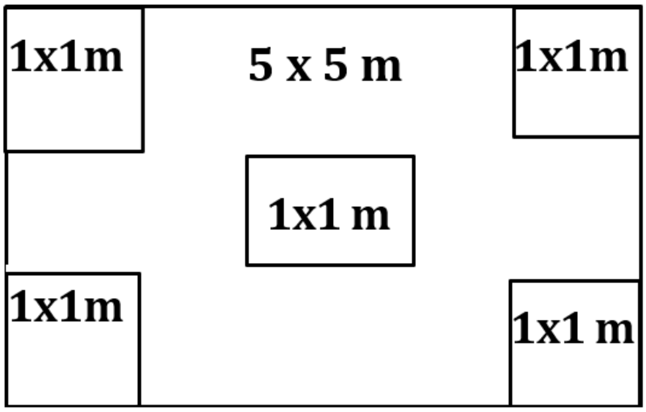

Figure 3. Sketch of transect placement for macrobenthos data collection.

2.3. Data analysis

2.3.1. Marine debris

Analysis of marine debris data was carried out on the type, weight and volume of debris (Johan *et al.* 2020). Classification of various types of waste followed NOAA in Opfer *et al.* (2012) and used the categories plastic, metal, glass, rubber, fabric, organic and other inorganic. To determine marine debris abundance and composition on Liquiça Municipality, look all factors such the weight and quantity. The following formula explains the density and relative density of marine debris (Coe and Rogers 1997) in **Equation 1, Equation 2** and **Equation 3.**

$$\text{Abundance of marine debris } (\text{item}/m^2) = \frac{\text{amount of waste}}{\text{area (m2)}} \quad (1)$$

$$\text{Mass of marine debris } (gr/m^2) = \frac{\text{waste weigth}}{\text{area (m2)}} \quad (2)$$

$$\text{Composition marine debris } (\%) = \frac{\text{waste weigth per category (g)}}{\text{total weigth of waste (g)}} \quad (3)$$

2.3.2. The effect of marine debris on mangrove ecosystems

2.3.2.1. Mangrove species density

Species density (Di) was calculated by dividing the total number of type I mangrove stands by the sampling region's area (Bengen 2001). The following formula (**Equation 4**) was used to determine the kind that was found.

$$Di = \frac{\text{Ni}}{\text{A}} \quad (4)$$

Description:
Di = Mangrove species density
Ni = Number of species of mangroves stands
A = Sampling area

2.3.2.2. Macrozoobenthos

Macrozoobenthos samples were evaluated using the density index formula to determine the population size of each type of benthic organism. The density of benthos at various locations was examined, especially between locations affected by waste and those not affected by waste. The following formula (**Equation 5**) was used to determine the density of related biota (Fitriana 2006).

$$\text{Total density} = \frac{\text{number individuals of the species (Ind)}}{\text{area size (m}^2\text{)}} \quad (5)$$

2.3.2.3. Water quality

Direct field observation (in situ) was used to collect water quality data around the location where stranded marine debris was found. Water quality data was analyzed descriptively to describe the condition of water quality and the level of pollution found around the mangrove area (Kurniawan 2013).

2.3.2.4. Sediment/substrate quality

At each transect plot, the substrate was sampled to about 20 cm depth using scope and placed in a plastic bag. Each bag was labelled with the plot and stations name and taken to the laboratory for analysis. The parameters measured from the sample were: Grain size of substrate, type of substrate and C-organic content.

2.3.2.5. Correlation statistical unit

The following step is to conduct correlation tests to determine whether there is a relationship between the variables. The analysis result is assessed according to the significance and strength of the link indicated by the correlation coefficient value r. The formula for calculating correlation as Steel and Torrie (1995), is as follows **Equation 6**. The correlation category of the relationship between the two variables is divided based on **Table 1**.

$$r = \frac{Sxy}{\sqrt{(Sxy^2)(Sy^2)}} \quad (6)$$

Description:
r = Correlation coefficient
Sxy = Distribution of x and y variable values
Sx2 = Diversity of variable x values
Sy2 = Diversity of variable y values

Table 1. The correlation category of the relationship between the two variables (Steel and Torrie 1995).

Interval	Category
0.00	No correlation
> 0.00 - 0.25	Very weak correlation
> 0.25 - 0.50	Sufficient correlation
> 0.50 - 0.75	Strong correlation
> 0.75 - 1.00	Very strong correlation

3. RESULTS AND DISCUSSION

3.1. Research site description

This study was conducted along the mangrove coastline of Liquiça Municipality, located on the northwestern coast of Timor-Leste, approximately 30 kilometers west of the capital, Dili. The area lies in a tropical coastal zone affected by monsoonal climate, characterized by wet season from November to April and dry season from May to October. It receives an average annual rainfall of around 1,500 mm that affects the seasonal dynamic of debris accumulation along the shore (Asian Development Bank 2016). Plastics, fishing nets, rope and glass bottles were among the stranded marine debris found in the area surrounding the mangrove forest’s silt layers and prop root system according to field observations.

3.2. Type of marine debris/waste

Observations at 3 stations in the research site, various types of waste were found, the dominant which was plastic waste. The highest amount of plastic waste was found at Station 1 (Tibar) with a weight of 4339 g/m^2, a total number of 155 items/m^2 and 235 cm^3/m^2. At the third station (Motaikun), a weight of 2695 g/m^2, a total number of 111 items/m^2 and a volume of 181 cm^3/m^2 was observed. At Station 2 (Ulmera), a mass of 2008 g/m^2 with a number of 111 items/m^2 and a volume of 146 cm^3/m^2 was observed. For the total weight of all waste combined, the first station contained 10814 gr/m^2, then the third station with a total weight of waste of 6451 g/m^2 and the second station was lower because it had a total weight of waste of 6042 g/m^2 (**Table 2**).

Table 2. Type and weight of marine debris in research location.

Category	Station 1 (Tibar)			Station 2 (Ulmera)			Station 3 (Motaikun)		
	N (item/m^2)	**W** (gr/m^2)	**V** (cm^3/m^2)	**N** (item/m^2)	**W** (gr/m^2)	**V** (cm^3/m^2)	**N** (item/m^2)	**W** (gr/m^2)	**V** (cm^3/m^2)
Plastic	155	4.339	235	111	2.008	146	137	2.695	181
Metal	33	427	10	4	127	4	3	331	6
Glass	2	592	5	1	113	5	3	309	7
Rubber	2	300	10	8	948	13	4	850	15
Fabric	9	2.171	32	16	1.297	87	5	1.380	45
Organic	23	2.219	55	2	695	6	1	560	3
Other Inorganic	8	766	31	9	854	27	6	326	27
Total	**232**	**10.814**	**378**	**151**	**6.042**	**288**	**159**	**6.451**	**283**

Notes:
N = number of item; W = weight ; V = volume

3.3. Abundance of stranded marine debris

The weight of stranded marine debris at Station 1 was higher than Station 2 and Station 3. The volume of waste items at Station 1was higher than at Stations 2 and 3. Likewise, the density of waste at Station 1 was also higher than at Station 3 and the lowest was observed at Station 2 (**Figure 4**).

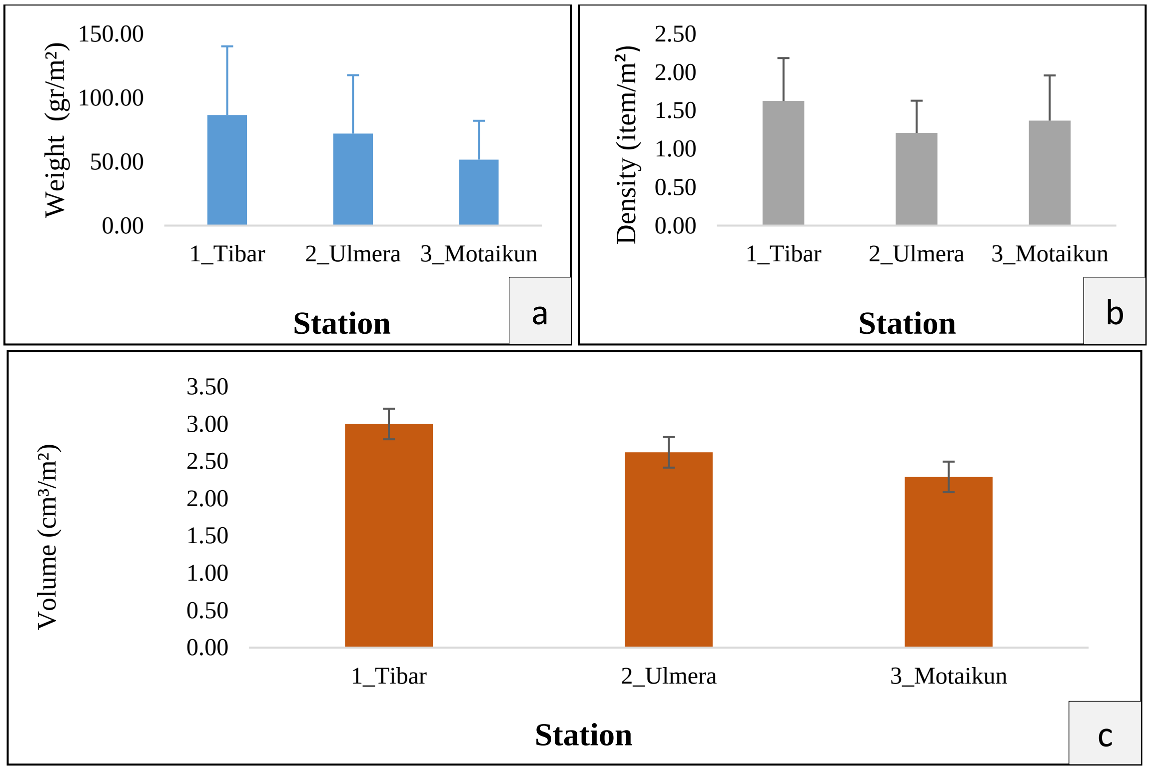

Figure 4. Abundance of stranded marine debris at mangrove in the study area; a) weight of of stranded marine debris; b) density of stranded marine debris; and c) volume of stranded marine debris.

3.4. Composition of marine debris

Plastic waste was the most frequently found and dominated the weight of waste at each station, with the highest percentage at Station 3, followed by Station 1 and the second station. In terms of abundance, the composition was even more strongly dominated by plastic. It was highest at Station 3 followed by Station 2 and Station 1. The proportion of plastic in terms of volume likewise was highest at Station 3, followed by Station 1 and Station 2 (**Figure 5**). These results indicate that plastic is the main source of pollution, and the high weight, abundance and volume of plastic at all three stations show that plastic waste is not only accumulated in one area but is widespread in several locations.

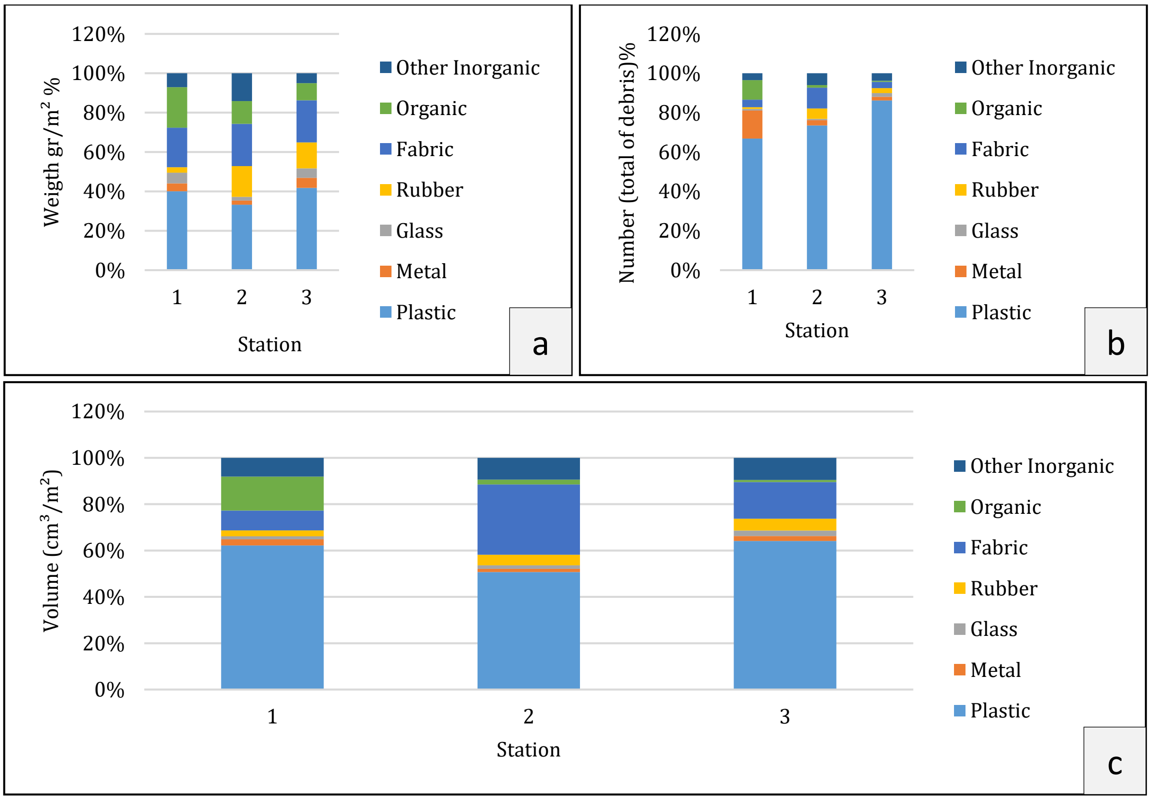

Figure 5. Composition of marine debris stranded at the research location; a) weight composition; b) density composition; and c) volume composition.

3.5. Mangrove type density

Based on the analysis of mangrove vegetation density, there are four types of mangroves found at the three observation stations, namely *Burguiera gymnorhiza, Rizophora stylosa, Sonneratia alba* and *Sonneratia ovata*. At Station 1 there were mangrove trees of the type *Rizophora stylosa* and *Sonneratia alba* and seedlings of the type *Rizophora stylosa*.

At Station 2, the type of *Rizophora stylosa* tree was found and *Sonneratia alba*, the category of seedlings contained the types *Rizophora stylosa* and *Sonneratia alba*. Station 3 is a location close to residential areas but there are 4 types of mangrove trees, namely *Burguiera gymnorhiza, Rizophora stylosa, Sonneratia alba* and *Sonneratia ovata*. There are also 3 types of mangrove seedlings, namely *Rizophora stylosa, Sonneratia alba* and *Sonneratia ovata* (**Figure 6**).

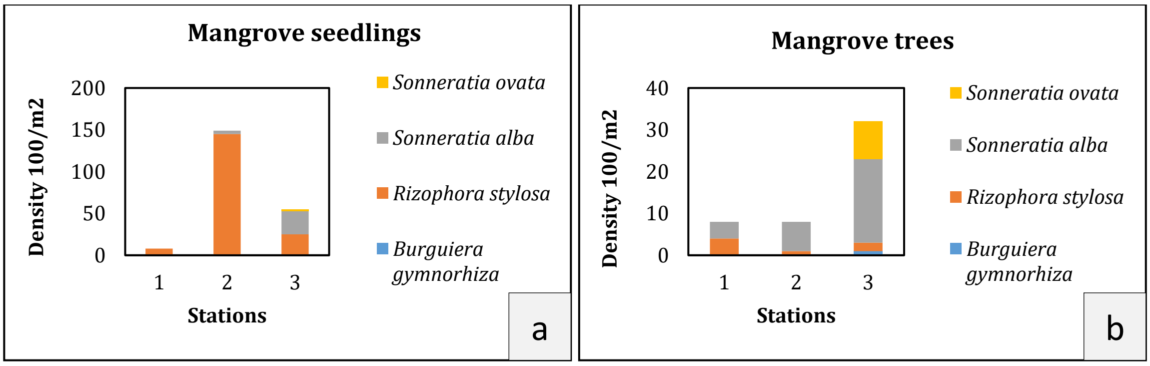

Figure 6. Mangrove type density in each station; a) mangrove seedling and b) mangrove trees.

3.6. Density of macrozoobenthos and epifauna

The results of the macrozoobenthos and epifauna density analysis show that the macrozoobenthos density is highest at the second station with 14 species, dominated by *Strombus labiatus* (**Figure 7**). The third station has a lower macrozoobenthos density than the second station, but higher than the first station with 17 species found. At the first station, the density of macrozoobenthos is relatively lower when compared to Stations 2 and 3.

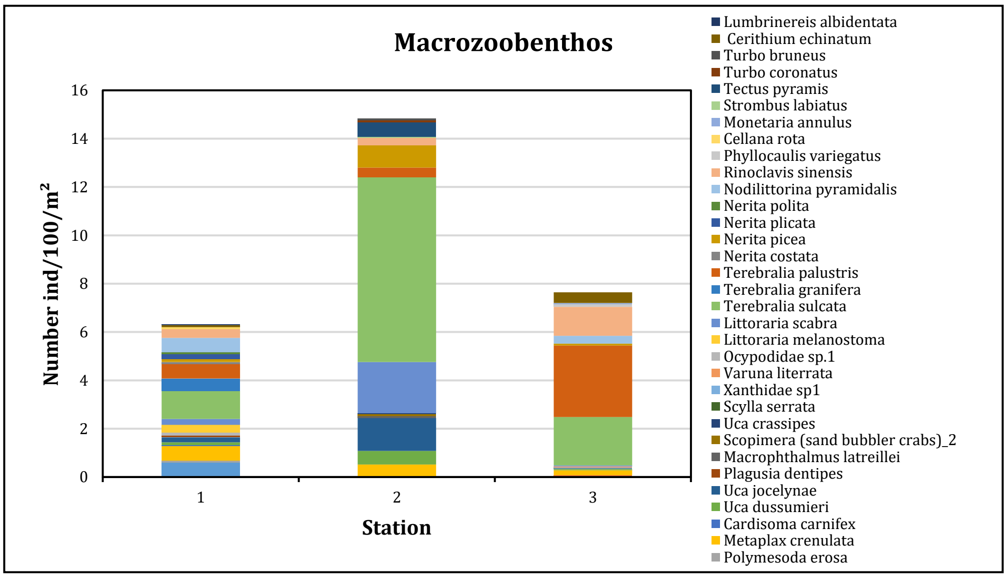

Figure 7. Species abundances of macrozoobenthos found at each station.

3.7. Sea water quality in the coastal waters

The results showed that salinity levels were relatively moderate at all station. The pH was within the range considered suitable for the survival and health of most aquatic organisms. The water temperature was relatively warm, in accordance with tropical coastal ecosystems. Meanwhile, dissolved oxygen (DO) levels were found to be sufficient to support aquatic life (**Figure 8**).

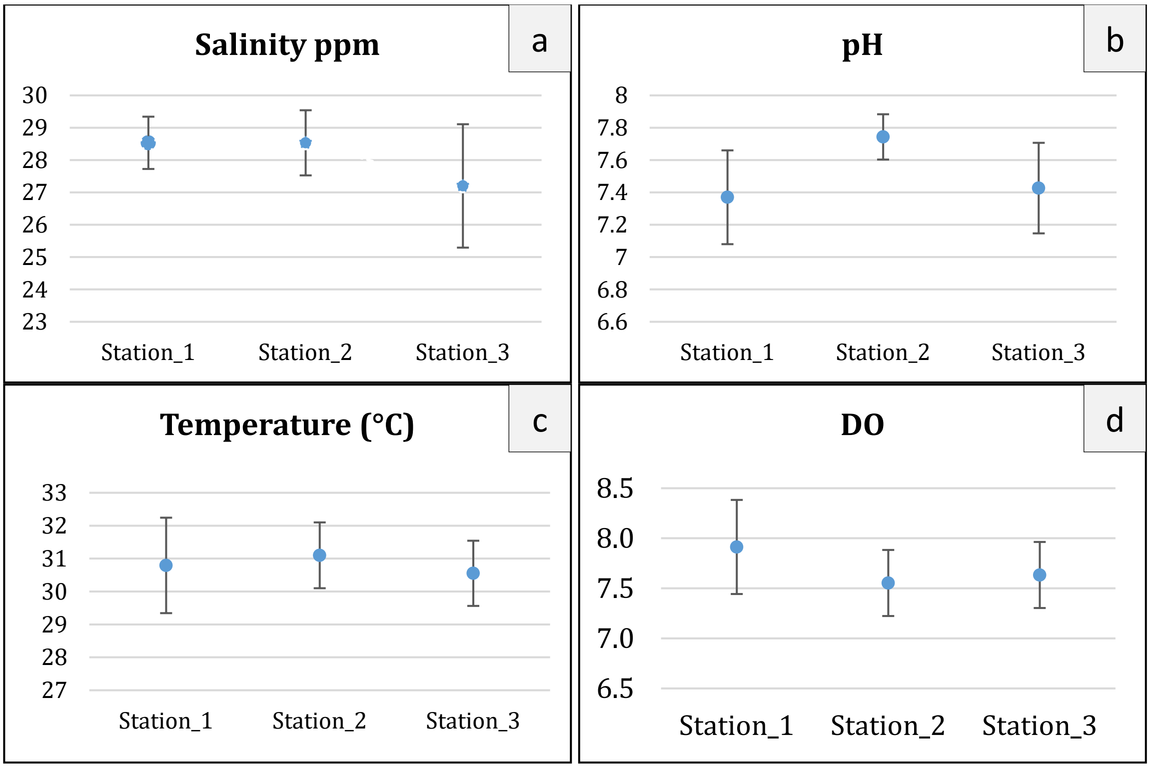

Figure 8. Sea water quality in the coastal waters; a) salinity; b)pH; c) temperature; and d) dissolved oxygen (DO).

3.8. Substrate

The result showed that sand was the dominant substrate component at all three stations, with variations in the proportion of clay and dust. Station 1 had a higher sand content compared to finer particles and the C-Organic content in the substrate was relatively low. Station 2 also showed a sandy substrate with lower C-Organic matter content. Station 3, sand remained dominant, but clay was also present in significant amounts, while the dust fraction was lower, C-Organic was slightly higher compared to the other two stations although overall it was still in the low range (**Figure 9**).

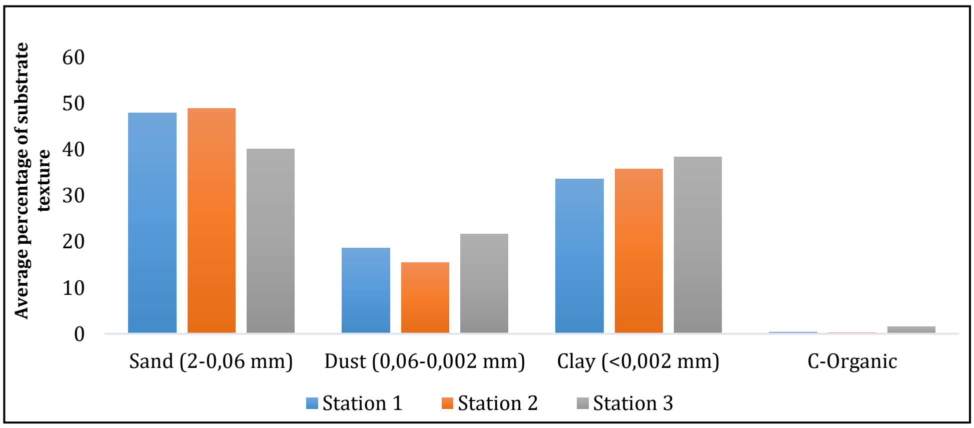

Figure 9. The average percentage of substrate texture in each station.

3.9. Correlation

The weight of waste and the mangrove ecosystem, namely macrozoobenthos, showed a correlation value of -0.3352, indicating a moderate negative relationship between the weight of marine debris and the abundance of macrozoobenthos in Administrative Bazartete, Liquiça Municipality, which means that there is a tendency that the higher the weight of marine debris in the research location, the lower the abundance of macrozoobenthos (**Figure 10**). However, the density of marine debris and mangrove seedlings, there is a value of r = -0.0594, only showed non-significant negative correlation. The results show that when the density of waste increases, the density of mangrove seedlings tends to decrease (**Figure 11**).

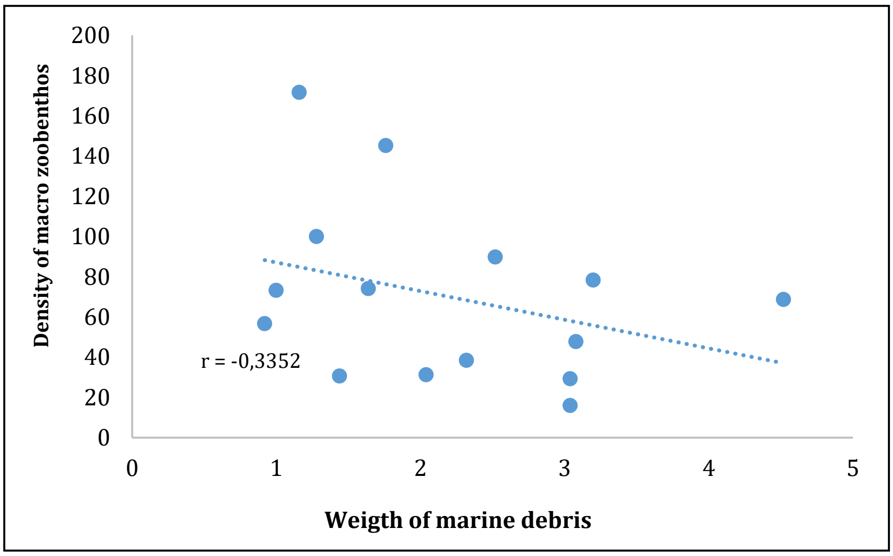

Figure 10. Correlation of marine debris weight to macrozoobenthos.

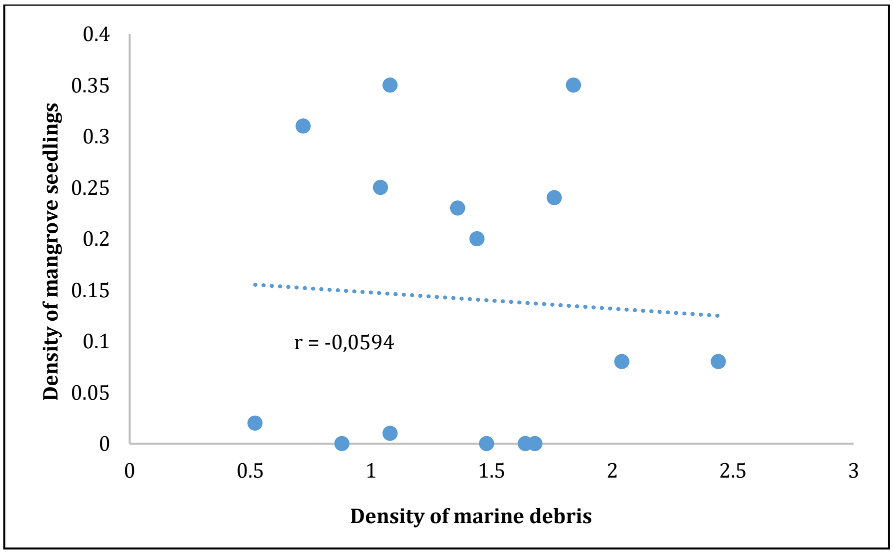

Figure 11. Correlation of marine debris density to density of mangrove seedlings.

Based on the results of the study, it can be concluded that plastic is the most common type of waste found and dominates in terms of weight composition, abundance and volume at the three stations. The types of plastic waste found came from plastic such as plastic beverage bottles, plastic bottle caps, plastic bags, plastic bags for dogs, plastic medicine bottles, plastic pipes, plastic balls, plastic electricity tokens, plastic cups and snack packaging. Numerous plastic waste materials have the potential to damage the ecosystem, which implies that their presence may lower soil fertility (Ruhiyat *et al.* 2023) and results of this study are in accordance with the majority of studies on the composition of marine waste which is dominated by plastic waste in coastal areas around the world (Araújo *et al.* 2018). Van *et al.* (2021) said that most global studies on marine pollution would classify plastic as the most common type of contamination.

The station with the most waste was Station 1 which was very close to human settlements. The distance between the nearest houses to the mangrove area was only 5 m. In a study of marine debris in coastal North Sulawesi, Indonesia approximately 80% of marine debris came human activities on land which are transported through rivers and 20% came from activities at sea especially in coastal area (Patuwo *et al.* 2020).

Plastic is the material most widely used by the public because it is a material that has high flexibility, is light, strong, durable and the price can be said to be cheap or affordable (Tuahatu and Tuhumury 2022). Due to its high usage and poor management, plastic is disposed of carelessly and when it rains, river water will carry it to the sea where it accumulates in coastal areas, which will have a negative impact. Apart from its high utility in society, plastic waste has significant negative effects on both the environment and socio-economic aspects (Arifianti et al. 2024). Marine debris can harm the environment by causing the extinction of targeted and non-target species and can pose a direct health risk to aquatic biota (Sagita *et al.* 2022). Plastic waste can have an impact on sediment, especially on biota that live in sediment, and thus disrupt aquatic ecology, both via biotic and abiotic effects in the ecosystem (Sherlin *et al.* 2023).

The research area has environmental pollution and human activities that can cause damage to mangrove. This demonstrated by the low densities seen at all stations and the minimal diversity of mangrove, only four species were identified. However, the diversity of macrozoobenthos was very higher at Station 2 then 3 and 1. Correlation studies were conducted at three locations to measure the impact of marine debris on the mangrove ecosystem. The results of the study will provide a picture that describes the relationship between waste weight and the presence of macrozoobenthos. From **Figure 10**, it can be seen that the correlation between the weight of marine debris and macrozoobenthos is -0.3352, which means that there is a negative correlation between the two variables. This shows that when the weight of marine debris increases, the density of macrozoobenthos tends to decrease and vice versa, reflecting results from a study in North Kalimantan (Salim *et al.* 2019). Meanwhile, the density of mangrove seedlings with the density of marine debris has a weak negative relationship because the results of the correlation analysis between the two variables show r = -0.0594, which means that although there is a tendency for mangrove seedling density to decrease along with the increase in marine debris. Salestin *et al.* (2021) stated that organic waste also has an impact on mangrove plants including mangrove seedlings.

4. CONCLUSION AND RECOMMENDATION

The types of waste identified at the research location include various types of waste such as plastic, metal, glass, rubber, fabric, organic and other inorganic and the most dominant type of marine debris at the three stations was plastic. The impact of marine waste on mangrove ecosystems was detected on the density of macrozoobenthos, nevertheless its impact on mangrove community was insignificantly revealed. Recommendations are the need for education and public awareness, improved waste management and monitoring or further research.

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