JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2024, 25(9), 70–80
https://doi.org/10.12911/22998993/190514
ISSN 2299–8993, License CC-BY 4.0

Received: 2024.05.29
Accepted: 2024.07.15
Published: 2024.08.01

The Occurrence of Marine Debris and Its Impacts on Coral Reefs in the Sempu Island Nature Reserve, Malang, Indonesia

Andik Isdianto[1,2*], Wanda Suryani Pangestu[1], Ade Yamindago[1,2],
Citra Satrya Utama Dewi[1,3], Dian Aliviyanti[1,2], Oktiyas Muzaky Luthfi[1,2],
Desy Setyoningrum[1], Aulia Lanudia Fathah[4], Berlania Mahardika Putri[5],
Intan Dwi Puspitasari[6]

[1] Department of Marine Sciences, Faculty of Fisheries and Marine Sciences, Brawijaya University, Jl. Veteran, Malang, 65145, Indonesia

[2] Coastal Resilience and Climate Change Adaptation Research Group, Brawijaya University, Jl. Veteran, Ketawanggede, Kec. Lowokwaru, Kota Malang, 65145, Indonesia

[3] Doctoral Program of Environmental Studies, Brawijaya University Postgraduate School, Jl. MT. Haryono 169, Malang 65145, Indonesia

[4] Master in Environmental Management and Development, Brawijaya University Postgraduate School, Jl. MT Haryono 169, Malang, 65145, Indonesia

[5] Master of Environmental Sciences, Graduate School of Universitas Gadjah Mada, Jl. Teknika Utara, Pogung, Sinduadi, Mlati, Sleman, Yogyakarta, 55284, Indonesia

[6] Institute of Marine Biology, National Taiwan Ocean University, No.2, Beining Rd., Jhongjheng District, Keelung City 20224, Taiwan

* Corresponding author's e-mail: andik.isdianto@ub.ac.id

ABSTRACT

Marine debris significantly impacts coral ecosystems, especially in regions with high biodiversity like the Sempu Island Nature Reserve in Malang, Indonesia. According to the guidelines of ReefCheck and KLHK 2020, this in-depth study looked at the types, amounts, and impacts of marine debris on coral health at five different sites close to the Pondokdadap Coastal Fishing Port. This study employs a belt transect method measuring 100 × 5 meters to systematically collect data. The obtained results indicate that cloth refuse is the most substantial form of waste, accounting for 84.65% of the weight of marine waste. The primary locations for this form of waste are areas with high human activity, particularly those near fishing ports. The impact of marine debris on coral reefs depends on its proximity to human activity, as it exhibits a wide range of density and composition. Millepora, a coral species characterized by its branching structure, was the most severely impacted, with damage levels spanning from 12.07% to 48.65%. This indicates its vulnerability to debris accumulation. The study determined the prevalence of a variety of waste categories, with plastic being the most prevalent. The study also focused on other types of inorganic waste, such as packaging, fishing lines, raffia ropes, rubber (flip-flops and tires), fabric, metal (cans and metal cutlery), glass bottles, and other items, primarily in the port area. The density of debris is an important indicator of the environmental pressure exerted on coral ecosystems. Among the examined locations, the Jetty station displayed the highest concentration of inorganic debris, with a density of 0.100 items/m^2. In contrast, Watu Meja Station had the lowest density of inorganic waste at 0.008 items/m^2, but the highest concentration of organic waste at 0.066 items/m^2. This indicates that there is less human impact but more accumulation of natural refuse. This study highlights the pressing necessity for effective marine waste management strategies, particularly near active ports like Pondokdadap, to mitigate the detrimental effects on coral reefs. The health and sustainability of this critical marine ecosystem can be ensured by reducing refuse accumulation through enhanced waste management protocols and community engagement.

Keywords: belt transect method, coral damage, marine debris impact, anthropogenic, environmental pressure, debris accumulation, debris composition, debris density.

INTRODUCTION

Marine debris refers to solid materials that enter the ocean via rivers or dumping. Along 50 km of coastline with more than 180 million inhabitants in Indonesia, around 5.4 million tonnes of plastic waste are generated, with 60% unmanaged, causing more than 1 million tonnes to end up in the sea, a major problem due to a lack of technology [Purba et al., 2021; Afianti et al., 2022]. Ocean waves and currents transport debris to the bottom, where it degrades over centuries [Handyman et al., 2018]. Heavy debris is harder to move than light debris caused by ocean waves and currents [Bauer-Civiello et al., 2018; Putra et al., 2021]. The sinking of marine debris to the bottom has the potential to indirectly damage coral reefs [Figueroa-Pico et al., 2016; Ballesteros et al., 2018]. Corals may become entangled, constricted, or damaged if deposition rates rise [Bauer-Civiello et al., 2018]. Recent research has linked soft plastics, fishing lines, and net lines to coral reef damage (fragmentation) and disease susceptibility [Lamb et al., 2016; Lamb et al., 2018]. Marine debris, especially plastic, releases hazardous VOCs and greenhouse gases, according to a recent report [Vaseashta et al., 2021].

Sempu Island's nature reserve (877 hectares) is managed by the East Java Natural Resources Conservation Center or BKSDA, which has a high potential for natural resources, particularly in coastal areas [Rahajeng et al., 2014]. The Sempu Strait is appropriate for shipping and fishing because of its coastal habitats, mangroves, macroalgae, and coral reefs (< 10 hectares) [Luthfi et al., 2018]. Shipping activities have both direct and indirect impacts on various marine habitats. Shipping impacts marine ecosystems because of physical disruption; pollution because of oil spills, ballast water discharge, and emission of harmful substances; and invasive species because of pollution and disease. Due to the fishing port and anthropogenic operations, Sempu Strait coral reef ecosystems are rapidly declining and severely vulnerable [Luthfi et al., 2016]. However, the El Nino-induced anomalous sea surface temperatures in the Indian Ocean produced extensive coral bleaching from 2009 to 2010, leading to a 37% live coral cover in the Sempu Strait (average data from 2009 to 2016) [Luthfi et al., 2018]. Coral cover in the Sempu Strait dropped from 23.3% in 2016 to 20% in 2018 [Luthfi, 2017; Luthfi et al., 2019]. After that, the percentage fell to 11.5% in 2021 [Isdianto et al., 2023].

Marine debris is one of several causes of coral loss. The Sempu Strait, near human settlements and community activities, allows marine waste from tourism, transportation, and household operations to enter [Kusumaningrum et al., 2022]. Ocean currents and surges carry as well as distribute debris, decreasing dissolved oxygen, damaging coral reefs, and reducing coral cover [Assuyuti et al., 2018]. Researchers are increasingly interested in marine debris, which threatens marine conservation zones. Therefore, researching the condition of marine debris and the extent of coral reef cover in the Sempu Strait, both of which have not been previously examined, is critical. The objective of this study was to determine the composition and density of marine debris, in addition to its effects on coral reefs.

MATERIALS AND METHODS

Five observation stations were set to monitor the Sempu Island Nature Reserve in Malang Regency, Indonesia, in April 2023. The five chosen stations, Watu Meja (WM), Waru-waru (WW), Banyu Tawar (BT), Jetty (JT), and Rumah Apung (RA), have different characteristics (Fig. 1). The first study station, WM, was located in the eastern part of the Sempu Strait, near the Indian Ocean, with strong currents and high waves [Kusumaningrum et al., 2022] and the least human effect [Luthfi et al., 2019]. The second WW station is in a tourist area with tourist activities. Due to coral destruction, tourist activities – including fishing, kayaking, and diving on coral reefs – harm coral growth [Luthfi, 2016]. The third station, BT, near the river's mouth mixes saltwater from the sea and freshwater from the river on sediment-rich Sempu Island [Luthfi, et al., 2018]. Debris rivers usually include high sediment concentrations [Tunas et al., 2024]. JT, the fourth station, is where the fishing port was developed; therefore, it is where unloading and loading activities take place [Isdianto et al., 2022a]. The final station, a RA near the community, pollutes coral with domestic debris [Wibawa and Luthfi, 2017].

The systematic methods used in this study were the belt transect methodology, which involves measuring and collecting data along specific regions of the reef, to assess the effects of debris on coral reefs. This approach helps quantify the types and amounts of debris present and their direct effects on coral health, with

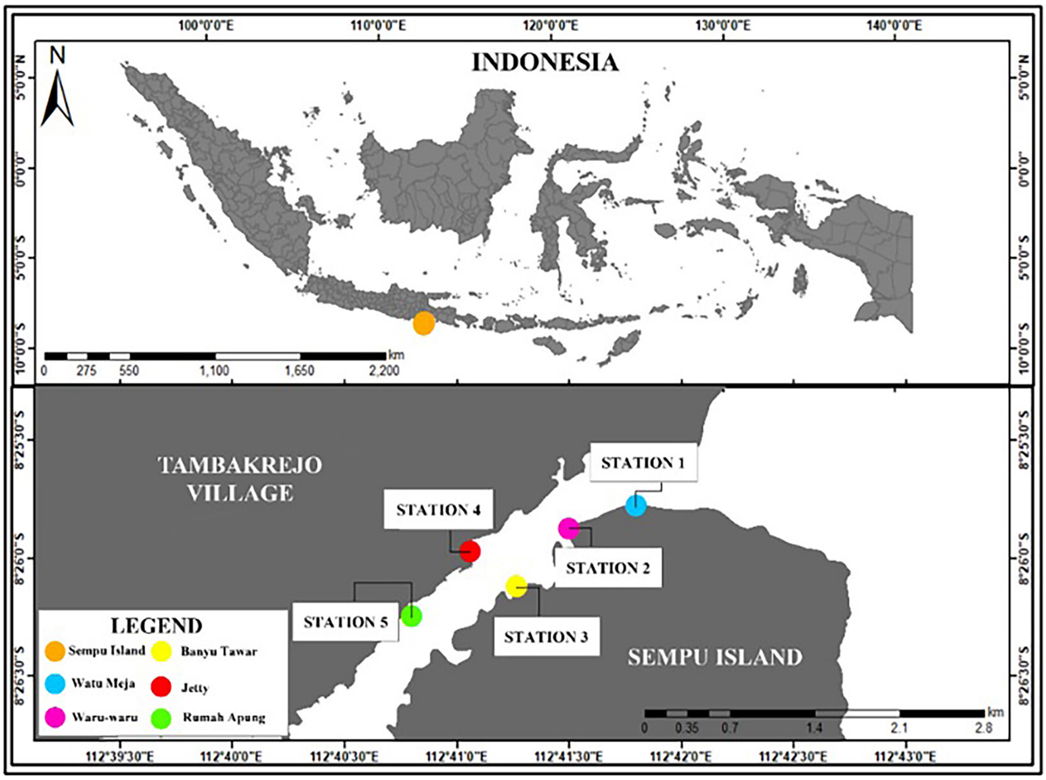


Figure 1. Location of marine debris data collection points

key indicators including the density and composition of debris, particularly in high-human activity areas where waste accumulation is most pronounced. Marine debris sampling followed ReefCheck guidelines [Hodgson et al., 2006]. Sampling devices were placed at a depth of 306 m on the seafloor using the above criteria. An imagined box 100 m long and 5 m wide constituted the sample unit (Fig. 2). Divers zigzagged along the transect belt, recording over 2.5 cm of marine debris [Dalongeville et al., 2018]. Researchers classified marine debris samples by

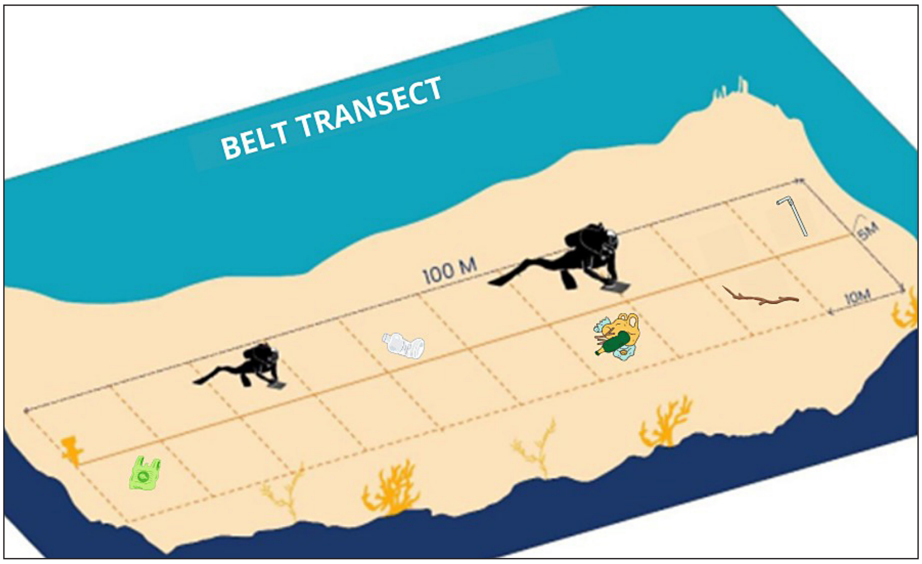


Figure 2. Belt transect for monitoring marine debris

type, including plastic, leaves, glass, wood, rubber, fabric, and metal. The findings of the marine debris sampling were input into a waste collecting form, and the weight, composition, and density of marine debris were calculated using the data processing method provided by the Ministry of Environment and Forestry's marine debris monitoring guidelines [Prajanti et al., 2020].

Marine debris density

The formula for calculating the density of marine debris can be expressed as the number of items per unit area (items/m²).

$$D = \frac{N}{A} \tag{1}$$

where: *D* – the density of marine debris (items/m²); *N* – the number of marine debris items; *A* – the area surveyed, where A = lenght × width (m²).

Composition of marine debris

Type-based composition

The type-based composition of marine debris refers to the proportion of different types of debris found in a surveyed area. Typically, it is expressed as a percentage of the total number of debris items. The formula is:

$$Ci, type = \frac{Ni}{Ntotal} \times 100\% \tag{2}$$

where: *Ci*, type – the percentage composition of the *i*-th type of marine debris; *Ni* – the number of items in the *i*-th type; *Ntotal* – the total number of all debris items collected.

Weight-based composition

The type-based composition of marine debris refers to the proportion of different types of debris found in a surveyed area. Typically, it is expressed as a percentage of the total number of debris items. The formula is:

$$Ci, weight = \frac{Wi}{Wtotal} \times 100\% \tag{3}$$

where: *Ci*, type – the percentage composition of the *i*-th type of marine debris; *Wi* – the number of items in the *i*-th type; *Wtotal* – the total number of all debris items collected.

Water current velocity and waves measure

Wave characteristics and current velocity are important factors in marine debris accumulation and distribution [Nawastuti and Lewoema 2019]. The current velocity was calculated from secondary sources from OSCAR (Ocean Surface Current Analysis Real-time) while monitoring ocean waves in situ using a scale stick.

RESULTS AND DISCUSSION

Type-based composition of marine debris in the Sempu Island Nature Reserve

The type-based marine debris composition of the Sempu Island Nature Reserve is presented in Figure 3. WM had the most twigs, 48.65%. The trees around the station drop some twigs, while the ocean current transports others. The current velocity of the WM station is moderate (0.49 m/s); therefore, lightweight debris like leaves will be carried by the ocean current and transported across the water surface. WM station has the least anthropogenic activity; hence, organic waste dominates. Moderate-velocity ocean currents carry lightweight marine debris like leaves, twigs, and plastics [Kusumawati et al., 2019]. JT station has a total of 86.21% (14 categories) of inorganic waste composition. Loading and unloading catches, refueling, marketplaces, and food kiosks generate inorganic waste in port areas. High activity at Pondokdadap Coastal Fishing Port includes port waste, ship activities, ship waste, and domestics rubbish [Wibawa and Luthfi, 2017].

Weight-based composition of marine debris in the Sempu Island Nature Reserve

Fabric formed most of the Sempu Island Nature Reserve marine debris at stations JT, RA, and WW (Fig. 4). Fabric material waste was highest at the RA station at 84.65% (317.03 g). Human activity in the JT and RA produces fabric, tires, and fishing lines. The RA is near a residential settlement and floating net cages. Sinking unused cage nets destroys coral reefs below [Tatanging et al., 2019]. According to studies in Manado Bay, North Sulawesi, plastic waste dominated with 40.63% (3,885.24 g) and fabric with 37.07% (3,544.93 g), which was leftover material from aquaculture cage production [Pane et al., 2020].

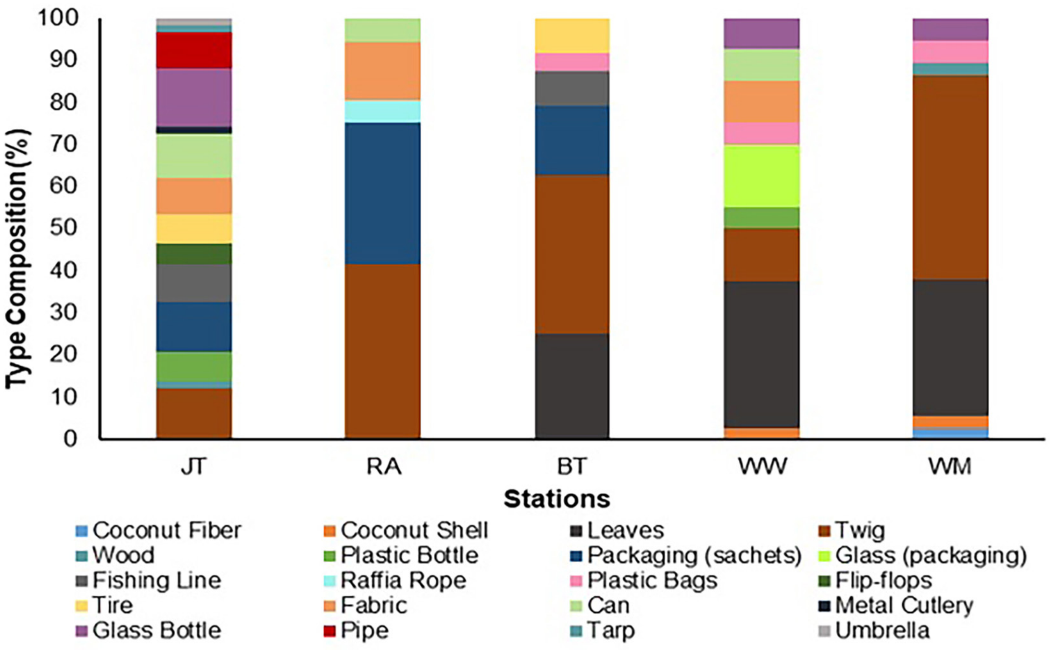
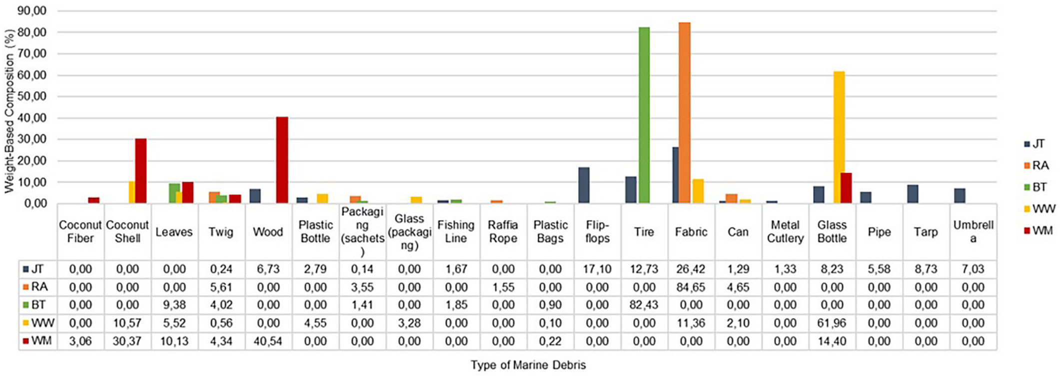


Figure 3. Type composition of marine debris in the Sempu Island Nature Reserve

Figure 4 shows that traders and individuals who deliberately litter the JT and WW sites contribute to plastic debris. Ocean currents easily take plastic and other lightweight debris. However, this study demonstrated no significant effect of current velocity (0.38 m/s) on JT station debris. Ships lean to reduce surface wind effects on the weak current velocity near the JT station [Isdianto et al., 2022b]. Near Sendang Biru Port, fishing boat activities, fish market waste disposal, and domestic garbage disposal left a lot [Wijaya et al., 2018].

Marine debris density in the Sempu Island Nature Reserve

The marine debris density graph at Sempu Island Nature Reserve is displayed in Figure 5. Marine debris may be organic or inorganic. Organic debris like coconut shells and fiber, leaves, twigs, and wood and inorganic waste, such as plastic bottles, packaging, fishing line, raffia ropes, glass and plastic bags, rubber (flip-flops and tires), fabric, metal (cans and metal cutlery), glass bottles, and other items, can pollute the environment [Li et al., 2023]. The JT station had the lowest organic waste density at 0.016 items/m^2, while the WM station had the highest at 0.066 items/m^2. The majority of organic waste in the Sempu Island Nature Reserve waters includes twigs from surrounding trees. JT had the highest inorganic debris density at 0.100 items/m^2, while WM had the lowest at 0.008 items/m^2. Inorganic debris in Sempu Strait waterways is mostly plastic packaging. The majority of plastic garbage found in the Sempu



	Coconut Fiber	Coconut Shell	Leaves	Twig	Wood	Plastic Bottle	Packaging (sachets)	Glass (packaging)	Fishing Line	Raffia Rope	Plastic Bags	Flip-flops	Tire	Fabric	Can	Metal Cutlery	Glass Bottle	Pipe	Tarp	Umbrella
■ JT	0,00	0,00	0,00	0,24	6,73	2,79	0,14	0,00	1,67	0,00	0,00	17,10	12,73	26,42	1,29	1,33	8,23	5,58	8,73	7,03
■ RA	0,00	0,00	0,00	5,61	0,00	0,00	3,55	0,00	0,00	1,55	0,00	0,00	0,00	84,65	4,65	0,00	0,00	0,00	0,00	0,00
■ BT	0,00	0,00	9,38	4,02	0,00	0,00	1,41	0,00	1,85	0,00	0,90	0,00	82,43	0,00	0,00	0,00	0,00	0,00	0,00	0,00
■ WW	0,00	10,57	5,52	0,56	0,00	4,55	0,00	3,28	0,00	0,00	0,10	0,00	0,00	11,36	2,10	0,00	61,96	0,00	0,00	0,00
■ WM	3,06	30,37	10,13	4,34	40,54	0,00	0,00	0,00	0,00	0,00	0,22	0,00	0,00	0,00	0,00	0,00	14,40	0,00	0,00	0,00

Figure 4. Weight composition of marine debris in the Sempu Island Nature Reserve

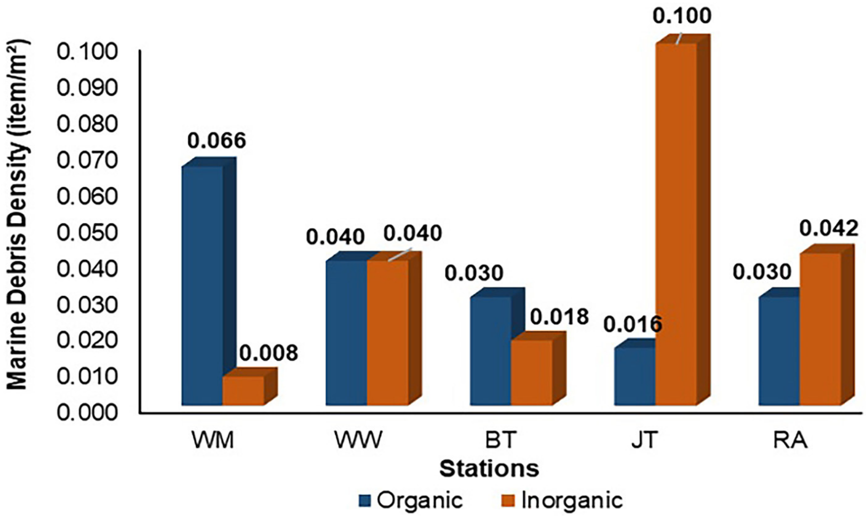


Figure 5. Marine debris density in the Sempu Island Nature Reserve. Note: WM (Watu Meja); WW (Waru-Waru); BT (Banyu Tawar); JT (Jetty); and RA (Rumah Apung).

Strait waterways is contributed by port loading and unloading, residential and tourism activities, and resident settlements at JT, RA, and WW stations. Community activities, fishing, and tourism could generate marine debris. The lack of waste and landfill facilities near residential areas and the existence of waters that connect resident settlements are two factors that contribute to the transport of waste into the water [Amri et al., 2023].

Water current velocity and waves measure in the Sempu Island Nature Reserve

Current velocity and waves impact marine debris distribution. The average of the waters current in the Sempu Island Nature Reserve is 0.46 m/s (Table 1). Very strong (> 1 m/s), strong (0.50–1 m/s), moderate (0.25–0.5 m/s), and weak (0.25–0.25 m/s) are current velocity criteria [Ramlah et al. 2015]. The closeness of the Sempu Island Nature Reserve waters to the Indian Ocean affects current velocity and wave energy [Kusumaningrum et al., 2022]. Thus, Indian Ocean events like the strong South Java Current (SJC), influenced by IOD and ENSO, affect ocean currents and water masses [Zhang et al., 2016]. The west monsoon season shifts the South Java Current east. However, this ocean circulation becomes highly complicated at the coast; therefore, its direction depends on the coastline layout [Amri et al. 2023].

The study took place in April, during the West Monsoon. The typical current velocity is 0.3–0.6 m/s during the Western and Eastern Monsoons (December–April and June–October) [Kusumaningrum et al., 2022]. The waters of the Sempu Island Nature Reserve waves are about 1 meter high. Five categories of wave height requirements exist: very high (> 6.9 m), high (6.0–6.9 m), moderate (5.0–5.9 m), low (3.1–4.9 m), and very low (2.90 m) [Kusumawati et al. 2019]. The island of Sempu blocks the ocean from entering the port. Sempu Island will indirectly shield the coral reefs facing the port from heavy waves.

Frequency of marine debris on corals in the Sempu Island Nature Reserve

A study of marine debris in the Sempu Island Nature Reserve identified many forms in the coral reef ecosystem. Table 2 shows 91 organic waste pieces. The least amount of debris discovered was

Table 1. Water current velocity and waves

Parameters	Unit	Stations					Avg.
		JT	RA	BT	WM	WW	
Current velocity	m/s	0.38	0.45	0.47	0.49	0.50	0.46
Waves	m	0.81	0.85	0.74	1.30	1.32	1

Note: JT – Jetty, RA – Rumah Apung, BT – Banyu Tawar, WM – Watu Meja, WW – Waru-waru.

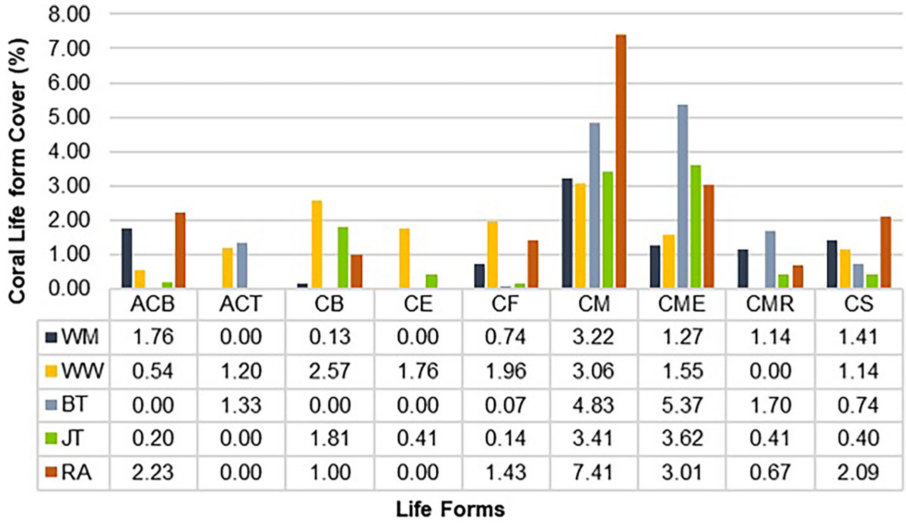
Table 2. Marine debris on coral reefs in the Sempu Island Nature Reserve

Life form	Marine debris							Total
	Organic	Plastic	Rubber	Textil	Metal	Glass	Others	
Massive	5	4	0	1	2	2	0	14
Foliose	6	4	1	2	1	1	0	15
Encrusting	7	4	1	1	1	0	0	14
Submassive	8	1	0	0	2	1	0	12
Branching	8	6	0	2	1	1	2	20
Mushroom	5	0	0	0	0	0	0	5
Tabulate	6	4	0	2	0	0	0	12
Millepora	12	7	1	3	1	2	0	26
Sedimen	34	19	6	3	4	6	5	76
Total	91	49	9	14	12	13	7	195

seven items of other waste, which in this study included umbrellas, tarps, and pipes. According to Table 2, millepora is the most common marine debris found in lifeforms, with 26 items, while organic waste occurs most frequently with 12 items. Figure 6. shows Coral Massive has the most coral lifeform cover at 4.39%, while Table 2 shows Coral Millepora has the most marine debris. The gaps in coral millepora facilitate the entanglement of trash, particularly lightweight items that can be easily carried away by the medium to strong ocean current in in the Sempu Island Nature Reserve, which flows at a speed of 0.46 m/s. This is because currents struggle with transporting heavier materials and may remain stationary. The heavier items at Coral Massive include glass bottles and cans (Fig. 7).

Impact of marine debris on coral reefs in the Sempu Island Nature Reserve

The following table shows the density of marine debris at five different stations in the Sempu Island conservation area. Table 3 depicts the density of marine debris (both inorganic and organic) measured in items per square meter (items/m^2) at five stations: JT, RA, BT, WW, and WM. The highest density was found at JT station with 0.116 items/m^2, indicating that this area has the most significant accumulation of marine debris. In contrast, the BT station has the lowest waste density, with only 0.048 items per m^2. Stations RA, WW, and WM show varying but lower waste densities than JT, with 0.072, 0.08, and 0.074 items/



	ACB	ACT	CB	CE	CF	CM	CME	CMR	CS
■ WM	1.76	0.00	0.13	0.00	0.74	3.22	1.27	1.14	1.41
■ WW	0.54	1.20	2.57	1.76	1.96	3.06	1.55	0.00	1.14
■ BT	0.00	1.33	0.00	0.00	0.07	4.83	5.37	1.70	0.74
■ JT	0.20	0.00	1.81	0.41	0.14	3.41	3.62	0.41	0.40
■ RA	2.23	0.00	1.00	0.00	1.43	7.41	3.01	0.67	2.09

Figure 6. Coral life form cover in the Sempu Island Nature Reserve. Note: WM (Watu Meja); WW (Waru-Waru); BT (Banyu Tawar); JT (Jetty); RA (Rumah Apung); ACB (Acropora Brancing); ACT (Acropora Tabulate); CB (Coral Branching); CE (Coral Encrusting); CF (Coral Foliose); CM (Coral Massive); CME (Coral Millepora); CMR (Coral Mushroom); and CS (Coral Submassive)

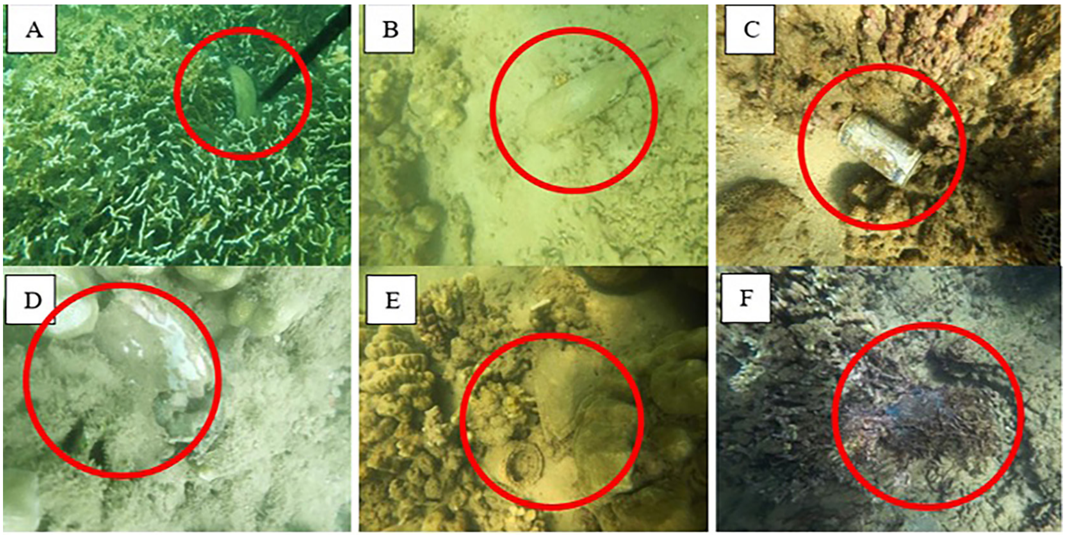


Figure 7. Marine debris on corals in the Sempu Island Nature Reserve: (a) coconut coir, (b) glass bottle, (c) can, (d) plastic glass, (e) cans and fabric, (f) raffia rope

Table 3. The density of marine debris at five stations

Station	Marine debris density (item/m²)
JT	0.116
RA	0.072
BT	0.048
WW	0.08
WM	0.074

m^2, respectively. These data indicate that the level of human activity and waste management at each station may contribute to differences in marine debris density, which in turn may affect the condition of coral ecosystems in the region.

Marine debris on coral reefs caused numerous issues (Fig. 8). Several coral reefs at the RA station were covered in fabric and raffia rope,

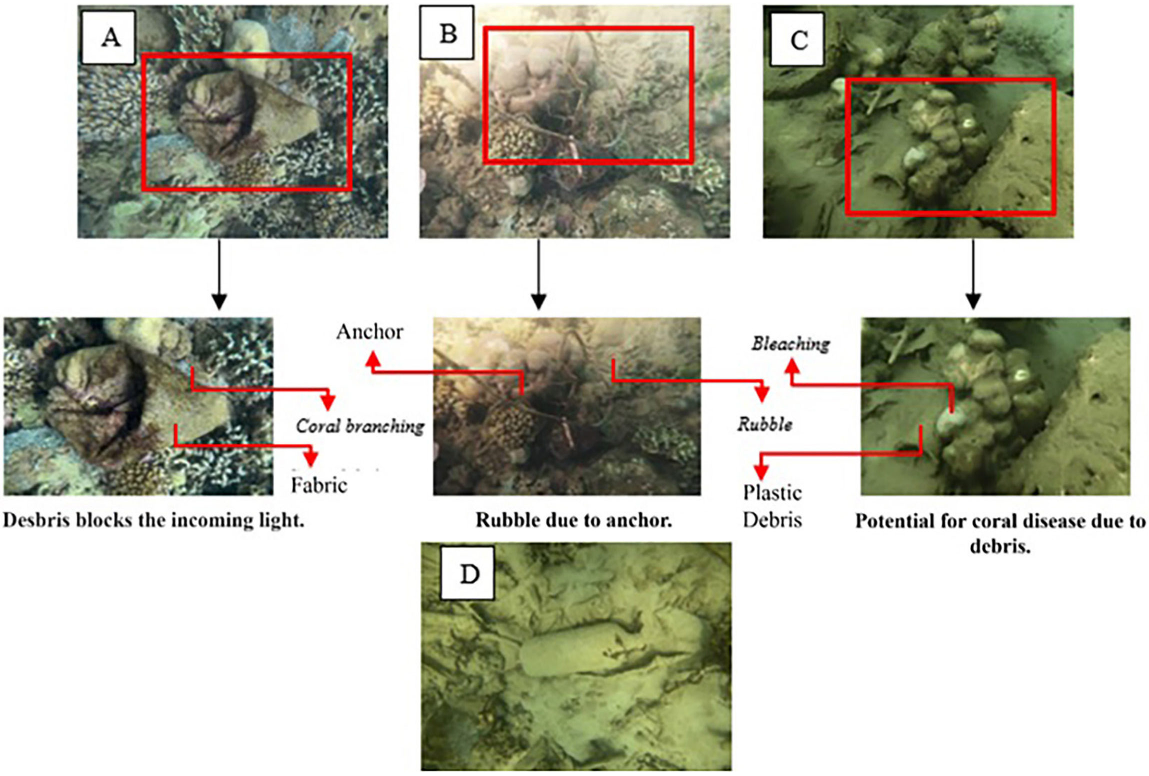


Figure 8. Impact of marine debris on Coral Reefs in the Sempu Island Nature Reserve: (a) blocking the incoming light; (b) coral damage due to anchors; (c) disease potential; (d) glass bottle at the seabed

which is above the coral tabulate and foliose and blocks sunlight for photosynthesizing (Fig. 8A). Coral reefs depend on light-dependent species for photosynthesis and rapid calcification [Edmunds et al., 2018]. Reef-building corals depend on the nutrients produced by the photosynthetic activities of zooxanthellae. When photosynthesis decreases, the coral's calcium carbonate production is reduced as well [LaJeunesse, 2020].

At the JT station, ropes, and ship anchors were found entangled and caused the breakage of the millepore (Fig. 8B). Pushing or stepping on Millepora's skeleton easily damages it [Zurba 2019]. Several other factors, such as bacteria, temperature, sedimentation, and the presence of macroalgae that compete for living space, can also cause diseases on coral reefs [Lamb et al., 2018; Edward et al., 2020]. Marine debris and sedimentation are believed to cause coral bleaching (Fig. 8C). At WW and RA stations, coral disease was found. Plastic waste in coral reefs disturbs the symbiotic interaction between corals and zooxanthellae, damaging coral tissue and immunity. This makes harmful viruses and bacteria easier to infiltrate coral tissue and kill [Tang et al., 2018; Utami et al., 2021]. At WM and BT, the marine debris was just at the bottom of the ocean; therefore, it did not affect the coral reefs (Fig. 8D). Overall, coral reefs in the study area are significantly affected by the spread of marine debris, with evidence of widespread ecosystem damage, and require effective management interventions for restoration and conservation.

CONCLUSIONS

On the basis of the detailed findings from the Sempu Island Nature Reserve, this study underscores the critical environmental pressures exerted on coral ecosystems by marine debris, notably from areas with heightened human activities such as the Pondokdadap Coastal Fishing Port. In terms of weight, fabric represents the majority of the marine debris in the Sempu Island Nature Reserve at 84.65%. Twigs account for the largest proportion of marine debris, ranging from 12.07% to 48.65%. Twigs have the highest density of marine debris at 0.108 items/m^2, whereas coconut fiber, tarp, and umbrellas have the lowest densities at 0.002 items/m^2. Port Jetty station produces the greatest waste, with a density value of 0.116 items/m^2, whereas Banyu Tawar station, which is located in the Sempu Island conservation area, has the lowest density value, at 0.048 items/m^2. With its branched morphology, Millepora coral is the coral species that accumulates the most debris, consisting of 12 organic items and 14 inorganic items. Furthermore, an analysis of the sediment revealed 76 fragments of marine debris, of which 34 were organic items and 42 were inorganic. The presence of marine debris in in the Sempu Island Nature Reserve waters has a damaging impact on compromised coral reefs due to the debris's mass and stability surpassing that of coral branches. Additionally, the debris that adheres to and covers coral reefs can introduce coral disease, which hinders the growth of coral reefs.

These findings illuminate the stark impact of anthropogenic activities on marine debris distribution and coral health, emphasizing the need for robust waste management and mitigation strategies to safeguard these vital marine habitats. Implementing comprehensive debris management protocols at local and regional levels, particularly near busy ports and human settlements, is imperative to reduce the influx of harmful materials into these ecosystems and ensure the sustainability of coral reefs, which are critical to marine biodiversity and local livelihoods.

Acknowledgements

This research is independent research supported by several parties who provide facilities so that this research runs well. We would like to thank the CFP Pondokdadap Sendang Biru Malang Regency for providing permits and information support that made it easier for the research team to carry out activities in the field. We are very grateful to the Fisheries and Marine Exploration and Resources Laboratory, Faculty of Fisheries and Marine Sciences, Brawijaya University, which has supported the existence of equipment that helps researchers in realizing the data that can be presented in this manuscript.

REFERENCES

1. Afianti N.F., Rachman A., Hatmanti A., Yogaswara D., Anggiani M., Fitriya N., Darmayati Y. 2022. Microbial Biofilm of Plastic in Tropical Marine Environment and their Potential for Bioremediation of Plastic Waste. J Ecol Eng. 23(4): 261–275. https://doi.org/10.12911/22998993/145463
2. Amri R., Kholifiyanti C., Wijayanti E.S., Bayan S.,

Hidayat R.R., Hidayati N.V. 2023. Composition and Distribution of Marine Debris at Pasir Putih Losari Beach, Brebes, Central Java. J Kel Trop. 26(1): 135–147. https://doi.org/10.14710/jkt.v26i1.15770. (In Indonesian).

3. Assuyuti Y.M., Zikrillah R.B., Tanzil M.A., Banata A., Utami P. 2018. Distribution and Types of Marine Debris and Their Relationship to the Coral Reef Ecosystems of Pramuka, Panggang, Air, and Kotok Besar Islands in the Seribu Islands, Jakarta. Majalah Ilmiah Biologi Biosfera: A Scientific Journal. 35(2): 91–102. https://doi.org/10.20884/1.mib.2018.35.2.707. (In Indonesian).
4. Ballesteros L.V., Matthews J.L., Hoeksema B.W. 2018. Pollution and coral damage caused by derelict fishing gear on coral reefs around Koh Tao, Gulf of Thailand. Marine Pollution Bulletin. 135: 1107–1116. https://doi.org/10.1016/j.marpolbul.2018.08.033
5. Bauer-Civiello A., Loder J., Hamann M. 2018. Using citizen science data to assess the difference in marine debris loads on reefs in Queensland, Australia. Marine Pollution Bulletin. 135: 458–465. https://doi.org/10.1016/j.marpolbul.2018.07.040
6. Dalongeville A, Jorcin A, Mills I. 2018. Coral Reef Monitoring Report 2018. People and The Sea.
7. Edmunds P.J., Tsounis G., Boulon R., Bramanti L. 2018. Long-term variation in light intensity on a coral reef. Coral Reefs. 37(3): 955–965. https://doi.org/10.1007/s00338-018-1721-y
8. Edward J.K.P., Mathews G., Raj K.D., Laju R.L., Bharath M.S., Kumar P.D., Arasamuthu A., Grimsditch G. 2020. Marine debris – An emerging threat to the reef areas of Gulf of Mannar, India. Marine Pollution Bulletin. 151: 110793. https://doi.org/10.1016/j.marpolbul.2019.110793
9. Figueroa-Pico J., Valle D.M-D, Castillo-Ruperti R., Macías-Mayorga D. 2016. Marine debris: Implications for conservation of rocky reefs in Manabi, Ecuador (Se Pacific Coast). Marine Pollution Bulletin. 109(1): 7–13. https://doi.org/10.1016/j.marpolbul.2016.05.070
10. Handyman D., Purba N., Pranowo W., Harahap S., Dante I., Yuliadi L. 2018. Microplastics Patch Based on HydrodynamicModeling in The North Indramayu, Java Sea. Pol J Environ Stud. 28(1): 135–142. https://doi.org/10.15244/pjoes/81704
11. Hodgson G., Hill, J., Kiene, W., Maun, L., Mihaly, J., Liebeler, J., Shuman, C., Torres, R. (eds). 2006. Reef check intruction manual: a guide to reef check coral reef monitoring. Reef Check, Inst. of the Environment, Los Angeles [Calif.].
12. Isdianto A., Haykal M.F., Putri B.M., Adibah F., Marhaendra Q.N.I., Fadhilah R.K., Prasetyo K.A.A., Hairuddin Q bin A, Andrimida A., Hardiyan F.Z. 2022a. Monitoring Coral Reefs around CMC Sempu Waters Rumah Apung Station In August 2021. Prosiding Seminar Nasional Perikanan dan Kelautan. 9(1): 47–58. (In Indonesian).
13. Isdianto A., Kurniawan A., Wicaksono A.D., Marhaendra Q.N.I., Putri B.M., Fathah A.L., Asadi M.A., Luthfi O.M., Pratiwi D.C.., Harahab N. 2023. Observation of Coral Reef and Macroalgae Competition in the Sempu Strait, Malang. J Ecol Eng. 24(10): 174–184. https://doi.org/10.12911/22998993/170246
14. Isdianto A., Luthfi O.M., Asadi M.A., Prasetyo K.A.A., Marhaendra Q.N.I., Fadhilah R.K., Hairuddin Q.B.A., Taufik M.Z., Mahardita R., Lelyemin B.Y., Putri B.M., Haykal M.F., Andrimida A., Hardiyan F.Z. 2022b. The Relation of Hydro-Oceanographic Parameters and Coral Cover in Sempu Strait. jfmr. 6(3): 45–53. https://doi.org/10.21776/ub.jfmr.2022.006.03.7. (In Indonesian).
15. Kusumaningrum, A., Bengen, D.G., Nurjaya, I. W. 2022. Suitability of Tourism Zone Based on Oceanographic Characteristics and Coastal Ecosystems in Sendang Biru Waters and Sempu Island, Malang Regency. Asian Journal of Fisheries and Aquatic Research, 23–33. https://doi.org/10.9734/ajfar/2022/v20i5506
16. Kusumawati I., Nasution M.A., Alamsyah A. 2019. Distribution and Composition Coastal Marine Garbage in The Sub-District Nagan Raya District. JLIK. 1(1). https://doi.org/10.35308/jlaot.v1i1.1073. (In Indonesian).
17. LaJeunesse T.C. 2020. Zooxanthellae. Current Biology. 30: R1110–R1113.
18. Lamb J.B., Wenger A.S., Devlin M.J., Ceccarelli D.M., Williamson D.H., Willis B.L. 2016. Reserves as tools for alleviating impacts of marine disease. Phil Trans R Soc B. 371(1689): 20150210. https://doi.org/10.1098/rstb.2015.0210
19. Lamb J.B., Willis B.L., Fiorenza E.A., Couch C.S., Howard R., Rader D.N., True J.D., Kelly L.A., Ahmad A., Jompa J., Harvell C.D. 2018. Plastic waste associated with disease on coral reefs. Science. 359(6374): 460–462. https://doi.org/10.1126/science.aar3320
20. Li, R., Wang, Q., Qu, G., Zhang, Z., Wang, H. 2023. Green utilization of organic waste resource. Environmental Science and Pollution Research, 30(4), 8899–8901. https://doi.org/10.1007/s11356-022-25127-6
21. Luthfi O.M. 2017. Substrates monitoring using reef check method in Sempu Strait Waters, Malang Regency. Depik. 6(1): 72–80. https://doi.org/10.13170/depik.6.1.5840
22. Luthfi O.M. 2016. Coral reef conservation using coral garden initiative in Sempu Island. JIAT. 2(1): 210–216. https://doi.org/10.21776/ub.jiat.2016.002.01.7. (In Indonesian).
23. Luthfi O.M., Akbara D., Ramadhan M.G., Rohman M., Wahib N.K. 2019. Comparative study of living and non-living cover of the bottom substrate

of Sempu Island Waters, Malang Regency Using the Reef Check Method. JFMR. 3(2): 1–8. https://doi.org/10.21776/ub.jfmr.2019.003.02.1. (In Indonesian).

24. Luthfi O.M., Dewi C.S, Dwi Sasmitha R., Syarif Alim D., Dwi Putranto D.B. 2018. Abundance of Invertebrates on Sempu Island as a Bioindicator Index, Economically Important Consumption, and Aquarium Collection Commodity. jfmr. 2(3): 137–148. https://doi.org/10.21776/ub.jfmr.2018.002.03.1. (In Indonesian).
25. Luthfi O.M., Pujarahayu P, S K.F., Wahyudiarto A., Fakri S.R., Sofyan M., Ramadhan F., A M.A.G., Murian S., Tovani I., Mahmud M., Adi D., Abdi F. 2016. Reef Fish Biodiversity and Population in Sempu Strait Waters Sendang Biru Malang Regency East Java. JK. 9(1): 43. https://doi.org/10.21107/jk.v9i1.1019. (In Indonesian).
26. Luthfi O.M., Rahmadita V.L., Setyohadi D. 2018. Examining the ecological equilibrium condition of Sempu Island, Malang's Coral Reefs Using the Hard Coral (Scleractinia) Colony Area Method. J Ilmu Lingk. 16(1): 1. https://doi.org/10.14710/jil.16.1.1-8 (In Indonesian).
27. Nawastuti D., Lewoema Z.K. 2019. Identification of Marine Debris for the Welfare of the Sinar Hading Village Community, Lewolema District, East Flores Regency. Jurnal AKRAB JUARA. 4(3): 1–13. (In Indonesian).
28. Pane L.R., Pelle W.E., Undap S.J., Rumampuk N.D.C., Warouw V., Mamuaja J.M., Lasut M.T. 2020. Type, composition, and density of marine litter in Manado Bay during rainy season. JAqSciMgmt. 8(1): 1. https://doi.org/10.35800/jasm.8.1.2020.29570
29. Prajanti A., Berlianto M., Simamora R.L., Imansari M.B., Sari N. 2020. Guidelines for Monitoring Marine Debris: Beach Debris, Floating Trash, and Seabed Debris. Direktorat Pengendalian Pencemaran dan Kerusakan Pesisir dan Laut, Jakarta.
30. Purba N.P., Faizal I., Cordova M.R., Abimanyu A., Afandi N.K.A., Indriawan D., Khan A.M.A. 2021. Marine Debris Pathway Across Indonesian Boundary Seas. J Ecol Eng. 22(3): 82–98. https://doi.org/10.12911/22998993/132428
31. Putra M.G.A., Zamani N.P., Natih N.M., Harahap S.A. 2021. Relationship Between Characteristics of Marine Debris and Impact to Coral Reef. JIPK. 13(1): 11–19. https://doi.org/10.20473/jipk.v13i1.18896
32. Rahajeng M.A., Hendrarto B., Purwanti F. 2014. Knowledge, Perceptions and Public Participation in Conservation at the Sempu Island Nature Reserve Malang. Diponegoro Journal of Maquares Management of Aquatic Resources. 3(4): 109–118. (In Indonesian).
33. Ramlah S., Fajri N.E., Adriman. 2015. Physical, Chemical Parameters and Saphrobic Coefficients (X) as Determinants of Water Quality in the Senapelan River, Pekanbaru. Jurnal Online Mahasiswa (JOM) Bidang Perikanan dan Ilmu Kelautan. 2(2): 1–12. (In Indonesian).
34. Tang J., Ni X., Zhou Z., Wang L., Lin S. 2018. Acute microplastic exposure raises stress response and suppresses detoxification and immune capacities in the scleractinian coral Pocillopora damicornis. Environmental Pollution. 243: 66–74. https://doi.org/10.1016/j.envpol.2018.08.045.
35. Tatanging D.Y., Luasunaung A., Modaso V.O.J., Kalangi P.N.I., Masengi K.W.A., Kumajas H.J. 2019. Lagrangian current around a FAD in the middle of Manado Bay. Jur Ilmu & Tek Perik Tangkap. 4(1): 26. https://doi.org/10.35800/jitpt.4.1.2019.22782 (In Indonesian).
36. Tunas I.G., Ishak M.G., Saparuddin S., Herman R. 2024. Characteristics of Bed Profiles Due to Sediment-Transport in a Debris River. Pol J Environ Stud. 33(2): 1347–1356. https://doi.org/10.15244/pjoes/170763
37. Utami D.A., Reuning L., Konechnaya O., Schwarzbauer J. 2021. Microplastics as a sedimentary component in reef systems: A case study from the Java Sea. Sedimentology. 68(6): 2270–2292. https://doi.org/10.1111/sed.12879
38. Vaseashta A., Ivanov V., Stabnikov V., Marinin A. 2021. Environmental Safety and Security Investigationsof Neustonic Microplastic Aggregates Near-Water-Air Interphase. Pol J Environ Stud. 30(4): 3457–3469. https://doi.org/10.15244/pjoes/131947
39. Wibawa I.G.N.A., Luthfi O.M. 2017. Water Quality of Coral Reef Ecosystem at Sempu Strait, Sendang Biru Malang. segara. 13(1): 25–35. https://doi.org/10.15578/segara.v13i1.6420. (In Indonesian).
40. Wijaya A.R., Farida I., Wonorahardjo S., Utomo Y., Daupor H., Hossain Md.S., Kunisue T. 2018. BCR Sequential Leaching for Geochemical Fractions and Assessment of Fe, Ni, and Mn in the Coastal Sediments Sendang Biru Port, East Java, Indonesia. J Phys: Conf Ser. 1093: 012002. https://doi.org/10.1088/1742-6596/1093/1/012002
41. Zhang, N., Feng, M., Du, Y., Lan, J., Wijffels, S.E. 2016. Seasonal and interannual variations of mixed layer salinity in the southeast tropical Indian Ocean. Journal of Geophysical Research: Oceans, 121(7), 4716–4731. https://doi.org/10.1002/2016JC011854
42. Zurba N. 2019. Introduction to Coral Reefs as the Main Foundation of Our Ocean. UNIMAL PRESS, Lhokseumawe. (In Indonesian).