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Plankton Community Structure in Mangrove Ecosystem Polluted by Microplastic Waste Pagatan Besar Village, Tanah Laut Regency

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ABSTRACT

Plastic waste continues to increase all the time without decreasing or ending, resulting in the sustainability and restoration of the mangrove ecosystem needing to be improved. The mangrove ecosystem is a place where plastic waste accumulates. The accumulation of plastic waste prevents photosynthesis in mangroves, reduces aquatic productivity and encourages microbial colonization. This research aims to identify the type abundance of plankton, waste and water quality. Sampling was carried out purposively from June to July 2023. STA 1 represents rivers, STA 2 estuaries and STA 3 coastal mangroves. Plankton, plastic waste and water quality samples were collected at the beginning of each month based on a 1x1 m2 plot. Furthermore, biological index calculations of plankton and the density of plastic waste were carried out and their relationship with water quality in each location. Mangroves in the village of Pagatan Besar are dominated by Avicennia marina, Avicennia alba, Bruguierra cylindrica and Rhizopora apiculata. The highest density was in STA 3, but it was inversely proportional to the abundance and diversity of plankton due to the dense waste cover between the roots, mainly plastic materials. The most significant increase in marine waste accumulated in STA 3 from 6697 grams at the beginning of the observation to 13820 grams. The most significant composition of waste in STA 3 consists of plastic bottles and plastic cups. Cyanophyta, Chlorophyta and Chrysophyta are plankton phyla from the research location. Plankton identified there are three phyla in STA 1 and STA 2, while in STA 3, there are only 2. Cyanophyta, Chlorophyta and Chrysophyta are phyla plankton from the study site. The types of plankton that are always present in all STAs are Gonatozygon and Ulothrix from Chloropyta. The survival of plankton and mangroves is influenced by water temperature, pH, salinity, dissolved oxygen and the type of material density of macroplastic waste.

Introduction

The increasing number of residents and visitors to the Takisung Beach tourist attraction has increased plastic waste pollution in the mangrove ecosystem in Pagatan Besar Village. Plastic waste from human activities always increases every year and has a direct impact on the aquatic biota of mangrove areas. Even though various regulatory and socialization instruments have been rolled out, the amount of plastic waste continues to increase on marine coasts (Lamb *et al.,* 2018), estuaries and sea embankments (Smith and Edgar, 2014) as well as mangrove ecosystems as accumulators of plastic waste (Juliana *et al.,* 2014; World Bank 1991; Wade *et al.,* 1991).

The accumulation of plastic waste encourages microbial colonization, disease and prevents photosynthesis in mangroves (Manullang, 2020). The accumulation of plastic waste can reduce the rate of mangrove recruitment. Plastic waste kills mangroves in the seedling phase (Makowski and Finkl, 2018). The accumulation of plastic waste can reduce the aesthetic value of mangroves from ecotourism activities.

Plastic waste research has been focused on aspects of abundance (Calcar dan Emmerik, 2016; Tibbetts *et al.,* 2018; Emmerik dan Schwarz, 2019; Riskiana *et al.,* 2020), impact on fish (Sequeira *et al.,* 2020; Sui *et al.,* 2020; Assuyuti *et al.,* 2018). Another study informs of

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economic losses experienced by fishing vessels or fishing gear (Lee, 2014), damage to ship propellers (Watskins, 2015), damage to fishing boats (Takehama, 1990) and aesthetic decline of Morotai Island's Dodola beach (Idrus *et al.,* 2023) due to plastic waste.

Mangroves are coastal plants influenced by sea tides that are able to adapt to changes in salinity (Kusmana and Sukristijiono, 2016), inhabit shallow and muddy beaches (Nagelkerken *et al.,* 2008; Kusmana and Ningrum, 2016), coastal protection (Tarigan 2008), trophic system buffer in the sea (Bulow and Ferdinand, 2013) and productivity contributor to shrimp and fish. (Dafikri *et al.,* 2016; Manson *et al.,* 2005).

Disruption to mangrove ecosystems due to the accumulation of macroplastic waste has an impact on damage to aquaculture activities, disruption of fish habitat and siltation. This condition causes ecological problems in changes in the structure, composition, productivity and function of aquatic ecosystems, especially plankton, which are directly associated with mangroves.

Indicators of diversity, uniformity and dominance of aquatic plankton become the focus of management. Macroplastic waste piles, especially from inorganic materials that cover the surface of the waters, inhibit the rate of photosynthesis of phytoplankton, and the role of roots decreases. (Thamaga dan Dube, 2018).

Nevertheless, it will interfere with the growth and interaction of plankton that depend on its life with mangrove ecosystems. Therefore, this study aims to identify the type abundance of plankton and garbage as well as the water quality of the Pagatan Besar mangrove ecosystem. The data displayed in this study is the latest local data related to mangrove plankton. The level of plankton vulnerability can be used as a diagnostic of mangrove environmental conditions due to plastic waste on the coast of Pagatan Besar.

Materials and Methods

Location and time of research

This research was carried out from June to July 2023, located on the Pagatan Besar and Tabanio rivers coast, Takisung District, Tanah Laut Regency, South Kalimantan (Figure 1). The sampling location consists of 3 locations representing the ecosystem characteristics of the STA-1 river, the STA-2 estuary, and the STA-3 coastal mangrove.

Samples collection and identification procedure

Macroplastic samples were taken from transects covering an area of 100 m^2 towards the sea, in which plots measuring 1x1 m^2 were installed at all locations. Area cover of transect area with high and low mangrove density. The macroplastic data taken included the number of pieces and type, length, weight, and thickness of the macroplastics on the substrate excavated on the plot.

Plankton and water quality samples were collected from the waters around the mangroves. Sampling was conducted in the first week of June and July 2023 dry season. Water quality analysis from temperature, brightness, dissolved oxygen (DO), pH, and salinity parameters in situ. The instruments used have been calibrated.

Data analysis

Plankton identification refers to the titles of Huyn L and Serediak (2006), Bigg and Kilroy (2000), Yunfang (1995), Bellinger and Singee (2010). The calculated ecological index is abundance, Shannon-Wiener diversity, evenness and dominance. Identification of mangrove species was carried out visually on selected transects.

Waste identification is carried out visually from the origin of the material and the calculation of its weight, abundance, and percentage. The composition of the waste is divided into organic and inorganic (Tangdesu 2018; Johan *et al.,* 2020), then divided according to the categories of plastic, rubber, metal, glass, wood, and derivatives (Djaguna *et al.*, 2019).

Analysis of abundance and waste composition/percentage refers to Coe and Roger (1997); Johan *et al.*, (2020) :

$$Density = \frac{\text{The Number of waste (item)}}{Area\ (m^2)}$$

$$Density\ (weight\ of\ \text{waste}) = \frac{\text{The Weight waste (gram)}}{Area\ (m^2)}$$

$$\text{Composition } marine\ debris = \frac{\text{The Number of Pieces in Category (gram)}}{\text{Total Weight of waste (gram)}} \times 100\%$$

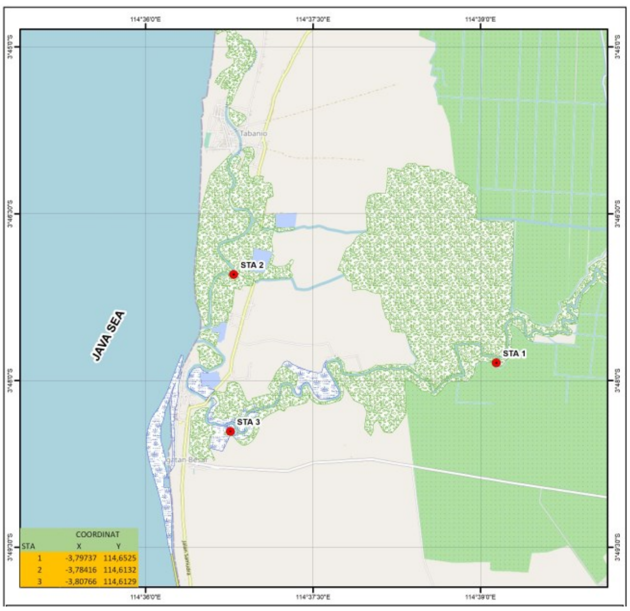


Figure 1. Map of sampling locations

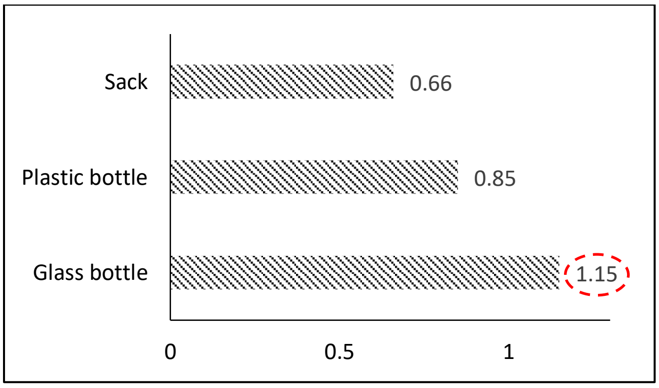
Results

Plankton collection and selected waste samples at the study site were inversely proportional between waste density and type to plankton abundance. Plankton variation is less at high and diverse waste densities than in areas with low waste density. Water quality components of pH, brightness, dissolved oxygen, and salinity differed between study sites..

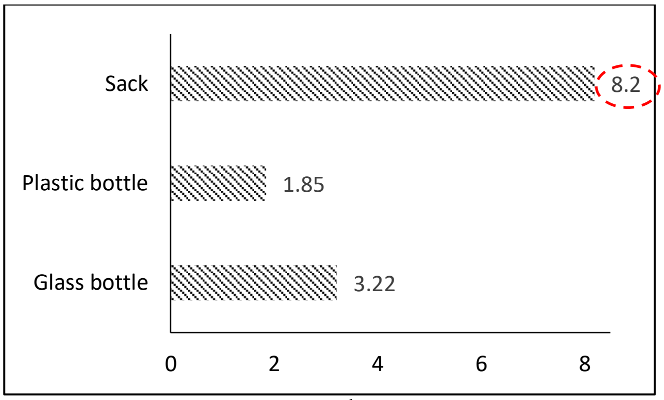
Mangroves and the abundance of plastic waste

Acanthus ilicifolius and *Rhizopora apiculata* mangroves in STA 1 have low diversity in residential areas. Garbage dominates in this location from plastic bottles and glass. *Avicennia marina*, *Avicennia alba*, *Bruguierra cylindrica*, *Pandanus odoratissima* and *Rhizopora apiculate* apiculate are quite diverse found in STA 2. The dominant waste in this location is plastic materials in bottles, hoses, glass bottles, clothes, and cans. Avicennia marina dominates STA 3 from previous reforestation activities and in the sapling phase, but in between, the roots have been covered with various kinds of waste, especially plastic food packaging materials, plastic bags, bottles, and mineral water glasses.

The results of marine debris monitoring at the three stations in Pagatan Besar Village during June and July have increased for STA 1 from 860 grams to 1327 grams while for STA 2 from 775 grams to 800 grams. Marine debris accumulates the most in STA 3. The value of waste weight in STA 3 went from 6697 grams at the beginning of the observation to 13820 grams at the end of the compliance with the addition of diaper type. Styrofoam material was only identified at STA 3 from 40 grams to 180 grams. The composition of the waste at each location is presented in **Figures 2, 3, and 4**.

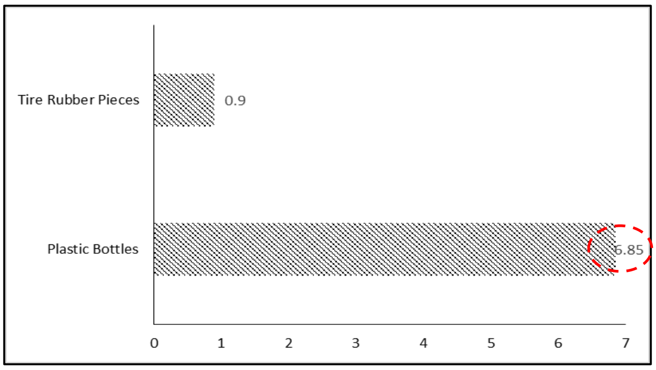


(a) June 4th, 2023



(b) July 4th, 2023

Figure 2. Waste composition STA 1



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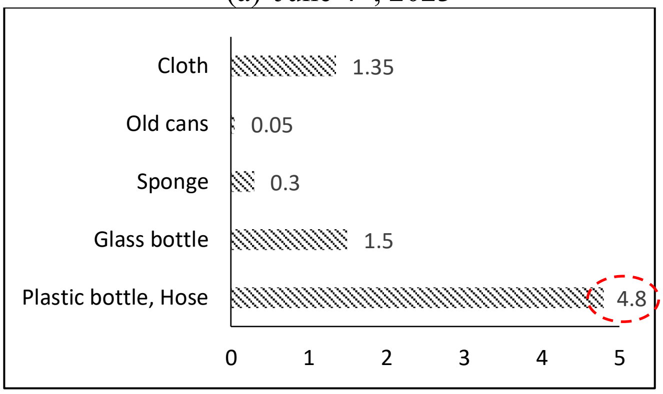

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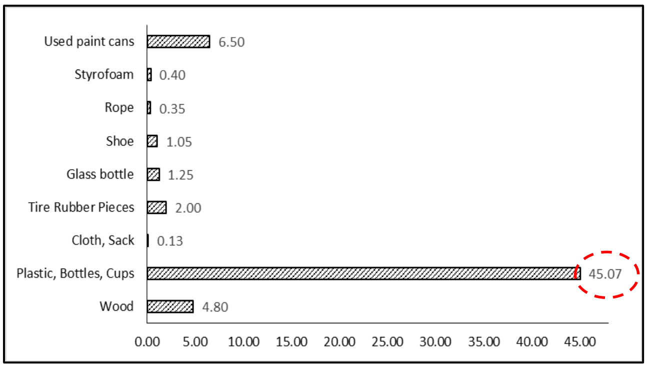
Figure 3. Waste composition STA 2



(a) June 4th, 2023

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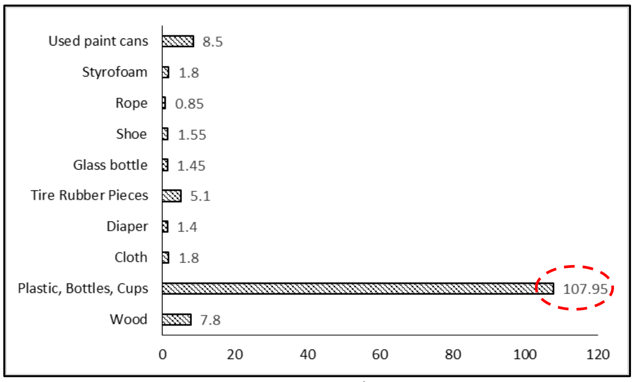

(b) July 4th, 2023

Figure 4. Waste composition STA 3

Plankton Community Structure and Water Quality

The results of plankton analysis at the study site during June (repetition 1) and July (repetition 2) 2023 obtained three phyla in STA 1 and STA 2, while STA 3 phyla found only 2 in all tests. The plankton phylum in question consists of *Cyanophyta*, *Chlorophyta*, and *Chrysophyta*. The types of plankton always present at all stations are *Gonatozygon* and *Ulothrix* from *Chloropyta*. The structure of plankton is the same, but the number is reduced for the 2nd test less than the 1st test (Table 1).

Table 1. Phylum Phytoplankton at the study site between June and July 2023

Phylum	Genera	Sample Code					
		STA 1_June	STA 1_July	STA 2_June	STA 2_July	STA 3_June	STA 3_July
Phytoplankton							
Cyanophyta	*Oscillatoria*	+	+	+	+	-	-
	Microcystis	-	-	+	-	-	-
Chloropyta	*Gonatozygon*	+	+	+	+	+	+
	Pediastrum	-	+	+	-	-	-
	Westella	+	+	+	+	-	-
	Schroederia	+	+	-	-	-	-
	Closterium	+	+	-	+	+	+
	Pediastrum	+	-	-	+	-	-
	Ulothrix	+	+	+	+	+	+
Chrysophyta	*Odontella*	+	-	+	-	-	-
	Rhizosolenia	-	-	+	+	-	-
	Tabellaria	-	-	-	+	-	-
	Corethron	+	+	-	-	+	+
	Navicula	+	+	-	+	+	+
	Nitzschia	-	-	+	+	+	+
	Synedra	+	+	+	-	-	-
Zooplankton							
Euglenozoa	*Phacus*	-	-	-	-	+	-
Rotifer	*Keratella*	-	-	-	-	+	-
	Lecane	+	+	-	-	-	-
Ciliophora	*Spirostomum*	-	-	+	+	-	-
	Dileptus	-	-	-	-	+	+

Remarks : (+) Present; (-) Absensce

STA 2, located at the estuary, identified ten genera in repetitions 1 and 2. While in the 2nd repetition found the change of genera into *Closterium*, *Pediastrum*, *Westella*, *Tabellaria* and *Navicula*. The condition of STA 3 compared to other STAs has decreased, represented by the genera *Corethron*, *Navicula*, *Nitzschia*, *Gonatozygon*, *Closterium*, and *Ulothrix*. In contrast to phytoplankton, zooplankton composition was more abundant in STA 3 in repetition 1 but decreased to 1 genera in repetition 2.

Characteristics of water, biota, and waste quality between stations

Water quality components from pH, brightness, dissolved oxygen, salinity, dominance, and taxa, as well as waste materials from plastics, fabrics, sacks, and cans, are components that interact with each other at each research site (Table 2).

Table 2 One Way ANOVA test of water quality, biological index, and waste abundance from each research location confidence level 0.05

Parameter	Station	Mean Difference (between STA)	Sig. Anova	Levene test	Sig. Post Hoc Tests	Conclusion
pH	STA 2 vs 1	0.300(*)	0.029	0,000	0,000	Significant
Brightness	STA 2 vs 1	2.040(*)	0.042			
	STA 2 vs 3	7.385(*)	0.001			
	STA 1 vs 3	5.345(*)	0.003			
DO	STA 2 vs 1	0.700(*)	0.012			
	STA 2 vs 3	0.550(*)	0.024			
Salinity	STA 2 vs 1	8.700(*)	0.003			
	STA 3 vs 1	7.100(*)	0.006			
Dominance Index	STA 3 vs 2	0.116(*)	0.018			
	STA 3 vs 1	0.103(*)	0.025			
Taxon	STA 2 vs 3	4.000(*)	0.005			
	STA 1 vs 3	4.500(*)	0.003			
Plastic waste	STA 2 vs 1	0.622(*)	0.037			
	STA 3 vs 1	0.586(*)	0.043			
Clotch waste, sack	STA 1 vs 2	0.692(*)	0.006			
	STA 1 vs 3	0.623(*)	0.008			
Old cans	STA 3 vs 1	0.079(*)	0.025			
	STA 3 vs 2	0.076(*)	0.028			

Remarks : (*) significantly

The value of 9 significant parameters interacts in STA 1, STA 2, and STA 3. Brightness parameters differ from location to location, while pH is only between STA 2 vs 1.

Discussion

Mangrove species in the study site were dominated by *Avicennia marina* and *Rhizopora sp*, due to differences in environmental factors and anthropogenic disturbances (Gumilar, 2012). *Avicennia sp.* is able to good reproduction and grow quickly (Sarno, 2016). The low-density value of mangroves in the saplings and seedlings in Pagatan Besar Village is due to the presence of mangroves that die at the beginning of the growth period and the failure of the germination process and environmental conditions. The failure of the sprouts is due to the absence of a substrate for the germination process because it is covered by plastic waste. The type of sandy mud substrate influences mangrove growth in addition to water temperature, pH, and salinity (Agustini *et al.,* 2016). Suboptimal nutrient absorption can have an impact on tree growth and development. One of them is macroplastic, which covers the substrate and becomes an obstacle to the absorption of nutrients by the roots (Kantharajan *et al.,* 2018).

The plankton composition of waters polluted with plastic waste is lower than those without plastic waste (Dodson *et al.* 2009; Rahayu *et al.* 2013; Widyarini *et al.* 2017; Persada *et al.* 2022; Yunandar *et al.,* 2023). It can be seen that the composition of the phyla

Chrysophyta and *Chlorophyta* is balanced, while *Cyanophyta* is the lowest. Phylum *Cyanophyta* hanyar is present in 2 locations, while *Chlorophyta* and *Chrysophyta* are scattered at all observation stations. Zooplankton are more diverse in STA 3 than the other 2 STA. The population is more experienced by STA 1 and STA 2, but STA 3 has decreased due to increased waste generation, which accelerates coastal sedimentation. The amount of waste, especially from plastic materials, supports the reduction of water biota. This statement is supported by Idrus *et al.,* (2023), in which inorganic debris got more to plastic bottles and glasses with a value of 65,56% to 79,17%. Plastic waste dominates other waste (Purba *et al.,* 2018).

The diversity of types of waste at the location amounted to 9 types identified in the plot created, STA 3 was where the most destruction was found compared to the other 2 STAs. Plastic waste in mangrove areas seriously disrupts physical and ecological functions. The biological process of mangroves prevents coastal erosion, block waves and seawater from entering the land (seawater intrusion). Meanwhile, the environmental role is as a place to feeding ground, to maintain and nurture mangrove biota (spawning/nursery area), and to exchange nutrients. Plastic waste that crushes mangrove roots is degraded into debris that remains in the aquatic environment. Larger plastic fragments that stay for a long time can become smaller due to weathering and mechanical energy, such as ocean waves. Plastic breaks down into microplastics with a diameter smaller than 5 millimeters. Microplastics that enter the marine food chain at low levels can affect the entire food chain.

The survival of plankton is influenced by water quality, such as temperature, pH, salinity, and dissolved oxygen content in the waters. The water temperature at the study site is 29.6 ℃ – 30 ℃ and is suitable for plankton survival. The temperature range plankton tolerates is 25 to 32 ℃ (Hutabarat and Evans, 1985). The salinity obtained in Pagatan Besar Village is 11.8 – 21.2 $^{0}/_{00}$. Field observations show that in the range of salinity values, there are still different types of plankton between STA and its repeats, although there is a decrease in genera in STA 3 to two classes. It means that plankton with existing genera have good tolerance to changes in salinity in the waters. Odum (1998) states that salinity in estuaries varies greatly, and living biota have a good tolerance level to changes in salinity.

pH parameters influence the survival of aquatic biota. The pH value obtained at the study site is suitable for plankton life. pH values between 6 to 7.5 can still be tolerated by plankton for their survival. The dissolved oxygen content is a factor that affects the survival of biota. The value of dissolved oxygen is a suitable condition for the survival of plankton and other aquatic biota. The limit value of dissolved oxygen for marine biota is ≥ 5 mg / L. The range of oxygen content in the field of 5.3 to 5.6 mg / L includes conditions suitable for aquatic organisms. The shape of muddy substrates polluted with plastic waste in mangrove ecosystems can still be tolerated so that plankton and other marine biota can survive changes in the quality of this aquatic environment. In each type of mangrove, there is a different plankton content. The most plankton are STA 1 and 2, natural habitats, while the lowest in STA 3 relies on *Avicennia* from planting activities (reforestation). This condition shows the relationship between mangrove density and plankton abundance in the waters. As an organism that can photosynthesize, plankton, in its breeding, needs light. The density of mangroves affects the brightness and cover of the canopy. The canopy cover area affects the intensity of light entering the mangrove roots at low tide, and sea level at high tide that inundates the mangrove area.

The primary productivity of phytoplankton largely depends on the intensity of light reaching the surface of the water. Each type of mangrove contains different plankton content (Halidah, 2016). The increase in salinity is followed by the abundance and diversity of plankton in zones that are overgrown by various mangrove vegetation, so it is very supportive of phytoplankton life. STA 2 which is an estuarine ecosystem shows that higher phytoplankton abundance, due to nutrient out welling from swamp and tributary mangrove sediments, thus supporting the high phytoplankton biomass in estuarine waters (Saifullah *et al.,* 2016). Class *Chlorophyceae* is the dominant class and is almost found in all mangroves in the tropics. This is because *Chlorophyceae* are cosmopolitan, have high tolerance and adaptability to environmental conditions (Thoha and Amri, 2011). Many classes of *Chlorophyceae* are found because organisms from that class are cosmopolitan and have high tolerance and adaptability to changes in the marine environment (Casteleyn *et al.,* 2010). Class *Chlorophyceae* is able to grow rapidly even in low light and nutrient conditions (Nybakken, 1992). This is because this type of phytoplankton has the ability to adapt well so that it is able to regenerate and reproduce in greater numbers than other types. This type of plankton is the type that is most resistant to environmental changes by tidal influences. The abundance of phytoplankton in a body of water is

always closely related to the conditions around the aquatic environment.

The ability of aquatic organisms to adapt to changing environmental conditions causes their existence in nature to be influenced by pollutants such as macro plastics. Differences in abundance and types of marine biota found at the study site due to differences in environmental conditions. At high tide, the water level in the estuary waters is higher than the low tide, resulting in a lot of plankton entering the estuary due to currents and waves from the sea. (Saifullah *et al.,* 2016).

The back-and-forth movement of water masses is essential in removing pollutants from the ecosystem and transporting food and nutrients from the surrounding environment. This condition affects the abundance of plankton, especially phytoplankton and biota, in the early stages. The quantity of phytoplankton and zooplankton is higher at high tide than at low tide (Andriani *et al.,* 2015; Nugroho *et al.,* 2020). The high biomass of phytoplankton in estuaries is caused by nutrients coming out of the mangrove area and tidal mixing of water, while the decrease in biomass is due to nutrient consumption (Saifullah *et al.,* 2016).

The existence of plankton in an aquatic ecosystem is influenced by biotic factors (competition between species) and the presence of predators. In contrast, abiotic factors are influenced by physical, chemical, aquatic, and human activities (Cronk dan Fennessy, 2001; Elger *et al.,* 2004; Sahidin *et al.,* 2021). Components that contribute to the abundance of a plankton species are stability, environmental heterogeneity, primary productivity of ecosystems, and the presence of predators and competitive interactions between species. The overall plankton abundance tends to fluctuate at all study sites; this condition is directly proportional to the density of mangroves and the quantity of waste. The diversity of plankton in the study site could be more diverse or even higher, evidenced by the identification of certain types of plankton that are able to adapt to environmental conditions. Low plankton diversity due to the low diversity of mangrove species (Fachrul, 2007; Novianto, 2011 and Azwar, 2013). The uniformity value is relatively evenly described as an increase in mangrove and plankton growth supported by calm waters and weak currents. Overall, the uniformity index value obtained during observations is quite evenly distributed, and the dominance index value is low.

The role of zooplankton is essential in the food chain cycle in estuaries because it is one of the intermediaries that converts energy from plants into energy for animals (Romimohtarto 2009). Meanwhile, phytoplankton have a role as producers, which are a source of energy for other living organisms (Desyana *et al.* 2017).

Marine debris impacts life through five mechanisms, namely (1) the digestive system and the trapping of biota, (2) accumulates and spreads to other regions, is toxic, bioavailability and impacts through the food chain, (3) as a vector of invasive species, (4) impacts on habitat and seabed life, and (5) impact economically (Stevenson, 2011). Plastic is a vector in the spread of microalgae that causes blooming (Maso *et al.,* 2003) and heavy metal (Holmes, 2013). The number of macro plastic pieces affects the presence and abundance of aquatic biota in mangrove ecosystems. The large number of plankton is strongly suspected because it is found in locations with small amounts of macro plastics. Macro plastics can affect the availability of habitats for faunal groups such as mollusks and crabs (Kantharajan *et al.*, 2018). It indicates that with the reduction of habitat for biota, its presence in a place is decreasing. Another study also explained that during the degradation process, macro plastics produce toxic chemical compounds that can reduce the number of offspring, cause reproductive failure, and interfere with the development of larva biota in mangroves (Hammer *et al.* 2012).

Plastic is made of hydrophobic materials, so contaminants on its surface act as reservoirs of toxic chemicals in the environment (Ivar do Sul and Costa, 2013). Heavy metals such as Cd, Co, Cr, Cu, Ni, and Pb can stick to plastics by being affected by pH and salinity. The ability of Cd, Co, Ni, and Pb to stick to plastics may increase with increasing pH and decreasing salinity. Still, conversely, the ability of Cr to attach to plastics may decrease. Plastics contain organic contaminants, including *polychlorinated biphenyls* (PCBs), *polycyclic aromatic hydrocarbons* (PAHs), *petroleum hydrocarbons*, *organochlorine pesticides*, *polybrominated diphenyl ethers*, *alkylphenols*, and *bisphenols* that cause chronic effects such as endocrine disruption in aquatic biota (Teuten *et al.,* 2009). The threat to the species is the absorption of PCBs through the digestive system (Derraik, 2002). Contaminants that can survive and accumulate through the food chain can harm human health. Marine mammals, birds, fish, and turtles receive the impact of marine debris pollution (STAP, 2011). The group of animals most affected by marine debris are mammals. Debris particles also affect the digestive system of sponges, cnidarians, worms, crustaceans, mollusks, bryozoans, echinoderms, ascidians, algae, seagrasses, and plankton (CBD-STAP, 2012).

The amount of plastic able to covered the essential soil of mangrove vegetation and *pneumatophores* (unique roots that grow upwards and allow the exchange of oxygen and carbon dioxide). Such root capillary pressure can force bubbles out of the lenticels in many *pneumatophores*. Interconnectivity between pneumatophores originating from the same root minimizes the effects of plastic scattering in the sediment, which covers only a few root pneumatophores. The remaining pneumatophores can keep the sediment oxygenated at all times. In addition, the plastic can still be carried back by the tide, causing only temporary suffocation of the roots.

In contrast, plastic on top of pneumatophores during sedimentation events can persist for weeks or months, depending on the incoming tidal wave. Some of the plastic in the sediment was there for a long time because more than half of the plastic found was buried under 2 cm of sediment. The finding that plastic is not only trapped but also buried in mangrove sediments is in agreement with Costa *et al*., (2011), who found plastic in varying degrees of degradation buried to a depth of at least 20 cm in mudflats on the fringes of mangroves in Brazil. The amount of plastic buried in the sediment at the site is equal to the layer of plastic visible on the surface of the sediment, causing a stress effect. Because penetration of oxygen into the sediment through the sediment surface and pneumatophores increases disturbance, this condition makes it difficult for root respiration by the tree due to plastic stress. The adaptation made by mangrove roots due to being covered in plastic in their root zone responds with extreme root elongation to overcome this suffocating substance. If roots are 100% covered by plastic, they will die, but 50% plastic coverage shows that the mangrove is able to withstand suffocation. Resistance to repeated anoxic conditions is a characteristic of all mangrove species; in addition to evolutionary adaptations of roots, most mangrove species can adapt to prolonged flooding events (Youssef and Saenger, 1996).

Twisted roots indicate the tree is trying to overcome the substance gripping it. The disposal of plastic waste into the environment is expected to increase in the future (Jambeck *et al.,* 2015). Mangroves are relatively cheap ecosystems to restore compared to other marine ecosystems (Narayan *et al.,* 2016). However, success is still low compared to marine ecosystems, such as coral reefs (Bayraktarov *et al.,* 2016). The success rate of mangrove restoration has the potential to increase, in addition to the availability of budget for mangrove planting and mitigation of plastic waste reduction

Conclusion

Cyanophyta, *Chlorophyta* and *Chrysophyta* are plankton phyla from the research location except in STA 3 without the presence of *Cyanophyta*. The plankton genera always present at all stations are *Gonatozygon* and *Ulothrix* from *Chloropyhta*. The most extensive waste composition in STA 1 is glass bottles and sacks, STA 2 is plastic bottles, and STA 3 consists of plastic bottles and glass. The most significant increase in marine debris accumulated in STA 3, from 6697 grams at the beginning of the observation to 13820 grams. Based on stations, the abundance value of marine debris in Pagatan Besar is 107.95 ± 0.05 items/m^2. The survival of mangroves and plankton is influenced by pH, brightness, dissolved oxygen, salinity, dominance, taxa, and waste materials, mainly plastic. Mitigation studies related to trash traps on mangrove roots to increase the success rate of restoration.

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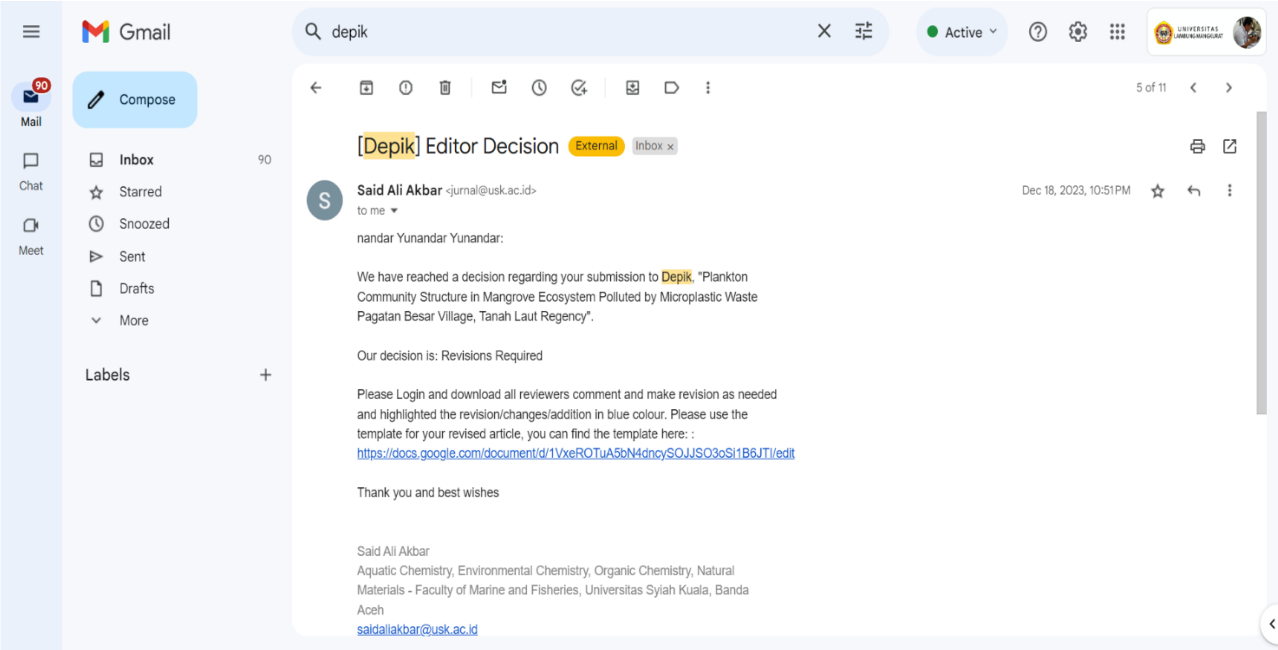
2. Bukti Konfirmasi Review dan Hasil Review Pertama (18 Desember 2023)



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Thank you and best wishes

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ABSTRACT

Plastic waste continues to increase all the time without decreasing or ending, resulting in the sustainability and restoration of the mangrove ecosystem needing to be improved. The mangrove ecosystem is a place where plastic waste accumulates. The accumulation of plastic waste prevents photosynthesis in mangroves, reduces aquatic productivity and encourages microbial colonization. This research aims to identify the type abundance of plankton, waste and water quality. Sampling was carried out purposively from June to July 2023. STA 1 represents rivers, STA 2 estuaries and STA 3 coastal mangroves. Plankton, plastic waste and water quality samples were collected at the beginning of each month based on a 1x1 m2 plot. Furthermore, biological index calculations of plankton and the density of plastic waste were carried out and their relationship with water quality in each location. Mangroves in the village of Pagatan Besar are dominated by Avicennia marina, Avicennia alba, Bruguierra cylindrica and Rhizopora apiculata. The highest density was in STA 3, but it was inversely proportional to the abundance and diversity of plankton due to the dense waste cover between the roots, mainly plastic materials. The most significant increase in marine waste accumulated in STA 3 from 6697 grams at the beginning of the observation to 13820 grams. The most significant composition of waste in STA 3 consists of plastic bottles and plastic cups. Cyanophyta, Chlorophyta and Chrysophyta are plankton phyla from the research location. Plankton identified there are three phyla in STA 1 and STA 2, while in STA 3, there are only 2. Cyanophyta, Chlorophyta and Chrysophyta are phyla plankton from the study site. The types of plankton that are always present in all STAs are Gonatozygon and Ulothrix from Chloropyta. The survival of plankton and mangroves is influenced by water temperature, pH, salinity, dissolved oxygen and the type of material density of macroplastic waste.

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Introduction

The increasing number of residents and visitors to the Takisung Beach tourist attraction has increased plastic waste pollution in the mangrove ecosystem in Pagatan Besar Village. Plastic waste from human activities always increases every year and has a direct impact on the aquatic biota of mangrove areas. Even though various regulatory and socialization instruments have been rolled out, the amount of plastic waste continues to increase on marine coasts (Lamb *et al.,* 2018), estuaries and sea embankments (Smith and Edgar, 2014) as well as mangrove ecosystems as accumulators of plastic waste (Juliana *et al.,* 2014; World Bank 1991; Wade *et al.,* 1991).

The accumulation of plastic waste encourages microbial colonization, disease and prevents photosynthesis in mangroves (Manullang, 2020). The accumulation of plastic waste can reduce the rate of mangrove recruitment. Plastic waste kills mangroves in the seedling phase (Makowski and Finkl, 2018). The accumulation of plastic waste can reduce the aesthetic value of mangroves from ecotourism activities.

Plastic waste research has been focused on aspects of abundance (Calcar dan Emmerik, 2016; Tibbetts *et al.,* 2018; Emmerik dan Schwarz, 2019; Riskiana *et al.,* 2020), impact on fish (Sequeira *et al.,* 2020; Sui *et al.,* 2020; Assuyuti *et al.,* 2018). Another study informs of economic losses experienced by fishing vessels or fishing gear (Lee, 2014), damage to ship propellers (Watskins, 2015), damage to fishing boats (Takehama, 1990) and aesthetic decline of Morotai Island's Dodola beach (Idrus *et al.,* 2023) due to plastic waste.

Mangroves are coastal plants influenced by sea tides that are able to adapt to changes in salinity

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(Kusmana and Sukristijiono, 2016), inhabit shallow and muddy beaches (Nagelkerken *et al.,* 2008; Kusmana and Ningrum, 2016), coastal protection (Tarigan 2008), trophic system buffer in the sea (Bulow and Ferdinand, 2013) and productivity contributor to shrimp and fish. (Dafikri *et al.,* 2016; Manson *et al.,* 2005).

Disruption to mangrove ecosystems due to the accumulation of macroplastic waste has an impact on damage to aquaculture activities, disruption of fish habitat and siltation. This condition causes ecological problems in changes in the structure, composition, productivity and function of aquatic ecosystems, especially plankton, which are directly associated with mangroves.

Indicators of diversity, uniformity and dominance of aquatic plankton become the focus of management. Macroplastic waste piles, especially from inorganic materials that cover the surface of the waters, inhibit the rate of photosynthesis of phytoplankton, and the role of roots decreases. (Thamaga dan Dube, 2018).

Nevertheless, it will interfere with the growth and interaction of plankton that depend on its life with mangrove ecosystems. Therefore, this study aims to identify the type abundance of plankton and garbage as well as the water quality of the Pagatan Besar mangrove ecosystem. The data displayed in this study is the latest local data related to mangrove plankton. The level of plankton vulnerability can be used as a diagnostic of mangrove environmental conditions due to plastic waste on the coast of Pagatan Besar.

Materials and Methods

Location and time of research

This research was carried out from June to July 2023, located on the Pagatan Besar and Tabanio rivers coast, Takisung District, Tanah Laut Regency, South Kalimantan (Figure 1). The sampling location consists of 3 locations representing the ecosystem characteristics of the STA-1 river, the STA-2 estuary, and the STA-3 coastal mangrove.

Samples collection and identification procedure

Macroplastic samples were taken from transects covering an area of 100 m^2 towards the sea, in which plots measuring 1x1 m^2 were installed at all locations. Area cover of transect area with high and low mangrove density. The macroplastic data taken included the number of pieces and type, length, weight, and thickness of the macroplastics on the substrate excavated on the plot.

Plankton and water quality samples were collected from the waters around the mangroves. Sampling was conducted in the first week of June and July 2023 dry season. Water quality analysis from temperature, brightness, dissolved oxygen (DO), pH, and salinity parameters in situ. The instruments used have been calibrated.

Data analysis

Plankton identification refers to the titles of Huyn L and Serediak (2006), Bigg and Kilroy (2000), Yunfang (1995), Bellinger and Singee (2010). The calculated ecological index is abundance, Shannon-Wiener diversity, evenness and dominance. Identification of mangrove species was carried out visually on selected transects.

Waste identification is carried out visually from the origin of the material and the calculation of its weight, abundance, and percentage. The composition of the waste is divided into organic and inorganic (Tangdesu 2018; Johan *et al.,* 2020), then divided according to the categories of plastic, rubber, metal, glass, wood, and derivatives (Djaguna *et al.,* 2019).

Analysis of abundance and waste composition/percentage refers to Coe and Roger (1997); Johan *et al.*, (2020) :

$$Density = \frac{\underline{The\ Number\ of\ \text{waste}\ (item)}}{Area\ (m^2)}$$

$$Density\ (weight\ of\ \text{waste}) = \frac{\underline{The\ Weight\ \text{waste}\ (gram)}}{Area\ (m^2)}$$

$$\text{Composition}\ marine\ debris\ = \frac{\underline{The\ Number\ of\ Pieces\ in\ Category(gram)}}{Total\ Weight\ of\ \text{waste}\ (gram)}\ x\ 100\%$$

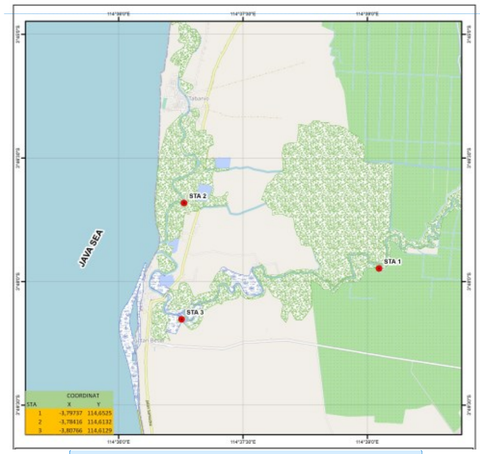

Figure 1. Map of sampling locations

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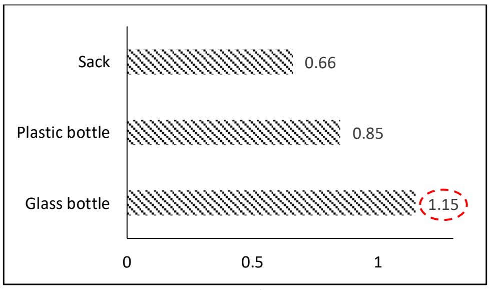
Results

Plankton collection and selected waste samples at the study site were inversely proportional between waste density and type to plankton abundance. Plankton variation is less at high and diverse waste densities than in areas with low waste density. Water quality components of pH, brightness, dissolved oxygen, and salinity differed between study sites..

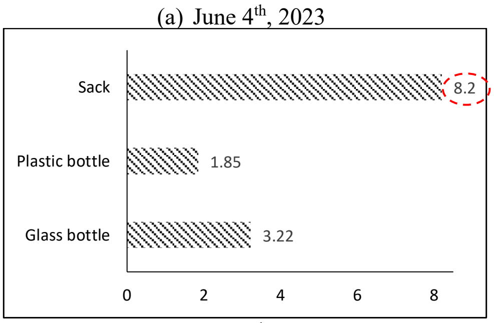
Mangroves and the abundance of plastic waste

Acanthus ilicifolius and *Rhizopora apiculata* mangroves in STA 1 have low diversity in residential areas. Garbage dominates in this location from plastic bottles and glass. *Avicennia marina*, *Avicennia alba*, *Bruguierra cylindrica*, *Pandanus odoratissima* and *Rhizopora apiculate* apiculate are quite diverse found in STA 2. The dominant waste in this location is plastic materials in bottles, hoses, glass bottles, clothes, and cans. Avicennia marina dominates STA 3 from previous reforestation activities and in the sapling phase, but in between, the roots have been covered with various kinds of waste, especially plastic food packaging materials, plastic bags, bottles, and mineral water glasses.

The results of marine debris monitoring at the three stations in Pagatan Besar Village during June and July have increased for STA 1 from 860 grams to 1327 grams while for STA 2 from 775 grams to 800 grams. Marine debris accumulates the most in STA 3. The value of waste weight in STA 3 went from 6697 grams at the beginning of the observation to 13820 grams at the end of the compliance with the addition of diaper type. Styrofoam material was only identified at STA 3 from 40 grams to 180 grams. The composition of the waste at each location is presented in **Figures 2, 3, and 4**.

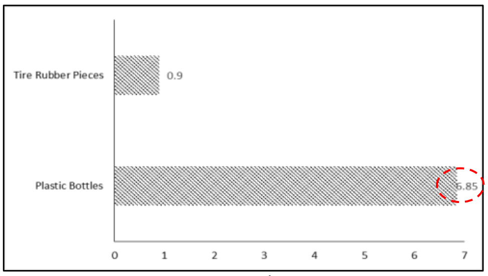


(a) June 4th, 2023

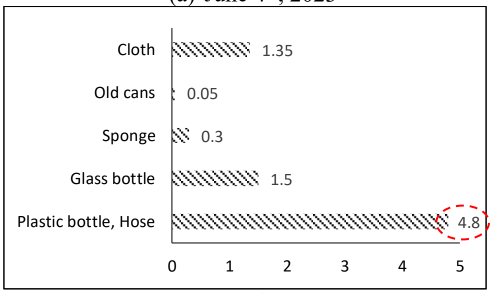


(b) July 4th, 2023

Figure 2. Waste composition STA 1

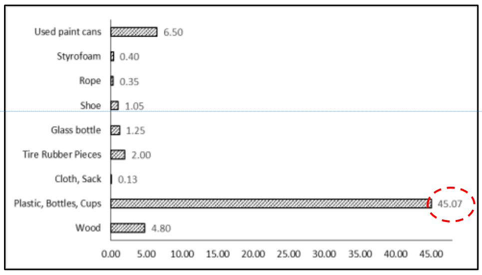


(a) June 4th, 2023



(b) July 4th, 2023

Figure 3. Waste composition STA 2



(a) June 4th, 2023

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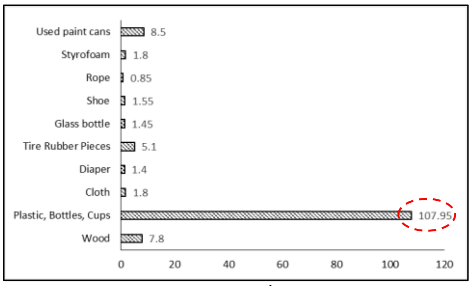

(b) July 4th, 2023

Figure 4. Waste composition STA 3

Plankton Community Structure and Water Quality

The results of plankton analysis at the study site during June (repetition 1) and July (repetition 2) 2023 obtained three phyla in STA 1 and STA 2, while STA 3 phyla found only 2 in all tests. The plankton phylum in question consists of *Cyanophyta*, *Chlorophyta*, and *Chrysophyta*. The types of plankton always present at all stations are *Gonatozygon* and *Ulothrix* from *Chloropyta*. The structure of plankton is the same, but the number is reduced for the 2nd test less than the 1st test (Table 1).

Table 1. Phylum Phytoplankton at the study site between June and July 2023

Phylum	Genera	Sample Code					
		STA 1_June	STA 1_July	STA 2_June	STA 2_July	STA 3_June	STA 3_July
Phytoplankton							
Cyanophyta	*Oscillatoria*	+	+	+	+	-	-
	Microcystis	-	-	+	-	-	-
Chloropyta	*Gonatozygon*	+	+	+	+	+	+
	Pediastrum	-	+	+	-	-	-
	Westella	+	+	+	+	-	-
	Schroederia	+	+	-	-	-	-
	Closterium	+	+	-	+	+	+
	Pediastrum	+	-	-	+	-	-
	Ulothrix	+	+	+	+	+	+
Chrysophyta	*Odontella*	+	-	+	-	-	-
	Rhizosolenia	-	-	+	+	-	-
	Tabellaria	-	-	-	+	-	-
	Corethron	+	+	-	-	+	+
	Navicula	+	+	-	+	+	+
	Nitzschia	-	-	+	+	+	+
	Synedra	+	+	+	-	-	-
Zooplankton							
Euglenozoa	*Phacus*	-	-	-	-	+	-
Rotifer	*Keratella*	-	-	-	-	+	-
	Lecane	+	+	-	-	-	-
Ciliophora	*Spirostomum*	-	-	+	+	-	-
	Dileptus	-	-	-	-	+	+

Remarks : (+) Present; (-) Absensce

STA 2, located at the estuary, identified ten genera in repetitions 1 and 2. While in the 2nd repetition found the change of genera into *Closterium*, *Pediastrum*, *Westella*, *Tabellaria* and *Navicula*. The condition of STA 3 compared to other STAs has decreased, represented by the genera *Corethron*, *Navicula*, *Nitzschia*, *Gonatozygon*, *Closterium*, and *Ulothrix*. In contrast to phytoplankton, zooplankton composition was more abundant in STA 3 in repetition 1 but decreased to 1 genera in repetition 2.

Characteristics of water, biota, and waste quality between stations

Water quality components from pH, brightness, dissolved oxygen, salinity, dominance, and taxa, as well as waste materials from plastics, fabrics, sacks, and cans, are components that interact with each other at each research site (Table 2).

Table 2 One Way ANOVA test of water quality, biological index, and waste abundance from each research location confidence level 0.05

Parameter	Station	Mean Difference (between STA)	Sig. Anova	Levene test	Sig. Post Hoc Tests	Conclusion
pH	STA 2 vs 1	0.300(*)	0.029	0,000	0,000	Significant
Brightness	STA 2 vs 1	2.040(*)	0.042			
	STA 2 vs 3	7.385(*)	0.001			
	STA 1 vs 3	5.345(*)	0.003			
DO	STA 2 vs 1	0.700(*)	0.012			
	STA 2 vs 3	0.550(*)	0.024			
Salinity	STA 2 vs 1	8.700(*)	0.003			
	STA 3 vs 1	7.100(*)	0.006			
Dominance Index	STA 3 vs 2	0.116(*)	0.018			
	STA 3 vs 1	0.103(*)	0.025			
Taxon	STA 2 vs 3	4.000(*)	0.005			
	STA 1 vs 3	4.500(*)	0.003			
Plastic waste	STA 2 vs 1	0.622(*)	0.037			
	STA 3 vs 1	0.586(*)	0.043			
Clotch waste, sack	STA 1 vs 2	0.692(*)	0.006			
	STA 1 vs 3	0.623(*)	0.008			
Old cans	STA 3 vs 1	0.079(*)	0.025			
	STA 3 vs 2	0.076(*)	0.028			

Remarks : (*) significantly

The value of 9 significant parameters interacts in STA 1, STA 2, and STA 3. Brightness parameters differ from location to location, while pH is only between STA 2 vs 1.

Discussion

Mangrove species in the study site were dominated by *Avicennia marina* and *Rhizopora sp*, due to differences in environmental factors and anthropogenic disturbances (Gumilar, 2012). *Avicennia sp.* is able to good reproduction and grow quickly (Sarno, 2016). The low-density value of mangroves in the saplings and seedlings in Pagatan Besar Village is due to the presence of mangroves that die at the beginning of the growth period and the failure of the germination process and environmental conditions. The failure of the sprouts is due to the absence of a substrate for the germination process because it is covered by plastic waste. The type of sandy mud substrate influences mangrove growth in addition to water temperature, pH, and salinity (Agustini *et al.,* 2016). Suboptimal nutrient absorption can have an impact on tree growth and development. One of them is macroplastic, which covers the substrate and becomes an obstacle to the absorption of nutrients by the roots (Kantharajan *et al.,* 2018).

The plankton composition of waters polluted with plastic waste is lower than those without plastic waste (Dodson *et al.* 2009; Rahayu *et al.* 2013; Widyarini *et al.* 2017; Persada *et al.* 2022; Yunandar *et al.,* 2023). It can be seen that the composition of the phyla

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Chrysophyta and *Chlorophyta* is balanced, while *Cyanophyta* is the lowest. Phylum *Cyanophyta* hanyar is present in 2 locations, while *Chlorophyta* and *Chrysophyta* are scattered at all observation stations. Zooplankton are more diverse in STA 3 than the other 2 STA. The population is more experienced by STA 1 and STA 2, but STA 3 has decreased due to increased waste generation, which accelerates coastal sedimentation. The amount of waste, especially from plastic materials, supports the reduction of water biota. This statement is supported by Idrus *et al.,* (2023), in which inorganic debris got more to plastic bottles and glasses with a value of 65,56% to 79,17%. Plastic waste dominates other waste (Purba *et al.,* 2018).

The diversity of types of waste at the location amounted to 9 types identified in the plot created, STA 3 was where the most destruction was found compared to the other 2 STAs. Plastic waste in mangrove areas seriously disrupts physical and ecological functions. The biological process of mangroves prevents coastal erosion, block waves and seawater from entering the land (seawater intrusion). Meanwhile, the environmental role is as a place to feeding ground, to maintain and nurture mangrove biota (spawning/nursery area), and to exchange nutrients. Plastic waste that crushes mangrove roots is degraded into debris that remains in the aquatic environment. Larger plastic fragments that stay for a long time can become smaller due to weathering and mechanical energy, such as ocean waves. Plastic breaks down into microplastics with a diameter smaller than 5 millimeters. Microplastics that enter the marine food chain at low levels can affect the entire food chain.

The survival of plankton is influenced by water quality, such as temperature, pH, salinity, and dissolved oxygen content in the waters. The water temperature at the study site is 29.6 ℃ – 30 ℃ and is suitable for plankton survival. The temperature range plankton tolerates is 25 to 32 ℃ (Hutabarat and Evans, 1985). The salinity obtained in Pagatan Besar Village is 11.8 – 21.2 $^0/_{00}$. Field observations show that in the range of salinity values, there are still different types of plankton between STA and its repeats, although there is a decrease in genera in STA 3 to two classes. It means that plankton with existing genera have good tolerance to changes in salinity in the waters. Odum (1998) states that salinity in estuaries varies greatly, and living biota have a good tolerance level to changes in salinity.

pH parameters influence the survival of aquatic biota. The pH value obtained at the study site is suitable for plankton life. pH values between 6 to 7.5 can still be tolerated by plankton for their survival. The dissolved oxygen content is a factor that affects the survival of biota. The value of dissolved oxygen is a suitable condition for the survival of plankton and other aquatic biota. The limit value of dissolved oxygen for marine biota is ≥ 5 mg / L. The range of oxygen content in the field of 5.3 to 5.6 mg / L includes conditions suitable for aquatic organisms. The shape of muddy substrates polluted with plastic waste in mangrove ecosystems can still be tolerated so that plankton and other marine biota can survive changes in the quality of this aquatic environment. In each type of mangrove, there is a different plankton content. The most plankton are STA 1 and 2, natural habitats, while the lowest in STA 3 relies on *Avicennia* from planting activities (reforestation). This condition shows the relationship between mangrove density and plankton abundance in the waters. As an organism that can photosynthesize, plankton, in its breeding, needs light. The density of mangroves affects the brightness and cover of the canopy. The canopy cover area affects the intensity of light entering the mangrove roots at low tide, and sea level at high tide that inundates the mangrove area.

The primary productivity of phytoplankton largely depends on the intensity of light reaching the surface of the water. Each type of mangrove contains different plankton content (Halidah, 2016). The increase in salinity is followed by the abundance and diversity of plankton in zones that are overgrown by various mangrove vegetation, so it is very supportive of phytoplankton life. STA 2 which is an estuarine ecosystem shows that higher phytoplankton abundance, due to nutrient out welling from swamp and tributary mangrove sediments, thus supporting the high phytoplankton biomass in estuarine waters (Saifullah *et al.,* 2016). Class *Chlorophyceae* is the dominant class and is almost found in all mangroves in the tropics. This is because *Chlorophyceae* are cosmopolitan, have high tolerance and adaptability to environmental conditions (Thoha and Amri, 2011). Many classes of *Chlorophyceae* are found because organisms from that class are cosmopolitan and have high tolerance and adaptability to changes in the marine environment (Casteleyn *et al.,* 2010). Class *Chlorophyceae* is able to grow rapidly even in low light and nutrient conditions (Nybakken, 1992). This is because this type of phytoplankton has the ability to adapt well so that it is able to regenerate and reproduce in greater numbers than other types. This type of plankton is the type that is most resistant to environmental changes by tidal influences. The abundance of phytoplankton in a body of water is

always closely related to the conditions around the aquatic environment.

The ability of aquatic organisms to adapt to changing environmental conditions causes their existence in nature to be influenced by pollutants such as macro plastics. Differences in abundance and types of marine biota found at the study site due to differences in environmental conditions. At high tide, the water level in the estuary waters is higher than the low tide, resulting in a lot of plankton entering the estuary due to currents and waves from the sea. (Saifullah *et al.,* 2016).

The back-and-forth movement of water masses is essential in removing pollutants from the ecosystem and transporting food and nutrients from the surrounding environment. This condition affects the abundance of plankton, especially phytoplankton and biota, in the early stages. The quantity of phytoplankton and zooplankton is higher at high tide than at low tide (Andriani *et al.,* 2015; Nugroho *et al.,* 2020). The high biomass of phytoplankton in estuaries is caused by nutrients coming out of the mangrove area and tidal mixing of water, while the decrease in biomass is due to nutrient consumption (Saifullah *et al.,* 2016).

The existence of plankton in an aquatic ecosystem is influenced by biotic factors (competition between species) and the presence of predators. In contrast, abiotic factors are influenced by physical, chemical, aquatic, and human activities (Cronk dan Fennessy, 2001; Elger *et al.,* 2004; Sahidin *et al.,* 2021). Components that contribute to the abundance of a plankton species are stability, environmental heterogeneity, primary productivity of ecosystems, and the presence of predators and competitive interactions between species. The overall plankton abundance tends to fluctuate at all study sites; this condition is directly proportional to the density of mangroves and the quantity of waste. The diversity of plankton in the study site could be more diverse or even higher, evidenced by the identification of certain types of plankton that are able to adapt to environmental conditions. Low plankton diversity due to the low diversity of mangrove species (Fachrul, 2007; Novianto, 2011 and Azwar, 2013). The uniformity value is relatively evenly described as an increase in mangrove and plankton growth supported by calm waters and weak currents. Overall, the uniformity index value obtained during observations is quite evenly distributed, and the dominance index value is low.

The role of zooplankton is essential in the food chain cycle in estuaries because it is one of the intermediaries that converts energy from plants into energy for animals (Romimohtarto 2009). Meanwhile, phytoplankton have a role as producers, which are a source of energy for other living organisms (Desyana *et al.* 2017).

Marine debris impacts life through five mechanisms, namely (1) the digestive system and the trapping of biota, (2) accumulates and spreads to other regions, is toxic, bioavailability and impacts through the food chain, (3) as a vector of invasive species, (4) impacts on habitat and seabed life, and (5) impact economically (Stevenson, 2011). Plastic is a vector in the spread of microalgae that causes blooming (Maso *et al.,* 2003) and heavy metal (Holmes, 2013). The number of macro plastic pieces affects the presence and abundance of aquatic biota in mangrove ecosystems. The large number of plankton is strongly suspected because it is found in locations with small amounts of macro plastics. Macro plastics can affect the availability of habitats for faunal groups such as mollusks and crabs (Kantharajan *et al.*, 2018). It indicates that with the reduction of habitat for biota, its presence in a place is decreasing. Another study also explained that during the degradation process, macro plastics produce toxic chemical compounds that can reduce the number of offspring, cause reproductive failure, and interfere with the development of larva biota in mangroves (Hammer *et al.* 2012).

Plastic is made of hydrophobic materials, so contaminants on its surface act as reservoirs of toxic chemicals in the environment (Ivar do Sul and Costa, 2013). Heavy metals such as Cd, Co, Cr, Cu, Ni, and Pb can stick to plastics by being affected by pH and salinity. The ability of Cd, Co, Ni, and Pb to stick to plastics may increase with increasing pH and decreasing salinity. Still, conversely, the ability of Cr to attach to plastics may decrease. Plastics contain organic contaminants, including *polychlorinated biphenyls* (PCBs), *polycyclic aromatic hydrocarbons* (PAHs), *petroleum hydrocarbons*, *organochlorine pesticides*, *polybrominated diphenyl ethers*, *alkylphenols*, and *bisphenols* that cause chronic effects such as endocrine disruption in aquatic biota (Teuten *et al.,* 2009). The threat to the species is the absorption of PCBs through the digestive system (Derraik, 2002). Contaminants that can survive and accumulate through the food chain can harm human health. Marine mammals, birds, fish, and turtles receive the impact of marine debris pollution (STAP, 2011). The group of animals most affected by marine debris are mammals. Debris particles also affect the digestive system of sponges, cnidarians, worms, crustaceans, mollusks, bryozoans, echinoderms, ascidians, algae, seagrasses, and plankton (CBD-STAP, 2012).

The amount of plastic able to covered the essential soil of mangrove vegetation and *pneumatophores* (unique roots that grow upwards and allow the exchange of oxygen and carbon dioxide). Such root capillary pressure can force bubbles out of the lenticels in many *pneumatophores*. Interconnectivity between pneumatophores originating from the same root minimizes the effects of plastic scattering in the sediment, which covers only a few root pneumatophores. The remaining pneumatophores can keep the sediment oxygenated at all times. In addition, the plastic can still be carried back by the tide, causing only temporary suffocation of the roots.

In contrast, plastic on top of pneumatophores during sedimentation events can persist for weeks or months, depending on the incoming tidal wave. Some of the plastic in the sediment was there for a long time because more than half of the plastic found was buried under 2 cm of sediment. The finding that plastic is not only trapped but also buried in mangrove sediments is in agreement with Costa *et al.*, (2011), who found plastic in varying degrees of degradation buried to a depth of at least 20 cm in mudflats on the fringes of mangroves in Brazil. The amount of plastic buried in the sediment at the site is equal to the layer of plastic visible on the surface of the sediment, causing a stress effect. Because penetration of oxygen into the sediment through the sediment surface and pneumatophores increases disturbance, this condition makes it difficult for root respiration by the tree due to plastic stress. The adaptation made by mangrove roots due to being covered in plastic in their root zone responds with extreme root elongation to overcome this suffocating substance. If roots are 100% covered by plastic, they will die, but 50% plastic coverage shows that the mangrove is able to withstand suffocation. Resistance to repeated anoxic conditions is a characteristic of all mangrove species; in addition to evolutionary adaptations of roots, most mangrove species can adapt to prolonged flooding events (Youssef and Saenger, 1996).

Twisted roots indicate the tree is trying to overcome the substance gripping it. The disposal of plastic waste into the environment is expected to increase in the future (Jambeck *et al.,* 2015). Mangroves are relatively cheap ecosystems to restore compared to other marine ecosystems (Narayan *et al.,* 2016). However, success is still low compared to marine ecosystems, such as coral reefs (Bayraktarov *et al.,* 2016). The success rate of mangrove restoration has the potential to increase, in addition to the availability of budget for mangrove planting and mitigation of plastic waste reduction

Conclusion

Cyanophyta, *Chlorophyta* and *Chrysophyta* are plankton phyla from the research location except in STA 3 without the presence of *Cyanophyta.* The plankton genera always present at all stations are *Gonatozygon* and *Ulothrix* from *Chloropyhta.* The most extensive waste composition in STA 1 is glass bottles and sacks, STA 2 is plastic bottles, and STA 3 consists of plastic bottles and glass. The most significant increase in marine debris accumulated in STA 3, from 6697 grams at the beginning of the observation to 13820 grams. Based on stations, the abundance value of marine debris in Pagatan Besar is 107.95 ± 0.05 items/m^2. The survival of mangroves and plankton is influenced by pH, brightness, dissolved oxygen, salinity, dominance, taxa, and waste materials, mainly plastic. Mitigation studies related to trash traps on mangrove roots to increase the success rate of restoration.

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Acknowledgments

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Plankton Community Structure in Mangrove Ecosystem Polluted by Microplastic Waste Pagatan Besar Village, Tanah Laut Regency

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ABSTRACT

Plastic waste continues to increase all the time without decreasing or ending, resulting in the sustainability and restoration of the mangrove ecosystem needing to be improved. The mangrove ecosystem is a place where plastic waste accumulates. The accumulation of plastic waste prevents photosynthesis in mangroves, reduces aquatic productivity and encourages microbial colonization. This research aims to identify the type abundance of plankton, waste and water quality. Sampling was carried out purposively from June to July 2023. STA 1 represents rivers, STA 2 estuaries and STA 3 coastal mangroves. Plankton, plastic waste and water quality samples were collected at the beginning of each month based on a 1x1 m2 plot. Furthermore, biological index calculations of plankton and the density of plastic waste were carried out and their relationship with water quality in each location. Mangroves in the village of Pagatan Besar are dominated by Avicennia marina, Avicennia alba, Bruguierra cylindrica and Rhizopora apiculata. The highest density was in STA 3, but it was inversely proportional to the abundance and diversity of plankton due to the dense waste cover between the roots, mainly plastic materials. The most significant increase in marine waste accumulated in STA 3 from 6697 grams at the beginning of the observation to 13820 grams. The most significant composition of waste in STA 3 consists of plastic bottles and plastic cups. Cyanophyta, Chlorophyta and Chrysophyta are plankton phyla from the research location. Plankton identified there are three phyla in STA 1 and STA 2, while in STA 3, there are only 2. Cyanophyta, Chlorophyta and Chrysophyta are phyla plankton from the study site. The types of plankton that are always present in all STAs are Gonatozygon and Ulothrix from Chloropyta. The survival of plankton and mangroves is influenced by water temperature, pH, salinity, dissolved oxygen and the type of material density of macroplastic waste.

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Introduction

The increasing number of residents and visitors to the Takisung Beach tourist attraction has increased plastic waste pollution in the mangrove ecosystem in Pagatan Besar Village. Plastic waste from human activities always increases every year and has a direct impact on the aquatic biota of mangrove areas. Even though various regulatory and socialization instruments have been rolled out, the amount of plastic waste continues to increase on marine coasts (Lamb *et al.,* 2018), estuaries and sea embankments (Smith and Edgar, 2014) as well as mangrove ecosystems as accumulators of plastic waste (Juliana *et al.,* 2014; World Bank 1991; Wade *et al.,* 1991).

The accumulation of plastic waste encourages microbial colonization, disease and prevents photosynthesis in mangroves (Manullang, 2020). The accumulation of plastic waste can reduce the rate of mangrove recruitment. Plastic waste kills mangroves in the seedling phase (Makowski and Finkl, 2018). The accumulation of plastic waste can reduce the aesthetic value of mangroves from ecotourism activities.

Plastic waste research has been focused on aspects of abundance (Calcar dan Emmerik, 2016; Tibbetts *et al.,* 2018; Emmerik dan Schwarz, 2019; Riskiana *et al.,* 2020), impact on fish (Sequeira *et al.,* 2020; Sui *et al.,* 2020; Assuyuti *et al.,* 2018). Another study informs of economic losses experienced by fishing vessels or fishing gear (Lee, 2014), damage to ship propellers (Watskins, 2015), damage to fishing boats (Takehama, 1990) and aesthetic decline of Morotai Island's Dodola beach (Idrus *et al.,* 2023) due to plastic waste.

Mangroves are coastal plants influenced by sea tides that are able to adapt to changes in salinity

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(Kusmana and Sukristijiono, 2016), inhabit shallow and muddy beaches (Nagelkerken *et al.,* 2008; Kusmana and Ningrum, 2016), coastal protection (Tarigan 2008), trophic system buffer in the sea (Bulow and Ferdinand, 2013) and productivity contributor to shrimp and fish. (Dafikri *et al.,* 2016; Manson *et al.,* 2005).

Disruption to mangrove ecosystems due to the accumulation of macroplastic waste has an impact on damage to aquaculture activities, disruption of fish habitat and siltation. This condition causes ecological problems in changes in the structure, composition, productivity and function of aquatic ecosystems, especially plankton, which are directly associated with mangroves.

Indicators of diversity, uniformity and dominance of aquatic plankton become the focus of management. Macroplastic waste piles, especially from inorganic materials that cover the surface of the waters, inhibit the rate of photosynthesis of phytoplankton, and the role of roots decreases. (Thamaga dan Dube, 2018).

Nevertheless, it will interfere with the growth and interaction of plankton that depend on its life with mangrove ecosystems. Therefore, this study aims to identify the type abundance of plankton and garbage as well as the water quality of the Pagatan Besar mangrove ecosystem. The data displayed in this study is the latest local data related to mangrove plankton. The level of plankton vulnerability can be used as a diagnostic of mangrove environmental conditions due to plastic waste on the coast of Pagatan Besar.

Materials and Methods

Location and time of research

This research was carried out from June to July 2023, located on the Pagatan Besar and Tabanio rivers coast, Takisung District, Tanah Laut Regency, South Kalimantan (Figure 1). The sampling location consists of 3 locations representing the ecosystem characteristics of the STA-1 river, the STA-2 estuary, and the STA-3 coastal mangrove.

Samples collection and identification procedure

Macroplastic samples were taken from transects covering an area of 100 m^2 towards the sea, in which plots measuring 1x1 m^2 were installed at all locations. Area cover of transect area with high and low mangrove density. The macroplastic data taken included the number of pieces and type, length, weight, and thickness of the macroplastics on the substrate excavated on the plot.

Plankton and water quality samples were collected from the waters around the mangroves. Sampling was conducted in the first week of June and July 2023 dry season. Water quality analysis from temperature, brightness, dissolved oxygen (DO), pH, and salinity parameters in situ. The instruments used have been calibrated.

Data analysis

Plankton identification refers to the titles of Huyn L and Serediak (2006), Bigg and Kilroy (2000), Yunfang (1995), Bellinger and Singee (2010). The calculated ecological index is abundance, Shannon-Wiener diversity, evenness and dominance. Identification of mangrove species was carried out visually on selected transects.

Waste identification is carried out visually from the origin of the material and the calculation of its weight, abundance, and percentage. The composition of the waste is divided into organic and inorganic (Tangdesu 2018; Johan *et al.,* 2020), then divided according to the categories of plastic, rubber, metal, glass, wood, and derivatives (Djaguna *et al.,* 2019).

Analysis of abundance and waste composition/percentage refers to Coe and Roger (1997); Johan *et al.*, (2020) :

$$Density = \frac{The\ Number\ of\ \text{waste}\ (item)}{Area\ (m^2)}$$

$$Density\ (weight\ of\ \text{waste}) = \frac{The\ Weight\ \text{waste}\ (gram)}{Area\ (m^2)}$$

$$\text{Composition}\ marine\ debris = \frac{The\ Number\ of\ Pieces\ in\ Category (gram)}{Total\ Weight\ of\ \text{waste}\ (gram)}\ x\ 100\%$$

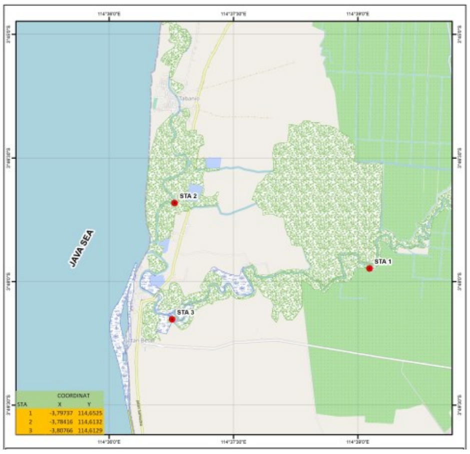

Figure 1. Map of sampling locations

Results

Plankton collection and selected waste samples at the study site were inversely proportional between waste density and type to plankton abundance. Plankton variation is less at high and diverse waste densities than in areas with low waste density. Water

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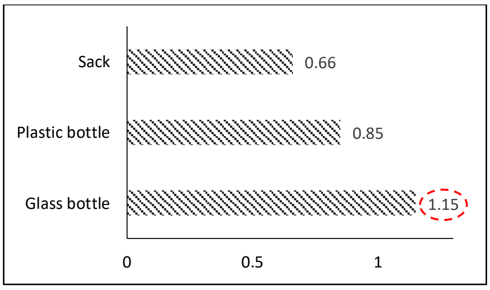
quality components of pH, brightness, dissolved oxygen, and salinity differed between study sites..

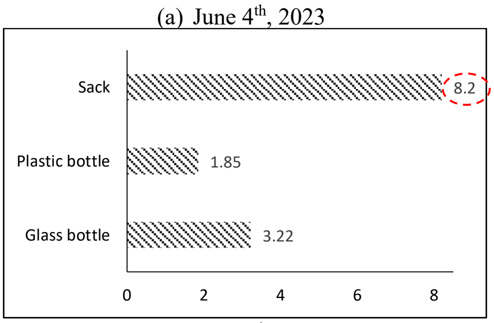
Mangroves and the abundance of plastic waste

Acanthus ilicifolius and *Rhizopora apiculata* mangroves in STA 1 have low diversity in residential areas. Garbage dominates in this location from plastic bottles and glass. *Avicennia marina*, *Avicennia alba*, *Bruguierra cylindrica*, *Pandanus odoratissima* and *Rhizopora apiculate* ~~apiculate~~ are quite diverse found in STA 2. The dominant waste in this location is plastic materials in bottles, hoses, glass bottles, clothes, and cans. Avicennia marina dominates STA 3 from previous reforestation activities and in the sapling phase, but in between, the roots have been covered with various kinds of waste, especially plastic food packaging materials, plastic bags, bottles, and mineral water glasses.

The results of marine debris monitoring at the three stations in Pagatan Besar Village during June and July have increased for STA 1 from 860 grams to 1327 grams while for STA 2 from 775 grams to 800 grams. Marine debris accumulates the most in STA 3. The value of waste weight in STA 3 went from 6697 grams at the beginning of the observation to 13820 grams at the end of the compliance with the addition of diaper type. Styrofoam material was only identified at STA 3 from 40 grams to 180 grams. The composition of the waste at each location is presented in **Figures 2, 3, and 4**.

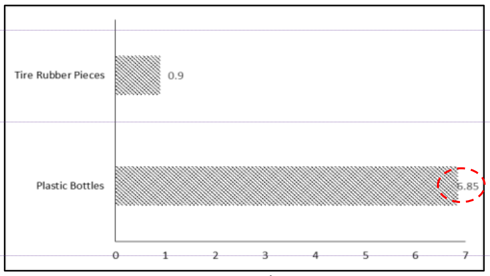


(a) June 4th, 2023



(b) July 4th, 2023

Figure 2. Waste composition STA 1



(a) June 4th, 2023

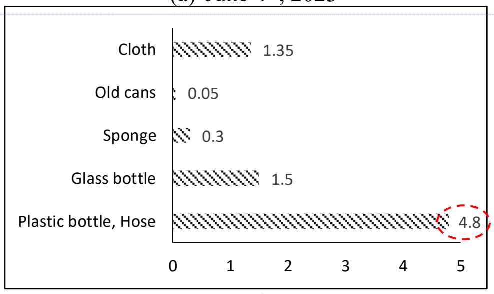


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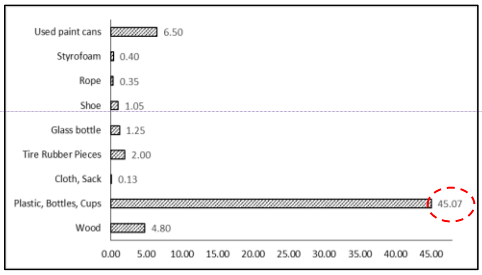
Figure 3. Waste composition STA 2



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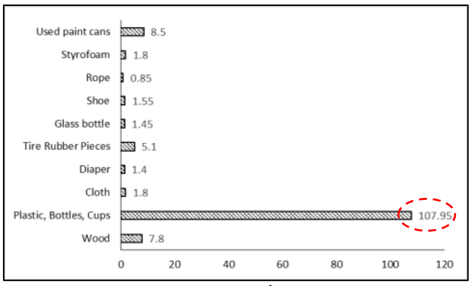

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Figure 4. Waste composition STA 3

Plankton Community Structure and Water Quality

The results of plankton analysis at the study site during June (repetition 1) and July (repetition 2) 2023 obtained three phyla in STA 1 and STA 2, while STA 3 phyla found only 2 in all tests. The plankton phylum in question consists of *Cyanophyta*, *Chlorophyta*, and *Chrysophyta*. The types of plankton always present at all stations are *Gonatozygon* and *Ulothrix* from *Chloropyta*. The structure of plankton is the same, but the number is reduced for the 2nd test less than the 1st test (Table 1).

Table 1. Phylum Phytoplankton at the study site between June and July 2023

Phylum	Genera	Sample Code					
		STA 1_June	STA 1_July	STA 2_June	STA 2_July	STA 3_June	STA 3_July
Phytoplankton							
Cyanophyta	*Oscillatoria*	+	+	+	+	-	-
	Microcystis	-	-	+	-	-	-
Chloropyta	*Gonatozygon*	+	+	+	+	+	+
	Pediastrum	-	+	+	-	-	-
	Westella	+	+	+	+	-	-
	Schroederia	+	+	-	-	-	-
	Closterium	+	+	-	+	+	+
	Pediastrum	+	-	-	+	-	-
	Ulothrix	+	+	+	+	+	+
Chrysophyta	*Odontella*	+	-	+	-	-	-
	Rhizosolenia	-	-	+	+	-	-
	Tabellaria	-	-	-	+	-	-
	Corethron	+	+	-	-	+	+
	Navicula	+	+	-	+	+	+
	Nitzschia	-	-	+	+	+	+
	Synedra	+	+	+	-	-	-
Zooplankton							
Euglenozoa	*Phacus*	-	-	-	-	+	-
Rotifer	*Keratella*	-	-	-	-	+	-
	Lecane	+	+	-	-	-	-
Ciliophora	*Spirostomum*	-	-	+	+	-	-
	Dileptus	-	-	-	-	+	+

Remarks : (+) Present; (-) Absensce

STA 2, located at the estuary, identified ten genera in repetitions 1 and 2. While in the 2nd repetition found the change of genera into *Closterium*, *Pediastrum*, *Westella*, *Tabellaria* and *Navicula*. The condition of STA 3 compared to other STAs has decreased, represented by the genera *Corethron*, *Navicula*, *Nitzschia*, *Gonatozygon*, *Closterium*, and *Ulothrix*. In contrast to phytoplankton, zooplankton composition was more abundant in STA 3 in repetition 1 but decreased to 1 genera in repetition 2.

Characteristics of water, biota, and waste quality between stations

Water quality components from pH, brightness, dissolved oxygen, salinity, dominance, and taxa, as well as waste materials from plastics, fabrics, sacks, and cans, are components that interact with each other at each research site (Table 2).

Table 2 One Way ANOVA test of water quality, biological index, and waste abundance from each research location confidence level 0.05

Parameter	Station	Mean Difference (between STA)	Sig. Anova	Levene test	Sig. Post Hoc Tests	Conclusion
pH	STA 2 vs 1	0.300(*)	0.029	0,000	0,000	Significant
Brightness	STA 2 vs 1	2.040(*)	0.042			
	STA 2 vs 3	7.385(*)	0.001			
	STA 1 vs 3	5.345(*)	0.003			
DO	STA 2 vs 1	0.700(*)	0.012			
	STA 2 vs 3	0.550(*)	0.024			
Salinity	STA 2 vs 1	8.700(*)	0.003			
	STA 3 vs 1	7.100(*)	0.006			
Dominance Index	STA 3 vs 2	0.116(*)	0.018			
	STA 3 vs 1	0.103(*)	0.025			
Taxon	STA 2 vs 3	4.000(*)	0.005			
	STA 1 vs 3	4.500(*)	0.003			
Plastic waste	STA 2 vs 1	0.622(*)	0.037			
	STA 3 vs 1	0.586(*)	0.043			
Clotch waste, sack	STA 1 vs 2	0.692(*)	0.006			
	STA 1 vs 3	0.623(*)	0.008			
Old cans	STA 3 vs 1	0.079(*)	0.025			
	STA 3 vs 2	0.076(*)	0.028			

Remarks : (*) significantly

The value of 9 significant parameters interacts in STA 1, STA 2, and STA 3. Brightness parameters differ from location to location, while pH is only between STA 2 vs 1.

Discussion

Mangrove species in the study site were dominated by *Avicennia marina* and *Rhizopora sp*, due to differences in environmental factors and anthropogenic disturbances (Gumilar, 2012). *Avicennia sp.* is able to good reproduction and grow quickly (Sarno, 2016). The low-density value of mangroves in the saplings and seedlings in Pagatan Besar Village is due to the presence of mangroves that die at the beginning of the growth period and the failure of the germination process and environmental conditions. The failure of the sprouts is due to the absence of a substrate for the germination process because it is covered by plastic waste. The type of sandy mud substrate influences mangrove growth in addition to water temperature, pH, and salinity (Agustini *et al.,* 2016). Suboptimal nutrient absorption can have an impact on tree growth and development. One of them is macroplastic, which covers the substrate and becomes an obstacle to the absorption of nutrients by the roots (Kantharajan *et al.,* 2018).

The plankton composition of waters polluted with plastic waste is lower than those without plastic waste (Dodson *et al.* 2009; Rahayu *et al.* 2013; Widyarini *et al.* 2017; Persada *et al.* 2022; Yunandar *et al.,* 2023). It can be seen that the composition of the phyla

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Chrysophyta and *Chlorophyta* is balanced, while *Cyanophyta* is the lowest. Phylum *Cyanophyta* hanyar is present in 2 locations, while *Chlorophyta* and *Chrysophyta* are scattered at all observation stations. Zooplankton are more diverse in STA 3 than the other 2 STA. The population is more experienced by STA 1 and STA 2, but STA 3 has decreased due to increased waste generation, which accelerates coastal sedimentation. The amount of waste, especially from plastic materials, supports the reduction of water biota. This statement is supported by Idrus *et al.,* (2023), in which inorganic debris got more to plastic bottles and glasses with a value of 65,56% to 79,17%. Plastic waste dominates other waste (Purba *et al.,* 2018).

The diversity of types of waste at the location amounted to 9 types identified in the plot created, STA 3 was where the most destruction was found compared to the other 2 STAs. Plastic waste in mangrove areas seriously disrupts physical and ecological functions. The biological process of mangroves prevents coastal erosion, block waves and seawater from entering the land (seawater intrusion). Meanwhile, the environmental role is as a place to feeding ground, to maintain and nurture mangrove biota (spawning/nursery area), and to exchange nutrients. Plastic waste that crushes mangrove roots is degraded into debris that remains in the aquatic environment. Larger plastic fragments that stay for a long time can become smaller due to weathering and mechanical energy, such as ocean waves. Plastic breaks down into microplastics with a diameter smaller than 5 millimeters. Microplastics that enter the marine food chain at low levels can affect the entire food chain.

The survival of plankton is influenced by water quality, such as temperature, pH, salinity, and dissolved oxygen content in the waters. The water temperature at the study site is 29.6 ℃ – 30 ℃ and is suitable for plankton survival. The temperature range plankton tolerates is 25 to 32 ℃ (Hutabarat and Evans, 1985). The salinity obtained in Pagatan Besar Village is 11.8 – 21.2 $^0/_{00}$. Field observations show that in the range of salinity values, there are still different types of plankton between STA and its repeats, although there is a decrease in genera in STA 3 to two classes. It means that plankton with existing genera have good tolerance to changes in salinity in the waters. Odum (1998) states that salinity in estuaries varies greatly, and living biota have a good tolerance level to changes in salinity.

pH parameters influence the survival of aquatic biota. The pH value obtained at the study site is suitable for plankton life. pH values between 6 to 7.5 can still be tolerated by plankton for their survival. The dissolved oxygen content is a factor that affects the survival of biota. The value of dissolved oxygen is a suitable condition for the survival of plankton and other aquatic biota. The limit value of dissolved oxygen for marine biota is ≥ 5 mg / L. The range of oxygen content in the field of 5.3 to 5.6 mg / L includes conditions suitable for aquatic organisms. The shape of muddy substrates polluted with plastic waste in mangrove ecosystems can still be tolerated so that plankton and other marine biota can survive changes in the quality of this aquatic environment. In each type of mangrove, there is a different plankton content. The most plankton are STA 1 and 2, natural habitats, while the lowest in STA 3 relies on *Avicennia* from planting activities (reforestation). This condition shows the relationship between mangrove density and plankton abundance in the waters. As an organism that can photosynthesize, plankton, in its breeding, needs light. The density of mangroves affects the brightness and cover of the canopy. The canopy cover area affects the intensity of light entering the mangrove roots at low tide, and sea level at high tide that inundates the mangrove area.

The primary productivity of phytoplankton largely depends on the intensity of light reaching the surface of the water. Each type of mangrove contains different plankton content (Halidah, 2016). The increase in salinity is followed by the abundance and diversity of plankton in zones that are overgrown by various mangrove vegetation, so it is very supportive of phytoplankton life. STA 2 which is an estuarine ecosystem shows that higher phytoplankton abundance, due to nutrient out welling from swamp and tributary mangrove sediments, thus supporting the high phytoplankton biomass in estuarine waters (Saifullah *et al.,* 2016). Class *Chlorophyceae* is the dominant class and is almost found in all mangroves in the tropics. This is because *Chlorophyceae* are cosmopolitan, have high tolerance and adaptability to environmental conditions (Thoha and Amri, 2011). Many classes of *Chlorophyceae* are found because organisms from that class are cosmopolitan and have high tolerance and adaptability to changes in the marine environment (Casteleyn *et al.,* 2010). Class *Chlorophyceae* is able to grow rapidly even in low light and nutrient conditions (Nybakken, 1992). This is because this type of phytoplankton has the ability to adapt well so that it is able to regenerate and reproduce in greater numbers than other types. This type of plankton is the type that is most resistant to environmental changes by tidal influences. The abundance of phytoplankton in a body of water is

Commented [A15]: What kind of destruction? Change to the most 'waste'

always closely related to the conditions around the aquatic environment.

The ability of aquatic organisms to adapt to changing environmental conditions causes their existence in nature to be influenced by pollutants such as macro plastics. Differences in abundance and types of marine biota found at the study site due to differences in environmental conditions. At high tide, the water level in the estuary waters is higher than the low tide, resulting in a lot of plankton entering the estuary due to currents and waves from the sea. (Saifullah *et al.,* 2016).

The back-and-forth movement of water masses is essential in removing pollutants from the ecosystem and transporting food and nutrients from the surrounding environment. This condition affects the abundance of plankton, especially phytoplankton and biota, in the early stages. The quantity of phytoplankton and zooplankton is higher at high tide than at low tide (Andriani *et al.,* 2015; Nugroho *et al.,* 2020). The high biomass of phytoplankton in estuaries is caused by nutrients coming out of the mangrove area and tidal mixing of water, while the decrease in biomass is due to nutrient consumption (Saifullah *et al.,* 2016).

The existence of plankton in an aquatic ecosystem is influenced by biotic factors (competition between species) and the presence of predators. In contrast, abiotic factors are influenced by physical, chemical, aquatic, and human activities (Cronk dan Fennessy, 2001; Elger *et al.,* 2004; Sahidin *et al.,* 2021). Components that contribute to the abundance of a plankton species are stability, environmental heterogeneity, primary productivity of ecosystems, and the presence of predators and competitive interactions between species. The overall plankton abundance tends to fluctuate at all study sites; this condition is directly proportional to the density of mangroves and the quantity of waste. The diversity of plankton in the study site could be more diverse or even higher, evidenced by the identification of certain types of plankton that are able to adapt to environmental conditions. Low plankton diversity due to the low diversity of mangrove species (Fachrul, 2007; Novianto, 2011 and Azwar, 2013). The uniformity value is relatively evenly described as an increase in mangrove and plankton growth supported by calm waters and weak currents. Overall, the uniformity index value obtained during observations is quite evenly distributed, and the dominance index value is low.

The role of zooplankton is essential in the food chain cycle in estuaries because it is one of the intermediaries that converts energy from plants into energy for animals (Romimohtarto 2009). Meanwhile, phytoplankton have a role as producers, which are a source of energy for other living organisms (Desyana *et al.* 2017).

Marine debris impacts life through five mechanisms, namely (1) the digestive system and the trapping of biota, (2) accumulates and spreads to other regions, is toxic, bioavailability and impacts through the food chain, (3) as a vector of invasive species, (4) impacts on habitat and seabed life, and (5) impact economically (Stevenson, 2011). Plastic is a vector in the spread of microalgae that causes blooming (Maso *et al.,* 2003) and heavy metal (Holmes, 2013). The number of macro plastic pieces affects the presence and abundance of aquatic biota in mangrove ecosystems. The large number of plankton is strongly suspected because it is found in locations with small amounts of macro plastics. Macro plastics can affect the availability of habitats for faunal groups such as mollusks and crabs (Kantharajan *et al.*, 2018). It indicates that with the reduction of habitat for biota, its presence in a place is decreasing. Another study also explained that during the degradation process, macro plastics produce toxic chemical compounds that can reduce the number of offspring, cause reproductive failure, and interfere with the development of larva biota in mangroves (Hammer *et al.* 2012).

Plastic is made of hydrophobic materials, so contaminants on its surface act as reservoirs of toxic chemicals in the environment (Ivar do Sul and Costa, 2013). Heavy metals such as Cd, Co, Cr, Cu, Ni, and Pb can stick to plastics by being affected by pH and salinity. The ability of Cd, Co, Ni, and Pb to stick to plastics may increase with increasing pH and decreasing salinity. Still, conversely, the ability of Cr to attach to plastics may decrease. Plastics contain organic contaminants, including *polychlorinated biphenyls* (PCBs), *polycyclic aromatic hydrocarbons* (PAHs), *petroleum hydrocarbons*, *organochlorine pesticides*, *polybrominated diphenyl ethers*, *alkylphenols*, and *bisphenols* that cause chronic effects such as endocrine disruption in aquatic biota (Teuten *et al.,* 2009). The threat to the species is the absorption of PCBs through the digestive system (Derraik, 2002). Contaminants that can survive and accumulate through the food chain can harm human health. Marine mammals, birds, fish, and turtles receive the impact of marine debris pollution (STAP, 2011). The group of animals most affected by marine debris are mammals. Debris particles also affect the digestive system of sponges, cnidarians, worms, crustaceans, mollusks, bryozoans, echinoderms, ascidians, algae, seagrasses, and plankton (CBD-STAP, 2012).

The amount of plastic able to covered the essential soil of mangrove vegetation and *pneumatophores* (unique roots that grow upwards and allow the exchange of oxygen and carbon dioxide). Such root capillary pressure can force bubbles out of the lenticels in many *pneumatophores*. Interconnectivity between pneumatophores originating from the same root minimizes the effects of plastic scattering in the sediment, which covers only a few root pneumatophores. The remaining pneumatophores can keep the sediment oxygenated at all times. In addition, the plastic can still be carried back by the tide, causing only temporary suffocation of the roots.

In contrast, plastic on top of pneumatophores during sedimentation events can persist for weeks or months, depending on the incoming tidal wave. Some of the plastic in the sediment was there for a long time because more than half of the plastic found was buried under 2 cm of sediment. The finding that plastic is not only trapped but also buried in mangrove sediments is in agreement with Costa *et al.*, (2011), who found plastic in varying degrees of degradation buried to a depth of at least 20 cm in mudflats on the fringes of mangroves in Brazil. The amount of plastic buried in the sediment at the site is equal to the layer of plastic visible on the surface of the sediment, causing a stress effect. Because penetration of oxygen into the sediment through the sediment surface and pneumatophores increases disturbance, this condition makes it difficult for root respiration by the tree due to plastic stress. The adaptation made by mangrove roots due to being covered in plastic in their root zone responds with extreme root elongation to overcome this suffocating substance. If roots are 100% covered by plastic, they will die, but 50% plastic coverage shows that the mangrove is able to withstand suffocation. Resistance to repeated anoxic conditions is a characteristic of all mangrove species; in addition to evolutionary adaptations of roots, most mangrove species can adapt to prolonged flooding events (Youssef and Saenger, 1996).

Twisted roots indicate the tree is trying to overcome the substance gripping it. The disposal of plastic waste into the environment is expected to increase in the future (Jambeck *et al.,* 2015). Mangroves are relatively cheap ecosystems to restore compared to other marine ecosystems (Narayan *et al.,* 2016). However, success is still low compared to marine ecosystems, such as coral reefs (Bayraktarov *et al.,* 2016). The success rate of mangrove restoration has the potential to increase, in addition to the availability of budget for mangrove planting and mitigation of plastic waste reduction

Conclusion

Cyanophyta, *Chlorophyta* and *Chrysophyta* are plankton phyla from the research location except in STA 3 without the presence of *Cyanophyta*. The plankton genera always present at all stations are *Gonatozygon* and *Ulothrix* from *Chloropyhta*. The most extensive waste composition in STA 1 is glass bottles and sacks, STA 2 is plastic bottles, and STA 3 consists of plastic bottles and glass. The most significant increase in marine debris accumulated in STA 3, from 6697 grams at the beginning of the observation to 13820 grams. Based on stations, the abundance value of marine debris in Pagatan Besar is 107.95 ± 0.05 items/m^2. The survival of mangroves and plankton is influenced by pH, brightness, dissolved oxygen, salinity, dominance, taxa, and waste materials, mainly plastic. Mitigation studies related to trash traps on mangrove roots to increase the success rate of restoration.

Commented [A16]: Value of waste composition in sta 3 july (plastic bottle, caps).

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Acknowledgments

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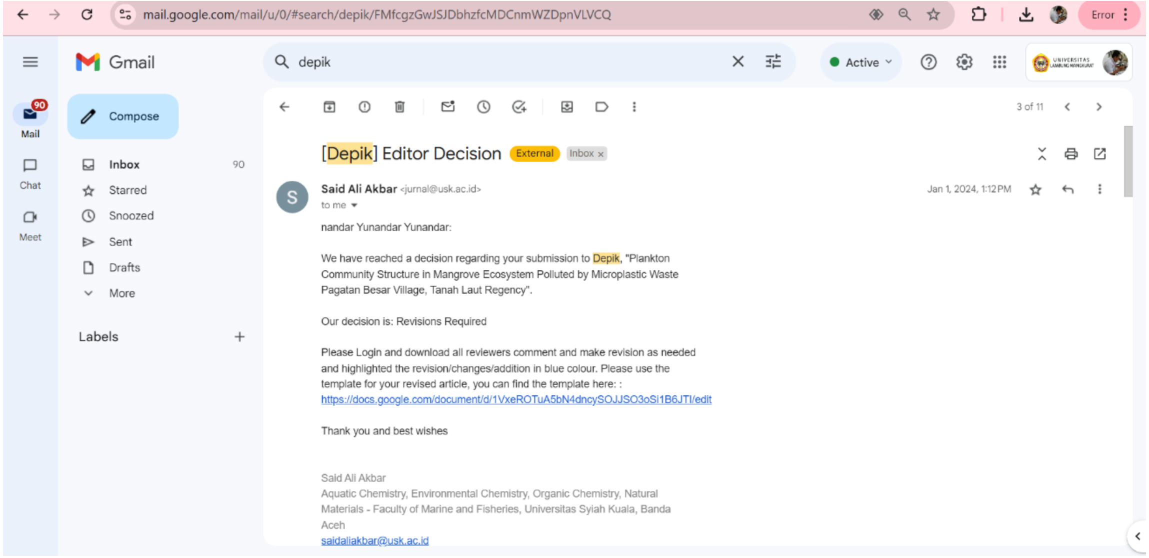
3. Bukti Konfirmasi Submit Revisi Pertama, Respon kepada Reviewer dan Artikel yang Diresubmit (1 Januari 2024)



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[Depik] Editor Decision

External | Inbox

Said Ali Akbar <jurnal@usk.ac.id>
to me

Jan 1, 2024, 1:12 PM

nandar Yunandar Yunandar:

We have reached a decision regarding your submission to Depik, "Plankton Community Structure in Mangrove Ecosystem Polluted by Microplastic Waste Pagatan Besar Village, Tanah Laut Regency".

Our decision is: Revisions Required

Please Login and download all reviewers comment and make revision as needed and highlighted the revision/changes/addition in blue colour. Please use the template for your revised article, you can find the template here: :
https://docs.google.com/document/d/1VxeROTuA5bN4dncySOJJSO3oSI1B6JTI/edit

Thank you and best wishes

Said Ali Akbar
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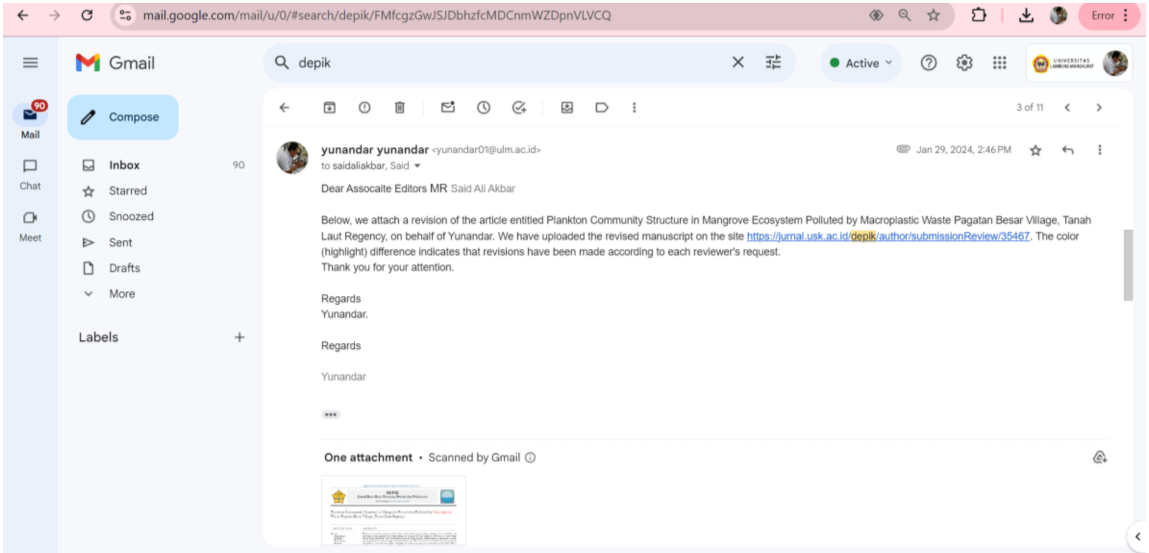

yunandar yunandar <yunandar01@ulm.ac.id>
to saidaliakbar, Said

Jan 29, 2024, 2:46 PM

Dear Assocaite Editors MR Said Ali Akbar

Below, we attach a revision of the article entitled Plankton Community Structure in Mangrove Ecosystem Polluted by Macroplastic Waste Pagatan Besar Village, Tanah Laut Regency, on behalf of Yunandar. We have uploaded the revised manuscript on the site https://jurnal.usk.ac.id/depik/author/submissionReview/35467. The color (highlight) difference indicates that revisions have been made according to each reviewer's request.
Thank you for your attention.

Regards
Yunandar.

Regards

Yunandar

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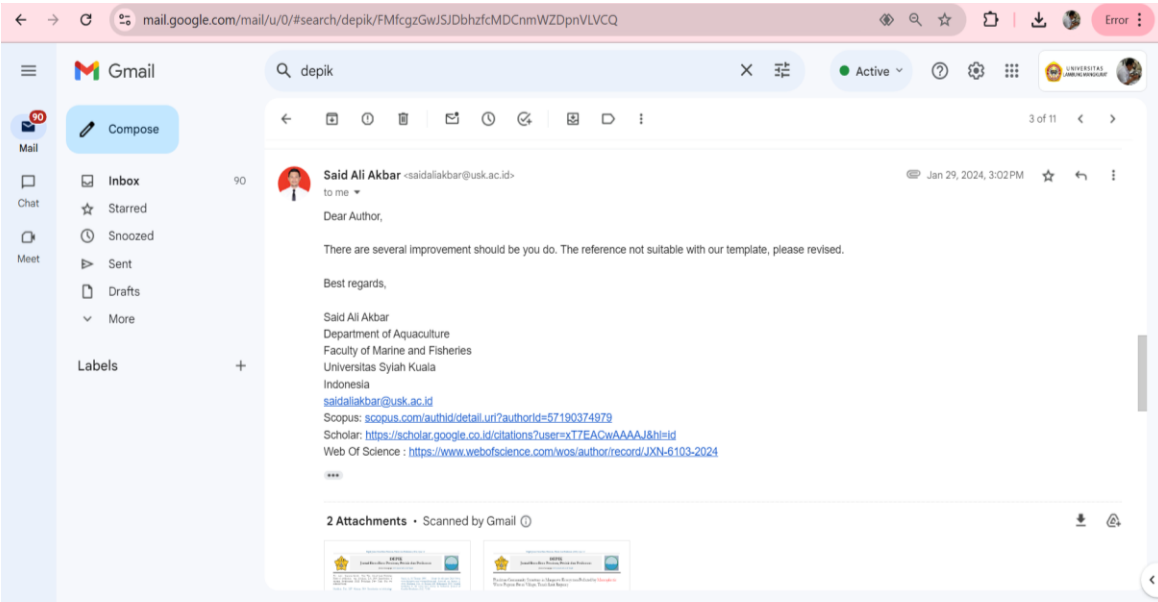

Said Ali Akbar <saidaliakbar@usk.ac.id>
to me

Jan 29, 2024, 3:02 PM

Dear Author,

There are several improvement should be you do. The reference not suitable with our template, please revised.

Best regards,

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Plankton Community Structure in Mangrove Ecosystem Polluted by Macro plastic Waste Pagatan Besar Village, Tanah Laut Regency

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ABSTRACT

Plastic waste continues to increase all the time without decreasing or ending, resulting in the sustainability and restoration of the mangrove ecosystem needing to be improved. The mangrove ecosystem is a place where plastic waste accumulates. This research aims to identify the type abundance of plankton, waste, and water quality. Sampling was carried out purposively from June to July 2023. STA 1 represents is rivers, STA 2 is estuaries and STA 3 was coastal mangroves. Plankton, plastic waste, and water quality samples were collected at the beginning of each month based on a 1x1 m² plot. These results indicated that mangroves in the village of Pagatan Besar are dominated by *Avicennia marina*, *Avicennia alba*, *Bruguierra cylindrica*, and *Rhizopora apiculata*. The highest density of was in STA 3, but it was inversely proportional to the abundance and diversity of plankton due to the dense waste cover between the roots, mainly plastic materials. The most significant increase in marine waste accumulated in STA 3 from 6155 grams at the beginning of the observation to 13820 grams. The most significant composition of waste in STA 3 consists of plastic, bottles and plastic cups. *Cyanophyta, Chlorophyta,* and *Chrysophyta* are phyla phytoplankton from the site. The types of phytoplankton that are always present in all STA's are *Gonatozygon* and *Ulothrix* from *Chloropyta. Rotifera* and *Ciliophora* as zooplankton are often performed at all stations and repetitions. The survival of plankton and mangroves is influenced by water temperature, pH, salinity, dissolved oxygen, and the type of material density of macro plastic waste.

Introduction

The increasing number of residents and visitors to the Takisung Beach tourist attraction has increased plastic waste pollution in the mangrove ecosystem in Pagatan Besar Village. Plastic waste from human activities always increases every year and has a direct impact on the aquatic biota of mangrove areas. Even though various regulatory and socialization instruments have been rolled out, the amount of plastic waste continues to increase on marine shores (Lamb *et al.,* 2018), estuaries and breakwater (Smith and Edgar, 2014) as well as mangrove ecosystems as accumulators of plastic waste (Wade *et al.,* 1991; Juliana *et al.,* 2014).

The accumulation of plastic waste encourages microbial colonization, disease and prevents photosynthesis in mangroves (Manullang and Suyadi, 2020). The accumulation of plastic waste can reduce the rate of mangrove recruitment. Plastic waste kills mangroves in the seedling phase (Makowski and Finkl, 2018). The accumulation of plastic waste able to reduce the aesthetic value of mangroves from ecotourism activities.

Plastic waste research has been focused on aspects of abundance (Calcar and Emmerik, 2016; Tibbetts *et al.,* 2018; Emmerik and Schwarz, 2019; Riskiana *et al.,* 2020), impact on fish (Sequeira *et al.,* 2020; Sui *et al.,* 2020; Assuyuti *et al.,* 2018). Another study informs of economic losses experienced by fishing vessels or fishing gear (Lee, 2014), damage to ship propellers (Watskins, 2015), damage to fishing boats (Takehama, 1990) and aesthetic decline of Morotai Island's Dodola beach (Idrus *et al.,* 2023) due to plastic waste.

Mangroves are coastal plants influenced by sea tides that are capable to adapt to changes in salinity (Kusmana and Sukristijiono, 2016), inhabit shallow and muddy beaches (Nagelkerken *et al.,* 2008; Kusmana and Ningrum, 2016), coastal protection (Tarigan, 2008), trophic system buffer in the sea

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Available online dd mm yy

(Bulow and Ferdinand, 2013) and productivity contributor to shrimp and fish (Dafikri *et al.,* 2016; Manson *et al.,* 2005).

Disruption to mangrove ecosystems due to the accumulation of macro plastic waste has an impact on damage to aquaculture activities, disruption of fish habitat and siltation. This condition causes ecological problems in changes in the structure, composition, productivity and function of aquatic ecosystems, especially plankton, which are directly associated with mangroves.

Indicators of diversity, uniformity and dominance of aquatic plankton become the focus of management. Macro plastic waste piles, especially from inorganic materials that cover the surface of the waters, inhibit the rate of photosynthesis of phytoplankton, and the role of roots decreases (Thamaga and Dube, 2018).

Nevertheless, it will interfere with the growth and interaction of plankton that depend on its life with mangrove ecosystems. Therefore, this study aims to identify the type abundance of plankton and garbage as well as the water quality of the Pagatan Besar mangrove ecosystem. The data displayed in this study is the latest local data related to mangrove plankton. The level of plankton vulnerability qualified used as a diagnostic of mangrove environmental conditions due to plastic waste on the coast of Pagatan Besar.

Materials and Methods

Location and time of research

This research was carried out from June to July 2023, located on the Pagatan Besar, Takisung District, Tanah Laut Regency, South Kalimantan (Figure 1). The sampling location consists of three locations represented the ecosystem characteristics of the STA-1 river, the STA-2 estuary, and the STA-3 coastal mangrove.

Samples collection and identification procedure

Macroplastic samples were taken from transects covering an area of 100 m^2 towards the sea, in which plots measuring 1x1 m^2 were installed at all locations. Area cover of transect area with high and low mangrove density. The macro plastic data taken included the number of pieces and type, length, weight, and thickness of the macro plastics on the substrate excavated on the plot.

Plankton and water quality samples were collected from the waters around the mangroves. Sampling was conducted in the first week of June and July 2023 (twice) dry season. Water quality analysis from temperature, transparency, dissolved oxygen (DO), pH, and salinity parameters in situ. The instruments used have been calibrated.

Data analysis

Plankton identification refers to the titles of Huyn L and Serediak (2006), Bigg and Kilroy (2000), Yunfang (1995), Bellinger and Singee (2010). The abundance of plankton was calculated using an Sedgwick-Rafter Counting Cell (SRC) cell/m^3 or ind/m^3 (Baird *et al.,* 2017).

$$K = n\ x \frac{Vt}{Vsrc} x \frac{Asrc}{Aa} x \frac{1}{Vd}$$

Notes: K = Plankton abundance (cell/m^3 or ind/m^3); n = number of observed plankton; Vd = volume of filtered water sample (m^3); Vt = volume of water in the sample bottle (ml); Vsrc = volume of water in the SRC (ml); Asrc = SRC's area of view (1000 mm^2); Aa = area of view (mm^2)

Shannon-Wiener diversity index (Odum, 1993):

$$H' = -\sum_{i-1}^{n} \text{pi} \ln \text{pi}$$

Notes: H' = Shannon-Wiener diversity index; Pi = ni/N; ni = number of individual species-ith; N = total number of individuals; H'< 1 = the biota community is unstable; 1<H'<3 = The stability of the biota community is moderate; H'> 3 = the stability of the biota community is in prime condition (stable).

Evenness index (Michael, 1994):

$$E = \frac{H'}{H\ max}$$

Notes: E = Evenness index; H' = Shannon Wiener diversity index; H max = Ln S (S is the number of genera); E = 1 the number of individuals of each species is relatively same.

Simpson Dominance index (Odum, 1993):

$$C = \sum_{n=1}^{n} (\frac{ni}{N})^2$$

Notes: ni = the number of individuals of each species, N = the total number of individuals. The dominance index values ranged from 0-1. A value one indicates that there is dominant.

Identification of mangrove species was carried out visually on selected transects. Waste identification is carried out visually from the origin of the material and the calculation of its weight, abundance, and percentage. The composition of the waste is divided into organic and inorganic (Tangdesu, 2018; Johan *et al.,* 2020), then divided according to the categories of plastic, rubber, metal, glass, wood, and derivatives (Djaguna *et al.*, 2019).

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Analysis of abundance and waste composition/percentage refers to Coe and Roger (1997); Johan *et al*., (2020):

$$Density = \frac{The\ Number\ of\ waste\ (item)}{Area\ (m^2)}$$

$$Density\ (weight\ of\ waste) = \frac{The\ Weight\ waste\ (gram)}{Area\ (m^2)}$$

$$Composition\ marine\ debris = \frac{The\ Number\ of\ Pieces\ in\ Category\ (gram)}{Total\ Weight\ of\ waste\ (gram)} \times 100\%$$

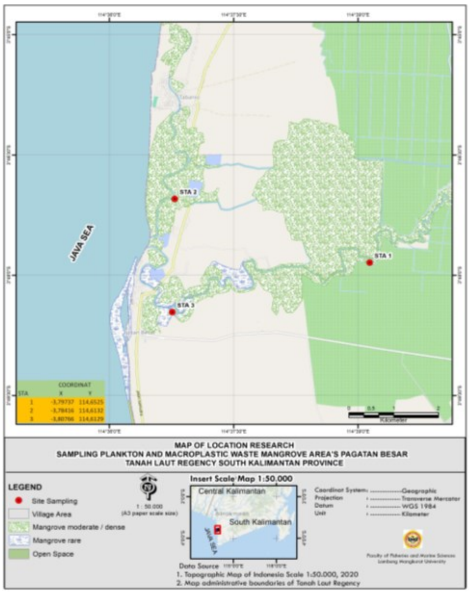


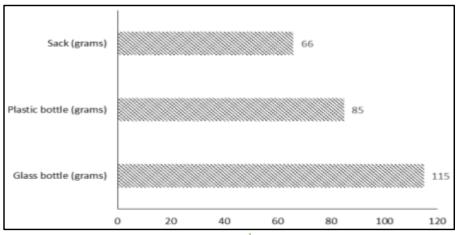
Figure 1. Map of sampling locations

Results

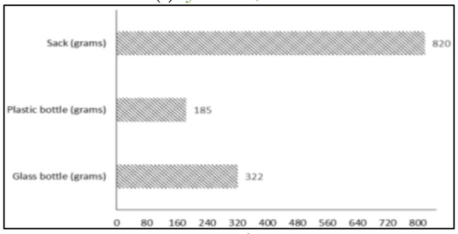
Mangroves and the abundance of plastic waste

There are only two species of mangroves found at STA 1, which are *Acanthus ilicifolius* and *Rhizopora apiculata*. Garbage dominates in this location from plastic bottles and glass. Mangrove species found in STA 2 are *Avicennia marina*, *Avicennia alba*, *Bruguierra cylindrica*, *Pandanus odoratissima* and *Rhizopora apiculate*. The dominant waste in this location is plastic materials in bottles, hoses, glass bottles, clothes, and cans. Only one species mangrove in STA 3 is *Avicennia marina* from previous reforestation activities and in the sapling, but in between, the roots have been covered with various kinds of waste, especially plastic food packaging materials, plastic bags, bottles, and mineral water glasses.

The results of marine debris monitoring at the three stations in Pagatan Besar Village during June and July have increased for STA 1 with total from 266 grams to 1327 grams, dominated by glass bottle and sack (Figure 2). Furthemore for STA 2 from 775 grams to 800 grams, dominated by plastics bottle, hose (Figure 3).

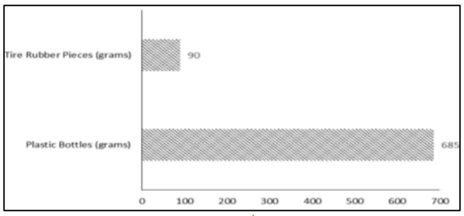


(a) June 4th, 2023

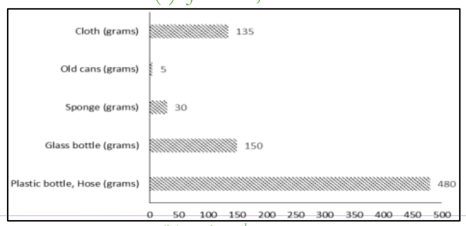


(b) July 4th, 2023

Figure 2. Waste composition STA 1



(a) June 4th, 2023



(b) July 4th, 2023

Figure 3. Waste composition STA 2

Marine debris accumulates the most in STA 3. The total number of waste weight in STA 3 from 6155 grams at the beginning of the observation to 13820 grams at the end, dominated by plastic, bottle, cup. The new waste in STA 3 is diaper found on July 2023. Styrofoam material was only identified at STA 3 from 40 grams to 180 grams. (Figure 4).

Commented [A3]: Mangrove species found in STA 2 are A. marina, ……,… . only one species mangrove in sta 3?

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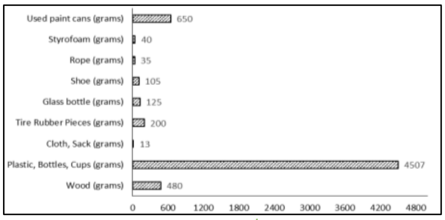
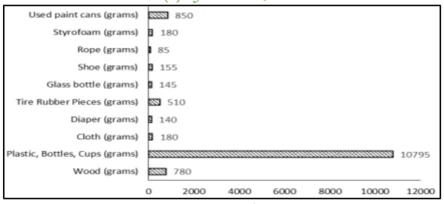


(a) June 4th, 2023



(b) July 4th, 2023

Figure 4. Waste composition STA 3

Plankton Community Structure and Water Quality

The results of plankton analysis at the study site during June (repetition 1) and July (repetition 2) 2023 obtained three phyla in STA 1 and STA 2, while STA 3 phyla found only 2 in all tests. The plankton phylum in question consists of *Cyanophyta*, *Chlorophyta*, and *Chrysophyta*. The types of plankton always present at all stations are *Gonatozygon* and *Ulothrix* from *Chloropyta*. The structure of plankton is the same, but the number is reduced for the 2nd test less than the 1st test (Table 1).

Table 1. Phylum plankton at the study site between June and July 2023

Phylum	Genera	Sample Code					
		STA 1_June	STA 1_July	STA 2_June	STA 2_July	STA 3_June	STA 3_July
Phytoplankton							
Cyanophyta	*Oscillatoria*	+	+	+	+	-	-
	Microcystis	-	-	+	-	-	-
Chloropyta	*Gonatozygon*	+	+	+	+	+	+
	Pediastrum	-	+	+	-	-	-
	Westella	+	+	+	+	-	-
	Schroederia	+	+	-	-	-	-
	Closterium	+	+	-	+	+	+
	Pediastrum	+	-	-	+	-	-
	Ulothrix	+	+	+	+	+	+
Chrysophyta	*Odontella*	+	-	+	-	-	-
	Rhizosolenia	-	-	+	+	-	-
	Tabellaria	-	-	-	+	-	-
	Corethron	+	+	-	-	+	+
	Navicula	+	+	-	+	+	+
	Nitzschia	-	-	+	+	+	+
	Synedra	+	+	+	-	-	-
Zooplankton							
Euglenozoa	*Phacus*	-	-	-	-	+	-
Rotifer	*Keratella*	-	-	-	-	+	-
	Lecane	+	+	-	-	-	-
Ciliophora	*Spirostomum*	-	-	+	+	-	-
	Dileptus	-	-	-	-	+	+

Remarks : (+) Present; (-) Absensce

STA 2, located at the estuary, identified of phytoplankton genera in repetitions 1 and 2. While in the 2nd repetition found the change of genera into *Closterium*, *Pediastrum*, *Westella*, *Tabellaria* and *Navicula*. The condition of STA 3 compared to other STAs has decreased, represented by genera *Corethron*, *Navicula*, *Nitzschia*, *Gonatozygon*, *Closterium*, and *Ulothrix*. In contrast to phytoplankton, zooplankton composition was more abundant in STA 3 in repetition 1 but decreased to one genus in repetition 2.

Characteristics of water, biota, and waste quality between stations

Observation of water quality values of Dissolved Oxygen (DO), pH, temperature, salinity and transparency show the normal range (Table 2). Water quality values vary depending on the characteristics of the sampling location between rivers, estuaries and mangroves. The phytoplankton community is still in moderate condition, while zooplankton condition is unstable. A water body is classified as lightly polluted if the DO value ranges from 4.5 to 6.5.

Table 2. Water quality parameters and index plankton of the Pagatan Besar, Takisung District

Parameters	STA 1		STA 2		STA 3	
	June	July	June	July	June	July
Water quality						
Temperature (⁰C)	29	31	27	28	30	33
Transparancy (cm)	90	95	23	92	72	70
DO (mg/l)	5	5.1	5.7	5.8	5.3	5.1
pH	7	6.92	7.21	7.32	7.07	7.05
Salinity (‰)	12.2	11.8	20.1	21.2	18.3	19.8
Phytoplankton						
Abundance (cell/m^3)	2680	3140	940	1620	1190	960
Shannon-Wiener diversity index	1.95	1.93	1.5	2.08	2.06	0.8
Evenness index	0.81	0.85	0.84	0.89	0.9	0.84
Simpson Dominance index	0.19	0.17	0.27	0.15	0.14	0.27
Zooplankton						
Abundance (cell/m^3)	230	60	50	100	100	50
Shannon-Wiener diversity index	0.97	0	0	0	0	0
Evenness index	0.89	0	0	0	0	0
Simpson Dominance index	1	1	1	1	1	1

The results of statistical tests on water quality parameter components are only pH, transparency, Dissolved Oxygen (DO), and salinity which have significant values (Table 3). The pH between STA 2 and STA 1 is significant ($p = 0.029$) and transparency is significant ($p = 0.042$) too. The transparency between STA 2 and STA 3 shows a highly significant ($p = 0.001$), and transparency between STA 1 and STA 3 shows a significant ($p = 0.003$). The Dissolved Oxygen (DO) levels between STA 2 and STA 1 show a significant ($p = 0.012$), and between STA 2 and STA 3 show a significant ($p = 0.024$) too. The salinity levels between STA 2 and STA 1 show a significant ($p = 0.003$) and between STA 3 and STA 1 show a significant ($p = 0.006$) too. The statistical test values for the biological index of phytoplankton and zooplankton are only significantly different in the

Commented [A6]: Plankton. Zooplankton also in the table

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dominance index, while in the abundance of waste material from plastics, fabrics, sacks, and cans. Components of significant value are differentiating and characterizing factors between research locations.

Table 3. One Way ANOVA test of water quality, biological index, and waste abundance from each research location confidence level 0.05

Parameter	Station	Mean Difference (between STA)	Sig. Anova	Levene test	Sig. Post Hoc Tests	Conclusion
pH	STA 2 vs 1	0.300(*)	0.029	0,000	0,000	Significant
Transparancy	STA 2 vs 1	2.040(*)	0.042			
	STA 2 vs 3	7.385(*)	0.001			
	STA 1 vs 3	5.345(*)	0.003			
DO	STA 2 vs 1	0.700(*)	0.012			
	STA 2 vs 3	0.550(*)	0.024			
Salinity	STA 2 vs 1	8.700(*)	0.003			
	STA 3 vs 1	7.100(*)	0.006			
Simpson Dominance Index	STA 3 vs 2	0.116(*)	0.018			
	STA 3 vs 1	0.103(*)	0.025			
Plastic waste	STA 2 vs 1	0.622(*)	0.037			
	STA 3 vs 1	0.586(*)	0.043			
Clotch waste, sack	STA 1 vs 2	0.692(*)	0.006			
	STA 1 vs 3	0.623(*)	0.008			
Old cans	STA 3 vs 1	0.079(*)	0.025			
	STA 3 vs 2	0.076(*)	0.028			

Remarks : (*) significantly

Discussion

Mangrove species in the study site were dominated by *Avicennia marina* and *Rhizopora sp*, due to differences in environmental factors and anthropogenic disturbances (Gumilar, 2012). *Avicennia sp.* is able to good reproduction and grow quickly (Sarno, 2016). The appearance of mangroves that still saplings and seedlings in Pagatan Besar Village is caused by the presence of mangroves that died at the beginning of the growth period as well as failure of the germination process and environmental conditions. The failure of the sprouts is due to the absence of a substrate for the germination process because it is covered by plastic waste. The type of sandy mud substrate influences mangrove growth in addition to water temperature, pH, and salinity (Agustini *et al.,* 2016). Suboptimal nutrient absorption can have an impact on tree growth and development. One of them is macroplastic, which covers the substrate and becomes an obstacle to the absorption of nutrients by the roots (Kantharajan *et al.,* 2018).

The plankton composition of waters polluted with plastic waste is lower than those without it (Dodson *et al.,* 2009; Rahayu *et al.,* 2013; Widyarini *et al.*, 2017; Persada *et al.* 2022; Yunandar *et al.,* 2023). It can be that the composition of the phyla *Chrysophyta* and *Chlorophyta* is balanced, while *Cyanophyta* is the lowest. Phylum *Cyanophyta* is present in 2 locations, while *Chlorophyta* and *Chrysophyta* are scattered at all observation stations. Zooplankton are more diverse in STA 3 than the other 2 STA. The population is more experienced by STA 1 and STA 2, but STA 3 has decreased due to increased waste generation, which accelerates coastal sedimentation. The amount of waste, especially from plastic materials, supports the reduction of water biota. This statement is supported by Idrus *et al.,* (2023), in which inorganic debris got more to plastic bottles and glasses with a value of 65,56% to 79,17%. Plastic waste dominates other waste (Purba *et al.,* 2018).

The diversity of types of waste at the location amounted to 9 types identified in the plot created, STA 3 was where waste was found compared to the other 2 STAs. Plastic waste in mangrove areas seriously disrupts physical and ecological functions. The biological process of mangroves prevents coastal erosion, block waves and seawater from entering the land (seawater intrusion). Meanwhile, the environmental role is as a place to feeding ground, to maintain and cultivate mangrove biota (spawning/nursery area), and to exchange nutrients. Plastic waste that crushes mangrove roots is degraded into debris that remains in the aquatic environment. Larger plastic fragments that stay for a long time can become smaller due to weathering and mechanical energy, such as ocean waves. Plastic breaks down into microplastics with a diameter smaller than 5 millimeters. Microplastics that enter the marine food chain at low levels affect the entire food chain. The survival of plankton is influenced by water quality, such as temperature, pH, salinity, and dissolved oxygen. The water temperature at the study site is 29.6 ℃ to 30 ℃ and suitable for plankton survival. The temperature range plankton tolerates is 25 to 32℃ (Hutabarat and Evans, 1985). The salinity obtained in Pagatan Besar Village is 11.8 to 21.2 $^{0}/_{00}$. Field observations show that in the range of salinity values, there are still different types of plankton between STA and its repeats, although there is a decrease genera in STA 3 to two classes. It means that plankton with existing genera have good tolerance to changes in salinity in the waters. Odum (1998) states that salinity in estuaries varies greatly, and living biota have a good tolerance level to changes in salinity.

pH parameters influence the survival of aquatic biota. The pH value obtained at the study site is suitable for plankton life. pH values between 6 to 7.5 are still tolerated by plankton for their survival. The dissolved oxygen content is a factor that affects the survival of biota. The value of dissolved oxygen is a suitable condition for the survival of plankton and other aquatic biota. The limit value of dissolved oxygen for marine biota is ≥ 5 mg/L. The range of oxygen content in the field of 5.3 to 5.6 mg/L includes conditions suitable for aquatic organisms. The shape of muddy substrates polluted with plastic waste in mangrove ecosystems can still be tolerated

Commented [A8]: What kind of destruction? Change to the most 'waste' so that plankton and other marine biota can survive changes in the quality of this aquatic environment. In each type of mangrove, there is a different plankton content. The most plankton are STA 1 and 2, natural habitats, while the lowest in STA 3 relies on *Avicennia* from planting activities (reforestation). This condition shows the relationship between mangrove density and plankton abundance in the waters. As an organism that can photosynthesize, plankton, in its breeding, require light. The density of mangroves affects the lightness and cover of the canopy. The canopy cover area affects the intensity of light entering the mangrove roots at low tide, and sea level at high tide that inundates the mangrove area.

The primary productivity of phytoplankton largely depends on the intensity of light reaching the surface of the water. Each type of mangrove contains different plankton content (Halidah, 2016). The increase in salinity followed by the abundance and diversity of plankton in zones that are overgrown by various mangrove vegetation, so it is very support of phytoplankton life. STA 2 which is an estuarine ecosystem shows that higher phytoplankton abundance, due to nutrient out welling from swamp and tributary mangrove sediments, thus supporting the high phytoplankton biomass in estuarine waters (Saifullah *et al.,* 2016). Class *Chlorophyceae* is the dominant class and is almost found in all mangroves in the tropics. This is because *Chlorophyceae* are cosmopolitan, have high tolerance and adapted to environmental conditions (Thoha and Amri, 2011) and marine environment (Casteleyn *et al.,* 2010). Class *Chlorophyceae* is able to grow rapidly even in low light and nutrient conditions (Nybakken, 1992). This is because this type of phytoplankton has the ability to adapt well so that it is able to regenerate and reproduce in greater numbers than other types. This type of plankton is the type that is most resistant to environmental changes by tidal influences. The abundance of phytoplankton in a body of water is always closely related to the conditions around the aquatic environment.

The ability of aquatic organisms to adapt to changing environmental conditions causes their existence in nature to be influenced by pollutants such as macro plastics. Differences in abundance and types of marine biota found at the study site due to differences in environmental conditions. At high tide, the water level in the estuary waters is higher than the low tide, resulting in a lot of plankton entering the estuary due to currents and waves from the sea. (Saifullah *et al.,* 2016).

The back-and-forth movement of water masses is essential in removing pollutants from the ecosystem and transporting food, and nutrients from the surrounding environment. This condition affects the abundance of plankton, especially phytoplankton and biota, in the early stages. The quantity of phytoplankton and zooplankton is higher at high tide than at low tide (Andriani *et al.,* 2015; Nugroho *et al.,* 2020). The high biomass of phytoplankton in estuaries is caused by nutrients coming out of the mangrove area and tidal mixing of water, while the decrease in biomass is due to nutrient consumption (Saifullah *et al.,* 2016).

The existence of plankton in an aquatic ecosystem is influenced by biotic factors (competition between species) and the presence of predators. In contrast, abiotic factors are influenced by physical, chemical, aquatic, and human activities (Cronk and Fennessy, 2001; Elger *et al.,* 2004; Sahidin *et al.,* 2021). Components that contribute to the abundance of a plankton species are stability, environmental heterogeneity, primary productivity of ecosystems, and the presence of predators and competitive interactions between species. The overall plankton abundance tends to fluctuate at all study sites; this condition is directly proportional to the density of mangroves and the quantity of waste. The diversity of plankton in the study site could be more diverse or even higher, evidenced by the identification of certain types of plankton that are able to adapt to environmental conditions. Low plankton diversity due to the low diversity of mangrove species (Fachrul, 2007; Novianto, 2011 and Azwar, 2013). The uniformity value is relatively evenly described as an increase in mangrove and plankton growth supported by calm waters and weak currents. Overall, the uniformity index value obtained during observations is quite evenly distributed, and the dominance index value is low.

The role of zooplankton is essential in the food chain cycle in estuaries because it is one of the intermediaries that converts energy from plants into energy for animals (Romimohtarto and Juwana, 2009). Meanwhile, phytoplankton have a role as producers, which are a source of energy for other living organisms (Desyana *et al.,* 2017).

Marine debris impacts life through five mechanisms, namely (1) the digestive system and the trapping of biota, (2) accumulates and spreads to other regions, is toxic, bioavailability and impacts through the food chain, (3) as a vector of invasive species, (4) impacts on habitat and seabed life, and (5) impact economically (Stevenson, 2011). Plastic is a vector in the spread of microalgae that causes blooming (Maso *et al.,* 2003) and heavy metal (Holmes, 2013). The number of macro plastic pieces affects the presence and abundance of aquatic biota in mangrove ecosystems. The large number of plankton is strongly suspected because it is found in locations with small amounts of macro plastics. Macro plastics can affect the availability of habitats for faunal groups such as mollusks and crabs (Kantharajan *et al.*, 2018). It indicates that with the reduction of habitat for biota, its presence in a place is decreasing. Another study also explained that during the degradation process, macro plastics produce toxic chemical compounds that can reduce the number of offspring, cause reproductive failure, and interfere with the development of larva biota in mangroves (Hammer *et al.,* 2012).

Plastic is made of hydrophobic materials, so contaminants on its surface act as reservoirs of toxic chemicals in the environment (Ivar do Sul and Costa, 2013). Heavy metals such as Cd, Co, Cr, Cu, Ni, and Pb can stick to plastics by being affected by pH and salinity. The ability of Cd, Co, Ni, and Pb to stick to plastics may increase with increasing pH and decreasing salinity. Still, conversely, the ability of Cr to attach to plastics may decrease. Plastics contain organic contaminants, including *polychlorinated biphenyls* (PCBs), *polycyclic aromatic hydrocarbons* (PAHs), *petroleum hydrocarbons*, *organochlorine pesticides*, *polybrominated diphenyl ethers*, *alkylphenols*, and *bisphenols* that cause chronic effects such as endocrine disruption in aquatic biota (Teuten *et al.,* 2009). The threat to the species is the absorption of PCBs through the digestive system (Derraik, 2002). Contaminants that can survive and accumulate through the food chain can harm human health. Marine mammals, birds, fish, and turtles receive the impact of marine debris pollution (STAP, 2011). The group of animals most affected by marine debris are mammals. Debris particles also affect the digestive system of sponges, cnidarians, worms, crustaceans, mollusks, bryozoans, echinoderms, ascidians, algae, seagrasses, and plankton (UNDP-SCBD, 2012).

The amount of plastic able to covered the essential soil of mangrove vegetation and *pneumatophores* (unique roots that grow upwards and allow the exchange of oxygen and carbon dioxide). Such root capillary pressure can force bubbles out of the lenticels in many *pneumatophores*. Interconnectivity between pneumatophores originating from the same root minimizes the effects of plastic scattering in the sediment, which covers only a few root pneumatophores. The remaining pneumatophores can keep the sediment oxygenated at all times. In addition, the plastic can still be carried back by the tide, causing only temporary suffocation of the roots.

In contrast, plastic on top of pneumatophores during sedimentation events can persist for weeks or months, depending on the incoming tidal wave. Some of the plastic in the sediment was there for a long time because more than half of the plastic found was buried under 2 cm of sediment. The finding that plastic is not only trapped but also buried in mangrove sediments is in agreement with Costa *et al.*, (2011), who found plastic in varying degrees of degradation buried to a depth of at least 20 cm in mudflats on the fringes of mangroves in Brazil. The amount of plastic buried in the sediment at the site is equal to the layer of plastic visible on the surface of the sediment, causing a stress effect. Because penetration of oxygen into the sediment through the sediment surface and pneumatophores increases disturbance, this condition makes it difficult for root respiration by the tree due to plastic stress. The adaptation made by mangrove roots due to being covered in plastic in their root zone responds with extreme root elongation to overcome this suffocating substance. If roots are 100% covered by plastic, they will die, but 50% plastic coverage shows that the mangrove is able to withstand suffocation. Resistance to repeated anoxic conditions is a characteristic of all mangrove species; in addition to evolutionary adaptations of roots, most mangrove species can adapt to prolonged flooding events (Youssef and Saenger, 1996).

Twisted roots indicate the tree is trying to overcome the substance gripping it. The disposal of plastic waste into the environment is expected to increase in the future (Jambeck *et al.,* 2015). Mangroves are relatively cheap ecosystems to restore compared to other marine ecosystems (Narayan *et al.,* 2016). However, success is still low compared to marine ecosystems, such as coral reefs (Bayraktarov *et al.,* 2016). The success rate of mangrove restoration has the potential to increase, in addition to the availability of budget for mangrove planting and mitigation of plastic waste reduction

Conclusion

Cyanophyta, *Chlorophyta* and *Chrysophyta* are plankton phyla from the research location except in STA 3 without the presence of *Cyanophyta*. The plankton genera always present at all stations are *Gonatozygon* and *Ulothrix* from *Chloropyhta*. The most extensive waste composition in STA 1 is glass bottles and sacks, STA 2 is plastic bottles, and STA 3 consists of plastic bottles and glass. The most significant increase in marine debris accumulated in STA 3, from 6155 grams at the beginning of the observation to 13820 grams. Based on stations, value of waste composition in STA 3 July (plastic bottle, cups) in location is 10795 grams, and the lowest at STA 2 is 5 grams for oil cans. The survival of mangroves and plankton is influenced by pH, brightness, dissolved oxygen, salinity, dominance, taxa, and waste materials, mainly plastic. Mitigation studies related to trash traps on mangrove roots will increase the success rate of restoration.

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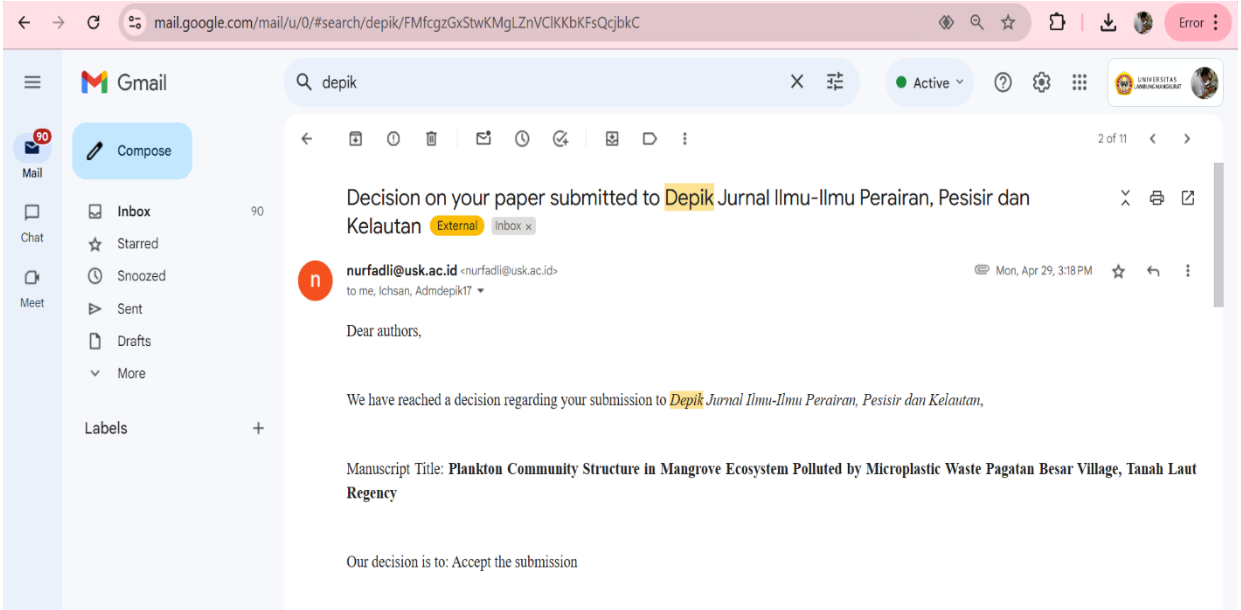
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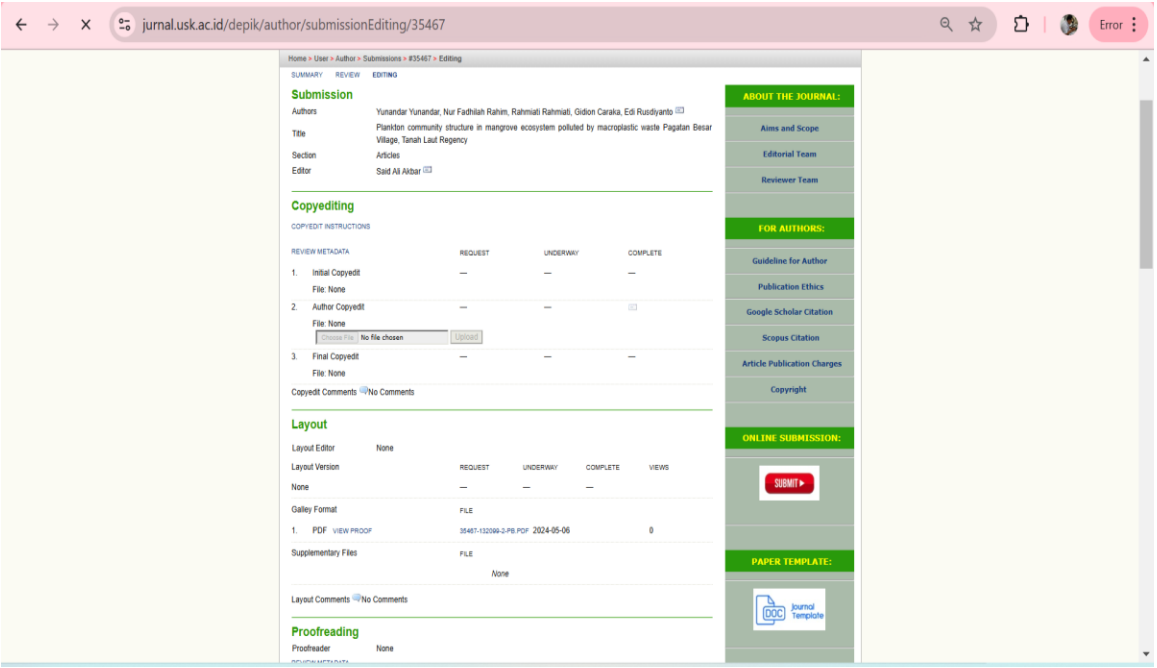

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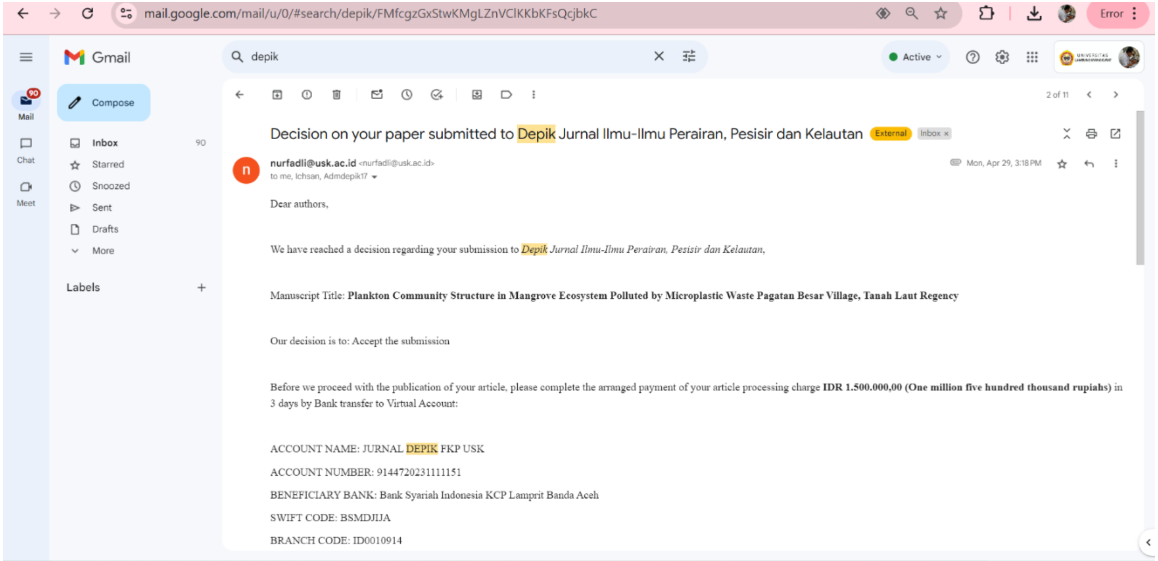

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TITLE AND ABSTRACT

Title: Plankton community structure in mangrove ecosystem polluted by macroplastic waste Pagatan Besar Village, Tanah Laut Regency

Abstract

Plastic waste continues to increase all the time without decreasing or ending, resulting in the sustainability and restoration of the mangrove ecosystem needing to be improved. The mangrove ecosystem is a place where plastic waste accumulates. The accumulation of plastic waste prevents photosynthesis in mangroves, reduces aquatic productivity and encourages microbial colonization. This