Journal of Coastal and Ocean Sciences
Volume 5 No. 3, September 2024: 195-207

e-issn: 2746-4512
p-issn: 2745-4355

Composition and Abundance of Marine Debris and Microplastic in the West Coast Mangrove Ecosystem of Bintan Island

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Received: 4 August 2024; Accepted: 9 September 2024

ABSTRACT

Plastic waste has been identified as an environmental problem by the UN Environment Program because it causes damage to the marine environment, organisms, and critical habitats. One ecosystem vulnerable to plastic waste is mangroves, so the government continues to tackle this problem. Bintan Island has a relatively large mangrove ecosystem, and some of it is included in the vulnerable category, so it is necessary to conduct a study regarding plastic waste and microplastics on Bintan Island. The research aims to identify the abundance of macro and meso debris in the mangrove ecosystem area, the abundance and characteristics of microplastics in sediment in the mangrove ecosystem area, microplastic contamination in gastropods (*Telescopium* sp), the relationship between mangrove density and macro debris density, and the relationship between macro debris density and mesoderm and microplastic. The research was conducted in October 2021 in Bintan Regency and Tanjung Pinang City. Data was collected using survey methods, microplastic abundance analysis, and correlation analysis. The mass of macro debris in the Tanjungpinang City administrative area is 743 g/m^2. It is dominated by plastic, with a percentage of 49%, and meso debris, 94% of the total waste, is dominated by plastic waste. The characteristics of microplastics in sediment at each sampling location consist of fibers, fragments, and films. The most common microplastic contamination in *Telescopium* sp in the Bintan Regency area was film-type microplastics, totaling 198.33 particles. The relationship between mangrove density and macro debris generation is very strong, with a correlation value of 0.872. The relationship between the abundance of macro debris and meso debris and microplastics was strong, with correlation values of 0.972 and 0.793, respectively.

Keywords: Macro Debris, Mangrove, Meso Debris, Microplastic

1. INTRODUCTION

Plastic waste represents 80-85% of the total marine debris (Derraik, 2002; UNEP, 2016) and has been identified as an environmental problem by the United Nations Environment Programme (UNEP, 2014) due to its damage to the marine environment organisms, and critical habitats. It is estimated that 8 million tons of plastic waste are dumped into the world's oceans yearly (Jambeck et al., 2015). The increasing production of plastic, coupled with slow degradation rates and improper disposal, can result in the continuous accumulation of plastic in the marine environment. Larger plastics released into the environment will degrade through mechanical processes, leading to the formation of new contaminants known as microplastics (Alimba & Faggio, 2019; Barnes et al., 2009).

Based on their source or origin, microplastics are generally divided into primary and secondary microplastics. Primary microplastics are intentionally made as microfibers used in textiles, microbeads in cosmetic products and scrubbers, and other microparticles used in various industrial processes (Cole et al., 2011; Naik et al., 2019), which are unintentionally or intentionally released from land-based activities and eventually enter the marine environment. Meanwhile, secondary microplastics are the result of the disintegration and weathering of macroplastics into smaller pieces by individual or combinations of physical, chemical, and biological processes (Alimba & Faggio, 2019; Naik et al., 2019; Wagner, 2018). These small plastic particles are mistaken for food by various marine organisms at almost every trophic level, including fish, invertebrates, turtles, seabirds, and large marine mammals (Auta et al., 2018;

Fred-Ahmadu et al., 2020). Once absorbed, the presence of microplastics can cause a series of adverse health effects on marine species, such as reduced feeding activity, weight loss, slow somatic and reproductive growth rates, and low fecundity rates (Lusher et al., 2017; Trestrail et al., 2020). Additionally, microplastics have the potential to act as vectors in the transport of persistent organic pollutants and heavy metals present in the environment due to their larger surface area, coupled with non-polar surfaces allowing, microplastics to absorb these chemical contaminants (Brennecke et al., 2016; Koelmans et al., 2016; Naik et al., 2019). Evidence suggests that microplastics in the sea are easily dispersed or transported over long distances by surface currents, winds, and tides, reaching coastal areas (Galgani et al., 2015).

Mangrove ecosystems are intertidal transition ecosystems in tropical and sub-tropical regions around 30°N and 30°S. These ecosystems are very important for populations in coastal zones in providing wood products and food sources, organism habitats, protecting coastal areas from the adverse effects of natural disasters such as wind and sea waves, and transporting carbon and nutrients to surrounding coastal or marine zones (Bayen, 2012; Dittmar et al., 2006; Kulkarni et al., 2018). Mangrove ecosystems are among the most threatened and vulnerable tropical ecosystems due to continuous exposure to contaminants, especially those from anthropogenic activities (Bayen, 2012). The uniqueness of mangrove ecosystems due to high primary production and abundant organic carbon identifies them as important absorbers for a broad spectrum of contaminants from land-based and marine activities (Bayen, 2012; Nor & Obbard, 2014).

Surface currents and waves are the main factors for delivering marine debris to mangrove areas (Martin et al., 2019). More importantly, the height of vegetation stands and the density of mangroves on the coast make waste easily trapped in these areas (Sul et al., 2014; Nabizadeh et al., 2019). In addition, the distance from population centers has also been shown to correlate positively with the abundance of plastic in mangrove areas (Garcés-Ordóñez et al., 2019). Once exposed to the environment, plastic waste in mangrove forests can decompose into microplastics. The prevalence and distribution characteristics of microplastics in the coastal mangrove ecosystem of Bintan Island have not been comprehensively studied compared to other marine environments or coastal areas such as estuaries.

The Indonesian government is committed to reducing 70% of marine debris by 2025. The government's seriousness in addressing marine debris is demonstrated by the issuance of Presidential Regulation Number 83 of 2018, which contains strategies for tackling marine debris in 2018-2025. The issuance of this regulation is the government's target in achieving the SDGs, namely protecting aquatic ecosystems. About 70-80% of marine debris is plastic from land diverted through rivers (Cable et al., 2017).

A study on plastic waste (macro) stranded on the beaches of Bintan Island found 3,378 plastic fragments (Syakti et al., 2019) while floating microplastics identified in Bintan waters amounted to 0.45 sheets per m3, which can be categorized as medium-low levels of microplastic pollution (Syakti et al., 2018). Based on this fact, plastic waste has become a problem for Bintan Island.

Bintan Island has a considerable area of mangrove ecosystems, and some of them are categorized as vulnerable. Activities in the mangrove ecosystem area and other areas on Bintan Island, such as port activities, industry, shipyards, power plants, fish landing sites, and domestic household activities, have the potential to produce plastic waste and pollute the sea. The lack of waste treatment facilities in several settlements around the mangrove area exacerbates this condition. Thus, a study on plastic waste and microplastics in the mangrove ecosystem on Bintan Island was carried out with several objectives.

The research objectives are to identify the abundance of macro and meso debris in the mangrove ecosystem area, the abundance and characteristics of microplastics in sediments in the mangrove ecosystem area, microplastic contamination in gastropods (*Telescopium* sp), the relationship between mangrove density and macro debris density, and the relationship between macro debris density with meso debris and microplastics.

2. RESEARCH METHOD

Time and Place

The research was conducted over one year, starting from October 2021. The research stages included preparation, sampling, sample analysis, and data analysis. The sampling locations comprised six points spread across Bintan Regency and Tanjung Pinang City (Figure 1).

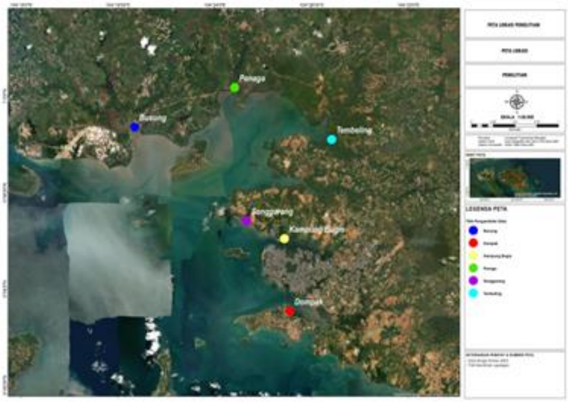

Figure 1. Research location

Methods

The research uses primary data through field sampling, which is then analyzed in the laboratory. Primary data includes direct measurement results of several parameters, both direct measurements in situ (in the field) and in the laboratory.

Procedures

Macro-Debris Sampling

The collection of macro-debris samples (larger than 20 mm) was carried out with three replications every two weeks using transects (1x1 m) from each substation (Smith & Markic, 2013). The grouping of macro-debris composition consists of styrofoam, foam, glass, plastic, rubber, cloth, wood, and metal. The samples taken were then collected in sacks for labeling. Items in each macro-debris group were dried, counted, and weighed. The parameters measured were weight (g/m^2) and number of items (items/m^2) (Peters & Flaherty, 2011).

Microplastic Survey in Sediment

Sediment samples (1L) were taken using a corer divided into three depth levels (0-30 cm). The corer was placed randomly at the outermost mangrove boundary substation and the innermost mangrove boundary. The separation of microplastic particles sized 0.045-5 mm from mangrove sediments went through several stages: (1) drying, (2) volume reduction, (3) density separation, (4) filtration, and (5) visual sorting. Sample drying was used in an oven at 105°C for 72 hours. In the dry sediment volume reduction stage, filtering was done with a 5 mm size (Hidalgo-Ruz et al., 2012). The density separation stage was carried out by mixing dry sediment samples (1 kg) with saturated NaCl solution (3L), followed by stirring the mixture for two minutes (Claessens et al., 2011). At this stage, floating plastics such as polyethylene, polystyrene, and polypropylene were present. The separated density was then filtered with a 45 µm supernatant. The filtered microplastic particles were then visually selected under a monocular microscope to be grouped into four types: fiber, film, fragment, and pellet.

Microplastic Survey in Telescopium

The benthos sample identified in this study was the *Telescopium* sp species, captured randomly at the sampling location. Benthos species were analyzed individually to assess the detection level of MP and the number of each Benthos species. Benthos species were measured for wet weight, dry weight, and body length. Benthos were dissected and sampled following the same steps described by Fang et al. (2018). Subsequently, the digestive organs of the benthos species and the flotation and filtration of MP. All suspected samples were transferred with a Fourier-transform infrared microscope (μ-FTIR) for further identification.

Each particle spectrum was recorded as 20 scans in the spectral wavenumber range of 400–600 cm−1 with a spectral resolution of 4 cm−1. Spectra were compared with the Bruker FTIR literature, which consists of organic compounds, polymers and polymer additives, natural/synthetic fibers, and rubber compound materials. The matching rate of infrared spectra between samples and reference substances >70% was acceptable. MPtype categories were classified according to standard protocols. The surface color of MP was identified under a stereo microscope by comparing it with a 72-color wheel.

Mangrove Species Density Survey

The collection of mangrove species density data at each substation, which is sized 10x10 m^2 with 10 m intervals. This survey was conducted on tree density with a diameter of more than 4 cm and a height of more than 1 m (Bengen, 2000). The parameters collected were mangrove species and the number of mangrove trees.

Data Analysis

Analysis of Microplastic Abundance

Microplastic abundance is calculated using the sweeping method on the Sedgwick

Rafter Counting Cell (SRC). Quantitative microplastic abundance in units of the number of particles/m³, using the equation according to APHA (2017):

$$N = \frac{c \times Vs}{Vo \times Va}$$

Description:

N = Particle abundance (particles/m³)
C = Number of particles observed on SRC
Vs = Sample volume (mL)
Vo = The volume of water observed on SRC (mL)
Va = Volume of filtered water (m³)

Correlation Analysis

The data obtained were analyzed with non-parametric statistical tests through a normality test followed by a Spearman correlation test. The null hypothesis can be accepted from this test if the p-value or significance level is more significant than 5% (0.05). It can then be concluded that the sample testing results are the same and not significantly different. However, if the null hypothesis is rejected, i.e., the p-value is smaller or the significance level is less than or equal to 5% (0.05), then the tested samples are significantly different from each other (Siegel & Castellan, 1988).

$$H = \frac{12}{N(N+1)} \sum_{i=1}^{k} \frac{R_j^2}{n_j} - 3(N+1)$$

Description:

H : Spearman Correlation value from the calculation
Rj : the sum of ranks from the j-th group/category
nj : number of cases in the sample in the j-th group/category
k : number of groups/categories
N : total number of observations (N = n1 + n2 + n3 + ... + nk)

3. RESULT AND DISCUSSION

Mangrove Ecosystem Condition

Measurement of Mangrove Conditions was carried out at 6 research locations using the transect method at each location, with sampling done in 3 plots. The condition of the mangrove ecosystem is presented in Table 1.

Table 1. Mangrove ecosystem condition

Station	Research Location	Canopy cover (%)	Density (ind/Ha)	Density Class	Status
1	Dompak	61,9	1500	Medium	Good
2	Kampung Bugis	65,08	3800	Very Dense	Good
3	Senggarang	63,47	1533	Very Dense	Good
4	Tembeling	48,44	987	Sparse	Damaged
5	Penaga	91,13	2966	Very Dense	Good
6	Busung	93,12	2100	Very Dense	Good

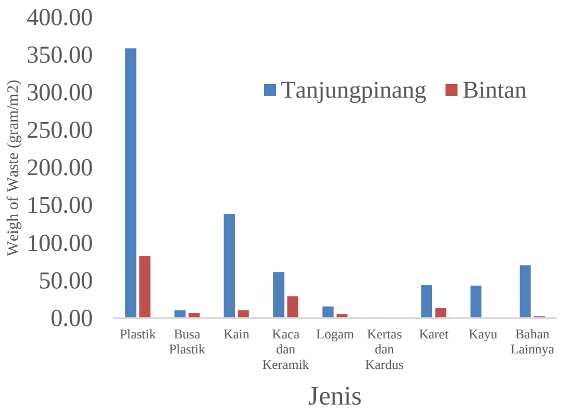

Figure 2. Abundance of macro debris

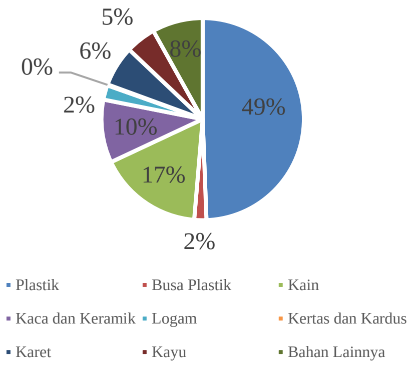

Figure 3. Macro debris density by type

Following the mangrove health standards set by the Ministry of Environment of the Republic of Indonesia (Decree of the Minister of Environment of the Republic of Indonesia No. 201 of 2004), the mangrove conditions at five stations are in good criteria, while one station with damaged criteria is located in Tembeling.

Abundance of Macro and Meso Debris in Mangrove Ecosystem Areas

Macro-debris waste was obtained through sampling in mangrove areas using line transects. Macro-debris waste consists of sizes ranging from 2.5 cm to 1 m. The types of macro-sized waste found include plastic, foam plastic, glass and ceramics, cloth, metal, rubber, wood, paper, cardboard, and other materials, with a total amount of waste scattered as much as 743 g/m² in the administrative area of Tanjungpinang City and 151 g/m² in Bintan Regency (Figure 2). The types of macro-sized waste encountered were dominated by plastic types with a percentage of 49%, followed by cloth types at 17% (Figure 3). Statistically, there is a difference between the density of macro-debris in the Tanjungpinang City area and Bintan Regency, with a p-value of 0.038 (<0.05).

Meso-sized waste types encountered at the research location include plastic, foam plastic, cloth, metal, paper, cardboard, and rubber. The density of meso-sized waste is dominated by plastic waste (Plastic and Plastic Foam), accounting for 94% of the total waste (Figure 4). The high amount of plastic waste is presumably due to plastic being lightweight, widely used, and quickly caught in mangrove roots (Ryan et al., 2009).

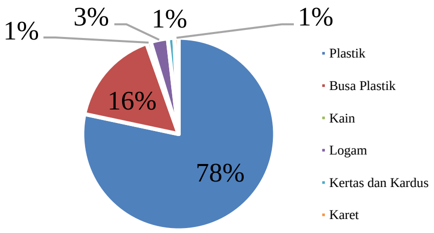

Figure 4. Meso debris composition

Plastic has the characteristics of being cheap, lightweight, strong, versatile, and durable, which is why plastic is used in every aspect of life. This plastic waste easily floats, is long-lasting, and can accumulate in mangrove roots. Furthermore, plastic marine debris has the highest density and composition value compared to other types of marine debris (Paulus et al., 2015), with composition values below 5% and density values below 1 item/m². In line with macro-debris, test results show a statistical difference between meso-debris density in the administrative areas of Tanjungpinang City and Bintan Regency with a p-value of 0.002 (<0.005).

The cause of high marine debris in the mangrove ecosystem in Tanjungpinang City is thought to be due to its location near settlements where anthropogenic activities of people dumping waste into the sea can return to land and get caught on mangrove tree trunks. The high amount of marine debris is caused by many people disposing of waste into the sea so that the waste on the beach is carried by seawater during high tide and will return from the sea to the coastal area (Fajriah et al., 2019). The difference in marine debris density is also suspected to be influenced by population size (He et al., 2020).

Abundance and Characteristics of Microplastics in Sediments of Mangrove Ecosystem Areas

Microplastics in mangrove sediments are primarily influenced by the following factors: intensive human activities, mangrove forest density, and mangrove sediment texture (Zhou et al., 2020). This study divides sediment texture into two types: sand and mud sediment. Sediments with sandy texture were found in 2 locations, namely Senggarang and Busung, while the other 5 locations had muddy sediment texture. The findings in this study show that Senggarang Village and Busung had higher amounts of microplastics, with 1246.5 particles/g and 1034.7 particles/g, respectively. These results align with previous studies (Eo et al., 2018; Maes et al., 2017; Vermaire et al., 2017), indicating that microplastic particles tend to accumulate in the same areas as larger sand particles. This is because the sedimentation of clastic and plastic particles is governed by the same environmental laws (Enders et al., 2019).

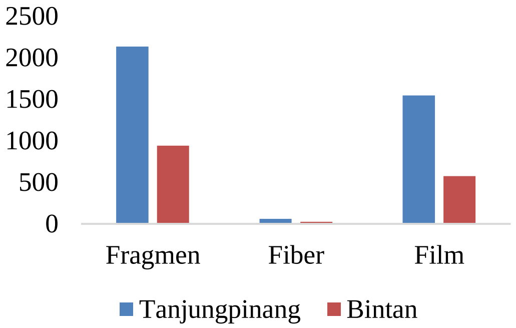

Figure 4. Abundance of microplastics in mangrove ecosystem sediments

Figure 6 shows that fragment-type microplastics dominate in the Tanjungpinang City and Bintan Regency, with 2,134.4 and 941.3 particles, respectively. The next type of microplastic is film, with 2,123.17 particles across all research locations, and fiber-type microplastics have the least amount.

Figure 5. Microplastics in sediment

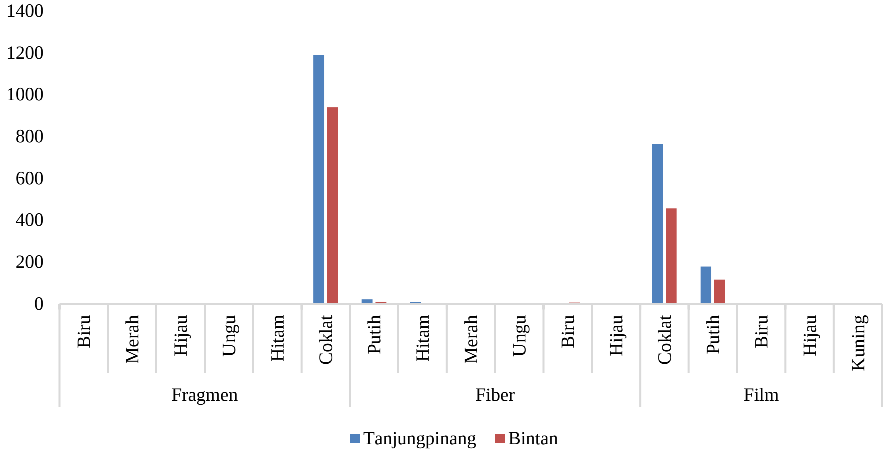

Figure 6. Color of microplastics in sediment

The visible colors of microplastics in the sediment are blue, red, green, purple, black, dark brown, white, brown, and yellow (Figure 7).

Microplastic Contamination in Gastropods (*Telescopium* sp)

The presence of microplastics in aquatic ecosystems can affect the surrounding biota. Microplastics can be a contaminant in gastropod species. *Telescopium* sp is a type of gastropod with the characteristics of fine particles, algae eaters, detritivores, and detritus. These gastropods are abundantly distributed in the Western and Central Indo-Pacific and are usually used as food sources or sustenance by the community (Harahap et al., 2022). *Telescopium* sp. usually lives in the mangrove ecosystem with temperatures between 25-32ºC (Sibua et al., 2021). The research results show microplastic contamination in gastropods, as shown in Figure 8.

Figure 8 shows the presence of microplastic contamination in gastropod species *Telescopium* sp found at the research location. The most commonly found film-type microplastics with a total contamination of 198.33 particles were found in the Bintan district area. The lowest type of microplastic is found in *Telescopium* sp a fiber. No contaminating pellet-type microplastics were found in *Telescopium* sp in Tanjungpinang City. In this study, the microplastic contamination of *T.telescopium* is higher than in research conducted on Rambut Island, Jakarta (Putri & Patria, 2021).

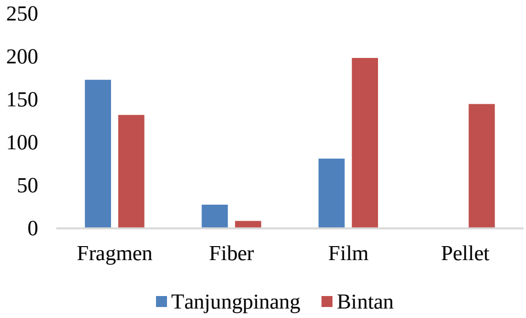

Figure 7. Microplastic contamination in gastropods (*Telescopium* sp)

Microplastics in contaminated water or sediment can directly or indirectly accumulate in the *Telescopium* sp. during food collection because most gastropods live in sediment, mangrove roots, and rocks exposed to microplastic contamination (Zaki et al., 2021). A study reported that six types of gastropods were contaminated with microplastics (Abidli et al., 2019). However, their behavior and occurrence remain relatively unchanged due to pollutants, such as *Littorina littorea* (Doyle et al., 2020). Concerns regarding introducing microplastics into aquaculture activities have been reported in marine areas around natural water bodies and ponds (Xiong et al., 2022; Le et al., 2022). A study reported that with the same unit ratio, the concentration of microplastics found in gastropod shells could be much higher than in sediment and surface water samples (Karlsson et al., 2017)

Based on their shape, the identified microplastics are fragments, fibers, films, and pellets (Figure 9), as found in other studies in East Java (Buwono et al., 2021; Radityaningrum et al., 2021). All forms of microplastics can be found in the *Telescopium*. Fragments were found to be more dominant than the others, followed by film and pellet forms which were the least and differed significantly from other forms, namely fiber (Wang et al., 2021; Riani & Cordova, 2022). Another study reported that over 86% of identified microplastics were fragmented into fragments (Morgado et al., 2022).

Figure 8. Microplastics in Biota a) Fiber b) Film c) Fragments d) Pellets

There are several colors of microplastics that are contaminated by the gastropod *Telescopium* sp. Fragment-type microplastics have blue and brown colors; fiber types are white, black, red, brown, green, and blue; brown, white, and blue film types; and the brown pellet type. The color of microplastic contamination in gastropods at each research location is shown in Figure 10.

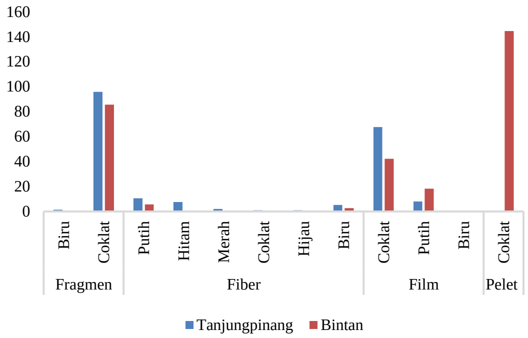

Figure 9. Color of microplastic contamination in gastropods *Telescopium* sp

Relationship between Mangrove Density and Macro Debris Density

The test results between the two variables obtained a correlation value of 0.872, which means the relationship between mangrove density and macro debris generation is very strong. Mangroves are unique intertidal habitats in terms of structural complexity, which makes them a prime coastal habitat for trapping trash (Martin et al., 2019). These forests represent a three-dimensional environment that reduces wave height and slows water flow, causing sediment deposition with direct consequences for waste generation (Deng et al., 2021).

Morphological adaptations developed for adaptation to soft-bottomed tidal areas of many true mangrove species (Tomlinson, 2016) form highly specialized and complex aerial root systems (Srikanth et al., 2015), which have high trapping potential in tidal areas for large trash. For example, *Rhizophora* sp. forms supporting roots that descend from the trunk and branches to form a complex barrier that has proven to be very efficient in absorbing extreme waves (Dahdouh-Guebas et al., 2006) but can also represent a very efficient trap for plastic and other waste. Solid pneumatophore forms in *Avicennia* spp, *Laguncularia* spp, and *Sonneratia* spp can also provide a very efficient trap for waste, especially for film-like plastics (e.g., plastic bags) (Martin et al., 2019).

Relationship between Macrodebris Density with Mesodebris and Microplastics

The test results between the density of macro debris and the density of meso debris and microplastics obtained correlation values of 0.972 and 0.793, meaning there is a strong relationship between the abundance of macro debris and meso debris and microplastics. This shows that the level of meso debris and microplastic contamination can be estimated from the level of macro debris contamination. This analysis's results strengthen this study's findings, which state that the size of macro debris will determine the size of meso debris and microplastics. In line with Jeyasanta et al. (2020), the number of macro debris can be used to infer mesoplastic and microplastic pollution levels. This is useful for predicting the amount of mesodebris and microplastics based on macroplastic deposits. The next test was carried out by grouping macrodebris and mesodebris types to see the relationship between the two. The test results showed a result of 0.788, which means there is a strong relationship between the two.

The formation of meso and microplastics formed through the fragmentation of large plastic objects occurs through different mechanisms individually and together, such as photooxidation by UV light, hydrolysis, mechanical cracking due to sand abrasion or water turbulence or bio assimilation by microorganisms (Gewert et al., 2015; Niaounakis, 2017). When exposed to UV light in water and outdoor conditions, oxidation of plastic pellets such as polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), and poly lactic acid (PLA) hydrolysis occurs (Cai et al., 2018; Cooper & Corcoran, 2010; Lambert et al., 2013; Lambert & Wagner, 2016). Hydrolysis is one of the main degradation processes of polymers containing heteroatoms (Gewert et al., 2015). The cleavage of ester bonds leads to the formation of carboxylate groups, which makes hydrolysis autocatalytic because acidic conditions increase the rate of hydrolysis. Both photooxidation and hydrolysis degradation processes cause the formation of cracks and holes on the surface of objects, thereby causing plastic weathering (Cai et al., 2018; Cooper & Corcoran, 2010). Therefore, plastic pieces become weak, and mechanical stress, such as friction or abrasion, can cause them to break apart into microplastic particles (Cooper & Corcoran, 2010; Klein et al., 2018; Lambert & Wagner, 2016). Fragmentation mechanisms depend on environmental conditions, the polymer material, but also on the additives in the plastic because they can influence the physicochemical properties of the material (Gewert et al., 2015; Klein et al., 2018; Niaounakis, 2017). For example, antioxidants and UV stabilizers such as Bisphenol A and Nonylphenol prevent the fragmentation of plastic materials through oxidation by UV light (Hahladakis et al., 2018).

Research by Weinstein et al., 2016 reported that after eight weeks of exposure to salt marsh habitat, HDPE and PP strips began to fragment into microplastics from 500 mm to 63 mm. Microplastic release increased from 21.5 parts/strip to 75.8 parts/strip after 32 weeks of exposure. Although plastic degradation in the environment is known to be slow and takes decades (Nirmala et al., 2023), this study revealed that microplastics were produced due to surface erosion and delamination of plastic waste within eight weeks of exposure to salt marshes. Fragmentation of plastic waste reduces the molecular weight of polymers.

Therefore, it increases their tendency to degrade by enzymatic action (Tokiwa et al., 2009). Previous research has recently shown that bacterial strains *Bacillus* sp and *Rhodococcus* sp are capable of degrading PP particles by 6.3% for 40 days (Auta et al., 2018), while the strain *I. sakaiensis* degraded almost all 60 mg PET films after six weeks at 30 C (Yoshida et al., 2016). Therefore, depending on environmental conditions and plastic materials, microparticles with various sizes, shapes, densities, and mechanical and chemical properties can be rapidly generated (Klein et al., 2018; Lambert & Wagner, 2016). However, the process and rate of microplastic fragmentation in the environment are still unclear and still need to be researched to assess the rate at which microplastics are produced due to fragmentation.

4. CONCLUSION

The abundance of macro debris in the Tanjungpinang City administrative area is 743 g/m^2. It is dominated by plastic, with a percentage of 49%, and mesodebris is dominated by plastic waste, which accounts for 94% of the total waste. The characteristics of microplastics in sediment at each sampling location consist of fragments, fibers, and films. Microplastic contamination of *Telescopium* sp Most commonly found in the Bintan Regency area were film-type microplastics with a total contamination of 198.33 particles. The relationship between mangrove density and macro debris generation is solid, with a correlation value of 0.872. The relationship between the abundance of macro debris, mesodebris, and microplastics was strong, with correlation values of 0.972 and 0.793, respectively.

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