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Rule of seagrass ecosystem as marine debris trap: A study case in seagrass ecosystems across a small island at Tanjungpinang city

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ABSTRACT

Seagrass ecosystems have an essential function as a feeding, spawning and nursery areas for various marine biota, etc. There are threats to the sustainability of seagrass ecosystems' biodiversity, one of which is the dumping of garbage into the sea, which causes damage to coastal ecosystems. This study aimed to determine the species and cover of seagrass ecosystems and the type and density of marine debris in seagrass ecosystems in the waters of small islands of Tanjungpinang City. There are three stations: Dompak Island, Penyengat Island, and Los Island. This research was conducted in May-June 2023. Seagrass cover data was collected using the line transect method with a quadrat transect of 50 cm x 50 cm to observe the species and cover. Data collection on marine debris in the seagrass ecosystem was taken on transects with an area of 100 m x 100 m. Marine debris obtained is then grouped by type to calculate density and weight. The types of seagrasses found include *Enhalus acoroides*, *Thalassia hemprichii*, *Cymodocea serrulata*, *Cymodocea rotundata*, *Halodule uninervis*, *Halodule pinifolia*, *Halophila ovalis*, and *Syringodium isoetifolium*. The highest total seagrass cover is found on Los Island, with a value of 25.81% classified as poor with a sparse cover category. The types of marine debris found are plastic, glass, rubber, wood, and its derivatives. According to the number of pieces, the highest density of marine debris is plastic waste, resulting in 0.0079 items/m^2, and the weight density is 0.0528 grams/m^2 found at Los Island.

Introduction

Seagrass meadows are highly productive ecosystems that provide critical habitat for diverse marine fauna, including feeding, spawning, and nursery grounds (Jayanti, 2020). The health of these ecosystems is intricately linked to the well-being of associated organisms, including sea urchins, sea cucumbers, fish, turtles, crabs, and bivalves (Jalaluddin *et al.*, 2020). Indonesian seagrass ecosystems are classified as "less healthy" (Sjafrie *et al.*, 2018), with only 42.23% coverage. They face a multitude of threats that compromise their ecological integrity.

Threats to seagrass ecosystems can be categorized as natural or anthropogenic (Julianinda, 2022). Natural disturbances include storms, volcanic eruptions, and the effects of global warming (Syukur *et al.*, 2017). Conversely, anthropogenic threats stem directly from human activities (Sari & Tambunan, 2021), encompassing fishing practices, coastal development, aquaculture, tourism, reclamation, and pollution in various forms (Rangkuti *et al.*, 2017; Herlina *et al.*, 2018; Utama *et al.*, 2019; Jalaluddin *et al.*, 2020; Rasyid *et al.*, 2022; Akbar *et al.*, 2023). Waste accumulation poses a particularly severe threat, disrupting community structure and limiting the essential light penetration required for seagrass photosynthesis (Rasyid *et al.*, 2022).

Marine debris, defined as persistent solid waste of human origin intentionally or unintentionally disposed of in marine environments (Patuwo *et al.*, 2020) comprises materials such as plastic, metal, glass, rubber, wood, and clothing (NOAA, 2015). This study focuses on macro-debris (2.5 cm - 1 m),

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frequently observed in coastal and surface waters (Andriani, 2021). Ocean currents play a pivotal role in transporting marine debris, potentially depositing it in seagrass beds (Navarrete-fernandez *et al*., 2022; Patuwo *et al*., 2020) and even reaching remote island ecosystems (Cozar *et al*., 2014 *in* Aji & Lestari, 2020).

Tanjungpinang City, the capital of the Riau Islands province, presents a unique case study to examine the effects of marine debris on small island seagrass ecosystems. This coastal city encompasses several smaller islands, including Dompak, Penyengat, and Los (Eriawati *et al*., 2019). The city's substantial population density and its location near international shipping routes likely contribute to a potential influx of marine debris within the surrounding waters. This pollution pressure, in addition to other potentially unsustainable coastal practices, puts the health and long-term viability of the island ecosystems at risk. Previous research has highlighted the degraded state of seagrass cover in several locations within Tanjungpinang waters (Sarinawaty *et al*., 2020; Nugraha *et al*., 2021).

Despite the clear threat posed by marine debris, a paucity of information specifically addresses this issue within the region. To address this knowledge gap, this study aimed to characterize seagrass ecosystems surrounding the small islands of Tanjungpinang City. Specifically, the study identified seagrass species, quantified percent cover, classified marine debris, and measured debris density within surveyed habitats.

Figure 1. Map of research stations located in Tanjungpinang city's small islands (Riau Islands province), highlighting data collection sites with red dot markers.

Materials and Methods

Site Selection and Temporal Context

The study was conducted within the coastal waters of select islands within the Tanjungpinang City municipality (Figure 1) during May-June 2023. Station locations were chosen strategically using purposive sampling (Widyasaputri, 2012), prioritizing sites exhibiting varying degrees of anthropogenic influence.

Equipment and materials

Essential tools and materials for data collection and analysis are summarized in Table 1 and Table 2.

Table 1. Instrumentation and applications.

Tool	Function
GPS	Geospatial positioning of sampling stations
Multitester	Measurement of temperature, pH, dissolved oxygen
Hand refractometer	Quantification of water salinity
Turbidimeter	Assessment of water turbidity
Camera	Photographic documentation
Mask and snorkel	Underwater observation and data collection
100 m roll meter	Establishment of line transects
Gloves	Safe handling of waste samples
Scales	Determination of waste sample mass
Ruler	Measurement of waste sample dimensions
Stepped sifter	Sediment particle size fractionation

Table 2. Experimental materials and their associated purposes.

Material	Purpose
Marine debris sample	Primary object of study
Seagrass sample	Target organism for identification and assessment
Substrate sample	Analysis of benthic sediment composition
Distilled water (Aquades)	Calibration and cleaning of field equipment

Station Delineation

A purposive sampling approach was employed for the selection of research stations. This strategy prioritizes sites with relevant characteristics to the research objectives (Widyasaputri, 2012). Three stations were established, each reflecting a distinct level of anticipated human impact (Table 3).

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Table 3. Research sites and associated human activity levels.

Station	Notable Human Activities
Dompak Island	Tourism
Penyengat Island	High population density
Los Island	Minimal human presence

Seagrass Species Identification

Seagrass species were identified in the field using the COREMAP LIPI seagrass monitoring guide as a taxonomic reference. Determinations were made by carefully comparing the morphology of observed specimens (e.g., leaf shape, flowers, roots) with descriptions and illustrations provided in the guide.

Seagrass Cover Assessment

Seagrass cover was quantified utilizing a line transect method. Three 100-meter transects, spaced 50 meters apart, were established at each station perpendicular to the coastline to delineate a 100m x 100m study area. Seagrass cover was assessed within 50cm x 50cm quadrats placed on the right side of each transect at 10-meter intervals (Figure 2). The initial placement of the quadrat (Point 0) was positioned 5-10 meters beyond the first occurrence of seagrass within the transect, following established protocols (Rahmawati *et al.*, 2014).

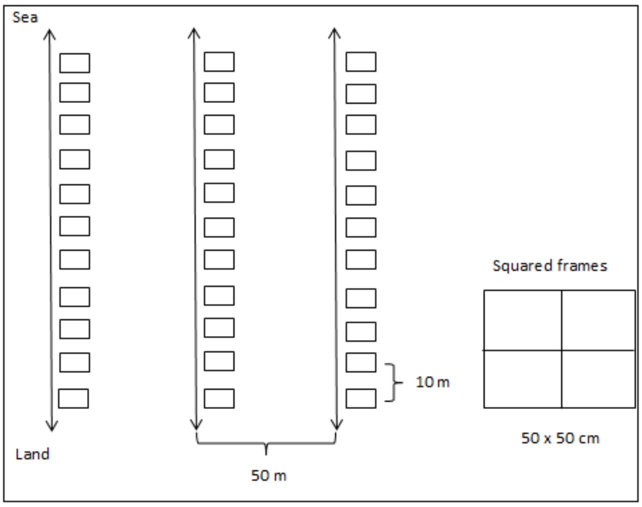

Figure 2. Seagrass transect sampling design (Rahmawati *et al.*, 2014).

Marine Debris Collection and Observation

Concurrent with seagrass assessments, marine debris surveys were conducted within 100m x 100m transects aligned with seagrass lines (Figure 3). Following Rasyid *et al.* (2022), debris accumulation was quantified within vertical and horizontal transects extending seaward from the shoreline. All macro-debris (2.5 cm - 1 m in size) encountered within transects was collected and removed. Collected debris was cleaned, air-dried, and classified by material type according to NOAA (2015) guidelines. Subsequently, debris was counted, weighed, and used for density calculations.

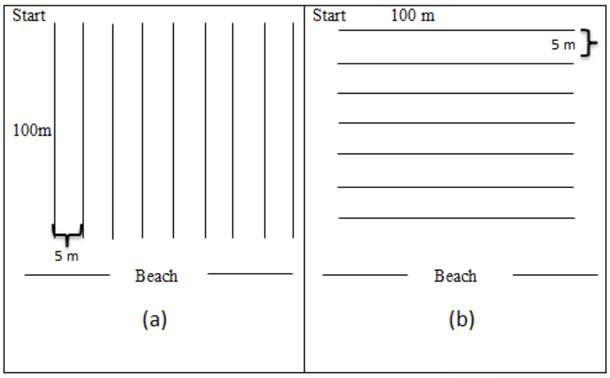

Figure 3. Vertical (a) and horizontal (b) transects for debris quantification (Rasyid *et al.*, 2022).

Data Analysis

Seagrass Cover

Seagrass cover analysis followed the methods established by Rahmawati *et al.* (2014). Both total seagrass cover and cover by individual species were expressed as percentages and calculated within Microsoft Excel using the following formula:

$$\text{seagrass cover} = \frac{\textit{sum of seagrass cover across transects}}{\textit{sum of squares of all transects}}$$

Marine Debris

Marine debris density calculations were performed according to the protocols established by Coe and Rogers (1997).

$$\text{Density (number of pieces of waste)} = \frac{\text{Number of waste items in each category (items)}}{\text{Area (m}^2\text{)}}$$

$$\text{Density (Weight of waste)} = \frac{\text{Weight of waste pieces in each category (grams)}}{\textit{Area}\ (\text{m}^2)}$$

Relationship of Seagrass Cover to Marine Debris Density

An analysis of correlation was conducted in Microsoft Excel to examine the potential relationship between seagrass cover and marine debris density. The following linear regression formula was employed:

$$y = ax + b$$

Where:

y = Marine debris density
x = seagrass cover (%)
a = regression constant
b = slope of the regression line

The strength of the correlation was interpreted using the coefficient interval guidelines presented in Table 4.

Table 4. Interpretation guide for correlation coefficients (r).

Coefficient interval	Relationship level
0,00 – 0,199	Very low
0,20 – 0,399	low
0,40 – 0,599	Medium
0,60 – 0,799	strong
0,80 – 1,000	Very strong

Source: Purba and Purba (2022)

Results

Water quality parameters measured across stations within the Tanjungpinang City region (Table 5) confirmed that water quality parameters at most study sites remained within established thresholds known to support seagrass ecosystems. However, the elevated turbidity observed at Penyengat and Los Islands exceeded recommended standards. Detailed substrate analysis revealed a predominance of muddy sand substrates across research stations. Variations in the specific composition of these substrates (Table 6) could have implications for the distribution and abundance of different seagrass species, as each species can exhibit preferences for particular sediment types.

A comprehensive survey of seagrass communities revealed remarkable diversity within the study region. Eight distinct seagrass species were identified, representing over half the known seagrass diversity within Indonesian waters. This underscores the region's ecological importance and the need for continued study to assess the health and resilience of these diverse communities. *Enhalus acoroides* (Ea), *Thalassia hemprichii* (Th), *Cymodocea rotundata* (Cr), and *Halophila ovalis* (Ho) emerged as the dominant species across the surveyed islands (Table 7). The less frequent occurrences of *Halodule uninervis* (Hu), *Cymodocea serrulata* (Cs), *Halodule pinifolia* (Hp), and *Syringodium isoetifolium* (Si) provide an intriguing opportunity to investigate factors influencing their more localized distributions.

Table 5. Water quality measurements at research stations.

No	Parameters	Unit	Station: Dompak Island	Penyengat Island	Los Island	Quality Standards
1	Temperature	^{o}C	29.4	27.8	27.4	28-32
2	Salinity	‰	30	31	30	33-34
3	pH	-	8.22	8.09	7.77	7-8,5
4	DO	mg/L	8.5	7.71	7.29	>5
5	Turbidity	Ntu	4.31	17.52	20.12	5
6	Substrate	-	Silty sand	Silty sand	Silty sand	-

Table 6. Substrate composition by research station (% of total).

Substrate	Station: Dompak Island	Penyengat Island	Los Island
Sand	99.95%	98.33%	99.25%
Mud	0.05%	1.67%	0.75%

Table 7. Percentage of Sand and Mud Substrates at Research Stations.

No	Seagrass species	Station: Dompak Island	Penyengat Island	Los Island
1	*Enhalus acoroides*	√	√	√
2	*Thalassia hemprichii*	√	√	√
3	*Cymodocea serrulata*	√	-	-
4	*Cymodocea rotundata*	√	√	√
5	*Halodule uninervis*	√	-	√
6	*Halodule pinifolia*	√	-	-
7	*Halophila ovalis*	√	√	√
8	*Syringodium isoetifolium*	-	-	√

(√) = yes, (-) = no

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Analysis of seagrass cover within the small islands of Tanjungpinang city revealed significant variation among research stations (Figure 4). Los Island exhibited the highest total seagrass cover (25.81%), followed by Penyengat Island, and finally, Dompak Island. Despite this variation, the relatively low density of seagrass across all sites resulted in a classification of poor condition with a sparse cover designation.

Enhalus acoroides and *Thalassia hemprichii* consistently emerged as the dominant seagrass species across all stations (Figure 5). Notably, *Enhalus acoroides* achieved its highest percent cover (16.75%) within the waters surrounding Penyengat Island.

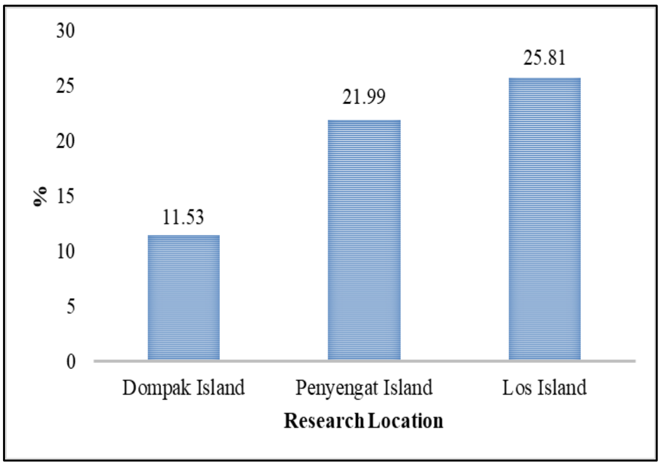

Figure 4. Total percentage of seagrass cover in selected Tanjungpinang city's small islands.

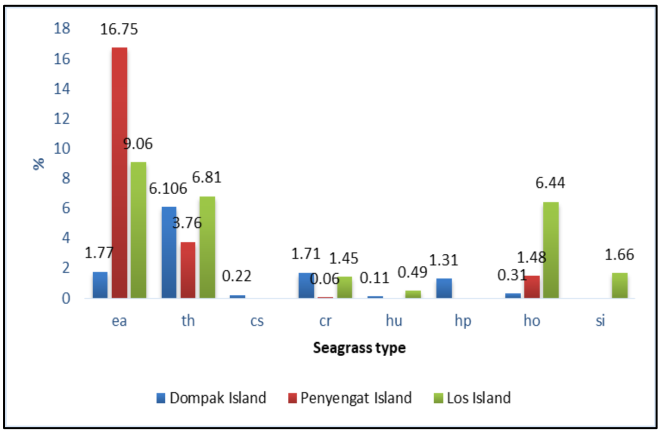

Figure 5. Seagrass community composition in selected Tanjungpinang City's small islands (percent distribution). Species identified include *Enhalus acoroides* (ea), *Thalassia hemprichii* (th), *Cymodocea serrulate* (cs), *Cymodocea rotundata* (cr), *Halodule uninervis* (hu), *Halodule pinifolia* (hp), *Halophila ovalis* (ho), and *Syringodium isoetifolium* (si).

Marine debris collected throughout the study area was categorized into six material types based on NOAA (2015) guidelines: plastic, metal, glass, rubber, wood and its derivatives, and clothing (Table 8).

Table 8. Categorization of marine debris observed at research stations.

No	Category	Type
1	Plastic	Beverage wrap, soap wrap, food wrap, plastic bag, plastic wrap, mesh, cork, beverage glass, bottle cap, plastic bottle, plastic beverage glass, regular plastic wrap, plastic bowl.
2	Metal	-
3	Glass	Broken glass and glass bottles
4	Rubber	Flip flops
5	Wood and its derivatives	Board and cock
6	Clothing	-

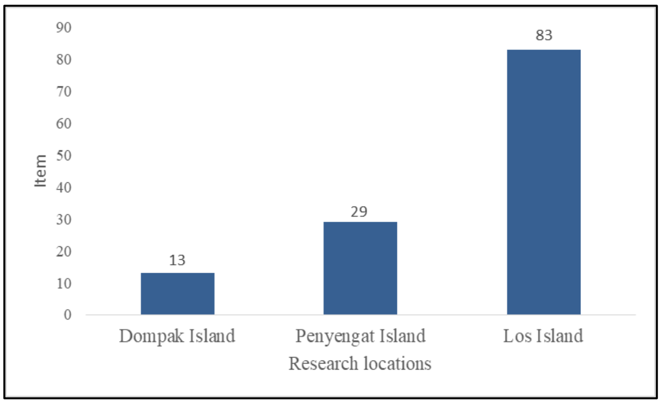

Figure 6. Marine debris accumulation within the seagrass bed of the selected Tanjungpinang city's small islands.

Los Island exhibited the highest accumulation of debris, with a total of 83 items, exceeding the amounts documented at Penyengat and Dompak Islands (Figure 6). Plastic debris represented the most abundant type found across all sites. The highest density of plastic debris (0.0079 items/m^2) was observed at Los Island. Los Island also had the highest weight density of marine debris (0.0528 grams/m^2) primarily attributable to plastic waste (Figures 7 & 8). Rubber and wood derivative waste were found in the lowest densities at Dompak and Penyengat Islands.

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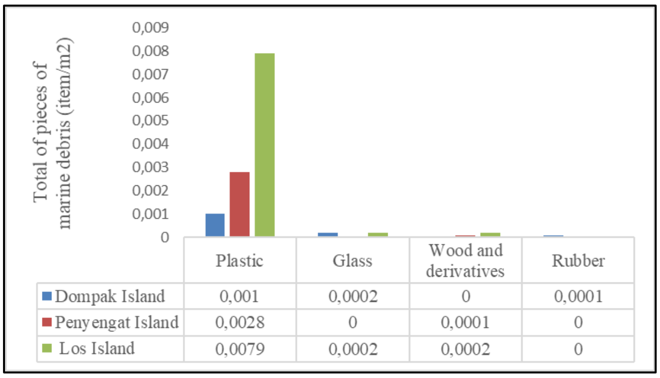

Figure 7. Density distribution of marine debris collected from seagrass bed across selected Tanjungpinang city's small islands (pcs/m^2).

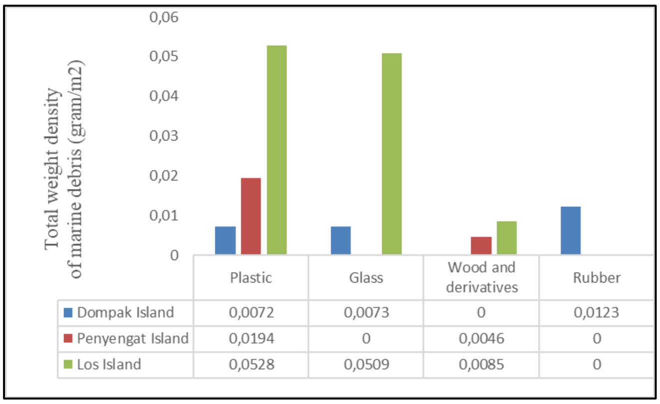

Figure 8. Weight density of marine debris (grams/m^2).

Linear regression analysis revealed a strong positive correlation (r = 0.844) between total seagrass cover and marine debris density within the surveyed region. The regression equation (y = 1701.2x + 12.688) and the high determination coefficient (R^2 = 0.7124) suggest a significant relationship between these variables (Figure 9). This finding indicates that areas with higher seagrass cover likely to experience increased debris accumulation, potentially due to the physical trapping effect of seagrass meadows.

Discuccion

Water quality exerts a profound influence on the growth and distribution of seagrass species. Parameters such as temperature, salinity, pH, dissolved oxygen (DO), turbidity, and substrate composition play crucial roles in determining seagrass resilience. Within the Tanjungpinang small island region, the majority of water quality parameters fell within acceptable ranges favorable to seagrass meadows.

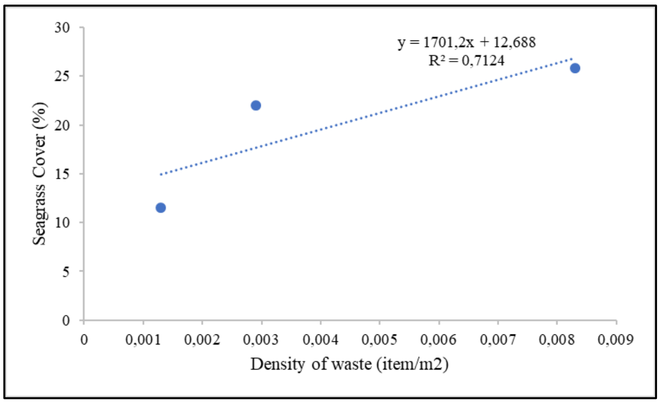

Figure 9. Correlation of seagrass cover and marine debris density in Tanjungpinang small islands.

However, a notable exception was observed at Penyengat and Los Islands, where turbidity levels exceeded established quality thresholds (Table 5). This excessive turbidity, potentially exacerbated by the region's characteristic muddy substrates (Hidayat *et al.*, 2018), could significantly impede light penetration, thereby hindering photosynthetic activity and limiting seagrass growth (Nugraha *et al.*, 2020). Paradoxically, muddy substrates contribute to reduced light transmission and are also a significant source of organic matter. This organic-rich sediment provides a vital reservoir of nutrients, readily absorbed by seagrass root systems, potentially facilitating growth despite potential light limitation (Riniatsih, 2016).

The presence of four seagrass species (*Enhalus acoroides*, *Thalassia hemprichii*, *Cymodocea rotundata*, *and Halophila ovalis*) across all surveyed locations (Table 7) suggests a degree of ecological stability within the study region. The consistent occurrence of *E. acoroides* and *T. hemprichii* highlights their adaptability. *E. acoroides* possesses robust roots, facilitating both secure anchoring and efficient nutrient uptake, enhancing its resilience (Devayani *et al.*, 2019). *T. hemprichii* demonstrates tolerance to diverse substrates, including the muddy sands characterizing the region, thanks to its thick, sturdy rhizomes (Wicaksono *et al.*, 2012). The adaptability of *C. rotundata*, capable of thriving in various habitats (Samosir *et al.*, 2022), and the preference of *H. ovalis* for muddy sand substrates. Seagrass *Halophila ovalis* species are most often found because all stations have muddy sand substrates (Togolo et al., 2023), further contributing to the observed diversity within this ecosystem.

The designation of *E. acoroides* and *T. hemprichii* as key species within Indonesian waters reflects their widespread distribution and dominance throughout the region (Hernawan *et al.*, 2021). Additionally, the presence of pioneering species from the genera *Halophila* and *Halodule* (Nugraha *et al*., 2023) is ecologically significant due to their demonstrated ability to rapidly colonize and recover from disturbances (Kilminster *et al*., 2015). This resilience offers hope that these seagrass meadows may possess mechanisms to withstand and adapt to potential environmental threats.

Compared to similar locations within Bintan Island (Nugraha *et al*., 2021), the total seagrass cover observed on small islands within the Tanjungpinang city region is notably low. This reduced cover on Dompak Island is likely attributable to intensive anthropogenic activities such as gleaning (Bongga *et al*., 2021). During low tide, gleaning practices can inadvertently damage seagrass meadows through direct trampling, inhibiting growth. Meanwhile, reduced seagrass covers on Penyengat and Los Islands appears strongly linked to elevated turbidity. High turbidity hinders light penetration, thereby interfering with the critical photosynthetic processes essential for seagrass survival (Bongga *et al*., 2021 This negative impact of turbidity on seagrass meadows is further supported by Rustam *et al*. (2015), who found that light limitation resulting from pollution-induced turbidity significantly disrupts seagrass photosynthesis.

The dominant seagrass species within the study area was *Enhalus acoroides*, with a cover of 16.75%. This dominance aligns with findings from Lubis *et al*. (2022) in the waters of Malang Rapat, where *E. acoroides* exhibited the highest cover value of 41.97%. The large individual size of *E. acoroides* contributes to its dominance in terms of percent cover (Nugraha *et al*., 2019). Additionally, this species demonstrates a wide distribution throughout Indonesian coastal waters, enhancing its prevalence (Sarinawaty *et al*., 2020). Conversely, the lowest observed cover (0.06%) belonged to *Cymodocea rotundata*. This contrasts markedly with the 6.1% cover of *C. rotundata* documented by Lubis *et al*. (2022) in Malang Rapat waters. The diminished cover of *C. rotundata* within the present study area suggests that the elevated turbidity observed around Penyengat Island may limit its growth by reducing crucial light availability for photosynthesis.

The total marine debris quantified within the waters surrounding the small islands of Tanjungpinang city varied by location: Dompak Island (13 items), Penyengat Island (29 items), and Los Island (83 items) (Figure 6). Compared to Pramuka Island, the debris accumulation observed in this study is lower (Rasyid *et al*., 2022). This discrepancy likely stems from multiple factors. Pramuka Island may experience increased debris due to deliberate localized disposal and the influx of waste from densely populated areas like Jakarta Bay. The proximity of certain Tanjungpinang islands to docks, tourism activities, and residential areas suggests that these local activities also contribute to marine debris levels within the region.

Los Island exhibited the highest density of marine debris among the surveyed locations. This elevated level of debris accumulation likely stems from a combination of the island's geographic position directly adjacent to Tanjungpinang city and its exposure to dominant oceanic currents. The proximity to a densely populated urban center implicates terrestrial waste originating from household activities as a primary source of this debris. Oceanographic transport mechanisms appear to be a major driver, delivering waste to the island's shores and facilitating its subsequent entanglement within seagrass meadows during tidal fluctuations.

Plastic constituted the most prevalent marine debris type across all survey sites, corroborating its insidious persistence within marine environments. Los Island exhibited the highest plastic density, with 0.0079 items/m^2 and 0.0528 gr/m^2. This underscores the widespread use of plastic in consumer goods and the challenges associated with its responsible disposal (Akbar & Aqila, 2022). Oceanographic currents likely facilitate the transport and subsequent entanglement of plastic debris within seagrass beds, posing substantial risks to marine biodiversity. The relative scarcity of other debris types (glass, rubber, wood derivatives) reflects their less frequent use in household products. Notably absent across all sites was metallic and textile debris. The higher density of these materials likely limits their dispersal by currents, promoting preferential deposition on the seafloor (Aji & Lestari, 2020).

The linear regression model demonstrated a robust positive correlation between seagrass meadows' spatial extent and marine debris's density. The high coefficient of determination ($R^2 = 0.7124$) indicates that a substantial portion of the variance in debris density (71.24%) can be attributed to variations in seagrass cover. This finding is further reinforced by a strong correlation coefficient ($r = 0.844$). Increased seagrass cover appears to directly enhance the accumulation of marine debris, likely due to the physical trapping of objects within the complex seagrass canopy. The prevalence of *Enhalus acoroides*, characterized by large leaves and a dense growth structure, may further exacerbate debris entrapment within these ecosystems. These observations are consistent with Navarrete-fernandez *et al.* (2022), who identified seagrass meadows as primary areas of marine debris deposition due to their ability to intercept waste from multiple environmental sources.

Oceanic currents exert a major influence on marine debris distribution, facilitating the long-distance transport of waste (Adibhusana *et al.*, 2016). Variations in debris density across survey sites reflect localized differences in current patterns. Terrestrial waste carried by surface runoff enters coastal waterways. Seasonal fluctuations in precipitation exacerbate this problem, intensifying debris transport into estuaries and open ocean environments (Subekti (2017).

Conclusion

This study identified eight seagrass species within the coastal waters of Tanjungpinang's small islands, demonstrating significant ecological diversity. Los Island exhibited the highest overall seagrass cover, dominated by *Enhalus acoroides*. Los Island also had the most significant marine debris accumulation, with plastic being the predominant waste type. A strong positive correlation emerged between seagrass cover and marine debris density, revealing the capacity of seagrass meadows to trap waste. While this service may provide some mitigation, it also highlights potential threats to seagrass health and ecosystem resilience. Ongoing monitoring is crucial to assess the long-term consequences of marine debris accumulation and develop targeted conservation strategies.

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