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RESEARCH

Microplastic contamination in the digestive tract of sea urchins (*Echinodermata: Echinoidea*) in Kepulauan Seribu, Indonesia

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Abstract The accumulation of microplastics on sediment surfaces contributed to the digestive tract of sea urchins contamination during foraging. Therefore, the aim of this study was to investigate the potential relationship between the accumulation of microplastics on sediment surfaces and the contamination of sea urchins' digestive tracts during their foraging activities. Sediment and sea urchins' samples were collected from Pari and Harapan Islands, in Kepulauan Seribu, DKI Jakarta, Indonesia. Microplastics were extracted and observed in sediment and the digestive tract of sea urchins' samples. Fourier transform infrared (FTIR) spectroscopy identified microplastic polymers. The average microplastic concentration on Pari Island was 160±158.75 particles/kg dry weight sediment and 3.93±2.25 particles/g dry weight in the digestive tract of sea urchins. Correspondingly, on Harapan Island, the values were 113±41.63 particles/kg dry weight and 0.27±0.28 particles/g dry weight. Fragment-type microplastics (75%) were predominantly detected in the digestive tract of sea urchins, while fiber-type microplastics (59%) were more common in sediments on Pari Island. Conversely, on Harapan Island fragment types were more prevalent (53%). Microplastics larger than 1000 μm were identified in both sediment and the digestive tract of sea urchins. The observed plastic polymers, such as polyethylene, polyester, and polypropylene were dominant at both study sites. This study postulated that microplastics in sediments may be ingested during sea urchins digestion, supported by a significant correlation of 0.016. Consequently, the presence of microplastics in sea urchins from Pari Island and Harapan Island in Kepulauan Seribu was confirmed. Future investigations should explore the toxic effects of absorbed microplastics on sea urchins' physiology, requiring further analysis.

Keywords Microplastics · Pollution · Sea urchins · Sediments · Kepulauan Seribu

Introduction

Environmental pollution caused by the distribution of plastic waste in waters has become a global issue and international concern (Hardesty et al., 2017). The spread of plastic waste in waterways can have a negative on the aquatic environment. Plastic is a synthetic material produced through polymerization (polycondensation),

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and it is commonly used due to its stability, versatility, affordability, long-term, and durability (Hopewell et al., 2009; Yona et al., 2020). The advantages of plastic continue to contribute to its growing user base and expansion each year. However, one significant drawback is that it does not easily decompose. Plastic packaging, plastic beverages, and styrofoam are all forms of its waste that require hundreds of years to fragment into small sizes, commonly called microplastics and nanoplastics, through physical, chemical, and biological processes (Bergmann et al., 2015; Sulistyo et al., 2020). The accumulation of plastic debris and the slow decomposition of plastic present a challenge for environmental ecosystem observers. As the plastic industry grows and the population increases, the negative impact on environmental conditions, particularly regarding the issue of microplastics, becomes more pronounced. Therefore, it is crucial to explore economic applications that capitalize on business opportunities arising from the presence of microplastics (Christiawan, 2018).

Decomposing plastic products through natural factors, such as exposure to sunlight, oxidation, and hydrolysis, cause fragmentations into small sizes of < 5 mm, known as microplastics (Andrady, 2011; Cordova et al., 2022; Forero-López et al., 2021). Based on the source, they can be grouped into primary and secondary. The primary microplastics are deliberately manufactured to a specific size, such as pellets and microbeads for cosmetics (Cordova et al., 2022; De Falco et al., 2019; GESAMP, 2015; Yurtsever, 2019). Meanwhile, secondary microplastics are formed from the fragmentation of large-sized plastics, in which nature directly influences the changes in substance, size, properties, and shape (Winkler et al., 2019). Fragmentation-based microplastics are considered a significant source of pollution due to their enormous contribution originating from human activities, particularly the disposal of garbage in urban areas and solid waste management. The photodegradation process of plastic waste, such as plastic packaging and household appliances, leads to the formation of smaller fragments through fragmentation. About 80% of this waste in water bodies comes from landfill, community activities, runoff, improper waste disposal, tourism, and industrial activities (Andrady, 2011).

Microplastics in water vary widely in size, shape, color, composition, and other properties. Previous studies categorized microplastics based on sizes, such as > 1000 µm, 500–1000 µm, 300–500 µm, and < 300 µm. Furthermore, the types are categorized as fiber, granule, fragment, and foam (Cordova et al., 2019). Previous studies reported that plastic waste caused harm to the environment due to its small size, thereby increased the likehood of ingestion by aquatic biota, mistaking it for prey (Omeyer et al., 2022). This effect is caused by the chemicals present during the formation of plastic (Guzzetti et al., 2018). For example, European flat oysters (*Ostrea edulis L.*) are contaminated with high-density polyethylene (HDPE) and polylactic acid (PLA), highlighting the impact of plastic waste on marine organisms (Green, 2016). Several studies explained the major impact caused by pollutant accumulation. These manifest in the form of cell damage that inhibits the response and impact of oxidative stress (Sureda et al., 2018). In the case of blue mussels (*Mytilus edulis*), the accumulation of polystyrene-type microplastics has been discovered in various parts, such as the digestive cavity (2 µm) tubules (4–16 µm), as well as circulatory system (hemolymph and hemocytes) (3 µm and 9.6 µm) Browne et al. (2008). The accumulation of microplastic is possible in the digestive tract and gonads of sea urchins, which are benthic organisms at the bottom of the water.

There are limited studies on microplastics in sea urchins in Indonesia particularly in Kepulauan Seribu. Therefore, further investigation is necessary to explore this area, given its significance as one of the busiest regions in Jakarta. According to previous studies, microplastics were discovered to be widespread at the bottom of the waters (Raintung et al., 2021). The concentrations of sedimentary microplastic were observed in various aquatic ecosystems in Indonesia, including coral reef ecosystems, mangrove areas and beach sediment to be 48.3 ± 13.98 particles/kg (Cordova & Hernawan, 2018), 896.96 ± 160.28 particles/kg (Yona et al., 2019), and 90.7 ± 59.1 particles/kg (Mauludy et al., 2019). Furthermore, Goss et al. (2018) found microplastics in the tropical seagrass *Thalassia testudinum* 4.0 ± 2.1 particles/blade. The distribution of microplastics in the water column can accumulate in sediments. This process was attributed to their transport properties which tend to be slower in sediments (Mauludy et al., 2019). Furthermore, continuous deposition lead to the accumulation in deeper layers (Efadeswarni et al., 2019). Factors causing the accumulation in sediments include hydro-oceanographic factors, fishing activities conducted by fishermen, microplastic density, gravity, and the role of biota (Azizah et al., 2020).

The presence of microplastics in sediments has implications for the bioavailability of bottom waters, leading to biological interaction with deposit and detritus-eating organisms and potentially impacting their health (Wright et al., 2013). Organisms commonly found in coral reef ecosystems, such as those belonging to the echinoderm and gastropod phyla, can accumulate these particles from their environment (Tahir et al., 2019). Benthic organisms are organisms that live permanently on the bottom of the waters. Hence, they are susceptible to microplastics. The bottom organisms such as sea urchins which are herbivores, omnivores, and detrivores can be exposed to microplastics in sediments, contaminants in the digestive tract (Arthaz et al., 2015; Wijaya et al., 2022). Hennicke et al. (2021) reported the presence of microplastic pollution in wild *Paracentrotus lividus* species in the Aegean Sea, Greece, with an average concentration of 1.95 ± 1.70 particles/g wet weight in the digestive tract of *Tetrapygus niger* from the coast of Lima, Peru, with an abundance of 0.07 ± 0.01 particles/g wet weight. Considering the occurrence of microplastics in sea urchins, this study aimed to provide information on the quantity, composition, and type of polymer detected. Additionally, details about the most common plastic polymers were presented. This hypothesis suggested that the digestive tract of sea urchins was affected by the presence of microplastics in sediment.

Materials and methods

Study area

The study area covered Pari and Harapan Islands, which are located in Kepulauan Seribu and represent the north and south parts of the district, as presented in Fig. 1. Pari Island is a renowned tourist destination within the Kepulauan Seribu, and it is administratively situated in Pari Island village, South Seribu district, DKI Jakarta. Meanwhile, Harapan Island is situated in the Kepulauan Seribu Administrative Regency which is inside the Kepulauan Seribu National Park, a marine conservation area in Indonesia. Furthermore, the park was located approximately 45 km of the north coast off Jakarta with a geographical location of 5°23′–5°40′S, 106° 25′–106°37′ E.

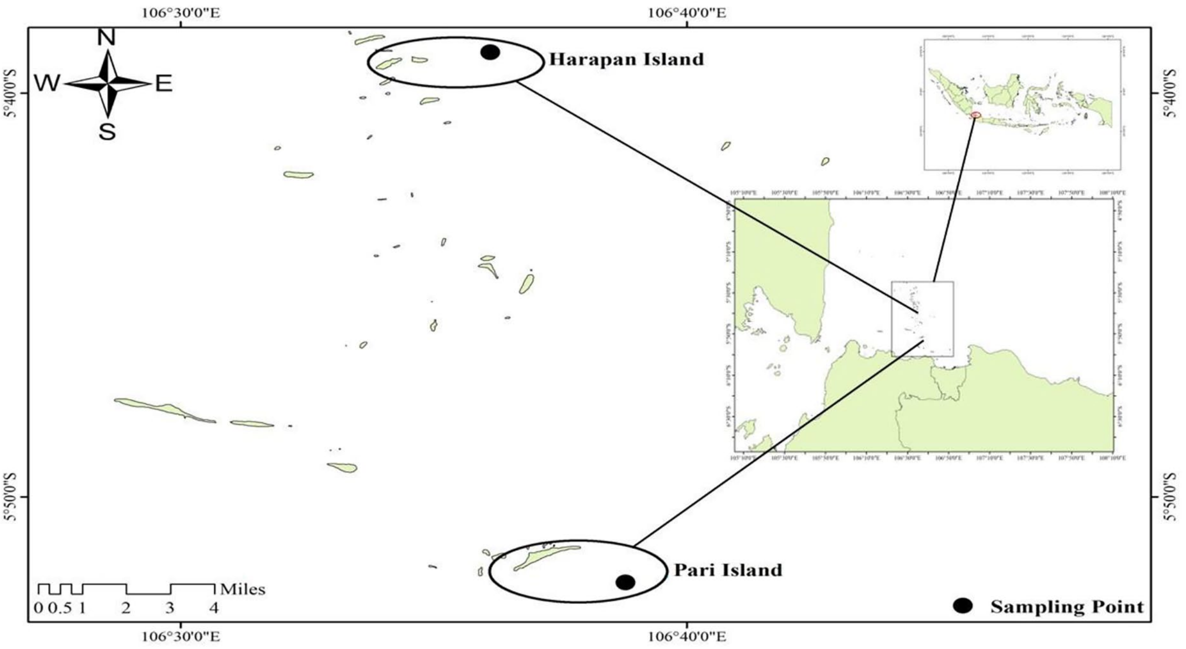

Fig. 1 Map of the study area. Sampling points are labeled with a circle in each region

Sampling method

The microplastic sampling was conducted in July 2022 to coincide with Indonesia's dry season, also known as the east monsoon. Furthermore, the process involved using tools made of metal and glass. A stainless steel shovel was used during surface sediment sampling. The samples were collected at locations where common sea urchins existed, with three repetitions conducted. In this study, a sum of 21 samples of sea urchins was retrieved through direct extraction by divers from natural coral reef ecosystems at a depth ranging between 5 and15 m. Sea urchins were obtained by free diving when performing random sampling, and the type identified at the sampling point on Pari and Harapan Islands were *Echinometra mathaei* (Blainville, 1825) and *Diadema setosum* (Leske, 1778), respectively. It should be noted that none of the sea urchins is obtained through aquaculture but are obtained from their natural habitat. Each sea urchin was dissected using stainless steel scissors and a blade. The dissection begins by cutting to prevent damaging the internal organs. Furthermore, the digestive tract was separated and weighed using a balance with an accuracy of 0.01 mg (SAYAKI High Precision Balance SSA).

Treatment of sediment samples

Sediment samples obtained were pretreated by mixing high-density solutions for separation protocols and biological digestion operations (Cordova et al., 2022; Hennicke et al., 2021). A total of 200 g samples were dried in an oven for 24 h at 40 °C. The density separation process was performed on 50 g of dry sediment by mixing it with a 200 ml zinc chloride ($ZnCl_2$) solution. The mixture was then stirred using a sieve shaker at a rotation speed of 200 revolutions per minute (rpm) for 10 min and left for 24 h (Kurniawan et al., 2021). Subsequently, the supernatant was separated from the residue through decantation and filtered using Whatman's filter paper (paper diameter: 47 mm, pore size: 0.45 µm) with the assistance of a help of a vacuum pump (Cordova & Hernawan, 2018). The sample was filtered on Whatman's filter paper before adding 5–20 ml of hydrogen peroxide (30% H2O2) and Fe(II)SO4 (10 mg/mL, 6–10 mL) to speed up the reaction rate; Merck Millipore, EMSURE® ACS, ISO, Reag. Ph Eur) (Nurhasanah et al., 2021) The solution was allowed to stand in a water bath (B-One DWBC-30L-6H) at 40 °C for 24 h or until the sample became clear. Subsequently, the sample was filtered again using a sterile Whatman filter paper (paper diameter: 47 mm, pore size: 0.45 µm) with the help of a vacuum pump (Vacuubrand ME2C). Before the next microplastic identification stage, the filtered sample was transferred to a Petri dish (Chazuru CLW E09) and sealed using Parafilm® to keep it sterile. Finally, the characteristics and polymer content were identified.

Sea urchins sample treatment

A total of 21 samples of sea urchins were collected with 5 and 16 belonging to the species *Echinometra matthaei* and *D. setosum*, respectively, on Pari and Harapan Island. These species have a habit of living in coral reef ecosystems. Furthermore, the sea urchins were collected by divers directly from nature at a depth of 5–15 m. The collection was not based on cultivation results and there was no amalgamation of the two different species in each destruction process. A total of 5 g digestive tract of sea urchins was collected at each location. The digestive tract was then placed into a glass Petri dish and covered using Parafilm® to minimize the risk of contamination. The treatment of the samples was adapted based on references (Lusher et al., 2017; Cordova et al., 2020; Sevillano-González et al., 2022). Samples of digestive tract organs were dried using an oven for 48 h at 40 °C, and 5–10 ml of 30% H_2O_2 (Merck Millipore Emprove®) (10 ml of H_2O_2 used per gram of sample; ratio maintained for each sample analysis) was added and the mixture was allowed to stand (Sevillano-González et al., 2022). The H_2O_2 solution in the oxidation process was needed to remove the organic matter digested in the body of sea urchins (Avio et al., 2017; Cordova et al., 2019). This step was commonly employed to determine the microplastics in marine organisms (Avio et al., 2020; Hennicke et al., 2021; Sevillano-González et al., 2022). The sample was put into a water bath (B-One DWBC-30L-6H) at 40 °C for 36–48 h or until the sample becomes clear. Subsequently, it was filtered using sterile Whatman filter paper (paper diameter: 47 mm, pore size: 0.45 µm) with the help of a vacuum pump (Vacuubrand ME2C) having a pressure setting of 30 mbar. As in the microplastic stage in the sediment, the samples in the filtered sea urchins were stored in a sterile Petri dish (Chazuru CLW E09) and sealed using Parafilm® to maintain sterility.

Identification process of microplastics and polymers

Microplastic particles were identified and classified into size, color, and shape. This was conducted using an Olympus CX31 microscope with × 4–40 magnification, along with a Nikon IMX307 camera connected to a computer with S-EYE software. The identification process followed the procedures of Cordova et al. (2019), where the particles were categorized into fragments, fiber, foam, and pellets. These categories were then adjusted according to the color of the microplastics, with size ranges of 300–500 µm, 500–1000 µm, and > 1000 µm. Additionally, the type of polymer was also determined (Cordova et al., 2019).

The chemical structure of the suspected microplastic samples was analyzed using a Fourier transform infrared (FTIR) spectrometer (Agilent Cary 630, with attenuated total reflectance diamond and MicroLab FTIR Software). This instrument was configured with a resolution of 4 cm^{-1} using 32 scans and in the band region in the spectral range of 650–3000 cm^{-1} (Cordova et al., 2022). The identification of the polymer present in each test sample was determined based on the functional group exhibiting peak absorbance intensity in the spectra. A similarity score of ≥ 70% with the standard library was considered acceptable for assigning a particular polymer following the method proposed by Zhang et al. (2021) and Ni'am et al. (2022). A total of 56 suspected microplastic samples were identified and the results of the FTIR test were displayed in graphical form with a particular wavelength value indicating the plastic-forming compounds (Lestari et al., 2021).

Quality control and quality assurance (QC/QA)

To minimize contamination, blank samples were used to estimate the amount of impurities during the activities, and they do not contain any microplastic. Each extraction process for the particles was conducted in a clean room. To maintain cleanliness, laboratory coats were made of 100% cotton and only worn during activities. Furthermore, the laboratory equipment was appropriately wrapped after use, and the tools made of glass and metal were rinsed with filtered water. Before using the laboratory, all instruments were rinsed and cleaned. Additionally, chemical solutions were filtered through sterile filter paper before being used to remove any residual microparticles.

QC and QA monitoring was conducted during sample analysis in the laboratory. The results obtained showed the existence of 1 particle/blank fiber and 1 particle/blank fragment. The presence of identified microplastics indicated the possibility of contamination occurring from the air. Other studies have also provided evidence of the presence of these particles in blanks. For instance, Giani et al. (2019) indicated the existence of two types of microplastics (MP) or fibers in blanks. While certain studies have implemented QC/QA procedures, not all have strictly adhered to this process. Zhang et al. (2021) highlighted the need for improvements in laboratory preparation, clean air conditions, and positive controls in QC/QA procedures to minimize potential risks that could affect the results. Lastly, it is advisable to enhance air contamination control procedures to prevent cross-contamination.

Analysis statistics

This study applied both descriptive and statistical method of analysis. Statistical analysis used nonparametric analysis through PAST4.11 and R-based packages software. The Spearman correlation was employed to determine the relationship between the abundance of microplastics found in sediments and the digestive tract of sea urchins. The abundance values in sea urchin and sediment samples were compared using the Kruskal–Wallis test. This was conducted to investigate the microplastic differences in sediment and sea urchins on the two islands with a p-value of < 0.05 being considered significant for all analyses.

Results and discussion

Microplastic abundance

Data on the abundance of microplastics in sediments were presented in the form of averages and standard deviations. In this study, the average abundance of microplastics in sediments is varied, as shown in Table 1. On Pari and Harapan Islands, it was 160 ± 158.75 particles/kg dry weight and 113.33 ± 41.63 particles/kg dry weight, respectively. In addition, Table 1 presents a comparison of the results of this study with others conducted in various areas. Lots et al. (2017) stated that most of the identified surface sediment was lower than 200 particles/kg dry weight. However, some other areas showed greater concentrations of microplastics. This was in line with the results of the average abundance of these particles in sediments obtained in the eastern waters of the Java Sea (Yona et al., 2019) and the Belgian coast (Claessens et al., 2011).

Surface sediments extracted from coral reef ecosystems were analyzed in this study. Furthermore, they were the potential cause of pollution by microplastics due to the influence of activities on land and the effect of marine transportation (Yona et al., 2019). The abundance of microplastics in Indonesian waters was quite high compared to the East Aegean Sea, Greece (Table 1) (Hennicke et al., 2021). This is most likely due to the large population and human activities in Indonesia, causing a buildup of waste. This is evidenced by data which states that 5.4 million tons plastic waste was produced in Indonesia in 2017 (Syakti et al., 2017). Pari and Harapan Islands, which were the center of this study, had a fairly high population density with several community activities. As of June 2022, the population of Java Island reached 154.34 million. Additionally, tourist visits to Pari and Harapan Islands were frequent, with a total of 4612 visitors from January to August 2022. Different waves and currents contributed to the variation in microplastic abundances. However, the highest average abundance was discovered in the high seas of the eastern waters of the Java Sea, measuring 639.51 ± 121.58 particles/kg dry weight (Yona et al., 2019). This observation was made during the rainy season and indicated the transport and subsequent precipitation of microplastics from other locations, resulting in an increased concentration in sediment. Factors such as low water currents and the presence of a significant human population on the islands contributed to a higher accumulation. Gravity and the high density of plastic particles led to their deposition in sediments (Woodall et al., 2015). The abundance of microplastics in sediments has been confirmed to have a higher yield than in surface water (Hidalgo-Ruz et al., 2012). In this study, microplastic samples collected in July and November did not exhibit statistically significant differences (Kruskal–Wallis, $1 > 0.05$).

Data on the abundance of microplastics in the digestive tract of sea urchins are presented in Table 2, in the form of average and standard deviation. The results of this study will be compared with other regions. Table 2 shows that different species of sea urchins were discovered on the two islands. A total of 63 microplastic items were found in 21 sea urchins' samples, with 59 and 4 items being from Pari Island and Harapan Island, respectively. The average abundance in the digestive tract of sea urchins from Pari and Harapan Islands was 3.93 ± 2.25 particles/g dry weight and 0.27 ± 0.28 particles/kg dry weight, respectively. This indicated that all samples contained at least one microplastic item. The presence

Table 1 Comparison of microplastic yield data in sediments on Pari and Harapan Islands with several studies from other regions

Sampling location	Water area	Mean ± SD (particles/kg dw)	Season	Size range (µm)	Reference
Kepulauan Seribu, Indonesia	Pari Island	160 ± 158.75	Dry season	20–2880	This study
Kepulauan Seribu, Indonesia	Harapan Island	113.33 ± 41.63	Dry season	130–3100	This study
Eastern Aegean Sea, Greece	Tourkomnima	70 ± 25	All seasons	200–2500	Hennicke et al. (2021)
Eastern Aegean Sea, Greece	Mersini	87 ± 48	All seasons	200–2500	Hennicke et al. (2021)
Eastern Aegean Sea, Greece	Hochlakura	105 ± 13	All seasons	200–2500	Hennicke et al. (2021)
Eastern Aegean Sea, Greece	Katsadia	93 ± 25	All seasons	200–2500	Hennicke et al. (2021)
Eastern Aegean Sea, Greece	Kampos	428 ± 204	All seasons	200–2500	Hennicke et al. (2021)
Coastal area in East Surabaya, Indonesia	Rungkut, Gunung Anyar Bulak, Kenjeran district (coastal)	73.9 ± 157	Wet season	500–1000	Ni'am et al. (2022)
The eastern waters of the Java Sea	High seas	639.51 ± 121.58	Wet season	n/a	Yona et al. (2019)
Belgian coast	Nieuwpoort Harbour	390.7 ± 32.6	n/a	n/a	Claessens et al. (2011)

of the particles in the digestive tract of sea urchins was attributed to the accumulation during the feeding process (Savoca et al., 2019). The differences in microplastic concentrations in each region were due to variations in the types of organism and their feeding habits. Some species are known to consume algae and function as decomposers (Zhu et al., 2018). Furthermore, significant differences were observed in the abundance of microplastics in the digestive tract of sea urchins collected in July and November (Kruskal–Wallis, $0.04 > 0.05$).

The variations in habitat contribute to differences in limiting microplastics, as indicated in Table 2. *E. mathaei*, which tends to inhabit individual in holes in dead coral to evade predators (Suryanti et al., 2020) exhibits limited movement, resulting in an average microplastic content of 0.27 ± 0.28 particles/g dry weight in its digestive tract. The abundance of microplastics in the digestive tract of sea urchins examined in this study was higher compared to the results of De-la-Torre et al. (2019), which reported 0.07 ± 0.01 particles/g dry weight for *T. niger*. This specie prefers habitats with rocky structures, specifically dense grasslands, and strong sea waves (Mabin et al., 2015). The influence of strong waves will affect the distribution of microplastics, resulting in lower quantities in sea urchins compared to other species. Meanwhile, *D. setosum* is spread all over the world and can be found in various coral reef zones. The widespread living habits of this specie facilitate the occurrence of microplastic contamination in the digestive tract of sea urchins, as observed in this study and the investigation conducted in Tajao and El Poris, Canary Islands, Spain (Sevillano-González et al., 2022).

There was a significant relationship between microplastic abundance in sediments and sea urchins, as indicated by a correlation value of 0.89 (Spearman's correlation, $0.016 < 0.05$). Calculations for this analysis are based on overall microplastic results, without taking into account differences in size, shape, and color. The study by Hennicke et al. (2021), who produced a unidirectional relationship, stated that microplastic particles in sea urchins was increased following their presence in sediments. The piles can continue to increase when plastic particles with a density exceeding that of seawater (> 1.02 g/cm^3) sink and accumulate in sediments (Zettler et al., 2013). The abundance of microplastics in both sea urchins and sediments is influenced by various habitat factors, as shown by significant results on both islands. Additionally, the increased concentration of microplastics within the bodies of sea urchins is believed to originate from their food sources. Sea urchins are widely distributed marine organisms that are vulnerable to environmental pollutants. As a result, they can serve as bioindicators (Sevillano-González et al., 2022) providing quantitative insights into the level of microplastic pollution within their environment

Table 2 Comparison of microplastic analysis data in sea urchins in Pari and Harapan Islands with several other regional studies

Sampling location	Water area	Sea urchins types	Mean ± SD	Season	Size range (μm)	Reference
Kepulauan Seribu, Indonesia	Pari Island	*E. mathaei*	0.27 ± 0.28 (particles/gr dw)	Dry season	200–2070	This study
Kepulauan Seribu, Indonesia	Harapan Island	*D. setosum*	3.93 ± 2.25 (particles/gr dw)	Dry season	140–2690	This study
North China coast	Dalian, Weihai, Qingdao, Rizhao, Lianyungang Yancheng	*S. intermedius*, *T. reevesii*, *T. hardwickii*, and *H. pulcherrimus*	2.20 ± 1.50 to 10.04 ± 8.46 (particles/gr)	Wet season	n/a	Feng et al. (2020)
Cañete Province, Lima Region, Peru	Sandy Beach	*T. niger*	0.07 ± 0.01 (particles/gr)	Wet season	n/a	De-la-Torre et al. (2019)
Canary Island, Spain	Tajao	*D. setosum*	6.4 ± 2.8	Wet season	110–6709	Sevillano-González et al. (2022)
Canary Island, Spain	El Poris	*D. setosum*	5.6 ± 2.9	Wet season	83–11,638	Sevillano-González et al. (2022)

(Pinheiro et al., 2020). The particles present in the digestive tract of sea urchins can come from the waters directly through the process of searching for food or from the food chain (biomagnification). The digestive tract is a part of the body which functions in the final collection process, specifically in terms of larger particles that cannot be excreted through feces (Jabeen et al., 2017; Yona et al., 2019).

Types, colors and sizes of microplastics

The identified forms of microplastic in sediments included fibers, fragments, and films. The dominant fiber form was observed on Pari Island (59%). Meanwhile, the fragment form was more common on Harapan Island, constituting 52.94%. At the sampling location, visible fragments in the form of plastic bottles and plastic packaging were discovered floating, and this suggested that fragments may be the predominant form in sediments. In terms of sea urchins, the form of the microplastic present in the digestive tract of those identified on the Pari and Harapan Islands was fragmented, with percentages of 74.58% and 75%, respectively as shown in Fig. 2. Furthermore, it was assumed that anthropogenic activities conducted by the surrounding community contributed a large percentage of fragment and fiber type of microplastics. Activities such as household waste, industry, fisheries, and marine tourism were important sources of these particles.

The dominant type of microplastic in both island locations was fragments with a concentration of 8.5 ± 0.71 particles/kg dry weight. This was formed from the degradation of large plastic (Cordova et al., 2020). The distribution of microplastic fragments in marine waters was attributed to plastic waste from land, including household appliances, kitchen utensils, plastic bottles, plastic bags, pipe scraps, and single-use packaging. Furthermore, these items were transported by surface water runoff and eventually reached the sea after undergoing degradation in rivers (Chubarenko et al., 2018). In Jakarta Bay waters, the concentration of microplastic fragments in sediments was also high, followed by fiber types (Manalu et al., 2017).

Fragment-type microplastics were the most common in waters and likely to be ingested by several marine organisms such as whales and detritus-eating organisms such as clams (Carson et al., 2013; von Moos et al., 2012). Their presence in sediments was comparable to the digestive tract of sea urchins on Pari and Harapan Islands, with a concentration of 23.5 ± 28.99 particles/g dry weight. Sea urchins were particularly vulnerable to microplastics in the digestive tract due to their feeding technique, which involved grazing and eroding sediment. This behavior provided the possibility of microplastic contamination from aquatic sediments. Furthermore, adult sea urchins could inadvertently consume these particles through two routes, namely consumption of food and water filtered with madreporite (Hennicke et al., 2021). However, these results differed from the study of) regarding the shape of the particles in sea urchin organisms, where the types of microplastics identified were mostly fibers.

Fiber is the second most commonly observed form, following fragments, and it generally comes from clothing, rope, and fishing lines. The habit of washing

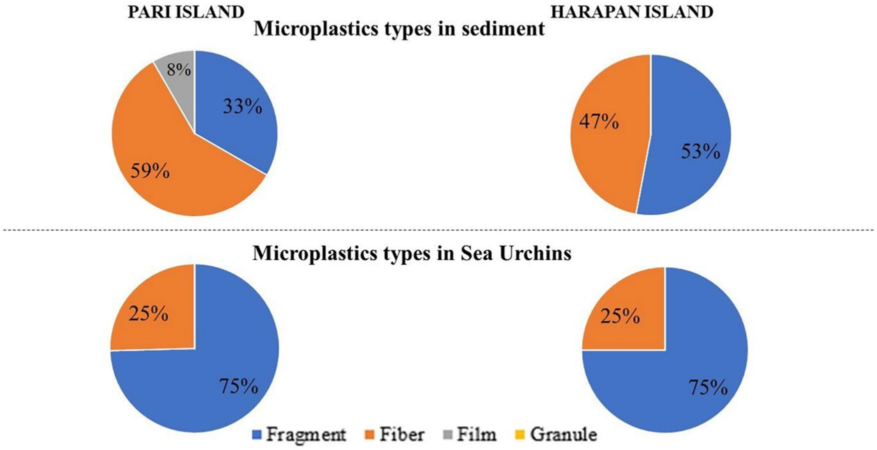

Fig. 2 Comparison of microplastic types at Pari Island and Harapan Island in sediments (top) and the digestive tract of sea urchins (bottom), July 2022

which cannot be separated from the daily lives of Indonesian people results in the accumulation of various types of fiber. This was evident from the statement of Gallagher et al. (2016) that rinsing clothing materials led to the presence of a type of microplastic fiber. Several studies stated that this form was the most abundant of marine microplastic due to the high use of plastic fishing gear, fishing nets, and ropes (Taylor et al., 2016). Additionally, organisms inhabiting areas with common human activities tended to be potentially contaminated with fiber-type particles (Pozo et al., 2019). Similar results were observed in sediment samples from the Bohai and Yellow Seas. Feng et al. (2020) also reported a 92.91% dominance of fiber types in the digestive tract of sea urchins (*S. intermedius*). These differences can be attributed to causal factors, such as eating habits, behavior, and types of sea urchins. Alomar et al. (2016) explained that the main source of microplastic contamination in the form of fiber identified in Andratx was waste disposal from the manufacture of synthetic clothing produced by the textile industry. In general, two types of microplastics, such as fibers and fragments, were dominant in this study, and they were categorized under the secondary class which was derived from plastics that had undergone fragmentation.

The dominant color of microplastics in sediment samples at Pari and Harapan Islands was red, accounting for 29.17% and 29.41%, respectively. In addition to red, other colors identified include blue, white, black, and green. The blue color was predominant in the digestive tract of the sea urchins on Pari Island, while red was more dominant on Harapan Island. Only red and white microplastics were discovered in the digestive tract of sea urchins on Pari Island (Fig. 3). Lestari et al. (2021) stated that microplastics with blue and red colors were also identified in seagrass sediments on Panjang Island, Jepara. In the Yellow Sea and East China Sea, China, blue microplastics account for a relatively common percentage of 64% (Zhang et al., 2019a, b). The blue microplastics identified in the digestive tract of sea urchins in this study were comparable to several previous studies. For example, the predominant percentages of blue and black microplastics were 43.26% to 54.29% and 36.67% to 44.83%, in the digestive tract of sea urchins such as *S. intermedius*, *T. Reevesii*, *T. Hardwickii*, and *H. Pulcherrimus* (Feng et al., 2020). The results of another study on *D. Setosum* in Barrang Lompo Island also showed a high percentage of blue color (73.8%) (Sawalman et al., 2021). According to Massos and Turner (2017), the influence of heavy metals was one of the causes of variation in colors. The different and diverse colors of microplastics are attributed to factors such as the duration of exposure to sunlight, which leads to an oxidation process (Browne et al., 2013).

The size of most microplastics identified in the sediment samples varied across the islands, ranging from < 300 μm to > 1000 μm (Fig. 3). Those at Pari and Harapan Islands had dominant sizes of < 300 μm (37.50%) and > 1000 μm (52.94%), respectively. The size category identified in the digestive tract of sea urchins varied from < 300 μm to > 1000 μm. On Pari Island, sizes > 1000 μm were more often discovered followed by 500 to 1000 μm, < 300 μm, and 300 to 500 μm. This was different from the microplastic size commonly observed on Harapan Island, which was < 300 μm, followed by 500 to 1000 μm and 300 to 500 μm. Furthermore, it was discovered that microplastic measurement of > 1000 μm was not available at this location.

The influence of different waves and currents, as well as human activities, can affect the degradation of microplastics in these waters. In this study, the two species of sea urchins have different living habits in coral reef ecosystems. *Diadematidae* can occupy areas of sand flats and coral reef edges (Laning et al., 2015). Meanwhile, *E. mathaei* prefers to live alone in dead coral holes to avoid predators, and this species has little diversity because of its limited movement (Suryanti et al., 2020). These contribute to the differences in the size characteristics of microplastics identified in the digestive tract of sea urchins between Pari and Harapan Islands to be different. The previous study by Feng et al. (2020) stated that the microplastic size categories of < 300 μm and > 1000 contributed 60%, and < 5000 μm was often discovered in sediments at locations such as Port of Victoria, Tolo Port, Tsing Yi, and Deep Bay, Hong Kong (Tsang et al., 2017). However, in this study, there was no significant relationship between the size of microplastics in sediments and the digestive tract of sea urchins on Pari (Spearman's correlation, 1 > 0.05) and Harapan Islands (Spearman's correlation, 0.68 > 0.05).

Microplastic polymer

FTIR was used to determine the chemical composition of the microplastic polymers discovered in sediments and sea urchins as shown Fig. 4a is the result of the polymer sample and b is an image of the microplastic identified by FTIR.

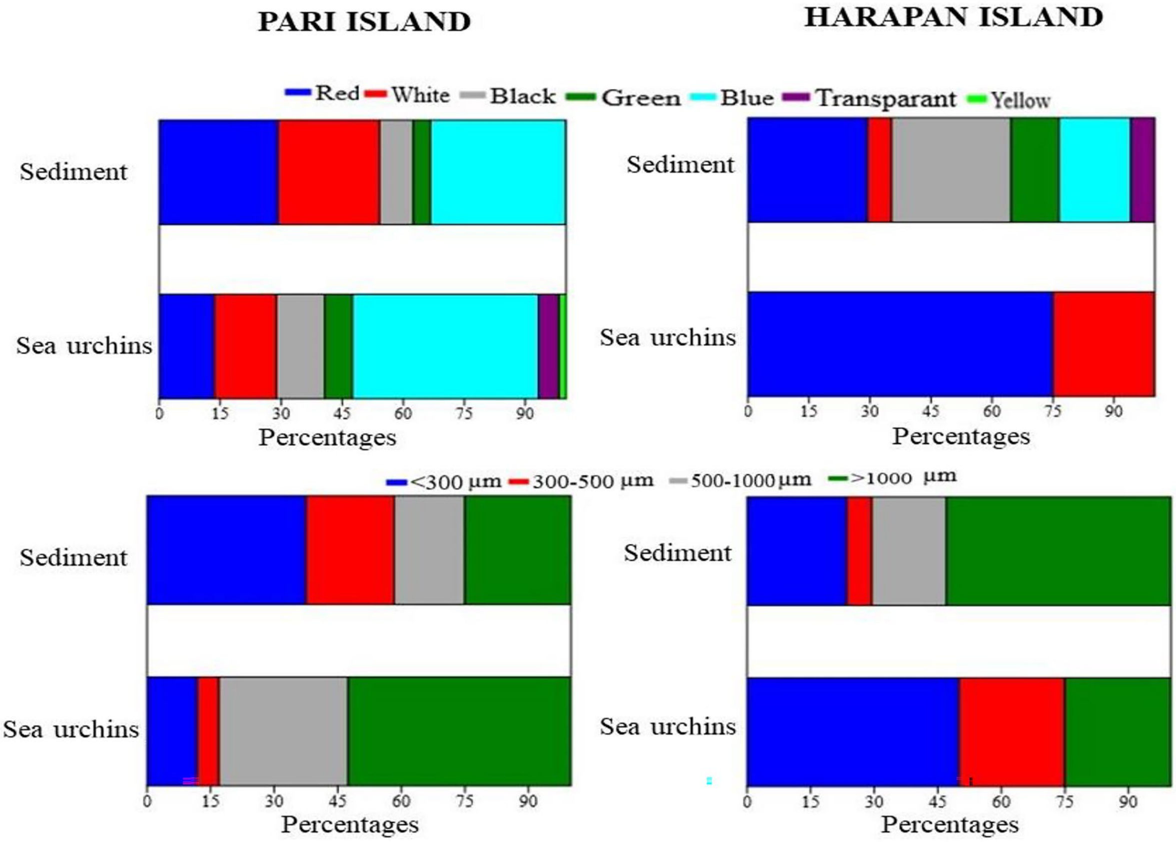

Fig. 3 Comparison of the number of colors (top) and size (bottom) of microplastics found in sea urchins and sediment collected at Pari and Harapan Islands in July 2022

The FTIR results identified the chemical composition of 39, 42% of the microplastic particles arbitrarily collected from the digestive tract (22 samples) and sediments (19 samples) at the two locations as presented Table 3.

The polymer content that was successfully identified in sediments and the digestive tract of sea urchins quite varied on Pari and Harapan Islands, as presented in Table 3. Furthermore, the types are more diverse on Pari Island. Commonly encountered polymer types include polyethylene, polyester, polypropylene, and ethylene propylene. Pari Island sediments contained up to 4 different microplastic polymers, including the exclusive presence of polyacrylate. Only 2 were identified in the digestive tract of sea urchins on Harapan Island, while on Pari Island, it was about 6. Polyester and polypropylene were identified in each sample and location, as shown in Table 3. The percentage of polypropylene was fairly light, with a density of 0.90–0.92 g/cm^3 (Khavilla et al., 2019), rendering it easily transportable by currents and prone to accumulation in sediments. The prevalence of polyester signifies widespread usage of plastic products incorporating this polymer in daily activities, owing to its economic viability and extensive applicability (Barot et al., 2019). Furthermore, the contamination from air and cross-contamination during the QC and QA testing laboratory analysis was monitored.

The chemical composition of the microplastics discovered in this study showed that polypropylene and polyester in sediment and the digestive system of sea urchins, respectively, were the dominant polymers as presented in Table 3. Several studies stated that these two polymers had a high proportion in the environment and marine organisms (Zhang et al., 2019a, b). Polyester has a fiber-like shape, hence, it is widely used as a raw material for making clothes, with its global synthetic fiber usage reaching 60% (Sasmitha & Marsono, 2017). Polypropylene exposed to direct light will experience photooxidation, causing this

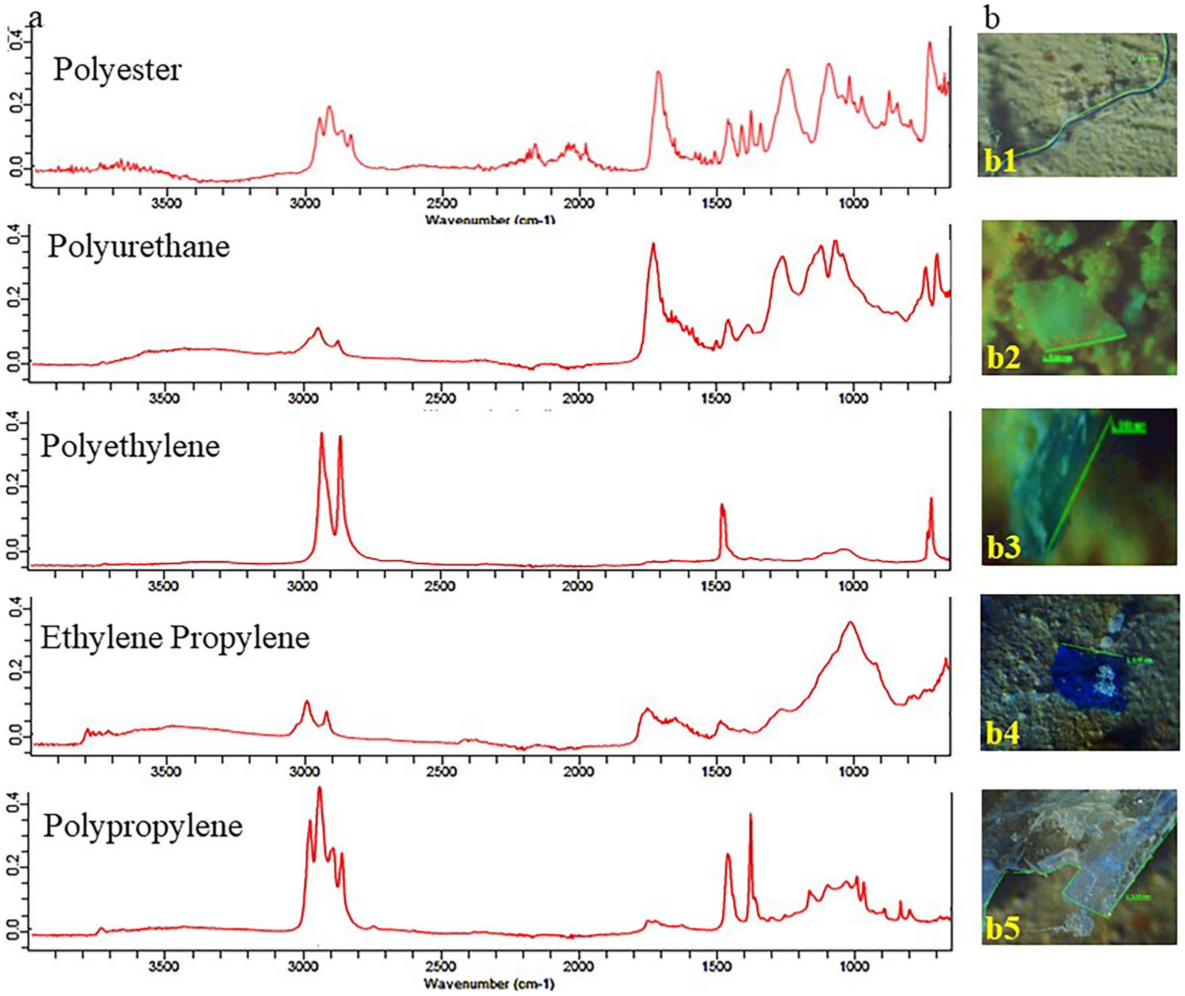

Fig. 4 Forms of microplastics that have been found: **a** results of polymer samples of sea urchins and sediments. **b1** Fiber. **b2–b5** Fragment with a size scale category of < 300 µm to > 1000 µm

type of plastic to tear easily (Forero-López et al., 2021). Its versatile properties make polypropylene extensively employed in diverse sectors, ranging from automotive and medical applications to packaging requirements. Meanwhile, polyester fiber is made from chemical compounds such as ethylene glycol and terephthalic acids, which are combined with polyethylene terephthalate (PET) derived from petroleum (petroleum). Polyester is widely used in the textile industry, not only for clothing but also as a raw material for bed sheets, blankets, carpets, and others. Microplastics contain chemical additives and organic materials mixed in a complex way and are considered xenobiotics for the marine ecosystem. This was evidenced by references from several studies reporting that marine organisms, from tiny invertebrates to large vertebrates, were susceptible to microplastic contamination (Guzzetti et al., 2018). Microplastics are considered bioinert compounds that cannot be digested or absorbed within the bodies of aquatic

Table 3 Microplastic polymers identified using FTIR

No	Polymer	Sediment (%)		Sea urchins (%)	
		Pari	Harapan	Pari	Harapan
1	Polyethylene	0	11.11	21.05	0
2	Polyester	40	33.33	31.58	33.33
3	Polypropylene	40	44.44	21.05	66.67
4	Ethylene propylene	10	11.11	10.53	0
5	Polyurethane	0	0	5.26	0
6	Polyvinyl chloride	0	0	10.53	0
7	Polyacrylate	10	0	0	0

organisms (Andrady, 2011). Furthermore, they can pose harmful effects by absorbing and accumulating metals and persistent organic pollutants (POPs), such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and dichloro-diphenyl-trichloroethane (DDT). These pollutants originated from anthropogenic activities, such as industrial waste, fuel combustion, and the antifouling industry (Brennecke et al., 2016). Microplastics recognized as new pollutants and carry significant risks that can cause oxidative and pathological stress, decreased immune function, and cancer (Guzzetti et al., 2018). Therefore, urgent development of effective solutions is necessary to prevent further harm and alleviate the mounting pressure exerted by microplastics on the environment.

To combat the issue of microplastics stemming from plastic waste, it is crucial for society, the scientific community, industry, and policies to take positive actions. The initial step involves reducing society's reliance on plastic. Simultaneously, there should be stricter adherence to policies and legislation, coupled with early-age environmental hygiene education, for effective management, particularly single-use plastics. The widespread and global problem of plastic pollution in the environment needs to be addressed effectively. Supporting and enhancing waste recycling capacity is essential and should be accompanied by accessible information facilities. Another recommendation is the conversion of plastic waste, comprising various polymer types into fuels with plastic being the main essential ingredient. Some of these solutions are effective, especially when performed by every community. Plastic production regulations in each country can be applied in further study. Therefore, management practices that are more accurate and effective locally and globally are needed to address the source of microplastics.

Conclusion

In conclusion, microplastics discovered in sediments and sea urchins from Pari and Harapan Islands indicated the extent of pollution in these areas. This study established a strong correlation (0.895) between sediments and sea urchins, revealing a significant relationship with a *p*-value of 0.016, showing the close connection between these variables. The primary form of microplastics found in the sampling locations was fragmented resulting from plastic waste fragmentation originating from household activities, industries, and tourist attractions. Polyester and polypropylene were the dominant polymers in these areas. The presence of microplastic content in aquatic biota posed potential risks, including disruptions within the food chain. Sea urchins, for instance, were susceptible to accidental ingestion of microplastics, leading to blockages in the digestive tract and a false sense of satiety. Furthermore, microplastics had the potential to absorb pollutant compounds such as polycyclic aromatic hydrocarbons (PAHs), which could cause chronic and even carcinogenic effects. Further studies were required to precisely determine the impact as particle polymers like polyester and polypropylene showed a high capacity for absorbing PAH pollutants. To address these concerns, future investigations should focus on determining the chronic effects of ingested microplastics on organisms. A policy-oriented approach was necessary to tackle plastic usage and promote waste reduction. Efforts should be made to encourage consumers to change their habits regarding plastic usage, enabling the effective implementation of policies and regulations. Public awareness played a vital role in reducing the production and accumulation of plastic waste. Promoting individuals to opt for reusable water bottles and shopping bags as alternatives to single-use plastic bottles and bags could significantly contribute to waste reduction efforts.

Abbreviations mm: Millimeter; µm: Micrometer; HDPE: High-density polyethylene; PLA: Polylactic acid; km: Kilometer; ml: Milliliter; /cm: Reciprocal centimeter; °C: Degree Celsius; Gr: Gram; $ZnCl_2$: Zinc chloride; H_2O_2: Hydrogen peroxide; $\geq$: Greater than or equal to; QC/QA: Quality control and quality assurance; n/a: Not available; g/cm^3: Gram per square centimeter; %: Percent; FTIR: Fourier transform infrared spectrometer; POPs: Persistent organic pollutants; PAHs: Polycyclic aromatic hydrocarbons; PCBs: Polychlorinated biphenyls; PBDEs: Polybrominated diphenyl ethers; GESAMP: Group of Experts for Scientific Aspects of Marine Protection

Author contribution Rahmawati did the draft, writing design, analysis, and identification as well as data processing. Majariana Krisanti made adjustments to the writing structure and grammar as well as critical revisions of the intellectual content of important manuscripts. Etty Riani made adjustments to the writing structure and critical revision of the manuscript for important intellectual content. Muhammad Reza Cordova supervised, obtained funding,

drafted the script, and provided material support. All authors have read, understood, and complied as applicable with the statement on "Ethical responsibilities of Authors" as presented in the Instructions for Authors.

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Data availability The authors confirm that the data supporting the findings of this study are available within the article and its supplementary material. Raw data that support the findings of this study are available from Muhammad Reza Cordova (Coordinator, microSEAP Indonesia).

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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