Unravelling the pathway of macro and micro debris in the beach of uninhabited Semak Daun reef platform, Kepulauan Seribu.

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Abstract. Marine debris is ubiquitous and possess threats to marine organism and ecosystem. Due to its small size, micro debris can be consumed by marine organism. Ingestion of micro debris including microplastic can be detrimental. We investigate the pathway of macro and micro debris in the beach of Semak Daun, an uninhabited island in the Kepulauan Seribu which is famous for tourism. Macro debris sampling was done in the intertidal and subtidal beach, covering both northern and southern part. Micro debris sampling was conducted in the northern part of intertidal beach, three replicate samples were gathered within a radius of 5 m. The most abundance macro debris in the study area were plastic cup and plastic wrap, most of them were found sinking in the seawater. Foam, potentially originated from camping mattress or footwear, composed as the most abundance micro debris. Beach sediment were seen filling the void on the foam surface, a feature that can facilitate density modification which generates foam to sink on the seafloor. Our finding implies that uninhabited island can be polluted by marine debris due to mismanaged waste from tourism. The fact that a large number of marine litters were found in subtidal beach should raise our concern, as hydrodynamic process potentially transported and accumulated them in lagoon or reef front. Further research is crucial to investigate the pathways of marine debris in the reef environment, the result is expected to provide knowledge on better waste management.

1. Introduction

Marine debris has been a worldwide problem due to its potential harmful effect to marine organism and ecosystem. Currently, plastics are acknowledged as the most abundant category of marine litter and larger proportion is projected to sink and remain in marine sediments [1]. Nevertheless, plastic accumulation on the seafloor remains largely unquantified. The presence of macroplastic in marine ecosystem have significant environmental concerns as many reports on entanglement and digestion of macroplastic by marine animal [2,3] as well as entanglement and equipment damage on numerous marine industries [2,4]. Marine micro debris, in particular microplastic, has also increase global concern. Microplastic is commonly derived as fragmentation of larger plastic pieces due to UV radiation, oxidation, and mechanical forces known as secondary plastic [5] or directly manufactured as in many cosmetics exfoliates or synthetic fibers from textiles [6,7]. The presence of microplastic is widespread and accumulate in benthic sediments and shorelines and has the potential harmful effects to the environment due to their small size. Ingestion of microplastic by marine species has been widely
documented, and the greater consideration is that it can potentially impact higher trophic levels. Microplastic ingestion can negatively affect food intake, benthic fauna may suffer a 50% reduction in energy reserves [8], increased metabolic rates [9], and reduced reproductive success [10,11]. Studies have reported that microplastic can adsorb toxic chemicals from surrounding sea water [12,13] which can be pathologic if transferred into the food chain [14]. Abundance of microplastic are most likely depend on the distance from the sources and human population centers, as similarly reported for macroplastic [15].

The largest proportion of marine debris are known to be land-derived plastic litter [16], whether directly or indirectly entering marine environment. Plastic litter from the mainland can enter river system then transported to the ocean. Marine tourism, fishing activity, marine vessels and aquaculture have the potential to be the sources of plastic that directly enter the ocean, with risk of macroplastic or secondary microplastic contamination. Plastic litter has pervaded the global ocean driven by ocean currents, winds, river discharge, and drift [4,17]. Plastic litter has been a major problem in Kepulauan Seribu, most of the litter is considered come from Jakarta [18] but nowadays tourist activities also play an important role than before. Densely populated island in Kepulauan Seribu (Pulau Harapan) has been reported as an evident source of plastic bags [18]. Litter level in Kepulauan Seribu have almost doubled on island close inshore, and are more than five times higher on the offshore islands [19]. Polyester blocks, plastic bags, discarded footwear, drinking bottle, ropes and pieces of fishing net have been reported as the plastic litter items [18,19].

Knowledge of the plastic debris dynamic within spatial and temporal changes, accumulation, size and fragmentation are essential for understanding fate and impact of microplastics [20]. To understand how this pollution widespread within marine environment is in urge since it has the potential to threatened the ecosystems and human health. This preliminary study is aim to investigate the linkage between macro and micro debris in a beach of uninhabited island famous for marine tourism. The result is expected to contribute on better knowledge of marine debris pathway, thus better waste management on coastal environment can be achieved.

2. Study area and method
Semak Daun Island, located in the middle range of Kepulauan Seribu (the Thousand Island) reef platforms in the Java Sea is the focus of this study (figure 1). Semak Daun is an uninhabited island famous for tourism. Tourist are coming to Semak Daun Island in daily basis, whether for short trip or camping activity. Semak Daun reef platform has the morphology of an atoll with a few small inlets across the sand apron, allowing limited connection between the lagoon and open ocean [21]. Kepulauan Seribu is classified as middle shelf patch reef complex [22]. Reef-related depositional environments occur in Kepulauan seribu are island and shoals, reef flat, reef flat lagoons, reef and small crags of reef growth, and reef sediment slopes, inter-reef lagoon, and middle shelf [22]. Like other reef platforms in the Java Sea, Kepulauan Seribu is dominated by bioclastic assemblages with very minor non-skeletal grains and rock fragments [23–25]. The bimodal of monsoon wind-driven current and wave climate exert significant influence on reef growth [26,27]. The Java Sea is characterized by the monsoonal wind with a seasonal reversal between the west monsoon (December – February), and the east monsoon (April - October). The east monsoon wind is two times more persistent than the west monsoon wind, but the west monsoon wind shows more extreme variations in wind strength [28]. Sea surface temperature (SST) in Kepulauan Seribu is showing different value during season, with maximum/minimum SST being May/February in the Seribu inshore and May/September in Seribu offshore [29]. A different month of minimum SST in the Seribu islands from the offshore and inshore is due to the peak of wet monsoon in February, resulting in an increase of fresh water discharge from the mainland to the Seribu inshore waters. Climate variability in the Indonesian archipelago has a strong role on the intensity of rainfall patterns and tropical convections in the highly populated region related to global warming impact in the future [29,30].
Figure 1. (A) Location of Kepulauan Seribu island chain in the western Java Sea, north of Jakarta as also show in the inset map. (B) Location of study area, Semak Daun reef platform (map from Google Earth).
The sampling was done on the intertidal and subtidal beach of Semak Daun Island (figure 2). Macro debris surveyed conducted in the northern and southern shoreline area following method from NOAA Marine Debris Shoreline Survey Field Guide [31]. Debris item with the size over 2.5 cm or 1 inch collected by walking along the line with 100 m long x 1 m width between high tide zone in the intertidal dan subtidal beach. Each debris then counted and categorized into 6 materials types; plastic, metal, glass, rubber, processed wood and cloth/fabric.

Micro debris sampling was conducted on the high tide zone intertidal beach of Semak Daun, in sampling site M1 (figure 2). Three replicate samples were gathered from this site, each were taken within a radius of 5 m. A 50 cm x 50 cm x 7 cm area was dug in the surface of the high tide line and the sediment subsequently sieved using a 1 mm mesh metal sieve following method by [32]. Visual identification based on morphological and physical characteristic were then use to identified microplastic in the sieved sediment. An optical analysis of the particles recovered was performed using a stereomicroscope (Wild M3Z, Heerbrugg, Switzerland). Unnatural colors and/or shininess and unnatural forms/structures were used as indicators of potential microplastics [33,34]. Particles with potentially cellular or organic structures and translucent fibers were rejected as microplastics [34]. Translucent fibers and fibers that were not characterized by three-dimensional bending and uniform thickness were also rejected [34,35].

3. Result and Discussion
Macro debris found on intertidal and subtidal beach of Semak Daun (table 1, figure 3) mostly are plastic (98%). Rubber and fabric debris are found in the northern shoreline, while processed wood, metal and glass were not found in both shorelines. The most abundance macro debris found were plastic cup and plastic wrap, supposedly from drinking and food package, 72% in northern and 79% in southern shoreline. Despite their low density and tendency to float on seawater, most of macro plastic found in subtidal beach are sink in the sediment. This signify that tourism and camping activity contribute to largest proportion of plastic contamination in Semak Daun.

![Figure 2. Survey point for macro debris and micro debris (M1) along intertidal and subtidal beach of Semak Daun. Bathymetry are redrawn after [36] with modification.](image)
Table 1. Macro debris density and material type

| Item         | Northern Shoreline | Southern Shoreline |
|--------------|--------------------|--------------------|
| Plastic      |                    |                    |
| Plastic cup  | 20                 | 9                  |
| Straw        | 7                  | 1                  |
| Plastic wrapper | 24                | 10                 |
| Burned plastic | 3                 | 0                  |
| Cigarette    | 3                  | 0                  |
| Plastic bottle | 1                 | 3                  |
| Toothbrush   | 1                  | 0                  |
| Styrofoam    | 0                  | 1                  |
| Rubber       |                    |                    |
| Flip flop    | 1                  | 0                  |
| Fabric       |                    |                    |
| Shoes        | 1                  | 0                  |
| Total item   | 61                 | 24                 |

Figure 3. Macro debris found in the subtidal and intertidal beach of Semak Daun. Plastic comprised 98% of total macro debris in the study area, mostly were plastic cup and plastic wrap.

Micro debris found on intertidal beach of Semak Daun are foam, glass, plastic film, and fragment of unknown material (figure 4). Their colours are blue, black, white, green, and transparent. The most abundance potential microplastic found in the study area are foam, suspected to be originated from camping matt or footwear/flip flop. Marine debris in northern part of Kepulauan Seribu are believe to be local anthropogenic stressor instead of transported from Greater Jakarta Area [37,38].

Figure 4. (A) Some of micro debris found in intertidal beach of Semak Daun, Kepulauan Seribu. (B) Beach sediment were seen filling the void on the foam surface.
The most abundance macro debris found on the subtidal and intertidal beach of Semak Daun is plastic, with plastic cup and plastic wrap composed 75% of total proportion. Plastic cup is usually made of polypropylene while plastic wrap is usually made of low-density polyethylene. The density of both plastic polymers is lower than the density of sea water. Nevertheless, most of plastic macro debris were found sinking on the sea water. This fact is alarming, as it is predicted that 70% of marine debris is known to sink and remain in marine sediment [1].

Foam as the most abundance micro debris found on the sampling site has ignite a question on the missing link of marine litter pathway. Foam, predicted to derived from camping mattress or flip flop is usually made of plastic (polyvinyl chloride, polyurethane) or rubber. This could imply that although plastic cup and plastic wrap were the most abundance macro debris in the sampling site, their material seems to be more durable hence more difficult to disintegrate into smaller particle. On the other hand, camping mattress or flip flop materials appear to be less durable. Therefore, although flip flop only made 1% of the total macro debris in the sampling area, it breaks down more easily thus arranged 44% of all micro debris in the northern part of Semak Daun beach. Beach sediment filled in the void of foam surface (figure 4) could be the source of density modification thus caused foam to be less buoyant. The ability of foam to adsorb material should also put into concern, since there has been report of microplastic adsorbing toxic chemicals [12,13] which can be pathologic if transferred into the food chain [14].

Debris in the subtidal environment are prone to be transported towards deeper lagoon or oceanwards (Utami et al., submitted). Ocean waves control sediment transport in subtidal sand apron, while sediment transport direction is driven by current [39]. A study by Utami et al (submitted) reveal that microplastic in the subtidal reef platforms will accumulates in low energy environment such as lagoon. However, microplastic can also accumulate in high energy environment, such as sand apron (Utami et al., submitted). Hydrodynamic simulation along Semak Daun reef platforms [40] indicate that debris from Semak Daun Island will not be transported far from its original position due to bathymetrical height difference between the inner reef and the outer reef. Reef rim that encircled Semak Daun lagoon act as a barrier for current and wave that will diminished its propagation. Largest proportion of debris from Semak Daun beach will therefore transported to the lagoon, and small proportion could outflow through the southwest channel into the reef front (figure 2). This also indicate that marine debris originating from outside lagoon will be detained by the outer reef so it cannot be transported to the Semak Daun beach.

Number of macro debris found in the northern shoreline are three times more abundance than in the southern shoreline. This result could be correlated with the sediment transport dynamic in Semak Daun reef platform. Measurement and hydrodynamic simulation in Semak Daun reef platform showed that current in Semak Daun lagoon predominantly generated by tides [40]. The residual current velocity is also slow (0.001 - 0.043 ms⁻¹), therefore although residual current played an important role for material transport for a long period of time, the influence of residual current inside the lagoon is relatively small.

Current flows to the southwest during the high tide and to the northeast during the low tide [40]. At low tide, the current velocity around Semak Daun Island is slow (0.025 – 0.08 ms⁻¹) [40] making the debris/sediment relatively will not be transported far from their original position. Movement of debris probably occurred during high tides with current velocity around 0.08 – 0.2 ms⁻¹ [40]. Due to the current movement, debris in the northern shoreline are dragged along the coastline to southwest and west part of the island. While in the southern shoreline, debris/sediments are moving outward. However, it should be noted that this survey was conducted during east monsoon. Surveys which cover both east and west monsoon are required to gain in-depth analysis of debris movement and its relation to hydrodynamics.
4. Conclusion
This preliminary study reveals that the largest macro debris concentration found in Semak Daun intertidal and subtidal beach are plastic cup and plastic wrap. Micro debris sampling in the northern part of Semak Daun intertidal beach exhibit that foam which presumably derived from camping mattress or flip flop is the most abundance. This imply that the material that form plastic cup and plastic wrap are more resilient to disintegrate into smaller particle. Meanwhile, camping mattress or flip flop materials appear to be easier to disintegrate. Macro debris in subtidal beach of Semak Daun are alarming, as hydrodynamic process potentially transported and accumulated them in lagoon or reef front. Local anthropogenic is thought to be the main stressor of marine litter in Semak Daun. Since tourism is contributed as the largest proportion of marine debris in Semak Daun, better waste management is urgently needed to protect the environment. Without improvement of waste management, marine debris will harm marine ecosystems, including coral reef and their potential ability as reef frame builder.

Author contributions
Both authors were equally involved in the conceptual design and writing of the manuscript.

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References
[1] Frias J P G L, Gago J, Otero V and Sobral P 2016 Microplastics in coastal sediments from Southern Portuguese shelf waters Mar. Environ. Res. 114 24–30
[2] Derraik J G . 2002 The pollution of the marine environment by plastic debris: a review Mar. Pollut. Bull. 44 842–52
[3] Gregory M R 2009 Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions Philos. Trans. R. Soc. B Biol. Sci. 364 2013–25
[4] Barnes D K A, Galgani F, Thompson R C and Barlaz M 2009 Accumulation and fragmentation of plastic debris in global environments Philos. Trans. R. Soc. B Biol. Sci. 364 1985–98
[5] Costa M F and Barletta M 2015 Microplastics in coastal and marine environments of the western tropical and sub-tropical Atlantic Ocean Environ. Sci. Process. Impacts 17 1868–79
[6] Cole M, Lindeque P, Halsband C and Galloway T S 2011 Microplastics as contaminants in the marine environment: A review Mar. Pollut. Bull. 62 2588–97
[7] Fendall L S and Sewell M A 2009 Contributing to marine pollution by washing your face: Microplastics in facial cleansers Mar. Pollut. Bull. 58 1225–8
[8] Wright S L, Thompson R C and Galloway T S 2013 The physical impacts of microplastics on marine organisms: A review Environ. Pollut. 178 483–92
[9] Green D S, Boots B, Sigwart J, Jiang S and Rocha C 2016 Effects of conventional and biodegradable microplastics on a marine ecosystem engineer (Arenicola marina) and sediment nutrient cycling Environ. Pollut. 208 426–34
[10] Cole M, Lindeque P, Fileman E, Halsband C and Galloway T S 2015 The impact of polystyrene microplastics on feeding, function and fecundity in the marine copepod Calanus helgolandicus Environ. Sci. Technol. 49 1130–7
[11] Sussarellu R, Suquet M, Thomas Y, Lambert C, Fabioux C, Pernet M E J, Le Goïc N, Quillien V, Mingant C, Epelboin Y, Corporeau C, Guyomarch J, Robbens J, Paul-Pont I, Soudant P and Huvet A 2016 Oyster reproduction is affected by exposure to polystyrene microplastics
[12] Gouin T, Roche N, Lohmann R and Hodges G 2011 A Thermodynamic Approach for Assessing the Environmental Exposure of Chemicals Absorbed to Microplastic *Environ. Sci. Technol* 45 1466–72

[13] Mato Y and Isobe T 2001 Plastic Resin Pellets as a Transport Medium for Toxic Chemicals in the Marine Environment 35 318–24

[14] Eriksen M, Lebreton L C M, Carson H S, Thiel M, Moore C J, Borerro J C, Galgani F, Ryan P G and Reisser J 2014 Plastic Pollution in the World’s Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea *PLoS One* 9 1–15

[15] Barnes D K A 2002 Invasions by marine life on plastic debris *Nature* 416 808–9

[16] Andrady A L 2011 Microplastics in the marine environment *Mar. Pollut. Bull.* 62 1596–605

[17] Martinez E, Maamaatuiahutapu K and Taillandier V 2009 Floating marine debris: Surface drift, Convergence and accumulation toward the South Pacific subtropical gyre *Mar. Pollut. Bull.* 58 1347–55

[18] Uneputty P A and Evans S M 1997 Accumulation of beach litter on islands of the Pulau Seribu Archipelago, Indonesia *Mar. Pollut. Bull.* 34 652–5

[19] Willoughby N G, Sangkoyo H and Lakaseru B O 1997 Beach litter: an increasing and changing problem for Indonesia *Mar. Pollut. Bull.* 34 469–78

[20] Maes T, Jessop R, Wellner N, Haupt K and Mayes A G 2017 A rapid-screening approach to detect and quantify microplastics based on fluorescent tagging with Nile Red *Sci. Rep.* 7 44501

[21] Utami D A, Reuning L and Cahyarini S Y 2018 Satellite- and field-based facies mapping of isolated carbonate platforms from the Kepulauan Seribu Complex, Indonesia *Depos. Rec.* 4 255–73

[22] Jordan C F 1998 The Sedimentology of Kepulauan Seribu: A Modern Patch Reef Complex in the West Java Sea, Indonesia *Indones. Pet. Assoc.* 1–81

[23] Solihuddin T, Utami D A, Salim H L and Prihantono J 2019 Sedimentary Environment of a Modern Carbonate Platform of Karimunjawa Islands, Central Java *Indones. J. Geosci.* 6 57–72

[24] Solihuddin T, Utami D A, Daulat A and Rustam A 2020 Geomorfologi terumbu karang dan habitat bentik gugusan Pulau Biawak, Indramayu: Integrasi studi citra satelit dan sedimen permukaan *J. Segara* 16

[25] Utami D A, Reuning L, Hallenberger M and Cahyarini S Y 2021 The mineralogic and isotopic fingerprint of equatorial carbonates: Kepulauan Seribu, Indonesia *Int. J. Earth Sci.* 1–22

[26] Park R K, Siemers C T and Brown A A 1992 Holocene carbonate sedimentation, Pulau Seribu, Java Sea—the third dimension *Carbonate Rocks and Reservoirs of Indonesia, A Core Workshop, Indonesian Petroleum Association*, Jakarta pp 2–1 – 2–15

[27] Scrutton M 1976 Modern Reefs in the West Java Sea *Indonesian Petroleum Association, Proceeding 5th Annual Convention* pp 14–36

[28] Poerbandono 2016 Wind characteristics and the associated risk of erosion in Seribu Islands patch reef complexes, Java Sea, Indonesia *The 5th International Symposium on Earthhazard and Disaster Mitigation, AIP Conf. Proc.* vol 1730 p 080001

[29] Cahyarini S Y, Hendrizan M, Utami D A and Blume A 2020 Coral Sr/Ca-based sea surface temperature variability at Seribu and Timor islands waters *IOP Conf. Ser. Earth Environ. Sci.* 618 012020

[30] Hendrizan M, Ningsih N S, Cahyarini S Y, Putri M R, Setiadi B, Anwar I P, Utami D A and Agusta V C 2020 Centennial-Millennial Climate Variability in the Makassar Strait during Early Holocene until the End of the Last Deglaciation *Int. J. Ocean. Oceanogr.* 14 197–220

[31] Opfer S, Arthur C and Lippiatt S 2012 *NOAA Marine Debris Shoreline Survey Field Guide*

[32] Galgani F, Hanke G, Werner S and De Vrees L 2013 Marine litter within the European Marine Strategy Framework Directive *ICES J. Mar. Sci.* 70 1055–64
[33] Fries E, Dekiff J H, Willmeyer J, Nuelle M-T, Ebert M and Remy D 2013 Identification of polymer types and additives in marine microplastic particles using pyrolysis-GC/MS and scanning electron microscopy *Environ. Sci. Process. Impacts* 15 1949

[34] Martin J, Lusher A, Thompson R C and Morley A 2017 The Deposition and Accumulation of Microplastics in Marine Sediments and Bottom Water from the Irish Continental Shelf *Sci. Rep.* 7 10772

[35] Nuelle M-T, Dekiff J H, Remy D and Fries E 2014 A new analytical approach for monitoring microplastics in marine sediments *Environ. Pollut.* 184 161–9

[36] Meliala L, Wibowo W A and Amalia J 2019 Satellite Derived Bathymetry on Shallow Reef Platform: A Preliminary Result from Semak Daun, Seribu Islands, Java Sea, Indonesia *KnE Eng.*

[37] Damar A, Colijn F, Hesse K-J and Wardiatno Y 2012 The Eutrophication states of Jakarta, Lampung and Semangka Bays: Nutrient and Phytoplankton Dynamics in Indonesia Tropical Waters *J. Trop. Biol. Conserv.* 9 61–81

[38] Baum G, Januar H I, Ferse S C A and Kunzmann A 2015 Local and Regional Impacts of Pollution on Coral Reefs along the Thousand Islands North of the Megacity Jakarta, Indonesia ed P A Todd *PLoS One* 10 e0138271

[39] Vila-Concejo A, Harris D L, Power H E, Shannon A M and Webster J M 2014 Sediment transport and mixing depth on a coral reef sand apron *Geomorphology* 222 143–50

[40] Saenuddin, Nurjaya I W, Bengen D G, Prartono T and Efendi I 2020 Hydrodynamics modeling with MIKE system in the Semak Daun Lagoon, Seribu Islands Indonesia *IOP Conf. Ser. Earth Environ. Sci.* 429 012010