Non-Destructive Transect Assessment of Marine Debris and Mangrove Density in Urban Mangrove Ecosystems

Nur Fa'izah Fitri Ramadhanti
Department of Marine Science, Brawijaya University, Indonesia
nurfaizah.fitri13@gmail.com

Aulia Lanudia Fathah
Master Program of Environmental Management & Development, Brawijaya University, Indonesia
aulialanudiaf@gmail.com

Muhammad Naufal Eka Putra
Department of Marine Science, Brawijaya University, Indonesia
naufaleka@student.ub.ac.id

Berlania Mahardika Putri
Master Program of Environmental Science, Universitas Gadjah Mada, Indonesia
berlaniamahardika@gmail.com

Andik Isdianto
Department of Marine Science, Brawijaya University, Indonesia
andik.isdianto@ub.ac.id (corresponding author)

Received: 7 August 2025 | Revised: 30 August 2025, 13 September 2025, 17 September 2025, and 12 October 2025 | Accepted: 13 October 2025

Licensed under a CC-BY 4.0 license | Copyright (c) by the authors | DOI: https://doi.org/10.48084/etasr.13930

ABSTRACT

The ecological integrity and sustainability of urban mangrove ecosystems are threatened by marine debris and especially plastic. This study examines a non-destructive technique to estimate the amount of marine debris and mangrove density in an urban mangrove forest. Field surveys, held from September 2024 to January 2025, were conducted across distinct hydrodynamic zones, showing that plastic accounted for up to 95% of the total debris, with the highest concentrations being observed in zones with dense mangrove stands and limited water flow. The proposed method leads to targeted debris removal and better management strategies, which combine waste reduction and the maintenance of healthy mangrove ecosystems.

Keywords-integrated coastal management; mangrove debris assessment; marine debris monitoring; non-destructive sampling; plastic pollution

I. INTRODUCTION

Mangrove ecosystems provide coastal protection and support local biodiversity [1, 2], but are threatened by pollution from marine debris, particularly plastic, as well as by deforestation and illegal logging [3-5]. Debris accumulation within mangrove forests can degrade ecosystem health and reduce the effectiveness of mangroves as natural filters and coastal buffers [3, 6]. A similar pattern was observed in the Wonorejo Mangrove Ecotourism area, where the density of marine debris was found to affect the density of mangrove seedlings by up to 88%, with the remaining 12% influenced by other factors [7]. Authors in [7] examined the relationship between debris abundance and Avicennia mangrove seedling density, while authors in [8] described debris occurrence and stated that debris accumulation was associated with lower mangrove density. However, these studies did not classify the sampling zones based on hydrodynamic characteristics. Since urban mangroves like Wonorejo are influenced by both anthropogenic factors and marine dynamics, the role of hydrodynamic processes in debris accumulation is not well understood. This study uses a non-destructive method to measure the presence of marine debris in the Wonorejo

Mangrove Ecotourism area of Surabaya, Indonesia. By monitoring the debris with hydrodynamic characterization across three zones (estuary, marine, and enclosed), the current study provides data on the distribution and the ecological impacts of the waste.

II. MATERIALS AND METHODS

A. Study Site

The present study was conducted in the Wonorejo Mangrove Ecotourism Area in eastern Surabaya, Indonesia, as shown in Figure 1. The site consists of tidal mangrove forests with complex root structures. It is situated at the estuary of the Jagir River and faces the Madura Strait. Wonorejo was selected as the case study site because it is a highly vulnerable urban mangrove ecosystem influenced by hydrodynamic processes (e.g., tides and river inflow) and anthropogenic activities (e.g., tourism, upstream pollution, and fisheries practices) [7, 9]. The area was divided into three zones based on hydrodynamic characteristics: estuary, marine, and enclosed.

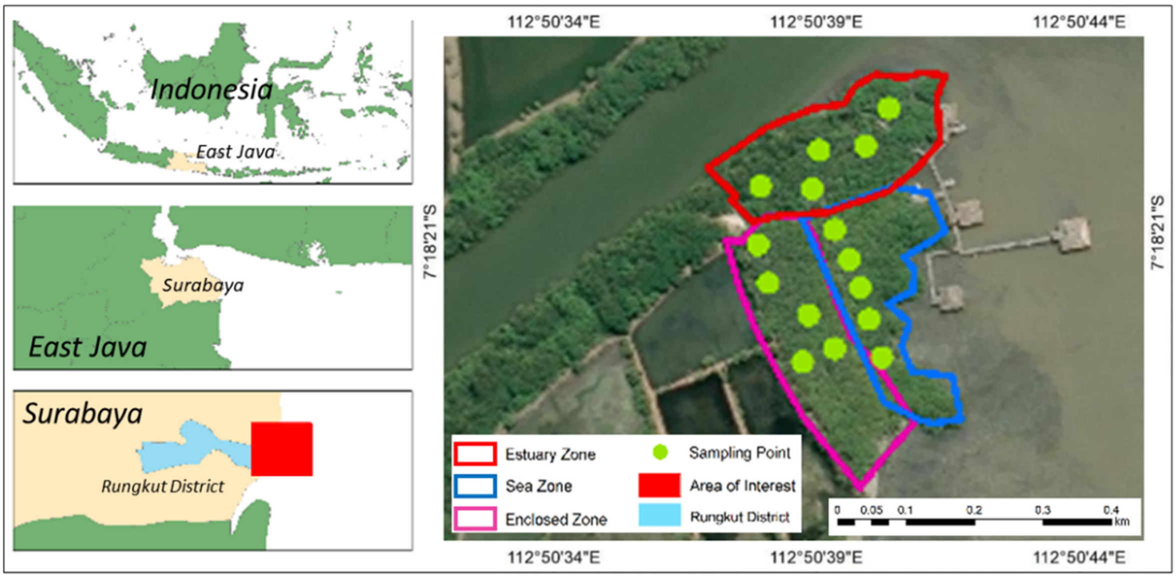


Fig. 1. Study site location.

B. Sampling Design

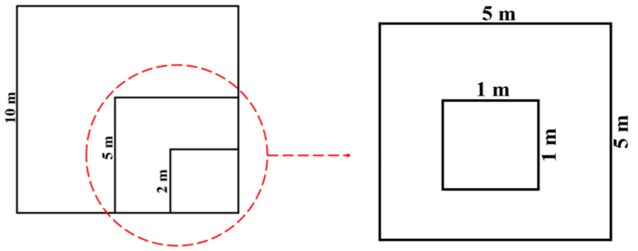
Samples were taken from September 2024 to January 2025, in order to capture the characteristics of the sites [10, 11]. The primary data included the amount and type of marine debris and the density of mangroves. Five transects were established in each hydrodynamic zone to ensure the right distribution across different hydrodynamic conditions. The secondary data included ocean current and tide information.

C. Mangrove Density Assessment

Mangrove growth stages were adapted for transect plots: 10 x 10 m for trees (>10 cm stem diameter), 5 x 5 m for saplings (height >1.5 m and diameter <10 cm), and 2 x 2 m for seedlings (<1.5 m height), as depicted in Figure 2 [7, 12]. The data collected included the tree diameter (measured at 1.3 m above the ground), number of trees in the area, and species identification. For multi-stemmed trees, each branch was measured separately [13].

D. Marine Debris Collection

At each point, a 5×5-m grid was used to collect macrodebris, and a nested 1×1-m grid was utilized to collect mesodebris [14]. Locations were recorded by GPS [15], and all visible debris on the sediment surface was collected, weighed, and sorted by material type (plastic, glass, metal, fabric, rubber, wood, ceramic, and HTMs), according to NOAA shoreline survey guidelines [16].



(a) (b)

Fig. 2. Sampling transect: a) mangrove density, b) marine debris.

E. Hydrodynamics: Current and Tides

Tidal data were retrieved from Geospatial Information Agency's website and processed in Excel using the least squares method, as displayed in Figure 3, while the current data for January were gathered from OSCAR and used to map the distribution, as portrayed in Figure 4.

F. Marine Debris Data Analysis

The primary data on marine debris were analyzed using [17]:

$$\text{Percentage (\%)} = \left(\frac{N_i}{\sum N_i}\right) \times 100 \quad (1)$$

$$\text{Item Abundance (items/ m}^2) = \frac{N}{A} \quad (2)$$

$$\text{Weight Abundance (kg/ m}^2) = \frac{\text{W}}{\text{A}} \quad (3)$$

where N_i is the number of debris items type i (items), $\sum N_i$ is the total number of debris items (items), N is the number of debris items within the transect (items), W is the total weight of debris within the transect (kg), and A is the transect area (m²).

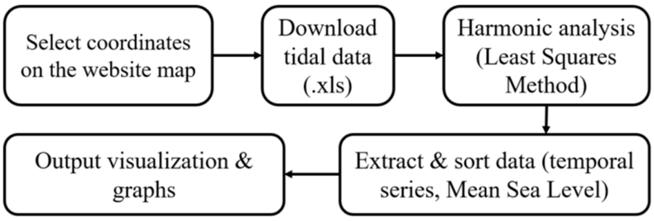


Fig. 3. Tidal data processing flow.

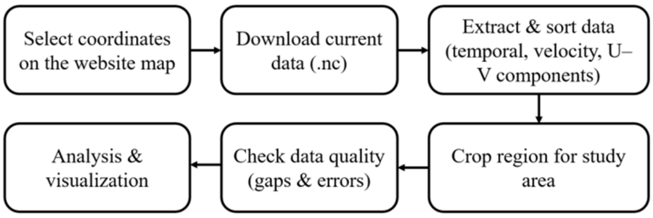


Fig. 4. Current data processing flow.

G. Mangrove Data Analysis

The number of specific stands refers to the total number of individuals of a particular mangrove species within each transect. The mangrove density is calculated using [7, 12]:

$$D = \frac{n_i}{A} \quad (4)$$

where D is the species density (individuals per ha), n_i is the number of individuals of the species, and A is the total plot area (m² converted to ha by dividing by 10,000).

III. RESULTS AND DISCUSSION

A. Mangrove Density and Species

As shown in Figure 5, the estuarine zone had the highest mangrove density (3,260 ind/ha), which is classified as high density (≥1,500 ind/ha) [18]. The enclosed zone had a high density of 2,760 ind/ha, while the marine zone had a medium density of 1,480 ind/ha. The dominant species were *Avicennia marina, A. alba, Excoecaria agallocha, Rhizophora mucronata, Nypa fruticans,* and *R. stylosa*. Authors in [19] reported similar density categories and species compositions in the Wonorejo area. The same transects were used for mangrove density and marine debris sampling, as displayed in Figure 6.

B. Hydrodynamic Conditions

The tidal elevation graph, as illustrated in Figure 7, reveals a mixed, predominantly semidiurnal tide (Formzahl = 1.21), confirming the previously described patterns for East Surabaya [19, 20]. The current speeds around the study site range from 0.379 m/s to 0.444 m/s, as presented in Figure 8, and are categorized as fast to very fast, while the current direction shifts seasonally [21]. These hydrodynamic conditions play a crucial role in controlling the distribution and accumulation of marine debris in the mangrove ecosystem and provide the basis for interpreting the debris composition and abundance patterns.

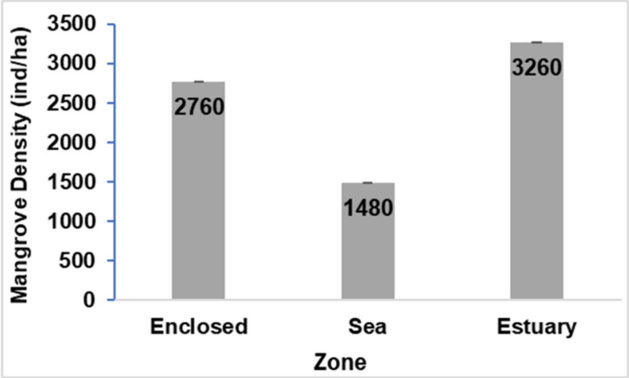


Fig. 5. Mangrove density in each zone.

Fig. 6. Transects for collecting marine (blue line) and mangrove debris (red line).

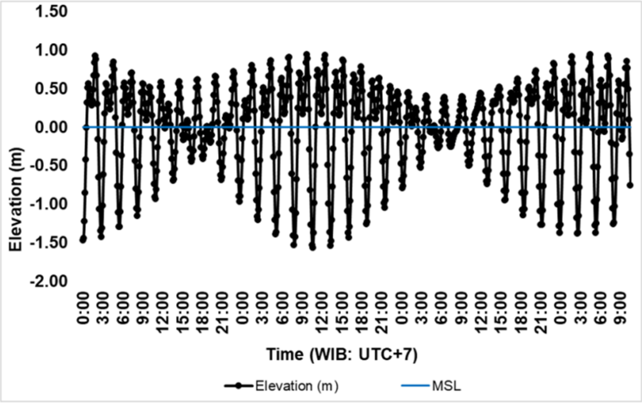


Fig. 7. Tidal elevation graph of research location.

C. Percentage of Marine Debris

Plastic was the most common type of debris in all zones, accounting for 95% of the estuarine zone, 89% of the marine zone, and 83% of the enclosed zone, as shown in Figure 9, which can be explained by its lightweight, buoyant, and durable nature, enabling widespread distribution [22]. The enclosed zone had the greatest variety of debris types, likely due to limited water flow allowing debris to pile up [23], as presented in Figure 10.

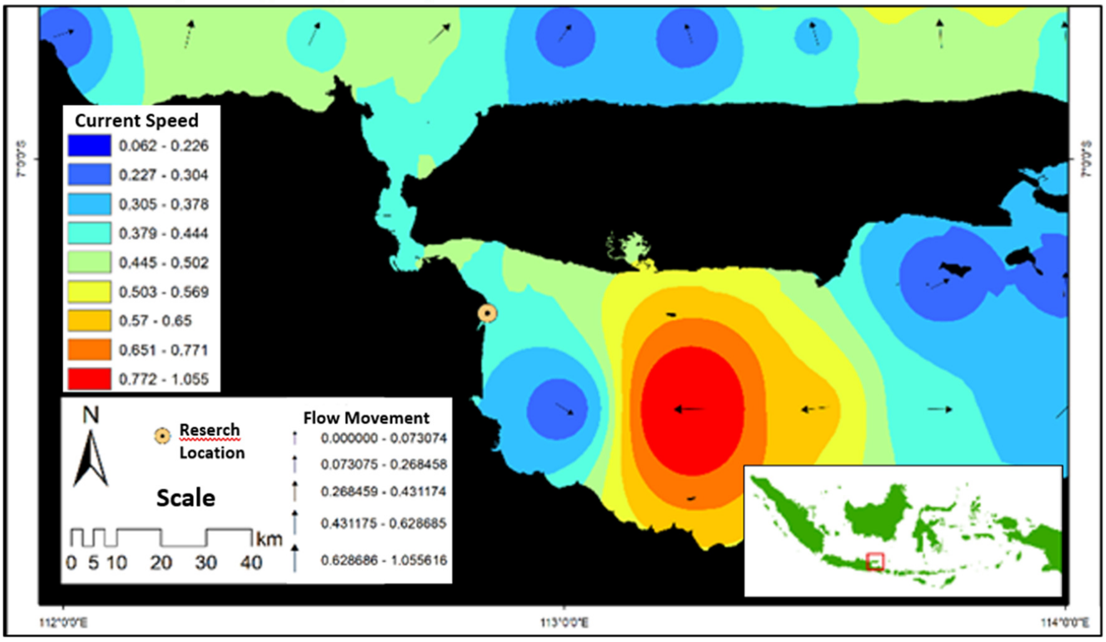


Fig. 8. Current velocity and direction in the study area (processed using ArcGIS 10.8).

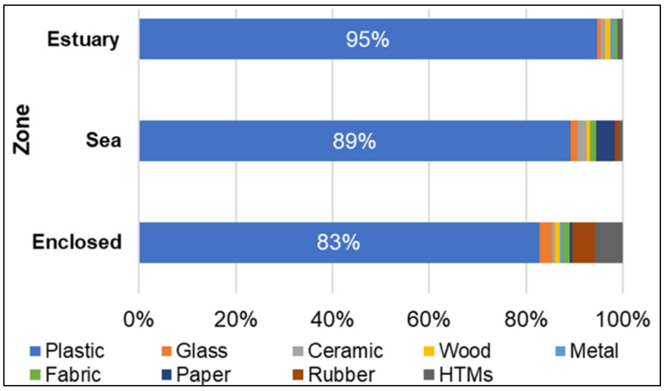


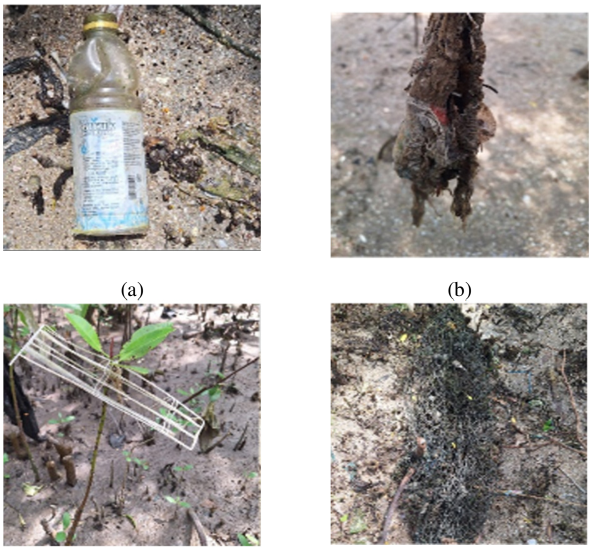
Fig. 9. Percentage of marine debris in each zone.

D. Debris Abundance by Item

The greatest number of debris (items/m²) was found in the marine zone (3.98 ± 1.92), followed by the enclosed zone (3.84 ± 1.34), and the least amount was found in the estuarine zone (3.43 ± 2.24). There were significant differences between the zones ($p < 0.05$), as evidenced in Figure 11 (a). The marine zone's exposure to multiple sources and the enclosed zone's limited water movement both contribute to debris deposition, which was observed in other Indonesian mangroves [24].

E. Debris Abundance by Mass

The marine zone had the greatest debris weight abundance (119.5 ± 66.84 g/m²), followed by the estuarine zone (77.6 ± 60.55 g/m²) and the enclosed zone (53.1 ± 30.78 g/m²), as presented in Figure 11 (b). Heavier items, such as metal and glass, as illustrated in Figure 12, contributed the most to the total mass of debris. The data show that the quantity and type of debris are shaped by the interplay of the mangrove structure and hydrodynamics.

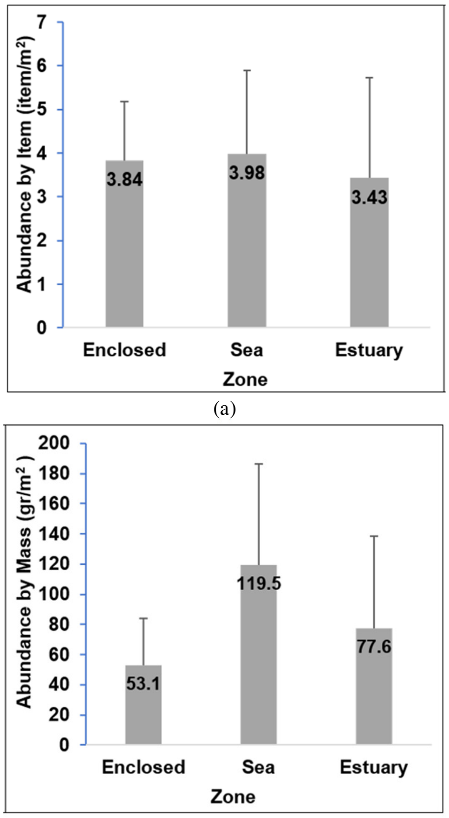


(a) (b)

(c) (d)

Fig. 10. Trash found: (a) plastic bottles, (b) diapers that have changed color and shape, (c) household appliances, (d) fishing nets.

The observed spatial variation in debris accumulation reflects the strong interaction between hydrodynamics, mangrove structure, and debris type. Areas with higher mangrove density and limited water flow collect a wider variety of debris, whereas open and dynamic zones receive more debris but have greater mobility. These findings confirm the role of mangroves as debris traps [1, 5, 25, 26], and emphasize the importance of maintaining healthy mangrove stands and considering local hydrodynamics for effective debris management and coastal ecosystem protection.



(a)

(b)

Fig. 11. Marine debris abundance: (a) based on items, and (b) based on mass.

(a) (b)

Fig. 12. Debris mass abundance: (a) glass, (b) metal.

F. Practical Management Implications

Based on these insights, the management strategies in mangrove ecotourism areas should prioritize maintaining or increasing mangrove stand density, controlling upstream sources of waste (especially plastics), and accounting for local hydrodynamic conditions that affect debris retention and transport. As portrayed in Figure 13, the interaction between debris input, hydrodynamic forcing, and mangrove density influences debris accumulation and ultimately mangrove health [27]. This framework supports strategies that combine maintaining mangrove cover, controlling upstream waste, and using hydrodynamic-aware monitoring. The proposed approach reduces the environmental impact of debris accumulation, supports the sustainability of ecotourism, and preserves the ecosystem services provided by mangroves. Monitoring and cleanup programs should focus on the most susceptible to debris trapping zones, such as areas with dense vegetation and limited water circulation. Community engagement in upstream waste management, coupled with the regular assessment of hydrodynamic changes, will further enhance the long-term resilience of these valuable coastal systems [28].

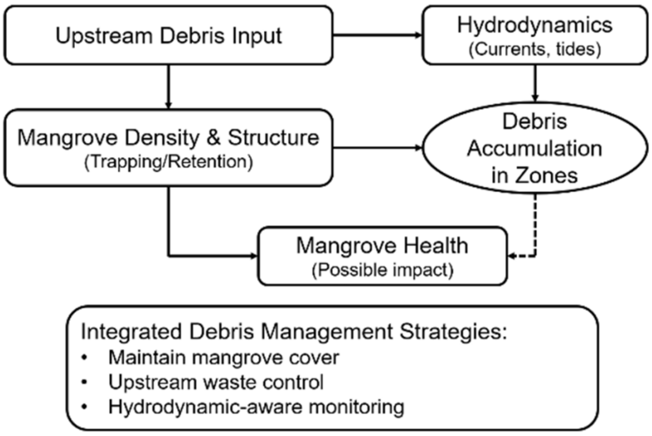


Fig. 13. Conceptual diagram showing the interrelationship of debris management, mangrove health, and hydrodynamic influence in the study area.

IV. CONCLUSIONS

This study revealed that the Wonorejo Mangrove Ecotourism area has dense mangrove stands (over 2,500 trees per ha), yet it is heavily influenced by the presence of marine debris, up to 95% of which is plastic. The marine zone was the most affected, with the highest abundance of debris at 3.98 items/m2 and 119.5 g/m^2. These results highlight the need for integrated management strategies that promote mangrove health, address upstream plastic waste, and consider local hydrodynamic conditions. However, this study focuses on surface-visible debris without considering tidal inundation modeling or measuring the current velocity from primary data, which may reduce hydrodynamic accuracy. Since debris distribution is strongly influenced by water flow, future studies should integrate hydrodynamic modeling and assess the long-term impacts on mangrove growth.

REFERENCES

[1] C. Martin, H. Almahasheer, and C. M. Duarte, "Mangrove forests as traps for marine litter," *Environmental Pollution*, vol. 247, pp. 499–508, Apr. 2019, https://doi.org/10.1016/j.envpol.2019.01.067.

[2] T. Warningsih, K. Kusai, Z. Zulkarnain, L. Bathara, I. Mulyani, and D. Sari, "Economic Valuation of Mangrove Ecosystem in Coastal Area of Rokan Hilir Regency, Riau Province," *Economic and Social of Fisheries and Marine Journal (ECSOFiM)*, vol. 7, no. 2, pp. 239–248, Apr. 2020, https://doi.org/10.21776/ub.ecsofim.2020.007.02.09.

[3] A. Malik, O. Mertz, and R. Fensholt, "Mangrove forest decline: consequences for livelihoods and environment in South Sulawesi," *Regional Environmental Change*, vol. 17, no. 1, pp. 157–169, Jan. 2017, https://doi.org/10.1007/s10113-016-0989-0.

[4] R. Rudianto, V. Darmawan, A. Isdianto, and G. Bintoro, "Restoration of coastal ecosystems as an approach to the integrated mangrove ecosystem management and mitigation and adaptation to climate changes in north coast of East Java," *Journal of Coastal Conservation*, vol. 26, no. 4, July 2022, Art. no. 37, https://doi.org/10.1007/s11852-022-00865-4.

[5] Y. Y. Luo, C. Not, and S. Cannicci, "Mangroves as unique but understudied traps for anthropogenic marine debris: A review of present information and the way forward," *Environmental Pollution*, vol. 271, Feb. 2021, Art. no. 116291, https://doi.org/10.1016/j.envpol.2020.116291.

[6] Suyadi and C. Y. Manullang, "Distribution of plastic debris pollution and it is implications on mangrove vegetation," *Marine Pollution Bulletin*, vol. 160, Nov. 2020, Art. no. 111642, https://doi.org/10.1016/j.marpolbul.2020.111642.

[7] S. F. Fatmalah, N. Sa'adah, and N. I. Wijaya, "The Impact of Inorganic Waste on Seedling-Level Mangrove Vegetation in the Wonorejo Mangrove Ecosystem, Surabaya," *Journal Of Tropical Marine Research (J-Tropimar)*, vol. 4, no. 2, pp. 82–96, Nov. 2022, https://doi.org/10.30649/jrkt.v4i2.57.

[8] N. F. F. Ramadhanti, "Identification of marine debris in the Wonorejo Mangrove Ecotourism Area, Surabaya," *Environmental Pollution Journal*, vol. 4, no. 2, pp. 1062–1074, July 2024, https://doi.org/10.58954/epj.v4i2.199.

[9] S. Wahyuni, B. Sulardiono, and B. Hendrarto, "Wonorejo Mangrove Ecotourism Development Strategy, Rungkut District, Surabaya," *Management of Aquatic Resources Journal (MAQUARES)*, vol. 4, no. 4, pp. 66–70, Oct. 2015.

[10] M. Asmal, "Identification of surface marine debris in relation to current patterns in the waters of Barrang Caddi Island, Sangkarrang District, Makassar City," B. Thesis, Department of Marine Science, Hasanuddin University, Makassar, Indonesia, 2021.

[11] D. Rosalina and D. Sofarini, "Diversity of Mangrove Species in Rukam Village, West Bangka Regency," *EnviroScienteae*, vol. 17, no. 2, pp. 57–61, Sept. 2021, https://doi.org/10.20527/es.v17i2.11495.

[12] D. Yoswaty, B. Amin, Nursyirwani, A. Diharmi, M. A. Wibowo, and A. Hendrizal, "Analysis of marine debris and mangrove forest density in Purnama village, Dumai city, Riau province," *IOP Conference Series: Earth and Environmental Science*, vol. 919, no. 1, Aug. 2021, Art. no. 012017, https://doi.org/10.1088/1755-1315/919/1/012017.

[13] W. B. Zukowska, B. Wojkiewicz, and A. Lewandowski, "Trunks of multi-stem black poplars may have different genotypes – evidence from the Oder valley in Poland," *Dendrobiology*, vol. 86, pp. 1–7, July 2021, https://doi.org/10.12657/denbio.086.001.

[14] N. Fajriah, M. Fauzi, and E. Sumiarsih, "Composition and Density of Marine Debris in the Mangrove Ecosystems of the Sungai Rawa Village, Sungai Apit Subsdistrict, Siak Regency, Riau Province," *Asian Journal of Aquatic Sciences*, vol. 2, no. 1, pp. 29–38, 2019.

[15] N. Sudirman, D. D. Suryono, A. Daulat, A. Rustam, H. L. Salim, and M. H. Jayawiguna, "Distribution of marine debris in Jakarta Bay and its implication to the coastal ecosystem," *IOP Conference Series: Earth and Environmental Science*, vol. 925, no. 1, Aug. 2021, Art. no. 012017, https://doi.org/10.1088/1755-1315/925/1/012017.

[16] D. Nurdiana, G. Ghitarina, A. Rafii, R. Eryati, and M. M. Yasser, "Identification of Types and Abundance of Marine Debris in the Coastal Area of Sambera Beach, Muara Badak District, Kutai Kartanegara Regency, East Kalimantan," *Jurnal Tropical Aquatic Sciences*, vol. 1, no. 1, pp. 24–30, Apr. 2022, https://doi.org/10.30872/tas.v1i1.469.

[17] A. Prajanti and M. Berlianto, "Beach litter monitoring," in *Marine Litter Monitoring Guidelines: Beach Litter, Floating Litter, and Seafloor Litter*, N. Farhani and S. Nugroho, Eds., 2nd ed. Jakarta, Indonesia: Ministry of Environment and Forestry of the Republic of Indonesia (in Indonesian), 2020, ch. 1, pp. 5–28.

[18] A. Suwanto, N. D. Takarina, R. H. Koestoer, and E. Frimawaty, "Diversity, biomass, covers, and NDVI of restored mangrove forests in Karawang and Subang Coasts, West Java, Indonesia," *Biodiversitas Journal of Biological Diversity*, vol. 22, no. 9, Sept. 2021, https://doi.org/10.13057/biodiv/d220960.

[19] N. I. Wijaya and M. Huda, "Monitoring the Distribution of Rehabilitated Mangrove Vegetation in the Wonorejo Mangrove Ecotourism Area, Surabaya," *Jurnal Ilmu dan Teknologi Kelautan Tropis*, vol. 10, no. 3, pp. 747–755, 2018, https://doi.org/10.29244/jitkt.v10i3.21271.

[20] T. Djamaluddin *et al.*, "Differences in Maximum Tides Responses of the North Coast and the South Coast of Java on the Effects of the Position of the Moon and the Sun," *Journal of Physics: Conference Series*, vol. 2773, no. 1, Mar. 2024, Art. no. 012010, https://doi.org/10.1088/1742-6596/2773/1/012010.

[21] A. S. Raihan, A. S. Atmadipoera, Y. Naulita, N. Balbeid, and R. Noviyanti, "Assessment of Oceanographic Trend and Ocean Health Index in The Gulf of Madura," *E3S Web of Conferences*, vol. 483, 2024, Art. no. 01012, https://doi.org/10.1051/e3sconf/202448301012.

[22] T. Galia, V. Skarpich, and J. Hradecky, "Connectivity of the coarsest fraction in headwater channels: imprints of fluvial processes and debris-flow activity," *Geografiska Annaler: Series A, Physical Geography*, vol. 97, no. 3, pp. 437–452, Sept. 2015, https://doi.org/10.1111/geoa.12086.

[23] V. K. Pham, "Performance of Artificial Bed-Wetting Parameter in a 1D Coulomb-Type Debris Flow Numerical Model," *Engineering, Technology & Applied Science Research*, vol. 15, no. 3, pp. 22612–22620, June 2025, https://doi.org/10.48084/etasr.10719.

[24] L. Rahman, N. P. Zamani, M. S. Ismet, and M. R. Cordova, "Effects of seasonal variation on the characteristics of stranded marine debris within Rambut Island Wildlife Reserve, Indonesia," *Jurnal Kelautan Tropis*, vol. 27, no. 1, pp. 129–138, Mar. 2024, https://doi.org/10.14710/jkt.v27i1.20655.

[25] G. R. L. Gonçalves, C. Grey, A. Koomson, J. Aggrey-Fynn, B. K. Nyarko, and B. E. Narayanaswamy, "Patterns and implications of plastic accumulation in mangrove ecosystems and sandy beaches in Western and Central regions of Ghana, West Africa," *Environmental Science and Pollution Research*, vol. 32, no. 19, pp. 11996–12012, Apr. 2025, https://doi.org/10.1007/s11356-025-36359-7.

[26] D. Li *et al.*, "Marine Debris in the Beilun Estuary Mangrove Forest: Monitoring, Assessment and Implications," *International Journal of Environmental Research and Public Health*, vol. 18, no. 20, Jan. 2021, Art. no. 10826, https://doi.org/10.3390/ijerph182010826.

[27] S. Sundaralingam and N. Ramanathan, "A Deep Learning-Based approach to Segregate Solid Waste Generated in Residential Areas," *Engineering, Technology & Applied Science Research*, vol. 13, no. 2, pp. 10439–10446, Apr. 2023, https://doi.org/10.48084/etasr.5716.

[28] E. V. Palconit *et al.*, "Resource Assessment of Tidal Stream Power in Pakiputan Strait, Davao Gulf, Philippines," *Engineering, Technology & Applied Science Research*, vol. 11, no. 3, pp. 7233–7239, June 2021, https://doi.org/10.48084/etasr.3853.