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Comparative Study on the Microplastics Abundance and Characteristics in Marine Protected Area in Karimunjawa National Park, Indonesia

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ABSTRACT

Microplastics (MPs) are discovered in various places even encroaching on marine protected areas (MPA). The aim of this research is to investigate the occurrences of MPs pollutant in MPA and non-MPA in Karimunjawa National Park (KNP). The results showed that MPs from sea surface water were higher in MPA than non-MPA with range as 47.89–106.20 items/L, dominated by fragment, 1–50 µm size, black color and HDPE, LDPE, PP, Nylon, PVC, ABS, and PET in polymer types. It induced since it supplied from it surrounding, specifically the south of MPA, whereas there have been cottage constructions generating many marine debris. These findings indicate that occurrence of MPs still dominantly influenced from anthropogenic activity. However, the hydrodynamic and MPs characteristic as well play an important role in MPs distributions.

Keywords: anthropogenic, characteristics, hydrodynamics, microplastics, marine protected area

INTRODUCTION

MPs are found everywhere, no exception in marine protected area (MPA) such as Karimunjawa National Park (KNP). KNP is one of the famous marine tourism icons in Java Island because of the colorful, the density and diversity of its coral reefs (Purnomo *et al.,* 2022). Consequently, it is known as the Paradise of Java, or Caribbean van Java (Himawan & Lestari, 2016). Many local and foreigner around 3000-6000 visitors per month come to relish snorkeling and diving to explore the diversity of coral reefs (Satya et al., 2023). There is a demand for visitors coming to KNP that tends to increase every year. However, KNP is one of the national conservation areas and as an effort to preserve nature and biodiversity in KNP, Karimunjawa National Park Agency (KNPA) divides KNP into 8 zones, namely: core zone, marine protection zone, marine cultivation zone, religious, cultural & historical zone, rehabilitation zone, zone traditional, land utilization zone, and marine utilization zone (Nadia et al., 2018).

MPs transportation starting from mainland, then involved by wind and rain and then flowing into the sea continuously and increasing, carried by long-distance distribution, and have pressure in the potential for toxicity (Matthews et al., 2021). As a consequence, MPs are found from shallow areas appearing from coastal areas to deepest areas such as troughs. However, MPs are found in marine biota which pose a threat, such as in fish where MPs cause oxidative stress (Capo' et al., 2021), in shellfish they cause changes in the structure of gills and digestive glands (Vasanthi et al., 2021). Furthermore, by the food chain mechanism, MPs can have harm impact on humans who consume it (Wang et al., 2021). Since KNP is famous for its diversity coral reefs which becomes an economic source from marine tourism for local communities, the threat of MPs on coral reefs raises concerns in itself which can have an impact on coral health. Coral health problems that arise such as blockages and failure of the coral's digestive tract such as occurred on Australia's Great Barrier Reef (Hall et al., 2015; Huang et al., 2021). Due to the severe impacts caused by MPs, those are recognized as a new contaminant that causes a major threat to marine biodiversity (Khalid et al., 2021).

Hence MPs have a very small size, smaller <5 mm (Bergmann et al., 2017), causing them difficult to detect directly visually. So even though the condition of the waters is clear, it is not a guarantee that the waters are free from MPs pollutants. Previous research related to MPs that has been carried out in KNP conducted by Lie et al. (2018), Kurniawan et al. (2021), Muchlissin et al. (2021), Ningrum and Patria (2022), Salsabila et al. (2022) and Seprandita et al. (2022). These previous studies were conducted in various locations and can be displayed in Figure 1. The objects observed or studied in the five studies were dominated by sediments, anchovies and surface water.

MPs pollution is increasingly alarmed and has even penetrated marine protected areas as well as found in Australia's Great Barrier (Carbery et al., 2022), protected Andaman Bay (Jaini & Namboothri, 2022), Baltic Sea (Esiukova et al., 2021) and others, whereas MPAs have high ecological values. The goal of this research is to investigate the comparison of the MPs abundances and characteristics including shape, color, size, and type of polymer occurrences in MPA and non-MPA zones in KNP. Especially for Non-MPA, it is taken from several types of utilization, namely maritime use areas, port areas, and areas outside the KNP. Detailly the MPA area is represented by Sintok Island, while the non-MPA area distinguished into Menjangan Besar Island for the marine utilization area, Karimunjawa Island for the port area and Seruni Island for the area outside the KNP (Figure 1).

MATERIALS AND METHODS

Study sites description

KNP is one of several marine national parks in Indonesia. The Decree of the Minister of Forestry and Plantations No. 74/Kpts-II/2001 states that the Karimunjawa Nature Reserve area has a total area of 110,117.30 ha and is designated as a marine protected area. Then on October 28th, 2020, the Karimunjawa area was established as part of a biosphere reserved by UNESCO with Jepara and Muria. This designation confirms that the Karimunjawa Islands belong to a unique ecosystem that needs to be preserved and protected for research and educational purposes. Due to

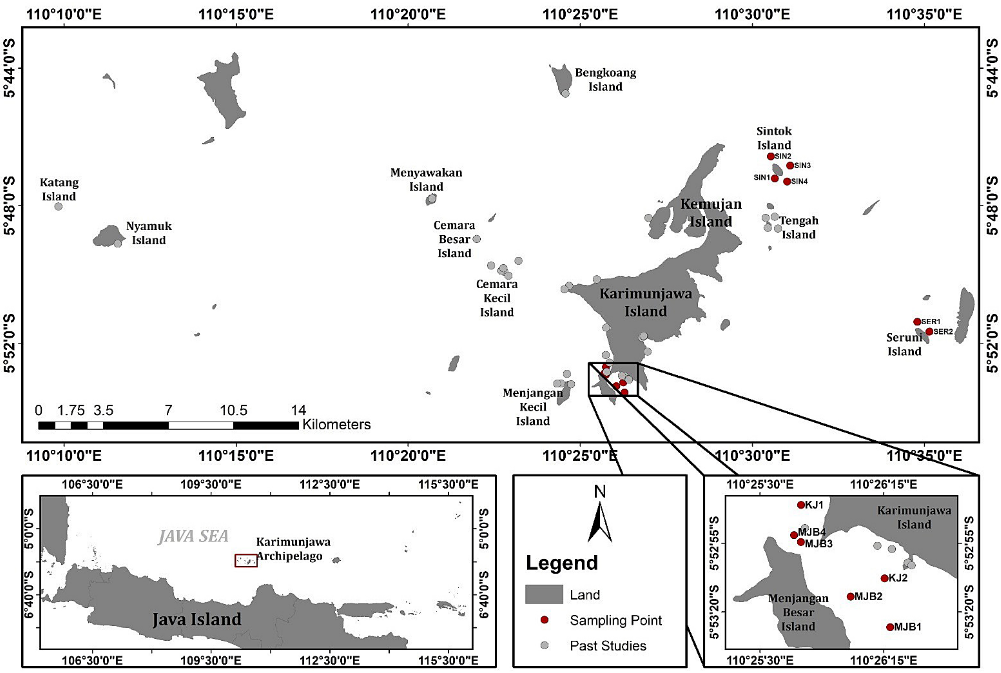

Figure 1. MPs previous study (grey dots) and research area (red dots) in KNP

MPs impact generate stress to ecological system, this research examines the MPs abundance and characteristic in MPA and non-MPA zone. Overall, the research area includes 4 islands, which categorized 1 island for MPA, and 3 islands for non-MPA. Detailly, non-MPA zone divided into 3 utilization for marine tourism represented by Menjangan Besar Island, Karimunjawa Island as port area, and Seruni Island for outside area of KNP.

Detailly, Sintok Island is chosen as MPA representations due to Sintok Island is used for a stopping-by and spawning destination for sea turtles (Marganita et al., 2022). While Menjangan Besar Island is intended as one of the marine tourism utilizations because it has diversity coral reefs and become a favorite spot for snorkeling (Januardi et al. 2016). Moreover, the Karimunjawa Island is chosen to represent the port area which busy with logistics and transportation activities (Anggrahini et al., 2022). While, Seruni Island is chosen to represent the outside area of KNP. Seruni Island is an uninhabited island but has high biodiversity, characterized by the diversity of coral reefs, pelagic fish and seaweed cultivation (Widiaratih et al., 2022).

Sample collection

Sea surface water samples were obtained on 10–12th April 2021 using the modified Viršek et al. (2016) method with a plankton net with an opening diameter of 25 cm and a mesh size of 95 μm during the certain time (3–5 minutes). While filtering the seawater, the boat speed and the starting position were recorded using GPS. The data of diameter size of plankton net, length of time filtered and speed of the boat used to calculate the total of volume filtered water (Cutroneo et al., 2020). Hereinafter, the filtered water put in bottle sample to identify the MPs characteristic in the laboratory.

Microplastic identification

In the laboratory, the volume of the water sample measured and recorded using a measuring cup. Each sample was added with ethanol>70% (Viršek et al., 2016) and H_2O_2 30% with a ratio of 1:1. The sample was left in a closed space for 3×24 hours. During this period, H_2O_2 will degrade the organic matter contained in the sample (Zhao et al., 2017). Therefore, all the remain is undegradable such as MPs. After that, each sample was filtered with 0.45 μm Millipore filter paper, transferred into a petri dish with a lid, and let dry at room temperature for 1×24 hours.

Visual identification of MPs was carried out with Olympus SZ2-ILST Microscope and a laptop with software ScopeImage 9.0 installed. The identified of MPs characteristic including the shape, size, color and polymer type. The MPs shape could be categorized in 8 types such as fragment, film, pellet, bead, sheets, filaments, fiber and foam. While for MPs size use the term microplastics as all particles with a size<5 mm from Arthur et al. (2009). In this study, the MPs size is distinguished into 4 classes such as: 1–10 μm, 1–50 μm, 5–250 μm, and 250 – 1,000 μm.

After calculating the abundance, the samples were analysed using Fourier transform infrared (FTIR). The types of polymers were identified with help from Open Specy (openanalysis.org/openspecy/) made by Cowger. In this study, Open Specy was used to view and identify material from the peak spectrum of samples tested by FTIR with the available peak spectrum libraries. The polymer types discussed in the FTIR results follow the suggestions from Hartmann et al. (2019) that are the most common synthetic polymers and copolymers.

RESULTS AND DISCUSSION

The abundance of MPs in MPA and non-MPA zone

Overall, the abundance of MPs found in the KNP was depicted in Figure 2. The highest number of MPs was discovered in Sintok Island which is categorized as one of conservation area in KNP with range of MPs discovered is 47.89–106.20 MPs/L and average 78.65 MPs/L. These findings had the similar pattern due to Garc´es-Ordo´nez et al., 2022 showed that coastal area in protected area was higher than unprotected coastal area generated by impacted of storms that occurs. Geographically, Sintok Island located in the east side of Karimunjawa Island, and has high influence from monsoonal pattern, as consequence resulted with the currents in Sintok Island is 0.05–0.3 m/s (Alhaq et al., 2021) that impacted in turbulence and distribution of MPs. Furthermore, these findings were strengthened due to Marganita et al., 2022 showed that the source of MPs based on backward particle tracking modeling, MPs came from Kemujan Island and Northern Java Island,

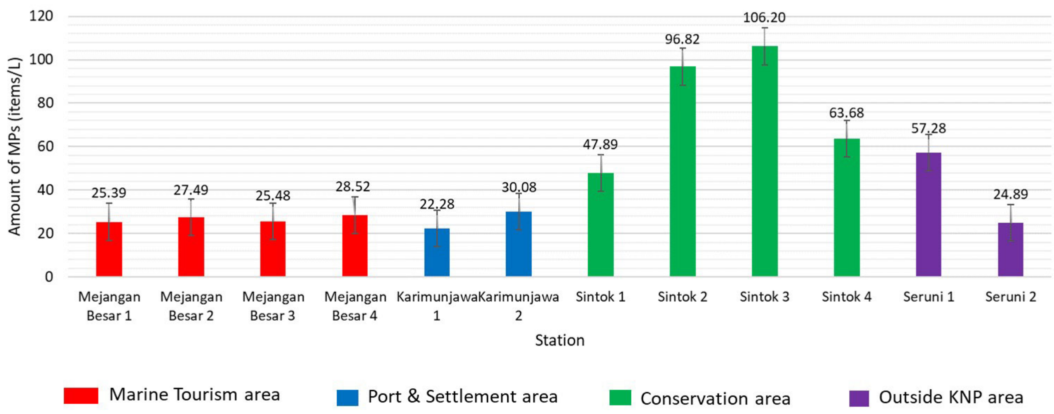

Figure 2. MPs abundance per island in KNP (items/L)

namely Cisanggarung River, Cirebon City, and Citarum River during 7 days, 30 days and 60 days backward modelling in April 11th 2020. These findings were in line to Alam & Rachmawati (2020), the highest MPs in Indonesia had been produced from Java Island which has the highest population and industrial level.

Moreover, the numbers of MPs discovered were carried away as well from it surrounding area. It had related with Salsabila Study (2022) in Tengah Island which is located in the south of Sintok Island and the MPs in sea water found in range 21.53–46.97 MPs/L and average 35.61 MPs/L, while MPs in sediment in Tengah Island is 53 MPs/kg (Muchlissin et al., 2021). This total number of MPs found were tended to be higher than port or settlement area in Karimunjawa Island. It occurred strengthened due to in Tengah Island there was a resort construction process which generates many marine debris and experiencing degradation to be smaller piece including the MPs and transported to Sintok Island by currents, waves and tidal, winds, other hydrodynamics processes.

These findings showed that the conservation area became the area which had susceptible to have high pollutant of MPs. Since, Sintok Island belong to conservation area due to this island used as a stopping-by and spawning destination for sea turtles. Previous studies had been showed that many sea turtles swallowed the marine debris including MPs because they presumed that it looks alike jellyfish (Chemello et al., 2023), that impacted on the digestive system, changes in swimming behavior, buoyancy difficulties and in the worst cases animal death has been reported in turtles that ingest plastic waste (Senko et al., 2020). Due to this finding, it must be preventive programs to be established to mitigate the MPs pollutant higher found in Sintok Island.

The second highest of MPs discovered in non-MPA area in Seruni island with range 24.89–57.28 MPs/L and average 41.09 MPs/L. Even though Seruni Island is outside the KNP area and uninhabited island, but still has good biodiversity and used for local people for seaweed cultivation. However, there was influence from surrounding areas, who the nearby people are lived in Genting Island which is next to the Seruni Island and impacted to the high MPs due to anthropogenic activity from settlement (Widiaratih, et al., 2022). Moreover, the waves in Seruni island are higher than the MPA area, due to it located further to east side of Karimunjawa which directly border to the offshore in its surrounding. However, the high waves can be identified by the type of coral reefs exist, such as massive type than branching coral type dominantly in Seruni Island due to high waves condition (Munasik et al., 2021).

Meanwhile, the lowest of MPs abundance was found in Karimunjawa Island which presented the port and dense settlement area in Karimujawa, MPs found with range is 22.28–30.08 MPs/L and average 26.18 MPs/L. Earlier study of MPs in sediment of Karimunjawa Island but in the different spot which is Boby Beach found 40 MPs/kg, Legon Boyo found 19 MPs/kg, Ujung Gelam Beach found 11 MPs/Kg based on Muchlissin et al (2021). These finding contrary where Karimunjawa Island is one of the busy port and dense population which should had high contribution of MPs, but the MPs abundance was the lowest than to the conservation area. It happened due to waves height in Karimunjawa Island were 0.09–1.22 m with significant wave (Hs) was 0.64 m and wave period were 4.3–7.3 s, with significant period (Ts) was 5.66 s (Gunawan et al., 2017). The highest wave height occurred in transition I (March-May) and east (June-August) monsoon, whereas the wind blows transition from northwest to southeast. So that, most of MP's source from Karimunjawa Island carried away from the coastal to the offshore.

Furthermore, the second lowest was found in Menjangan Besar island as representative as marine tourism area with range of MPs is 25.39–28.52 MPs/L with average 26.72 MPs/L which slightly different as found in Karimunjawa Island. Previous study by Muchlissin et al (2021) in sediment of Menjangan Kecil Island found 18 MPs/Kg. Menjangan Kecil and Menjangan Besar Island are favorite islands visited by tourist to enjoy the snorkeling activities. The tourists focus to enjoy the snorkeling for certain time duration and the MPs pollutant the lowest from type of utilization. However, its occurrence due the hydrodynamics especially currents play important roles in distribute the MPs forward far away the Menjangan Besar sland caused the monsoonal wind effect. Even tough, it is discovered in the lowest abundance of MPs, but it still MPs has negative impact to coral such as reduction in feed intake process, ineffective of photosynthetic, delay the rates of metabolic, decreased in bone formation until chlorination and necrotizing (Reichert et al., 2018; Berry et al., 2019; Reichert et al., 2019).

The shape of MPs in MPA and non-MPA zone

The results of visual observations using a microscope were classified based on the shape of MPs particles is illustrated in Figure 3. Fragment was the most dominant shape of MPs found of each island, followed by fiber, pellet and films (Figure 4). Fragment and film are categorized as MPs secondary, while the fiber and pellet are come from MPs primer which fabric form is made in a small size. Due to physically, chemically and biologically process the MPs secondary will be exposure, will be degraded become smaller pieces. These findings had similar pattern related due these fragments were resulted from break down, abrasion, and weathering of larger plastic products and are transported over the ocean (Jaini & Namboothri, 2022).

Overall, the shape of MPs effects the physical process that influence the distribution of MPs by

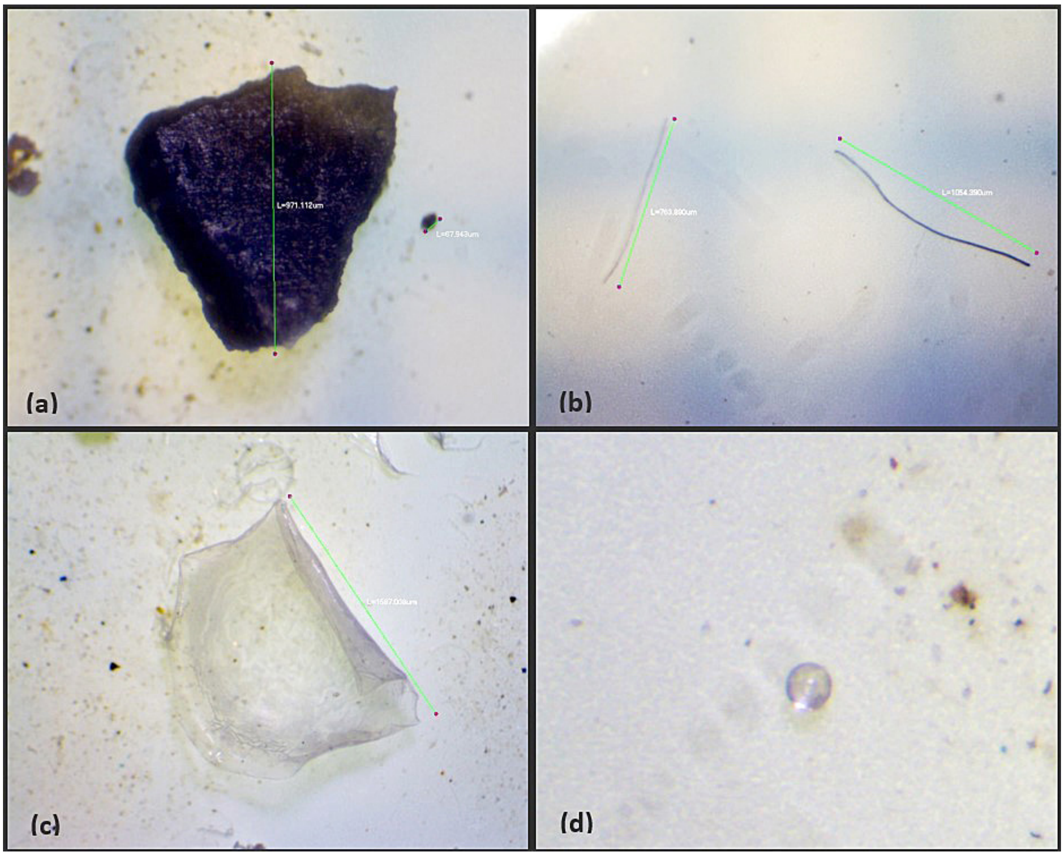

Figure 3. Examples of shapes of MPs discovered in the Seruni Island, which identified as: (a) fragment, (b) fiber, (c) film, and (d) pellet

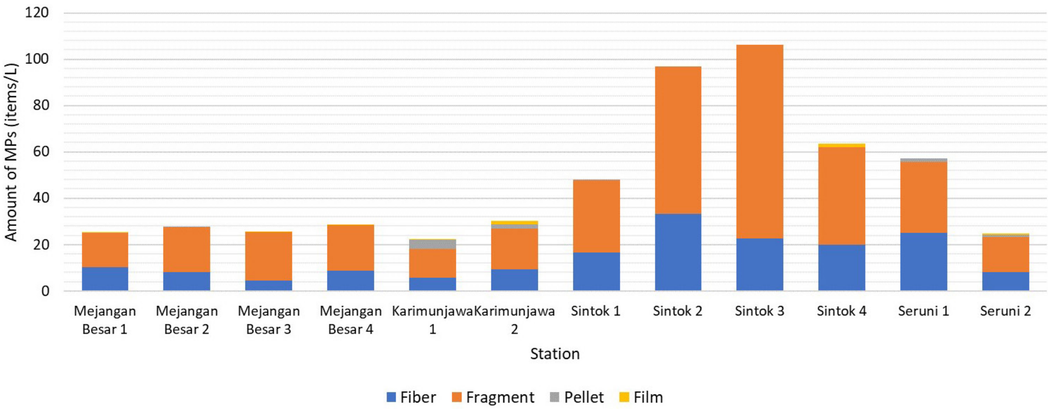

Figure 4. Shape of MPs per island in KNP (items/L)

advection, turbulence, negative buoyancy (sinking) or positive buoyancy (floating), transporting by wind, coastal wash off, transport by sediment gravity flow (Shamskhany, et al., 2021). Moreover, the process of biofouling and fragmentation play important roles in MPs transportation (Waldschläger et al., 2020). Furthermore, the ratio of outer surface area to volume is influenced by the shape of the MPs (Ballent et al., 2016), such as fibers and filaments will sink more quickly when exposed to biofouling compared to fragments and beads which are slower to respond to biofouling. So that, the fragment found mostly in the surface water due to it had large surface than other MPs so it required more time to get process to respond the biofouling and get sinking. While the fibers were figured lesser than fragment caused by it had small surface and it will sink faster when it goes biofouling. However, the surface roughness of MPs as well governs the biofouling process.

Hereinafter, pellets were the most found in third rank. Uniquely, pellets were found dominantly in Karimunjawa Island and Seruni Island, since both islands are inhabited island. Pellets are characterized as MPs with spherical and cylindrical shapes and categorized as primary MPs (Fig. 4). Source of pellets are produced from industrial from recycle or without recycled material (virgin plastic).

Films was the lowest of MPs found in this research. This type of film is characterized a piece of plastic that has a very thin layer in the form of a sheet with a low density (Dewi et al., 2015). Many of these microplastics come from cuts and degradation of plastic bags including as secondary MPs. Almost have similar pattern, films mostly found in Karimunjawa Island as center of capital and Sintok Island especially in station 4 which located nearest the both Island namely Karimunjawa Island whereas the capital of Karimmujawa Island and Tengah Island which has been construction process.

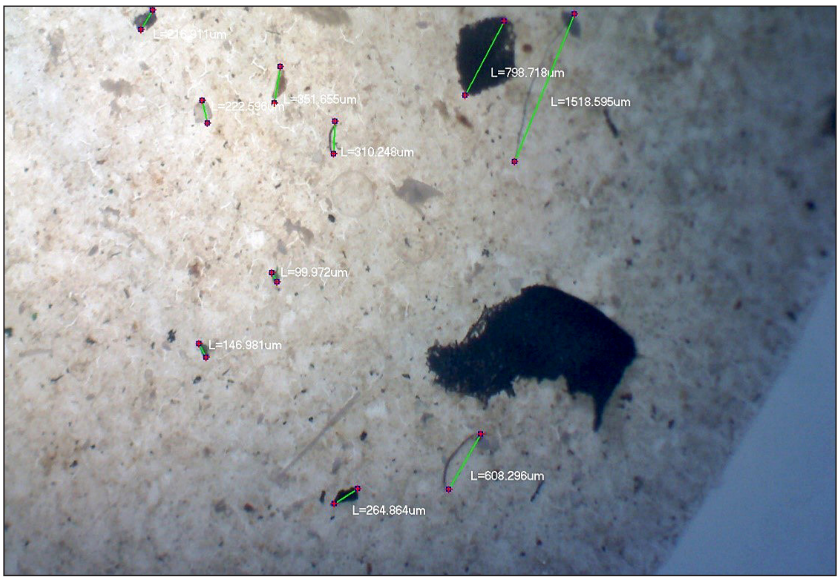

Figure 5. Example of MPs based on size class

Size of MPs in MPA and non-MPA zone

The sample of varied MPs size was presented in Figure 5. Overall, the size of MPs was categorized as 4 classes, such as: 1–10 µm, 1-50 µm, 50–250 µm, and 250–1000 µm. In Figure 6, it could be seen that the size class of 1–50 µm was the size class that dominate in the four islands. The predominance of small sizes correspond to the coastal environment's tendency to fragment become smaller microplastics. The tendency for fragmentation was due to the presence of UV light, physical erosion by wave energy, oxidation (Cole et al., 2011), and turbulence of ocean currents (Barnes et al., 2009; Auta et al., 2017). In addition, the fragmentation process occured due to microorganisms (Hidalgo-Ruz et al., 2012). The smaller the size of the plastic, the greater the diversity of the biota or organisms affected (Barnes et al., 2009; Auta et al., 2017). Kankılıç et al., (2023) highlighted the correlation marine biota size and MPs consumption, the MPs size with range 0.3–3.0 mm mostly frequency found inside marine biota that stressing the size selective uptake by organism. Moreover, the mesh size of plankton net used in this research was 95 µm, so that mostly the smaller size of MPs was filtered in this research.

MPs Size also contributed the transportation of MPs itself. Due to its small size, the movement of MPs was compared to the sediment's size, such as MPs size of 5 mm as equal as fine gravel, while MPs size of 10 µm as similar as silt (Shamskhany et al., 2021). Moreover, the size of sediment is a factor that predispose effect to the hydrodynamics process (Yang and Shi, 2019). Furthermore, the MPs size effected the process of MPs biofouling and defouling that prompting MPs sinking or floating (Kooi et al., 2017).

Color of MPs in MPA and non-MPA zone

Figure 7 showed the color of MPs discovered in four islands. Black was the dominant of MPs color found, then was followed by white, blue, red, brown and green color (Figure 8). Moreover, most of MP's color was black due to it was sourced from recycled plastic for packaging (Damanik, 2012). Furthermore, the color of MPs affects the level of toxicities (Chen et al., 2020). However, the fishes preferred to swallow the colorful of MPs than the dark color due to they suspect they are small fishes (Okamoto et al., 2022).

Polymer type of MPs in MPA and non-MPA zone

Examining the polymers of MPs in this research used Fourier transform infraRed. FTIR was using infrared to identify the characteristic of polymer materials and analyze the functional group. The principle of FTIR figured out the residual spectra by absorbing energy using infrared, so it worked based on movement of a molecule (Warrier et al., 2022). Each group in a molecule generally has its unique characteristics indicated with specific wave numbers so that FTIR could be used to detect specific groups in polymers.

Furthermore, these wave numbers were used as input in the open-source platform "Open Specy" (https://openanalysis.org/openspecy/) (Cowger et al., 2021) for examining the MPs polymer. Identification polymer processing was by comparing research data (white line) with reference spectrum data (red line) to identify the length of the Infrared spectra or wave number (Xu et al., 2019) as shown in Figure 9.

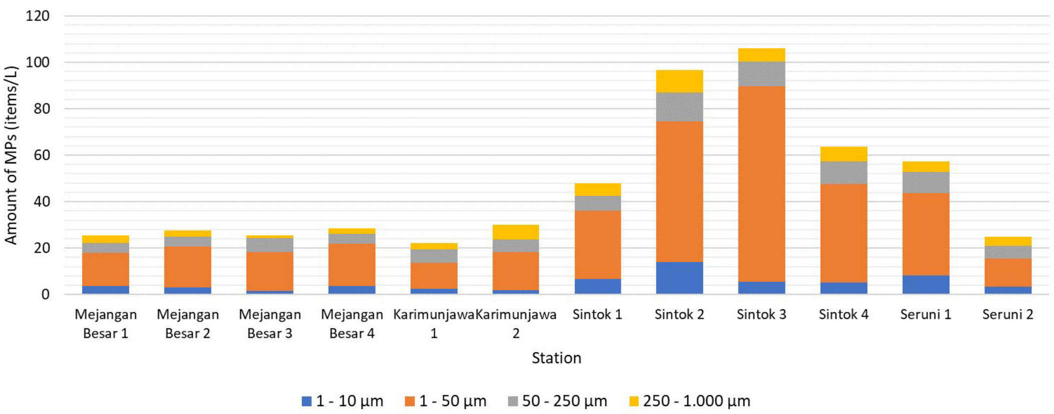

Figure 6. Size of MPs per island in KNP (items/L)

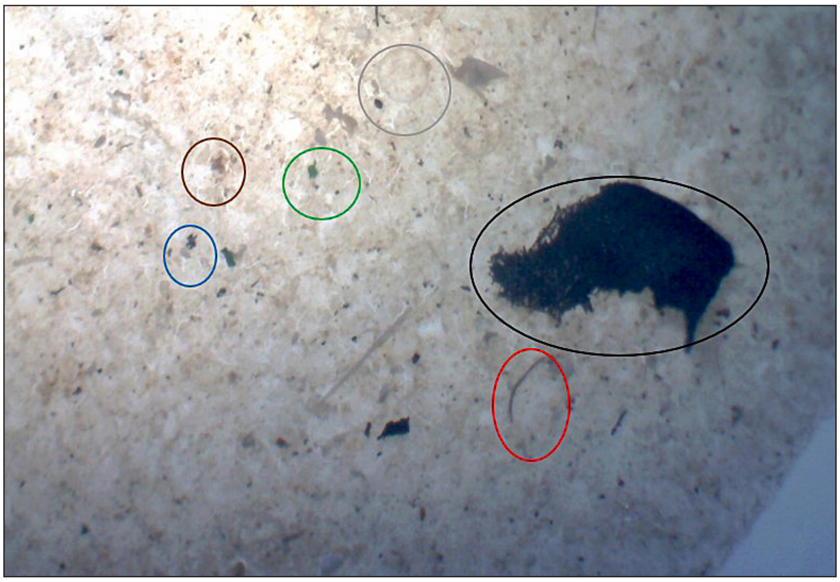

Figure 7. MPs particles based on color in Seruni Island for which identified as red color (red circle), brown (brown circle), blue (blue circle), green (green circle), black (black circle), and white (grey circle)

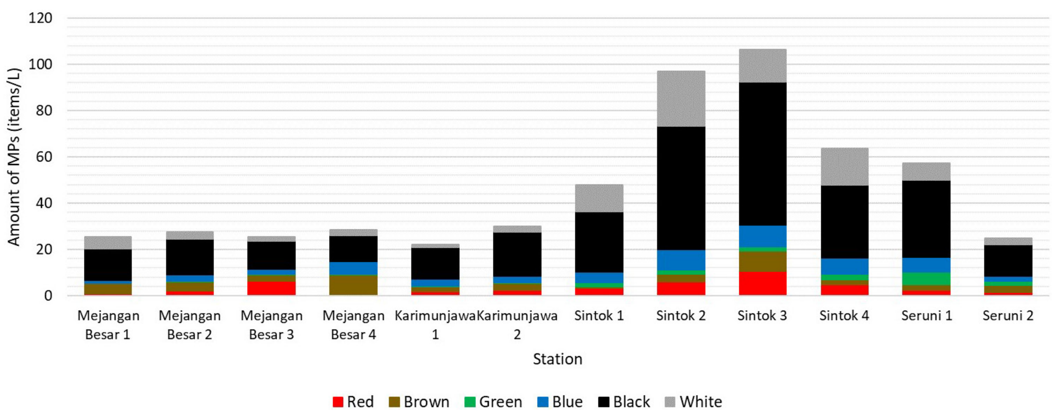

Figure 8. Color MPs per island in KNP (items/L)

Figure 9. Example of Fourier transform infrared analysis using openspecy in Menjangan Besar Island Station 2 (https://openanalysis.org/openspecy/)

Table 1. MPs polymer types based on FTIR analysis

Zone utilization	Station	Type of polymer
Marine tourism (Non-MPA Zone)	Menjangan Besar St. 1	HDPE, LDPE, PP
	Menjangan Besar St. 2	HDPE, Nylon, PVC
	Menjangan Besar St. 3	ABS, HDPE, PP
	Menjangan Besar St. 4	ABS, HDPE, LDPE, PP
Settlement & Port (Non-MPA Zone)	Karimunjawa St. 1	ABS, HDPE, LDPE, PP
	Karimunjawa St. 2	HDPE, LDPE, PP
Conservation (MPA Zone)	Sintok St. 1	ABS, HDPE, LDPE, PP
	Sintok St. 2	ABS, HDPE, LDPE, PP
	Sintok St. 3	ABS, HDPE, LDPE
	Sintok St. 4	ABS, HDPE, PP
Non-KNP (Non-MPA Zone)	Seruni St. 1	HDPE, Nylon
	Seruni St. 2	PET

The polymers type of MPs found in this research as much as 7 types of polymers i.e., high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), nylon, polyvinyl chloride (PVC), acrylonitrile butadiene styrene (ABS), polyethylene terephthalate (PET) as shown in Table 1. HDPE, LDPE, and PP were mostly of polymer types of MPs discovered in four islands. These findings were in line with Kannankai *et al.* 2022 showed that the high number of Polyolefins such as polyethylene (PE) and polypropylene (PP) in the marine environment can be attributed to their extensive worldwide production and consumption, which is manifold compared to other. Most of things such as household, clothing, electrical material using plastic of polyethylene (PE), while for food packaging dominantly use polypropylene (PP), since these plastic materials that are flexible and easy to shape.

Moreover, the polymer of MPs of nylon were limited discovered in 2 stations i.e., Menjangan Besar Station 2 and Seruni Station 2 due to distance to the settlement area Karimunjawa Island and Seruni Island that so many source of nylon such as fish net, clothes, that made from textile fiber that has strength, elasticity and transparency. Despite PVC and PET were found smaller in four islands, however it become concern due to it has high of level toxic, especially it needs time 50–1000 years to disjoint the polymer and harm impacted to health marine ecosystem (Yuan et al., 2022)

CONCLUSIONS

In this study, MPs were higher in MPA zone than non-MPA zone, indicating the threat of MPs encroaching on marine protection area that has high biodiversity even though it is uninhabited island. Moreover, the MPs characteristics also played important roles for the ingestion by marine organism including shape, size, color and polymer. The majority of MPs were fragments and size group of 1–50 µm and it potentially split into smaller size such as nano MPs that brought more dangerous to marine biota if they swallowed them. Black-color HDPE, LDPE, and PP were observed dominantly in the study area. A higher abundance of MPs in MPA zone sources from anthropogenic activity such as main pollutant source, as well as population, human behaviours. Moreover, the transportation of MPs is influenced by physical oceanography aspects such as current, tidal, waves, air-sea interactions that govern the advection, turbulence, and it strengthened the MPs were carried away from its surrounding from the nearby island where there was cottage construction and others island densely populated. Since, MPA has high ecological values, so this study highlights the urgency of better controlling marine debris especially MPs pollution due to it generates lethal impact on marine organism especially on vertebrate fauna such as turtles that be protected and become spawning destination in MPA island.

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