Microplastics in the sediment of intertidal areas of Lamongan, Indonesia

Muhammad A. Asadi, Asus Maizar S. Hertika, Feni Iranawati, Aisyah Y. Yuwandita

Faculty of Fisheries and Marine Science, University of Brawijaya, Jalan Veteran, 65145, Malang, Indonesia. Corresponding author: M. A. Asadi, asadi@ub.ac.id

Abstract. Microplastics are small plastic pieces which pose a great threat to marine ecosystems. Indonesia is among the world's largest contributors to microplastics pollution. This research aimed to identify and measure the abundance of microplastics in the intertidal areas of Lamongan, Indonesia. The sediment characteristics in the study areas were also examined for correlation between soil type and microplastics abundance. Microplastics characterization of the sediments were carried out using a modified flotation method. Sediment types were determined using sieve shaker analysis and hydrometer analysis. On average, there were 206 items kg^{-1} dry weight of microplastics in which fibers shared more than 85% of all microplastics found in the research areas, with an average abundance of 178 items kg^{-1} dry weight. Fragments constituted 12%, with an average concentration of 25 items kg^{-1} dry weight. There was no significant difference between microplastics abundance at depths of 0-5 cm and 5-10 cm. However, the sediment texture may contribute to a higher concentration of microplastics. On average, clayey silts held significantly higher concentrations of microplastics than sand and gravelly sand. The high concentration of microplastics in the intertidal areas of Lamongan could have a negative impact on intertidal organisms and therefore may affect humans through the food chain.
Key Words: microplastics, fiber, abundance, sediment, intertidal area, Lamongan.

Introduction. The use of plastics continues to increase in every aspect of daily life. Plastics are affordable and have incredible properties (strong, durable, lightweight, and versatile) that make them ideal for many applications, ranging from personal goods to construction materials and transport (Andrady 2011; Van Cauwenberghe et al 2015; Alam et al 2018). Today, global plastic production is estimated to exceed 300 million tons (Thompson et al 2009), and more than 10 million tons of terrestrial plastic wastes end up in the oceans every year (Löhr et al 2017).

In marine environment, forces including wave action and UV radiation degrade larger plastic fragments into smaller pieces, eventually breaking them down into microplastics (Van Cauwenberghe et al 2015). The sources of microplastics in the marine environment include industrial raw materials that are lost during transport, discharges of sewage sludge, and the release of microparticles from sources such as personal care products and facial scrubs in urban wastewater into the marine environment (Lei et al 2017).

Depending on the author and the purpose of the study, the defined size of microplastic varies; however, an upper size limit of 5 mm is generally accepted in the literature (Anderson et al 2016). The contamination of microplastics has been demonstrated in almost all marine environments worldwide, from intertidal sediments to continental shelves. They enter marine surface waters and reach even to the most remote deep-sea bottom waters and sediments. A range of potential harms caused by microplastic exposures have been suggested for various marine organisms, including reduced fitness and growth rates, carcinogenesis, liver toxicity, endocrine disruption, and reproductive failure (Martin et al 2017).

The intertidal environment is particularly susceptible to microplastic accumulation due to anthropogenic stressors such as marine and fishing activities, coastal industrializations, and population growth in coastal areas (Martin et al 2017). In the coastal seafloor sediments across south-eastern Australia, microplastic pollutants, mostly present as microfilaments, occur at high concentrations (Ling et al 2017). Meanwhile, Indonesia is the second-largest source of plastic pollution in the global marine environment (Jambeck et al 2015). Therefore, the study of microplastics in Indonesia, including measurement of the distribution of microplastic particles in its marine environment, is essential.

In this study, microplastic pollution in the intertidal area of Lamongan was examined. The aim was to characterize and calculate the concentration of microplastics in sediments in the study area. An understanding of the types of microplastic (fragment, fiber/line, pellet, foam, and film) present could help to reveal the dominant sources of microplastics in the research area. The particle size of the sediment was also measured to reveal the link between deposition of microplastic particles and sediment type (Ling et al 2017).

Material and Method

The study areas. The research was performed in the coastal areas of Lamongan regency bounded by the longitude 112.193853° to 112.342806°, and latitude -6.865753° to -6.884724° (Table 1). The regency is situated at the northern west of East Java province with a total coastal line of 47 km (Figure 1). There were more than 175,000 people living in its coastal areas, a total area of approximately 120 km^2. The environmental pressures in its intertidal areas have continued to increase as the population has continued to grow (Asadi et al 2018b). Based on the Köppen-Geiger climate classification, the study area has a tropical savannah climate, characteristically humid with a precipitation average of 1465 mm and an average temperature of 27.4^{o}C (Asadi et al 2017; Merkel 2012).

Table 1

Coordinates and characteristics of research stations

Station	*Coordinates*	*Characteristics*
1	112.193853°, -6.884724°	A recreational beach surrounded by mangrove forest
2	112.269441°, -6.879982°	Situated at the Bengawan Solo delta of Sedayulawas
3	112.289153°, -6.865753°	Located in PPN Brondong, the biggest fishing port in Indonesia
4	112.342806°, -6.867680°	Closed to densely populated area

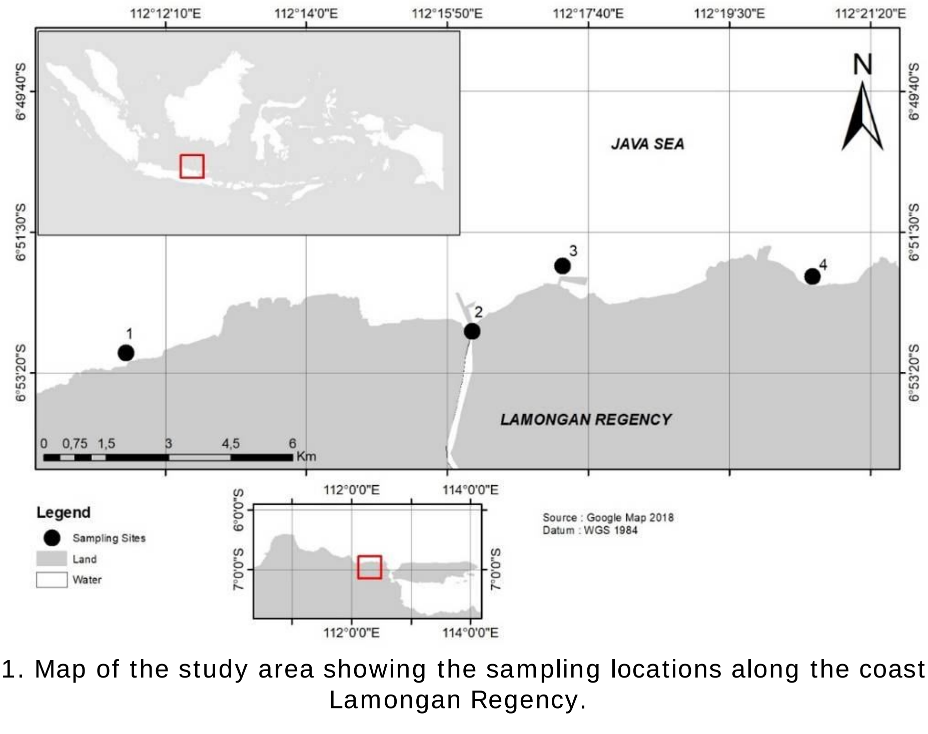

Figure 1. Map of the study area showing the sampling locations along the coastline of Lamongan Regency.

Sampling. The study was conducted in the intertidal areas of Lamongan in June 2018 during the dry season. In each sampling location, three transects of 50 x 50 cm were laid parallel to the coastline at a distance of 50 to 150 meters depending on the length of the coastline. In each transect, a total of two kilograms of soil, one for microplastic analysis and one for sediment analysis, was collected using soil augers with a diameter of 7.62 cm and a length of 10 cm. Soil samples were taken at depths of 0-5 cm and 5-10 cm and placed separate resealable plastic bags. Soil samples were packed in a cool box with ice and immediately transported to the laboratory for further analysis.

Sediment size analysis. Sediment particle size analysis was performed at the soil and water engineering laboratories at the University of Brawijaya. Sieve shaker analysis and hydrometer analysis were used for coarser and finer sediments, respectively. In the sieve shaker procedure, the samples were dried using a Memmert drying oven at approximately 60^{o}C until a constant weight was reached. The samples were then passed through different mesh sizes of test sieves and weighed for grain-size classification. In the hydrometer procedure, a 50 g sample of soil from each transect that passed through the No. 200 sieve was mixed with 125 mL of 4% sodium metaphosphate solution. After mixing, the contents of the dispersion cup were transferred to a sedimentation cylinder and filled with distilled water to the 1000 mL mark. A control cylinder was also prepared and laid beside the sediment cylinder for hydrometer reading. Wentworth's particle size scale and Shepard's classification diagram were used to classify the sediment after both particle size procedures (Asadi et al 2018a; Di Stefano et al 2010).

Microplastic analysis. To prepare soil samples for microplastic analysis, 150-g soil samples from each soil depth (0-5 cm and 5-10 cm) of each transect were dried using a Memmert drying oven at approximately 60^{o}C for 24 hours. The samples were then weighted and passed through a 5-mm sieve to obtain soil samples with particle sizes < 5 mm. Each sample was mixed in a beaker with 180 g sodium chloride and 500 mL of deionized water. Each sample was then stirred with a magnetic stirrer for 2 min. After stirring, the beakers were closed with aluminum foil and the contents allowed to settle for 24 h. Subsequently, the supernatant, containing the microplastic particles, was extracted and passed through a 0.3-mm sieve to obtain identifiable microplastics (Laglbauer et al 2014; Masura et al 2015). Microplastics particles were observed visually using a hand lens and selected using forceps. The particles were then observed and identified using a microscope; the particles were classified based on their characteristics as fragments, fibers, films, nurdles, and foams (Di & Wang 2018).

Statistical analysis. The average of film, fiber, and fragment in all stations at depth 0-5 cm and 5-10 cm were compared and analyzed using parametic paired t test. Meanwhile, at each depth, pos-hoc test of two way ANOVA was performed using Tukey's multiple comparisons. The data of microplastics was computed as mean±standard error of mean.

Results

Types of microplastics and their abundances. Microplastic particles collected from the intertidal areas of Lamongan were in the form of films, fibers, and fragments (Figure 2). The sizes of these particles ranged from 0.3 to 5 mm, with irregular shapes found for the film and fragment particles. Foams, nurdles, and other forms of microplastic particles were not found in the study area.

On average, microplastic concentrations in each sampling location varied from 145 items kg^{-1} dry weight at station 4 to 354 items kg^{-1} dry weight at station 2, with an overall average of 206 items kg^{-1} dry weight. Fiber was the most abundant microplastic, with an average concentration of 178 items kg^{-1} dry weight, while the average concentration of films was only 3 items kg^{-1} dry weight. Films were only found at station 4, with a concentration of 12 items kg^{-1} dry weight and 9 items kg^{-1} dry weight at depths of 0-5 cm and 5-10 cm respectively (Table 2). Meanwhile, the results of paired t test comparing the microplastic abundance between depths of 0-5 cm and 5-10 cm showed no significant differences ($p = 0.276$; Table 3).

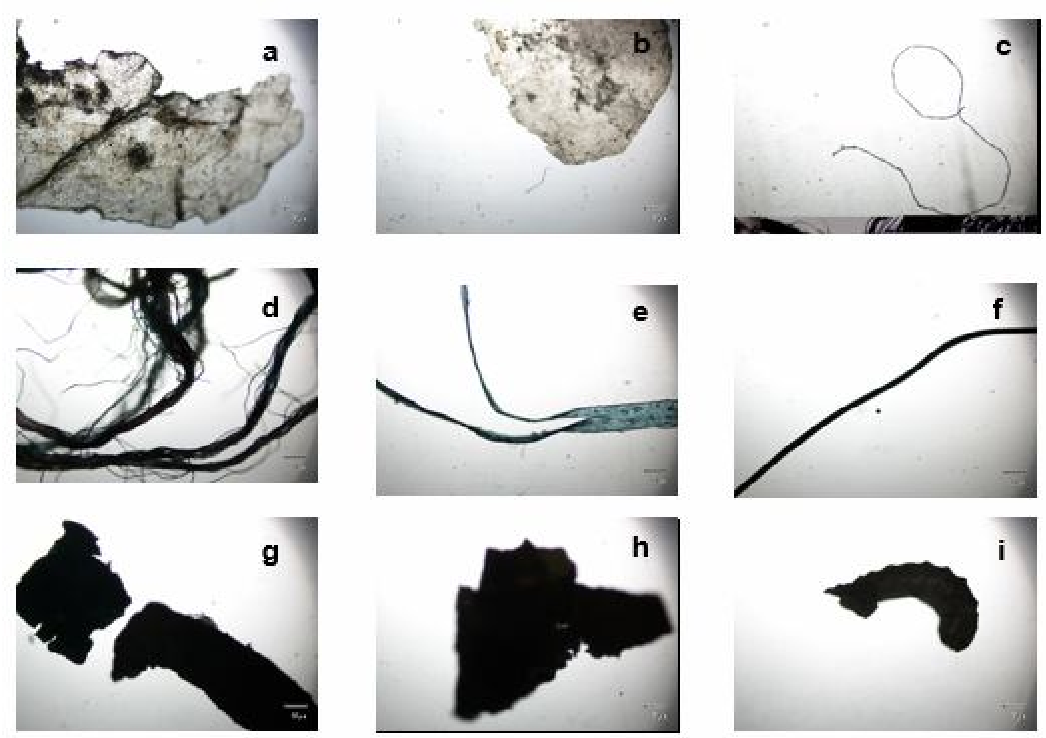

Figure 2. Microscopic photographs of the different types of microplastics found in the sediment of intertidal areas of Lamongan, Indonesia. The types observed include films (a-b), fibers (c-f), and fragments (g-h).

Table 2

Microplastics abundance of sediment at each sampling station in intertidal areas of Lamongan at depths of 0-5 cm and 5-10 cm

Station	*Depth (cm)*	*Microplastics abundance (items kg^{-1} dry weight)*			*Total*
		Film	*Fiber*	*Fragment*	
1	0-5	0	162.32±176.06	11.59±13.24	170.29±151.20
	5-10	0	160.92±108.10	5.75±4.99	
2	0-5	0	254.48±81	43.01±10.79	353.61±137.48
	5-10	0	333.33±130.56	76.39±52.61	
3	0-5	0	133.33±54.65	13.89±17.35	154.84±59.86
	5-10	0	156.86±38	5.60±9.73	
4	0-5	11.70±20.26	137.43±57.07	23.39±33.21	144.82±90.66
	5-10	9.01±15.65	84.08±29.05	24.02±26.09	
Average		2.59±4.49	177.84±84.31	25.46±21.0	205.89±109.80

Table 3

Paired t test (parametric test) of microplastics abundance between depths of 0-5 cm and 5-10 cm

Table analyzed	*Paired t test data*
Column B	5-10 cm
vs.	vs.
Column A	0-5 cm
Paired t test	
P value	0.2766
P value summary	ns
Significantly different ($p < 0.05$)?	No
One- or two-tailed p value?	Two-tailed
t, df	t = 1.482; df = 2
Number of pairs	3

Tukey's multiple comparisons test that compared microplastics among all stations showed that there were no significant differences (p = 0.33 to p > 0.99) of microplastics abundance in the sediment at the depth of 0-5 cm (Table 4). Meanwhile, at depths of 5-10 cm, there were significant differences between stations 1 and 2, stations 2 and 3, and stations 2 and 4 ($p < 0.05$). At the same depth, no significant differences were observed between stations 1 and 3, stations 1 and 4, and stations 3 and 4 ($p > 0.99$, $p = 0.91$, $p = 0.93$ respectively; Table 5).

Table 4
Tukey's multiple comparisons test of microplastics abundance of each station in the sediment of intertidal areas of Lamongan at a depth of 0-5 cm

Stations	*Mean diff.*	*95.00% CI of diff.*	*Significant?*	*Summary*	*Adjusted p value*
1 vs. 2	-41.19	-121.6 to 39.24	No	ns	0.5039
1 vs. 3	8.897	-71.54 to 89.33	No	ns	0.9899
1 vs. 4	0.4633	-79.97 to 80.9	No	ns	> 0.9999
2 vs. 3	50.09	-30.34 to 130.5	No	ns	0.3367
2 vs. 4	41.66	-38.78 to 122.1	No	ns	0.4945
3 vs. 4	-8.433	-88.87 to 72	No	ns	0.9913

ns = not significant.

Table 5
Tukey's multiple comparisons test of microplastics of each station in the sediment of intertidal areas of Lamongan at a depth of 5-10 cm

Stations	*Mean diff.*	*95.00% CI of diff.*	*Significant?*	*Summary*	*Adjusted p value*
1 vs. 2	-81.02	-151.1 to -10.95	Yes	*	0.0192
1 vs. 3	1.403	-68.66 to 71.47	No	ns	> 0.9999
1 vs. 4	16.52	-53.54 to 86.58	No	ns	0.9144
2 vs. 3	82.42	12.36 to 152.5	Yes	*	0.0169
2 vs. 4	97.54	27.47 to 167.6	Yes	**	0.0041
3 vs. 4	15.12	-54.95 to 85.18	No	ns	0.9325

ns = not significant; * = p value < 0.05; ** = p value < 0.005.

As the most dominant microplastic type in the sediment of all sampling stations, fibers constituted 87.05% and 86.81% of microplastics found at depths of 0-5 cm and 5-10 cm, respectively. Fragments made up 11.76% and 12.09% of total microplastics at depths of 0-5 cm and 5-10 cm, respectively. Meanwhile, films made up less than 2% of microplastics in the sediment at depths of both 0-5 cm and 5-10 cm (Figure 3).

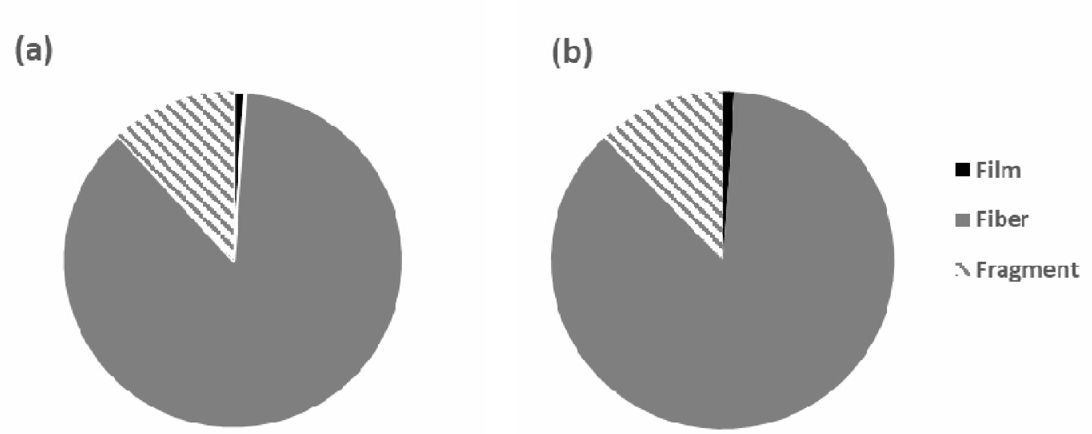

Figure 3. Types of microplastics found in the sediment of the intertidal areas of Lamongan, Indonesia. (a) Percentage at the depth of 0-5 cm. (b) Percentage at the depth of 5-10 cm.

Microplastics abundance and sediment characteristics. Clayey silt had significantly higher microplastic particle concentrations than both sand and gravelly sand ($p < 0.01$). In total, clayey silt held 354 items kg^{-1} dry weight, while microplastic concentrations in sand and gravelly sand were not significantly different ($p = 0.89$), with total concentrations of 150 items kg^{-1} dry weight and 170 items kg^{-1} dry weight, respectively (Tables 6 and 7).

Table 6

Microplastics abundance based on sediment characteristics

	Microplastics abundance (items kg⁻¹ dry weight)			*Total*
	Film	*Fiber*	*Fragment*	
Sand	5.18±8.98	127.93±44.69	16.73±21.59	149.83±75.26
Clayey silt	0	294±105.78	59.70±31.70	354±137.48
Gravelly sand	0	161.62±142.08	8.67±5.83	170.29±147.92

Table 7

Tukey's multiple comparisons test of microplastics abundance based on sediment characteristics

Tukey's multiple comparisons test	*Mean diff.*	*95.00% CI of diff.*	*Significant?*	*Summary*	*Adjusted p value*
Sand vs. clayey silt	-68.2	-106.3 to -30.14	Yes	***	0.0002
Sand vs. gravelly sand	-7.06	-45.12 to 31	No	ns	0.8967
Clayey silt vs. gravelly sand	61.14	17.19 to 105.1	Yes	**	0.0040

ns = not significant; * = p value < 0.05; ** = p value < 0.005.

Discussion. Microplastics are ubiquitous; they are present from the freshwater environment to the deep-sea floor and from tap water to table salt (Anderson et al 2016; Barrows et al 2018; Di & Wang 2018; Ling et al 2017; Renzi & Blašković 2018). This type of pollution has been a subject of intense research as the contaminants pose a potential threat to marine organisms (Almroth et al 2018).

The results of this study demonstrate that microplastic pollutions have become pervasive across the sediment of the intertidal areas of Lamongan. With an average of 206 items kg^{-1} dry weight, the abundance of microplastics in this study area is much higher than that found in the sediment of the Changjiang Estuary, China and the sediment of intertidal areas of Muara Badak, Kutai Kartanegara, Indonesia, which had averages of 121 items kg^{-1} dry weight and 105 items kg^{-1} dry weight, respectively (Dewi et al 2015; Peng et al 2017).

A *t*-test that compared microplastics abundance between depths of 0-5 cm and 5-10 cm showed no significant difference (*t*-test, $p = 0.209$) meaning that the microplastics were not only plentiful at the surface but also in deeper sediment (Table 3). Therefore, microplastic particles probably accumulated in those sediments over a long period of time. This was supported by the fact that many microplastics, particularly fragments found in the sediment, had undergone weathering processes which caused them to fade, losing their original colors (Hidalgo-Ruz et al 2012). Furthermore, the significant differences in spatial distribution of microplastics abundance among stations at the depth of 5-10 cm showed that the microplastics distribution was more stable in the deeper sediment, which is less affected by the effect of current and tides.

Most microplastics were in the form of fibers, with the average of 178 items kg^{-1} dry weight, more than 85% of all microplastics found in the research areas (Table 2, Figure 3). Microfibers are among the most dominant microplastics pollution along shorelines and have been documented on all ocean seafloors (Barrows et al 2018). They enter intertidal areas and subsequently travel to the oceans via wastewater and diverse non-point sources. It has been indicated that major source of microfibers is synthetic textiles (Almroth et al 2018). Polyester and polyamide are the main source of microfibers, with viscose, acrylic and polypropylene serving as relatively minor sources (Ravandi & Valizadeh 2011). The diameter of microfibers ranged from 11.9 and 17.7 μm, with lengths between 5.0 and 7.8 mm. It is estimated that over 700,000 microfibers are released in every 6-kilo wash (Napper & Thompson 2016). Therefore, these microfibers will continue to enter into the ocean as the annual production of textiles is over 9 million tons, of which 60% is in the form of synthetic textiles (Barrows et al 2018).

Meanwhile, with an average of 25 items kg^{-1} dry weight, microplastics in the form of fragments made up almost 12% of the total microplastics found in the research areas. Fragments are secondary microplastics generated by the breakdown processes of larger pieces of plastics, which occurs through physical wear and photodegradation (Tanaka & Takada 2016). Most fragments found in the research areas were degraded and exhibited weathering-related discoloration patterns.

The distance between and different characteristics of each sampling location led to observed differences in the distribution of microplastics. The shortest distance was between stations 2 and 3 (2.5 km) and the greatest between stations 1 and 2 (12 km). High variation was observed between each plot, or sub-station, as shown by the high standard deviation for each station. Similar spatial variation has been observed for sediments of the littoral zone of the north Tunisian coast, where measurements at five sites varied between 141 and 461 items kg^{-1} dry weight sediment (Abidli et al 2018). The abundance of microplastics at stations 1, 3, and 4 did not differ significantly; however, the abundance at station 2 was significantly different. Station 2 was located at a riverine estuary and received flows of fresh water and sediment from hinterlands of Solo River in which it passes through many town and villages along Central Java and East Java (Asadi et al 2017). Therefore, the river could bring along microplastics that ended up in the estuary. In addition, the station was dominated by clayey silt sediment.

This finer sediment holds a relatively higher concentration of microplastics: clayey silt had significantly higher concentrations microplastics than sand and gravelly sand ($p < 0.01$). The value was more than two times greater than those of found in sand and gravelly sand. A study of microplastics in the intertidal zone of Jaring Halus Village, North Sumatera, Indonesia also found a strong correlation between finer sediment and higher microplastics concentrations (Wahyuningsih et al 2018). Clayey silt may have better properties for trapping microplastics, as finer sediments are known to have a higher affinity to sorb carbon and other materials (Dahl et al 2016; Yang et al 2016).

Microplastics are bioavailable to marine organisms and affect a wide range of species, from planktivorous species to whales. They are easily ingested by small organisms and subsequently could appear in higher food chains (Tanaka & Takada 2016). As microplastic particles were ubiquitous in the intertidal areas of Lamongan, they may be also ingested by invertebrates and other benthic organisms, which in turn could enter the digestive system of organisms in the higher food chain, including humans. Mussels, for example, had been known to uptake high concentrations of microplastics (Van Cauwenberghe et al 2015), and mussels are among invertebrates widely collected and consumed by the local communities. Thus, microplastics pollution in this area could negatively affect their health.

Conclusions. Microplastics are ubiquitous in the intertidal areas of Lamongan. With an average 206 items kg^{-1} dry weight, this form of pollution was highly distributed between all sampling stations. Fibers were the most dominant microplastics found in the research area, with an average concentration of 178 items kg^{-1} dry weight, making up more than 85% of all microplastics found. Fragments and films made up 12% and less than 2%, respectively, with respective average concentrations of 25 and 3 items kg^{-1} dry weight.

Although there was no significant difference between sediments from depths of 0-5 cm and 5-10 cm (t-test, $p = 0.209$), deeper sediments showed significant differences between stations 1 and 2, 2 and 3, and 2 and 4 ($p < 0.01$). The high concentration of microplastics at station 2 was likely due to its geomorphological setting, as well as the sediment characteristic of the station, a clayey silt. This sediment type holds significantly higher concentrations of microplastics than other sediments ($p < 0.01$); the finer sediment appeared to possess had a higher ability to attract and trap microplastics. Furthermore, the high distribution and abundance of microplastics in the intertidal areas of Lamongan could be ingested by marine organisms in the areas, and therefore the contaminants could be transferred to higher trophic levels, including humans.

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Authors:
Muhammad Arif Asadi, Marine Science Department, Brawijaya University, Jl. Veteran no. 16, Malang 65144, Indonesia, e-mail: asadi@ub.ac.id
Asus Maizar Suryanto Hertika, Water Resources Management Department, Brawijaya University, Jl. Veteran no. 16, Malang 65144, Indonesia, e-mail: asusmaizar@yahoo.com
Feni Iranawati, Marine Science Department, Brawijaya University, Jl. Veteran no. 16, Malang 65144, Indonesia, e-mail: dzimi2012@gmail.com
Aisyah Yuninda Yuwandita, Marine Science Department, Brawijaya University, Jl. Veteran no. 16, Malang 65144, Indonesia, e-mail: aisyahyuninda@yahoo.com

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