Study on Macro and Microplastics Debris in Indonesian Water: Current Condition and Problem

2021

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Thesis in One Sentences

This PhD thesis addresses current knowledge gaps regarding the status of macro and microplastic litter in Indonesian water, by implement monitoring riverine plastics debris transport (Chapter 2 and 3), as well quantification and identification of microplastics in Indonesian marine ecosystem (Chapter 4, 5, 6, 7).

General overview of the thesis

In this thesis, the author presents the role of long-term field monitoring of marine debris in major Indonesian cities to provide crucial information for reducing land-derived debris into the oceans. From microplastics analysis indicates, microplastics are present in the water, the sediment, and the organism. Microplastics have pervaded relatively pristine environments, namely mangrove and coral reefs areas, which can interfere with commercial fisheries and aquaculture activities. The dominant macro and microplastic types found are those derived from single-use plastic.

Table of Content

List of Figures

List of Tables

List of Publication

Chapter 2:

1. **Cordova MR**, Nurhati IS. 2019. Major sources and seasonal variations of marine debris inflow from the Greater Jakarta area, Indonesia. Scientific Reports 9, 18730. https://doi.org/10.1038/s41598-019-55065-2 (IF:4.525)

Chapter 3:

2. **Cordova MR**, Nurhati IS, Riani E, Nurhasanah, Iswari, MY. 2021. Unprecedented plastic-made personal protective equipment (PPE) debris in river outlets into Jakarta Bay during COVID-19 pandemic. Chemosphere 268, 129360. https://doi.org/10.1016/j.chemosphere.2020.129360 (IF:5.778)

Chapter 4:

3. **Cordova MR**, Purwiyanto, AIS, Suteja~~,~~ Y. 2019. Abundance and characteristics of microplastics in the northern coastal waters of Surabaya, Indonesia. Marine Pollution Bulletin 142, 183-188. https://doi.org/10.1016/j.marpolbul.2019.03.040 (IF:4.409)

Chapter 5:

4. **Cordova MR**, Ulumuddin, YI, Purbonegoro T, Shiomoto, A. 2021. Characterization of microplastics in mangrove sediment of Muara Angke Wildlife Reserve, Indonesia. Marine Pollution Bulletin 163, 112012. https://doi.org/10.1016/j.marpolbul.2021.112012 (IF:4.409)

Chapter 6:

5. **Cordova MR**, Hadi TA, Prayuda B. 2018. Occurrence and abundance of microplastics in coral reef sediment: a case study in Sekotong, Lombok-Indonesia. Advance in Environmental Science Bioflux Vol 10 No. 1:23-29. http://dx.doi.org/10.5281/zenodo.1297719

Chapter 7:

6. **Cordova MR**, Riani E, Shiomoto A. 2020. Microplastics ingestion by blue panchax fish (*Aplocheilus* sp.) from Ciliwung Estuary, Jakarta, Indonesia. Marine Pollution Bulletin, 161, 111763. https://doi.org/https://doi.org/10.1016/j.marpolbul.2020.111763 (IF:4.049)

Chapter 1 Introduction and overview of the study

1.1 Background of the Study

Plastics are used in a myriad of purposes. The extensive use of plastics is reflected in the increase in production globally. Plastics are originated from organic and inorganic materials and characterized by their persistence, durability, versatility, density and relative affordability (Cordova, 2020). Therefore, plastics slowly degrade and persist within the environment, depending on the kind and morphology. However, the time plastics remain inside the surroundings is unknown (Syakti et al., 2017). Increase of plastics in production is evidenced by the frequent use and disposal of plastic (Eunomia, 2016). In the last decades, scientists and experts commenced publishing warnings of the ecological influences resulting from plastic litter within the environment. More significant consequences regarding plastic debris are being discovered. Nowadays, plastic debris particles may be found in almost every environment, particularly in marine ecosystem.

Plastic pollution in the sea is a new emerging field in marine environmental science. Plastic is a prevalent physical pollutant in all marine environment area. Plastic pollution was initially seen as an aesthetic problem (Galgani et al., 2013), but its potentially harmful impact on the marine environment has only very scarcely been researched so far. The proportion of plastic litter from anthropogenic activity (land-based and sea-based) that flows into the marine ecosystem may vary from 1.7 to 10% (Avio et al., 2017b; Jambeck et al., 2015a). Evidence suggests that the constant use and disposal of single-use plastic, particularly plastic packaging, is a dominant contributor to global ocean contamination (Eunomia, 2016; GESAMP, 2015). A higher number of marine plastic debris is generated by countries that have faster rates of economic growth and the rate of increase in population. As much as 12.7 million metric ton (MMT) of plastic litter entered the world oceans (Jambeck et al., 2015a). It has estimated that Indonesia considered as the world's second-largest plastic polluter to the ocean, with the amount of 0.48-1.29 MMT (Jambeck et al., 2015a). However, Indonesia lack of empirical and baseline data for marine plastics debris whereas Indonesia is the epicenter of the world's marine biodiversity (Veron, 1995), so that this data is essential for the proper management.

Marine plastics debris gives an impact, such as entanglement and ingestion, to over 46,000 individuals and 663 marine species (Global Environment Facility, 2012). High percentage of marine organism, such as 100% species of sea turtle, 67 % species of seals, 36 % species of seabirds and 31 % species of whales entangled by plastic was described (Kühn et al., 2015; Ryan, 2018). Entanglement, in most cases caused by discarded ropes, plastics bag, clothes, hard plastics or derelict fishing gears (Galgani et al., 2018; Raum-Suryan et al., 2009; Rodríguez et al., 2013; Stelfox et al., 2016; Thompson et al., 2009). Plastic entanglement can reduce movement, caused a direct wound, injury and skin infection, lead to amputation, interfere breathing, and non-direct mortality (Barreiros and Guerreiro, 2014; Barreiros and Raykov, 2014; Kühn et al., 2015; Laist, 1997; Moore et al., 2009; Orós et al., 2005; Wabnitz and Nichols, 2010). Ingestion of plastic frequently caused by misidentification plastic as a portion of food (Laist, 1997). However, plastic ingestion phenomenon is difficult to detect (Kühn et al., 2015). Recent study found that plastic ingestion were occur in all levels of aquatic trophic level, from producers, primary consumers to third consumer to top predator intermediates (de Sá et al., 2018; Nguyen et al., 2019). O'Hanlon et al. (2017) found that 74% of northeastern Atlantic seabird species ingest plastic. Moreover, de Sá et al. (2018) added fish and shellfish is the most commonly found plastic in the body (84%, from 130 studies). Considering fish and shellfish as seafood, they can be a source of microplastics contaminants from marine environments to humans (Bouwmeester et al., 2015). The smaller the size of the plastic, the more likely to be consumed by marine organisms.

After entering the aquatic environment, plastic will be exposed by UV, thermal oxidation, mechanic, or bacterial process, plastics can be degraded up to the microscopic size (Andrady, 2011; Wagner et al., 2014). This plastic has been known as microplastics. Besides the degraded plastic, microplastic sources may come from industrial pellets and microbeads included in a cosmetic product or textile material (Browne et al., 2011; Fendall and Sewell, 2009). The earliest publication of microplastics detected in 1971, in the Sargasso Sea, North Atlantic (Carpenter and Smith, 1972). However, according to previous studies, microplastic can be found in all marine ecosystem area such as in the coastal, coral reefs area, mangrove ecosystem, water column, and in the sediment of the sea bottom (Abayomi et al., 2017; Claessens et al., 2011; Cordova et al., 2019, 2018; Cordova and Hernawan, 2018; Cordova and Wahyudi, 2016; Mohamed Nor and Obbard, 2014; Moore et al., 2002; Ng and Obbard, 2006; Van Cauwenberghe et al., 2013). Microplastic has been observed in a wide range of marine organisms and can have an adverse effect, similar to larger plastic ingests by a marine organism (Browne et al., 2008; Cordova et al., 2020; Thompson et al., 2009; Wright et al., 2013). Besides that, microscopic plastic could also disrupt the endocrine and reproductive systems, preventing allocation and energy uptake, increase toxic load in smaller organisms, and disrupting brain function (Cedervall et al., 2012; Mattsson et al., 2015; Paul-Pont et al., 2016; Sussarellu et al., 2016; Von Moos et al., 2012; Wegner et al., 2012). The middle and long-term fate of macro and microplastics in the environment is basically not known as is its abundance and distribution in coastal ecosystems, particularly in Indonesia. Science is the key to getting the right alternative for processing debris.

1.2 Problem Statement

Large plastic litter in the aquatic environment worldwide, especially to the ocean, as the case, maybe new and significant challenges, besides climate change and ocean acidification in human history. In 2050, plastic is expected to exceed ocean fish stock by mass ratio (Ellen MacArthur Foundation, 2016; Jovanović, 2017), and there is the possibility of more microplastic than plankton in weight (Moore et al., 2001). The calculation is quite alarming, considering that in 2014, UNEP estimated that marine plastic litter causes $ 13 billion in global financial damage every year. In addition to financial problems, plastic will also cause health problems because plastic litter has the potential to transfer toxic elements to the food chain (Teuten et al., 2009). Moreover, plastic litter provides a mechanism for alien species to invade new habitats (Andrady, 2011). Plastic pollution is posing a serious threat to marine ecosystems that are projected to worsen without a strong policy intervention supported by high fidelity scientific data. As of now, only a few data are available on the volume of marine plastic wastes in Indonesia, which mostly are gathered by NGOs. Studies on macro and microplastic have emerged only recently, thus data from Indonesia are important to this global scientific effort. By fulfilling the database, will provide baseline data for improvement of the marine plastic waste management.

1.3 Objective of the Study

Research questions

The research was conducted to answer the following questions

1. What are the characteristics of land-derived marine debris in Greater Jakarta?
2. How the COVID-19 pandemic affects macroplastic debris in Greater Jakarta?
3. What are the characteristics of microplastic in the Indonesian shoreline (surface water and sediment)?
4. How was the distribution of microplastics from an anthropogenic area in shoreline to offshore?
5. What are the characteristics of microplastic that ingested by the Indonesian marine organism?

Hypothesis

This present study hypothesizes that plastic debris in the ocean is generated from land according to human activities, and single-use plastic is the dominant type of plastic waste found in Indonesian marine ecosystems, resulting in the dominant type of microplastic originating from single-use plastic-type.

General objectives

Monitoring data is key in formulating effective strategies to reduce land-derived debris. The aim of this research is to provide baseline data of plastics debris in Indonesian Sea, particularly to macro and microplastics. This data will be useful for managing marine litter, as has been stated in Indonesia's National Action Plan for combating marine plastic debris (Ocean Action #14387).

Specific objectives

The study will address the following objectives:

1. To provide *in situ* monitoring data on sources and inflow of debris from major Indonesian cities with high population density and river discharge as a baseline to better formulate environmental policies in reducing marine debris

   It is estimated that approximately 80% of marine debris in the coastal and open oceans originates from land-based human activities. The research results will highlight *in situ* data from the riverine area. To address this objective, the major sources and seasonal variations of marine debris across riverine pathways to the ocean, in the Greater Jakarta Area, as the highest population density in Indonesia was monitored. The amount of debris entering marine environments from river outlets in Jakarta due to the COVID-19 pandemic was also evaluated.

2. To investigate the abundance and distribution of microplastic from Indonesian marine ecosystem

   This will include a characterization of the plastic particles and their quantification in surface water, the sediment and that ingested by organism. Floating microplastics in surface water taken in northern coastal waters of Surabaya. The sediment sample was taken from mangrove area in Muara Angke wildlife reserve and at coral reefs area in Sekotong – Lombok. The microplastic ingests by fish was studied from Blue panchax fish (*Aplocheilus* sp.), an omnivorous and one of the most common fish in Indonesian fresh water and estuaries.

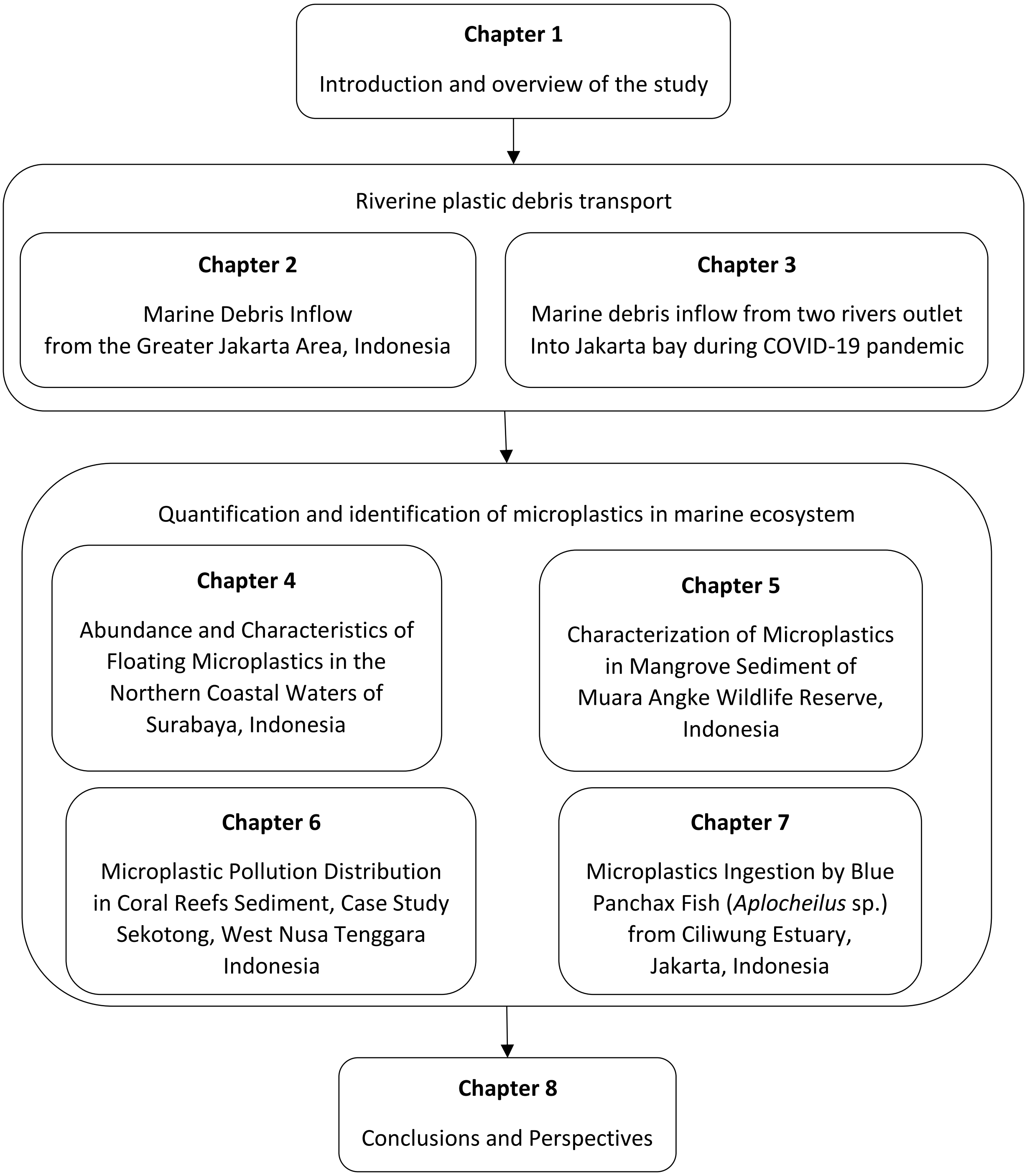

Figure 1. 1. Conceptual overview of the content of thesis

1.4 Structure of the Dissertation

This dissertation's structure is shown in Figure 1.1, and the rest of this dissertation is organized as follows. The dissertation consists of eight chapters. Chapter 1 provides the introduction and overview of the research, including a background of this research, problem identification, the objectives, and the structure of this dissertation.

Chapter 2 to chapter 7 will discuss two complementary research lines of this dissertation. Research line one will be explained in Chapter 2 and chapter 3. Chapter 4 until Chapter 6 clarify research line two.

Chapter 2 discussed riverine plastic debris transport, which is related to major sources and seasonal variations of marine debris inflow from the Greater Jakarta Area, Indonesia. Chapter 3 studied the impact of the COVID-19 pandemic on marine debris inflow from rover outlet into Jakarta Bay. After Chapter 2 and 3 are discussed, the study is divided into four parts of investigation regarding quantification and identification of microplastics in the marine ecosystem. Firstly, Chapter 4 analyzes floating microplastics in the northern coastal waters of Surabaya, Indonesia. Next, Chapter 5 and Chapter 6 examine microplastics in the sediment, namely microplastics extracted from sediment in mangrove area in Muara Angke Wildlife Reserve, Jakarta, and coral reefs sediment in Sekotong, West Nusa Tenggara. Chapter 7 investigates microplastic ingestion in first consumer organisms (Blue panchax Fish, *Aplocheilus* sp.) from Ciliwung Estuary, Jakarta, Indonesia. Chapter 8 summarizes the study's conclusion and discusses the remaining problems that should be focused on future research.

Chapter 2 and Chapter 3 presents riverine debris transport status, particularly land-derived litter in the river to the sea. Specifically, this chapter's study focused on the debris monitoring that primary sources and monthly variation of marine debris in river outlets into Jakarta Bay. Chapter 2 will discuss nine river outlets span across three municipalities in the Greater Jakarta area, which are Tangerang, Jakarta, and Bekasi. The rivers belong to several watersheds with varying population pressures. This chapter also provides an overview of the role of hydrometeorological variability on marine debris input from the Greater Jakarta area. The author discusses debris accumulation reported as items or weight daily from the three municipalities against rainfall records from nearby weather stations, as well as river discharge data collected in the field and from available sources. Chapter 3 provides updates on river debris monitoring data into Jakarta Bay to detect changes in land-to-sea waste leakages during the COVID-19 pandemic in March–April 2020.

The study has repeated the measurements in two out of the nine river outlets into Jakarta Bay. Due to the lockdown situation, it was impossible to replicate the nine river outlets' study. This chapter reported that monitoring data provides a valuable glimpse of river debris releases from the Greater Jakarta area to elucidate the urgency of improved medical waste management from domestic sources during the prolonged pandemic.

Chapter 4, 5, 6, and 7 evaluate abundance, quantification, distribution, and microplastic identification from the Indonesian marine ecosystem. These four chapters will examine the microplastics state in the water, the sediment, and the organism. Chapter 4 presents an analysis of floating microplastics in the coastal water that have quite dense population activities. Specifically, the study in this chapter focuses on the abundance, distribution, and characteristics of microplastics in the northern coastal waters of Surabaya, Indonesia. This section also discusses that microplastic abundance in the study area, associated with population density. Chapter 5 examines the state of microplastics in the sediment. This chapter investigated the current microplastic pollution conditions in Muara Angke

Wildlife Reserve, a remnant of extensive mangrove forests in Jakarta Bay. This section discusses microplastics concentration in the inner and outer layers of mangroves.

Chapter 6 discusses microplastics in the sediment from coral reefs area. Besides, this chapter provides an overview of microplastics concentration in Lombok, Indonesia, which is well known as part of coral triangle regions and one of the Indonesian Through Flow (ITF) locations. In particular, this chapter describes microplastics sources from anthropogenic activities on the mainland of Lombok and derived from ITF. Chapter 7 investigates microplastic ingestion at the second trophic level; in this case, choose blue panchax fish (*Aplocheilus* sp.) was chosen. The fish has a high potential risk of microplastics bioaccumulation due to its omnivorous feeding behavior. This chapter also discusses potential microplastic sources in the area, examines the relationship between microplastic concentration in fish and surface water, and discusses the impact of microplastic on fisheries.

Finally, Chapter 8 summarizes the study's conclusion and discusses the remaining problems that should be focused on future research.

Chapter 2 Marine Debris Inflow from the Greater Jakarta Area, Indonesia

2.1 Introduction

The presence of marine debris − a persistent, solid discarded waste in the marine environment, is pervasive in beaches, coastal waters and open oceans mainly due to land-based human activities. Marine debris pollutes the ocean from the water column to the seafloor (Cozar et al., 2014; Eriksen et al., 2014; Galafassi et al., 2019; Galgani et al., 2000) with detrimental consequences for marine ecosystems (López-López et al., 2018; Schuyler et al., 2016; Taylor et al., 2016) and the economy (Lee, 2015; Watkins et al., 2015). Currently, there are about 7,000-250,000 tons of plastic debris resides in the world oceans (Cozar et al., 2014; Eriksen et al., 2014; Galafassi et al., 2019). It has been estimated that approximately 80% of marine plastic debris originates from land-based human activities (Jambeck et al., 2015a; McKinsey & Company and Ocean Conservancy, 2015). The input of marine plastic debris from coastal areas varies substantially, depending on geographic factors related to humans (e.g., the coastal population, amount of waste generated, percentage of unmanaged waste (Jambeck et al., 2015a)) as well as the environment (e.g., river discharge that could deliver land-derived debris into the oceans (Jang et al., 2014; Lebreton et al., 2017)).

Indonesia's extensive coastline, large population and a high percentage of unmanaged waste are recipes for contributing significant amounts of land-derived debris into oceans. Studies have ranked Indonesia as the second-largest plastic waste contributor to the world's oceans after China (Jambeck et al., 2015a; Lebreton et al., 2017). The Indonesian archipelago covers a 99,093 km-long coastline (BIG, 2015). It is home to the world's fourth-largest population (255.46 million) where a majority (57%) resides in Java Island (BPS, 2014) with a concentration around the capital city of Jakarta. Indonesia produces about 200,000 tons of waste annually with only 64% reaching landfills while the rest ends up in the environment (Kementerian Lingkungan Hidup dan Kehutanan, 2018). Despite the reported impacts of debris on marine organisms and fisheries in Indonesia (Nash, 1992; Uneputty and Evans, 1997), long-term monitoring studies that characterize major sources and seasonal variations of debris release into marine ecosystems are lacking. Willoughby (1986) was the first to study the composition and distribution of debris in the Seribu Islands located offshore from Jakarta. Willoughby et al. (1997) also suggested that the island of Java may be the main source of marine debris in Indonesia. Besides being densely populated, Java Island has several rivers that serve as a conduit for land-derived debris such as plastics to reach the oceans (Syakti et al., 2017).

Under the United Nations' Sustainable Development Goals (SDGs), the SDG 14.1 aims to "by 2025, prevent and significantly reduce marine pollution of all kinds, particularly from land-based activities, including marine debris and nutrient pollution." In response, Indonesia has created a national action plan to combat marine plastic debris between 2017-2025 through several initiatives such as reducing land-derived plastic waste in rivers. To assess the effectiveness of ongoing initiatives in reducing marine plastic debris, it is important to conduct a spatially and temporally comprehensive marine debris monitoring in major Indonesian rivers.

Here, the first marine debris monitoring that characterized major sources and monthly variation of marine debris in nine river outlets into Jakarta Bay over the period June 2015 to June 2016 (13 months) was presented. The nine river outlets span across three municipalities in the Greater Jakarta area, which are Tangerang, Jakarta and Bekasi. The rivers belong to several watersheds with varying population pressures (Figure 2. 1). The Greater Jakarta area has a population of 30 million (BPS, 2014) and produces solid wastes of about 6,000-7,000 tons per day (Pemerintah Provinsi Daerah Khusus Ibukota Jakarta, 2016). With the assumption that about 10% make their ways to the oceans (Van Cauwenberghe et al., 2015), it is thus estimated that the amount of waste that enters Jakarta Bay may reach 600 to 700 tons daily. For this monitoring study, debris was collected, quantified by abundance into 6 types of debris (plastics, metal, glass, wood/paper, cloth/fiber, and others) (Lippiatt et al., 2013) and 19 categories of plastics (Kumar et al., 2016; Lippiatt et al., 2013) (Table 2. 1), and weighted (see Methods: Estimates of Marine and Plastic Debris Release). Estimation of debris release reported by abundance (items/day) and weight (tons/day) was compared from the three municipalities against rainfall records from nearby weather stations (BMKG, 2019) as well as river discharge data collected in the field (see Methods: Rainfall and River Discharge), to understand the role of hydrometeorological variability on marine debris release from the Greater Jakarta area.

2.2 Study Location

A monthly sampling of debris entering the Jakarta Bay from June 2015 to June 2016 at nine river outlets belonging to three municipalities in the Greater Jakarta area was conducted (Figure 2. 1). The nine river outlets are from west to east: Dadap River in Tangerang, Angke, Pluit, Ciliwung, Kali Item, Koja, Cilincing and Marunda Rivers in the capital city of Jakarta, and Bekasi River in Bekasi.

2.3 Sampling and Estimating Debris Release

Debris was collected from each river outlet using a 75 m-long and 1.5 m-deep net with a 5 cm mesh size. The river outlets have widths ranging between 18-64.9 m or under the length of this sampling net. The net was placed along the width of the river for 15 minutes and repeated for 3 to 6 times depending on river discharge. In this case, putting the net for more than 15 minutes at a time ran the risk of tearing the net from overfilling. The difference in sampling times between sites is accounted for in the subsequent calculation. The debris sampling was allocated about an hour at each site and sampled debris at the nine river outlets in 2-4 days.

The collected debris was categorized using a modified list of the NOAA Marine Debris Program datasheet (2013) to group the debris into six types: plastics, metal, glass, wood/paper, cloth/fiber, and others. Debris that was food waste, animal waste, too small or could not identified were put in the 'others' group. The plastics group was further classified into 19 categories (see Table 2. 1) as modified from existing categories (Kumar et al., 2016; Lippiatt et al., 2013). The collected debris was weighed on-site using a digital scale with a 0.1 g accuracy. Water from the debris was removed, therefore plastics, metal and glass debris were measured as dry weight; and semi-dry weight for wood/paper, cloth/fibre and other types of debris. The debris release was estimated at each river outlet by abundance and weight following the formula:

$$D = N \times \frac{1}{t} \times \frac{60\ minutes}{1\ hour} \times \frac{24\ hour}{1\ day}$$

where D is the debris release (the number of items or weight per day); N is the number (items) or weight (ton) of the collected debris, and t is observation time at each site (minutes).

The significance on the difference between monthly-averaged debris releases at the river outlets was tested using the Kruskal-Wallis test, followed by the Mann-Whitney pairwise and Dunn's post hoc tests using the Paleontological Statistics v.3 (PAST3) software.

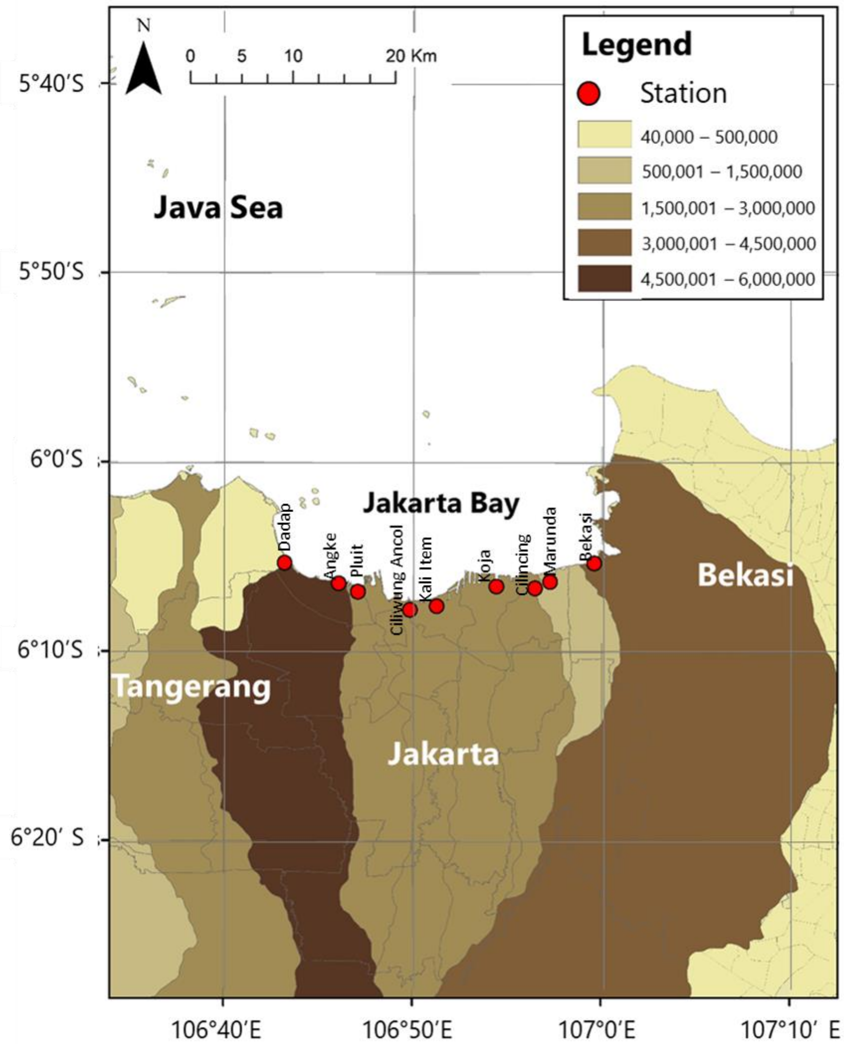

Figure 2. 1. The Greater Jakarta area showing the nine river outlets (circles) into Jakarta Bay that belong to several watersheds across Tangerang, Jakarta and Bekasi. The color gradient shows the population in the watersheds.

2.4 Rainfall and River Discharge

Rainfall data were acquired from four nearby meteorological stations of BMKG (Tanjung Priok, Halim, Jakarta, and Cengkareng station) and a station in Bogor as an upstream region for rivers flowing into Jakarta Bay (BMKG, 2019).

River River discharge (volume of flowing water through a river channel) data was collected in the field by factoring in the river area and velocity. The river area is defined by multiplying the width and depth of each river outlet. Three depth measurements were taken along the width of the river outlets. Water velocity was obtained using flow meters (Flowatch FL03 and Hydrobios 438115). River discharge measurement was carried out about 9 months out of the 13 months considering field conditions and excluding flooding events. The Dadap River has a mean discharge of 11.10 m^3/s (minimum and maximum values of 6.05-18.22 m^3/s), Angke is 16.10 (13.97-19.84) m^3/s, Pluit is 11.90 (8.50-14.84) m^3/s, Ciliwung is 39.70 (32.25-63.13) m^3/s, Kali Item is 4.10 (2.63-6.61) m^3/s, Koja is 17.20 (14.55-21.89) m^3/s, Cilincing is 11.00 (6.84-13.91) m^3/s, Marunda is 37.10 (32.94-42.83) m^3/s, and Bekasi is 20.90 (19.08-25.67) m^3/s.

Correlations between monthly debris release with rainfall variability and river discharge are examined using Microsoft Excel and PAST3 software.

2.5 Major Sources of Marine Debris into Jakarta Bay

This present study data reveal plastics as the single most dominant debris entering Jakarta Bay (Figure 2. 2), which accounted for 59% by abundance (57,668 ± 16,559 items) or 37% by weight (8.32 ± 2.44 tons) of the total collected debris over the period June 2015 to June 2016. In the municipality of Tangerang, plastics represented 71% by abundance (18,273 ± 5,292 items) or 28% by weight (2.15 ± 0.88 tons). In Jakarta, plastics were 57% by abundance (19,327 ± 4,767 items) or 50% by weight (3.56 ± 0.77 tons) of the total collected debris. And in Bekasi, plastics represented 53% by abundance (20,066 ± 10,074 items) or 33% by weight (2.61 ± 1.31 tons). Debris under the wood/paper type was the second most abundant after plastics, while debris under the type of cloth/fiber was also prominent vis-à-vis weight particularly in Bekasi.

Table 2. 1. Percentages of debris collected at the nine river outlets into Jakarta Bay across the municipalities of Tangerang, Jakarta and Bekasi under the 19 plastic categories by abundance and weight. The highest percentages at each municipality are noted with asterisks.

Plastics categories	**Tangerang**		**Jakarta**		**Bekasi**	
	Abundance (%)	**Weight (%)**	**Abundance (%)**	**Weight (%)**	**Abundance (%)**	**Weight (%)**
Ball, Tires, Balloons, Pieces	0.03	0.12	0.09	0.44	0.02	0.08
Plastic bottles	2.96	0.93	6.96	3.28	2.71	2.39
Plastic cups	6.67	1.66	9.17	0.88	7.30	1.47
Plastic cover	2.78	0.35	4.28	0.59	4.22	0.23
Plastic match, tips, cigarettes	4.45	0.38	4.24	0.41	1.93	3.07
Thin plastic wrap	9.64	3.30	7.24	1.26	12.49	1.22
Thick plastic wrap, sack	6.39	8.82	6.41	7.32	6.79	8.17
Rubber bands, rubber pieces	1.48	0.93	5.65	3.26	1.18	0.60
Masking tape, duct tape, plastic pieces	0.19	0.04	3.02	0.48	2.90	0.27
Medicine wrap	1.67	1.56	5.60	4.48	6.10	1.91
Straw, pieces	1.85	0.40	6.23	1.54	1.98	0.23
Food boxes, plastic utensil, etc.	9.26	0.28	5.80	0.38	6.62	0.05
Shoes, sandals, gloves, cuts	11.12	*33.60	4.85	9.15	5.09	4.86
Styrofoam	*31.69	1.48	*11.47	1.48	*25.45	2.13
Rope, fishing line, fishing rod	0.93	13.94	3.81	*25.54	3.56	7.99
Plastic rope/small net pieces	4.72	2.88	4.06	7.37	6.27	1.09
Pipe, hoses, pieces	0.93	16.51	3.72	12.62	1.41	*59.55
Another plastic fault	1.85	8.51	3.02	11.51	1.37	1.46
Wrap cosmetics, toiletries, etc.	1.39	4.31	4.37	8.01	2.62	3.24

Styrofoam represented the most abundant debris within the plastics category (Table 2. 1). By abundance, roughly 32%, 11% and 25% of the plastic debris found in Tangerang, Jakarta and Bekasi, respectively, were made of styrofoam. In the municipality of Tangerang, other abundant plastic items included shoes, sandals, gloves, cuts (11%), thin plastic wrap (10%), food boxes, plastic utensil, etc. (9%), and thick plastic wrap, sack (6%). Other abundant plastic items in Jakarta were plastic cups (9%), thin plastic wrap (7%), plastic bottles (7%) and thick plastic wrap, sack (6%). In Bekasi, thin plastic wrap (12%) and thick plastic wrap, sack (7%) were also abundant. With regards to weight, plastics belonging to the shoes, sandals, gloves, cuts category were dominant in Tangerang (34%), similarly for the rope, fishing line, fishing rod category in Jakarta (26%) and the pipe, hoses, pieces (60%) category in Bekasi.

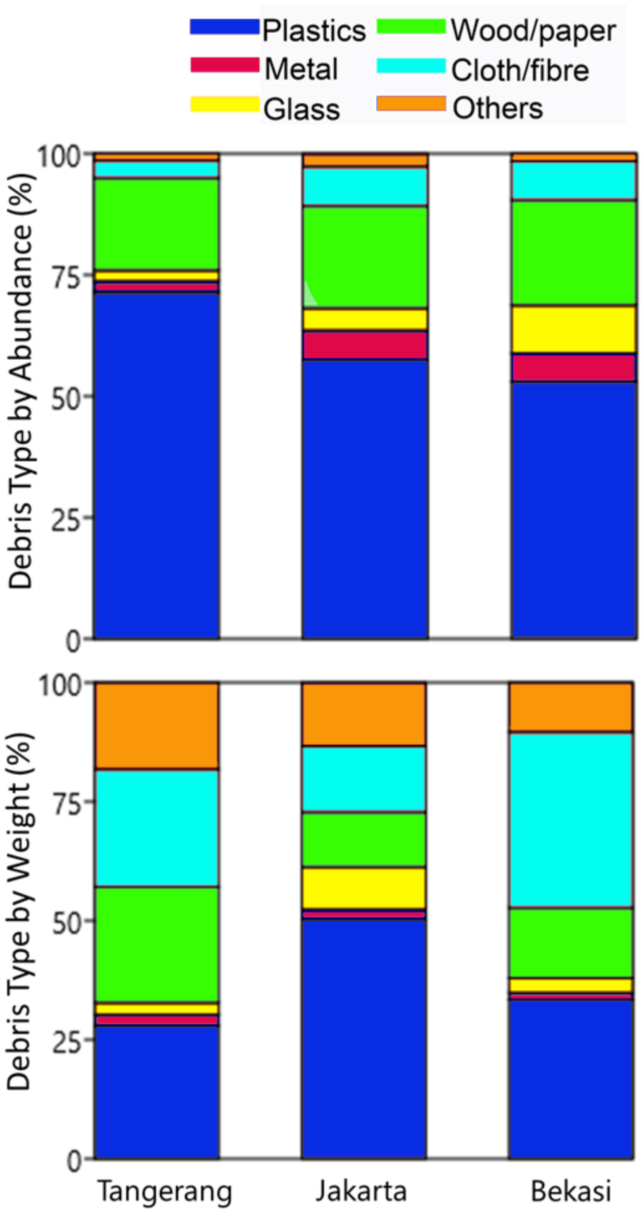

Figure 2. 2. Percentages of debris type by abundance (top) and weight (bottom) in the nine river outlets into Jakarta Bay across the municipalities of Tangerang, Jakarta and Bekasi over the period June 2015 to June 2016.

2.6 Estimates of Marine and Plastic Debris Release

The daily debris release was estimated at 97,098 ± 28,932 items or 23 ± 7.10 tons of debris into Jakarta Bay via the nine river outlets with significantly lower releases from individual river outlets in the capital city of Jakarta compared to its neighboring municipalities (*Figure 2. 3*). Over the period June 2015 to June 2016, Bekasi River had the highest debris release by abundance, while Dadap River in Tangerang contributed the most in term of weight. Bekasi River delivered 37,888 ± 19,022 items or 6.67 ± 2.20 tons of debris daily, whereas Dadap River delivered 25,584 ± 7,409 items or 7.92 ± 2.71 tons of debris daily into Jakarta Bay. When combined, the seven river outlets in Jakarta had a debris release of 33,626 ± 8,375 items or 7.07 ± 1.52 tons daily into Jakarta Bay.

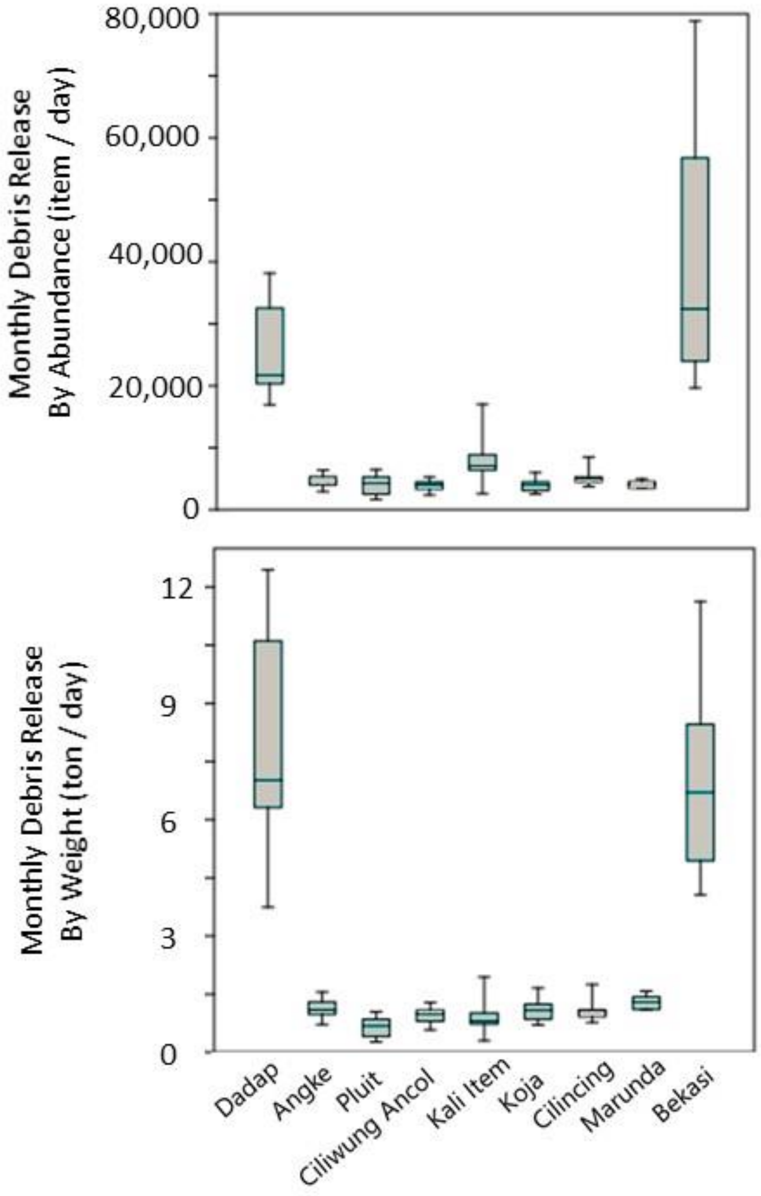

Figure 2. 3. Boxplot of debris release by abundance (top) and weight (bottom) from the nine river outlets in the Greater Jakarta area into Jakarta Bay. From west to east, the river outlets are: Dadap River in Tangerang, Angke to Marunda Rivers in Jakarta, and Bekasi River in Bekasi.

The possibility that the lower debris releases from individual river outlets in Jakarta may relate to any river discharge variation was investigated. The river outlets in the municipality of Jakarta did not have lower discharges compared to their counterparts in Tangerang and Bekasi during the study period. The river discharge data show values of 11.10 m^3/s in Tangerang, ranging between 4.10-39.70 m^3/s for river outlets in Jakarta, and 20.90 m^3/s in Bekasi (see Methods: Rainfall and River Discharge). It can be concluded that the Dadap River in Tangerang and Bekasi River indeed had higher densities of debris flowing into Jakarta Bay relative to river outlets in Jakarta.

Recognizing plastics as the dominant land-derived debris entering Jakarta Bay, daily plastic debris release was calculated at 57,668 ± 16,559 items or 8.32 ± 2.44 tons into Jakarta Bay. Bekasi River had the highest daily debris release both by abundance and weight (20,066 ± 10,074 items or 2.61 ± 1.31 tons) followed by Dadap River in Tangerang (19,327 ± 4,767 items or 2.15 ± 0.88 tons). Meanwhile, individual river outlets in the municipality of Jakarta had significantly lower debris release into Jakarta Bay that combined delivered 18,273 ± 5,292 items or 3.56 ± 0.77 tons of plastic debris daily during the study period.

Altogether, the monitoring data on major sources and monthly variations in the release of land-derived debris into Jakarta Bay inform stakeholders and policymakers to prioritize on particular types of debris, categories of plastics as well as months of the year to reduce land-derived debris from the Greater Jakarta area more effectively. Further, the data could help in assessing initiatives over the recent years in reducing land-derived debris through riverine channels.

This study findings showing plastics as the most dominant debris entering Jakarta Bay and styrofoam as the most abundant debris within the plastics category; convey the urgency of systematically reducing the use of plastics and styrofoam in the Greater Jakarta area. Indonesia produces 1.65 million tons of plastics yearly (Kementerian Perindustrian dan Perdagangan, 2013), in which a significant portion ends up in the environment (Kementerian Lingkungan Hidup dan Kehutanan, 2018). Regulations that ban the use of plastic bags in supermarkets in Tangerang, Jakarta and Bekasi have been in place since March 2019, however, single-use plastics are still used in traditional markets and online food delivery services. Styrofoam (polystyrene) is widely used for packaging foods, replacing the traditional use of organic food wraps such as banana leaves. To date, Bandung is the only Indonesian city that bans the use of styrofoam for packaging foods and beverages – an environmental initiative that the Greater Jakarta area needs to follow suit.

2.7 Monthly Variations of Marine Debris Releases

This year-long monitoring data revealed monthly variations in debris release into Jakarta Bay with significant correlations with rainfall amount (R^2 = 0.76 for abundance and 0.85 for weight, N=13, p<0.01; Figure 2. 4). The highest debris release into Jakarta Bay occurred at the peak of the rainy season in February 2016 (489.25 mm of rainfall) with a total of 129,643 items or 34.56 tons of debris daily, followed by December 2015 (302.43 mm of rainfall) with a total of 121,383 items or 30.41 tons of debris daily. The lowest debris release took place on September 2015 (64,371 items daily by abundance) and June 2015 (15.98 tons daily by weight), which occurred around July 2015 that experienced the lowest rainfall amount (0.75 mm). Moreover, there was no correlation between debris release and river discharge (R^2 = 0.02, N=9, p=0.75 for both by abundance and weight).

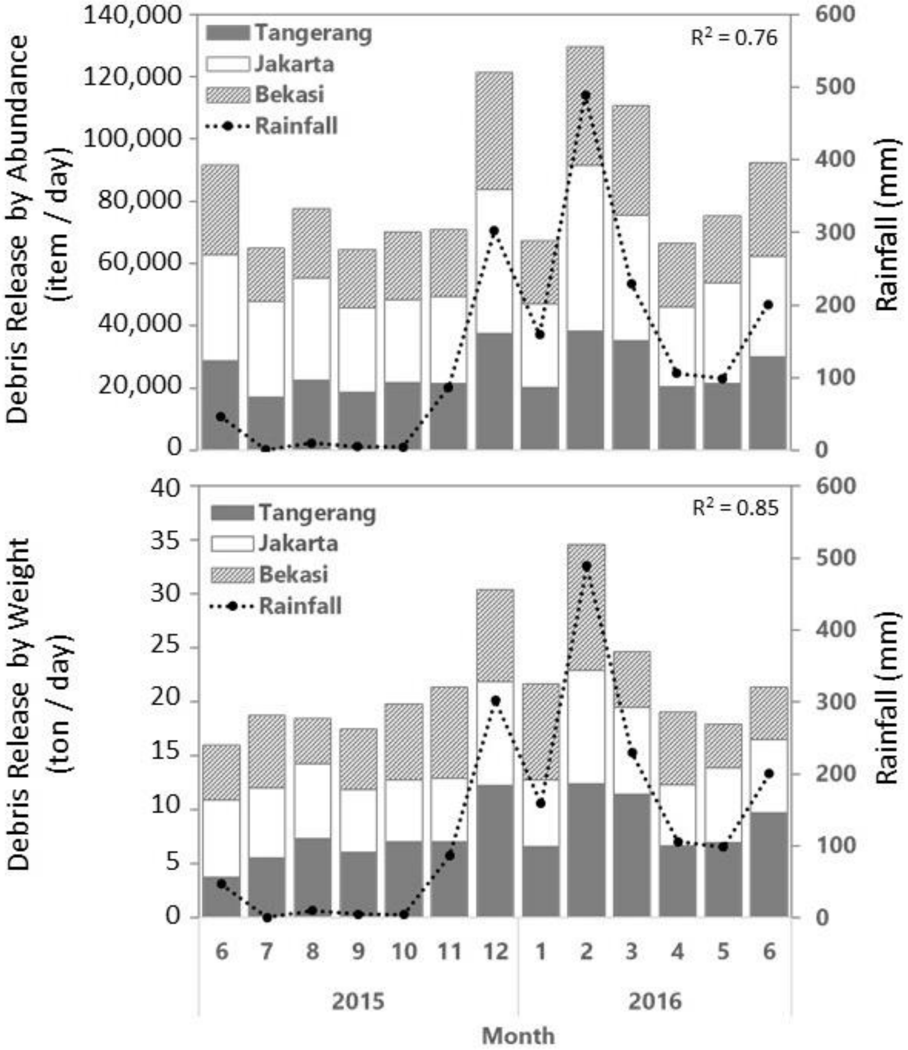

Figure 2. 4. The relationships between monthly rainfall and debris release by abundance (top) and weight (bottom) from the nine river outlets in the Greater Jakarta area into Jakarta Bay. The correlation coefficients are shown.

The significant correlation between marine debris releases and monthly rainfall variation echoes the need for more intensified river cleanup programs during the rainy season. High debris inputs entering the oceans via rivers during the rainy season have been documented in other cities worldwide (Cheung et al., 2018, 2016; Cho, 2005; Kementerian Perindustrian dan Perdagangan, 2013). In the case of the Greater Jakarta area, the higher debris releases may reflect not only a higher inflow of debris, but also a common practice of disposing more debris during the rainy season. Along with improved monitoring of marine debris release in major cities, this study reminds the importance of gathering environmental parameters such as rainfall, river discharge as well as water quality.

The lower debris releases from individual rivers in Jakarta compared to its neighboring municipalities during this study period cannot be explained by variations in river discharge, therefore it can be inferred that this may reflect improved river cleanup programs in the capital city in 2015. The formation of city cleaners known as the '*pasukan orange*' through Governor Regulation No. 169/2015 has been effective in cleaning up rivers in Jakarta. Albeit no available measurement of debris release before 2015, there were numerous visual documentations on markedly reduced debris in Jakarta's rivers during this time. Long-term marine debris monitoring using relatively simple methods as demonstrated in this research herein could provide crucial information for assessing the effectiveness of river cleanup programs in the recent years. Similar monitoring efforts could be repeated in the area, as well as replicated in other coastal cities particularly of the developing world to provide science-based information for policymakers to combat the marine debris issue.

The monthly monitoring of debris release into Jakarta Bay suggests a much lower value compared to existing global-scale model estimates of highly varying values. Adopting Jambeck et al. (2015)'s assumption of ~10.1% of mismanaged waste is plastic, it can be estimated that about 55.3-73.8 tons of plastic debris enter Jakarta Bay daily. By taking into account of waste management, population density and hydrological information, Lebreton et al. (Lebreton et al., 2017) estimated plastic inputs from five rivers into Jakarta Bay to be about ~130 tons of plastic waste per day. Whereas this *in situ* monitoring yields a considerably lower plastic debris release of 8.32 ± 2.44 tons daily that is about 8-16 times of the global-scale estimates. A simple explanation is that rivers in this study area have floating net booms in place that reduce debris releases, one of the factors that is not captured in the global-scale models. These findings do not negate the possibility of higher debris release in the field compared to the global-scale estimates in other cities considering varying levels of local commitment to reduce land-derived debris. When combined with global models of marine debris, field monitoring at river outlets serves as ground-truth data to refine the global-scale estimates by taking into account of local solutions that are in place to reduce marine debris.

2.8 Remarks of Chapter 2

This is the first study that characterized major sources and monthly variations of debris release at the nine river outlets in Indonesia's capital, the Greater Jakarta area. This work highlights the role of long-term field monitoring of marine debris in major Indonesian cities to provide crucial information for reducing land-derived debris into the oceans. Further works are needed to understand the sources, pathways and ecological impacts of marine debris using long-term field monitoring data.

The total debris flow to Jakarta Bay from nine river mouth was calculated at 8534.84 ton and 38,243,112 items for 13 months. This monitoring study confirms that plastics are the largest source of debris entering Jakarta Bay that accounts for 59.39% by abundance or 36.83% by weight of the total collected debris, with styrofoam being the most plastic found. Daily plastic debris inflow of 8.32 ± 2.44 tons from the Greater Jakarta area that is 8-16 times lower than existing global-scale estimates. Marine debris inflow into Jakarta Bay positively correlates with rainfall intensity over the study period. Across the sampling stations, the quantities of debris from the sampling stations in Tangerang and Bekasi are considerably more significant compared to the seven stations in Jakarta, which may be attributed to higher river discharge and population density along the watershed. Better waste management in Jakarta suspected that the litter entering the river in this area is lower than that of Tangerang and Bekasi.

A more accurate estimate of marine debris aids the effort to meet the Sustainable Development Goal 14.1 that is to prevent and significantly reduce marine debris from land-based activities by 2025. Steps have been taken to reduce marine debris in the Indonesian waters. Under the United Nations' SDGs, the Indonesian government has pledged to create a National Action Plan for combating marine plastic debris (Ocean Action #14387). The Coordinating Ministry of Maritime Affairs on Indonesia has identified 18 major cities in Indonesia including Jakarta that may contribute significantly to the marine debris problem and committed to allocate up to USD 1 billion annually to reduce 70% of plastics waste in the sea by 2025. Ultimately, public awareness instilled in the national curriculum and by the media, as well as technical solutions (e.g., waste management, recycling facilities, biodegradable plastic alternatives) are keys to accomplishing the goal.

Chapter 3 Marine Debris Inflow from Two Rivers Outlet into Jakarta bay during COVID-19 Pandemic

3.1 Introduction

The COVID-19 pandemic modifies our environmental imprints on the short and long terms. The novel SARS-CoV-2 coronavirus, which contracted more than 7.3 million people in 215 countries and territories by mid-June 2020 or mere three months after being declared a pandemic (World Health Organization, 2020a), have polarizing environmental repercussions. Air quality improved prominently in urban (He et al., 2020) and highly populated areas such as in Southeast Asia (Kanniah et al., 2020), and global greenhouse gas emissions such as atmospheric CO_2 dropped temporarily due to lockdown measures (Le Quéré et al., 2020; World Meteorological Organization, 2020). However, there have been increased demands for using plastic-made items such as surgical masks (Aragaw, 2020) that persist in the marine environments for centuries (Turner et al., 2020). Public health concerns associated with exposure to the coronavirus add challenges to mitigate macro and microplastics in the environments, existing recycling programs and medical waste management (Aragaw, 2020; Klemeš et al., 2020; Prata et al., 2020).

Increased plastic uses raise concerns over leakages into marine environments, particularly from coastal areas with high population and plastic waste emission but low recycling rates. The global annual land-to-ocean plastic waste may range from 1.15 to 12.7 million metric tonnes per year (Mt/y), in which Indonesia may contribute significantly to land-to-sea debris releases (Jambeck et al., 2015a; Lebreton et al., 2017). The capital city of Jakarta and perimeter areas that make up the Greater Jakarta area with about 30 million population have been the epicenter of COVID-19 in the country since the first confirmed cases on March 2, 2020. The nation-wide was urged to stay at home on March 16 which was followed by lockdown policies in Jakarta on April 10 and the Greater Jakarta area by April 18, 2020. The Bantar Gebang landfill, a major landfill serving the area, registered a declining trend in daily received waste from 9,346 tons (March 1–15) and 8,485 tons (March 16–April 9) to 6,342 tons (April 10–June 4) during the lockdown (DLH DKI Jakarta, 2020). However, the Indonesian Ministry for Environment and Forestry (2020a) projected increased medical waste by 30% during the pandemic. A consumer survey showed increased online purchases, particularly PPEs from 4.6% to 34.6%, with 96% of online packaging contained plastics in the Greater Jakarta area (Nurhati et al., 2020). Despite numerous visual accounts of increased PPE waste reported by environmental groups and the media, there had been no comparative quantification of wastes in the environments before and during the pandemic.

This research provided an update on river debris monitoring data into Jakarta Bay to detect changes in land-to-sea waste leakages during the COVID-19 pandemic. Based on *in situ* monitoring data, Chapter 2 characterized major sources and monthly variations of river debris releases from nine river outlets into Jakarta Bay between June 2015 – June 2016. Plastics emerged as the most common debris, representing 59% (abundance) or 37% (weight) of the total collected debris (Cordova and Nurhati 2019). The study reported a daily plastic debris release of 8.32 ± 2.44 tons from the Greater Jakarta area or 8-16 times less than global-scale model estimates, highlighting the importance of *in situ* monitoring (Jambeck et al., 2015a; Lebreton et al., 2017). Here, the measurements were repeated in two out of the nine river outlets into Jakarta Bay in March–April 2020 to assess the amount of debris entering marine environments from river outlets in Jakarta due to the COVID-19 pandemic. Due to the lockdown situation, it was impossible to repeat the study in all the nine river outlets. Nevertheless, the updated monitoring data provides a valuable glimpse of river debris releases from the Greater Jakarta area to elucidate the urgency of improved medical waste management from domestic sources during the prolonged pandemic.

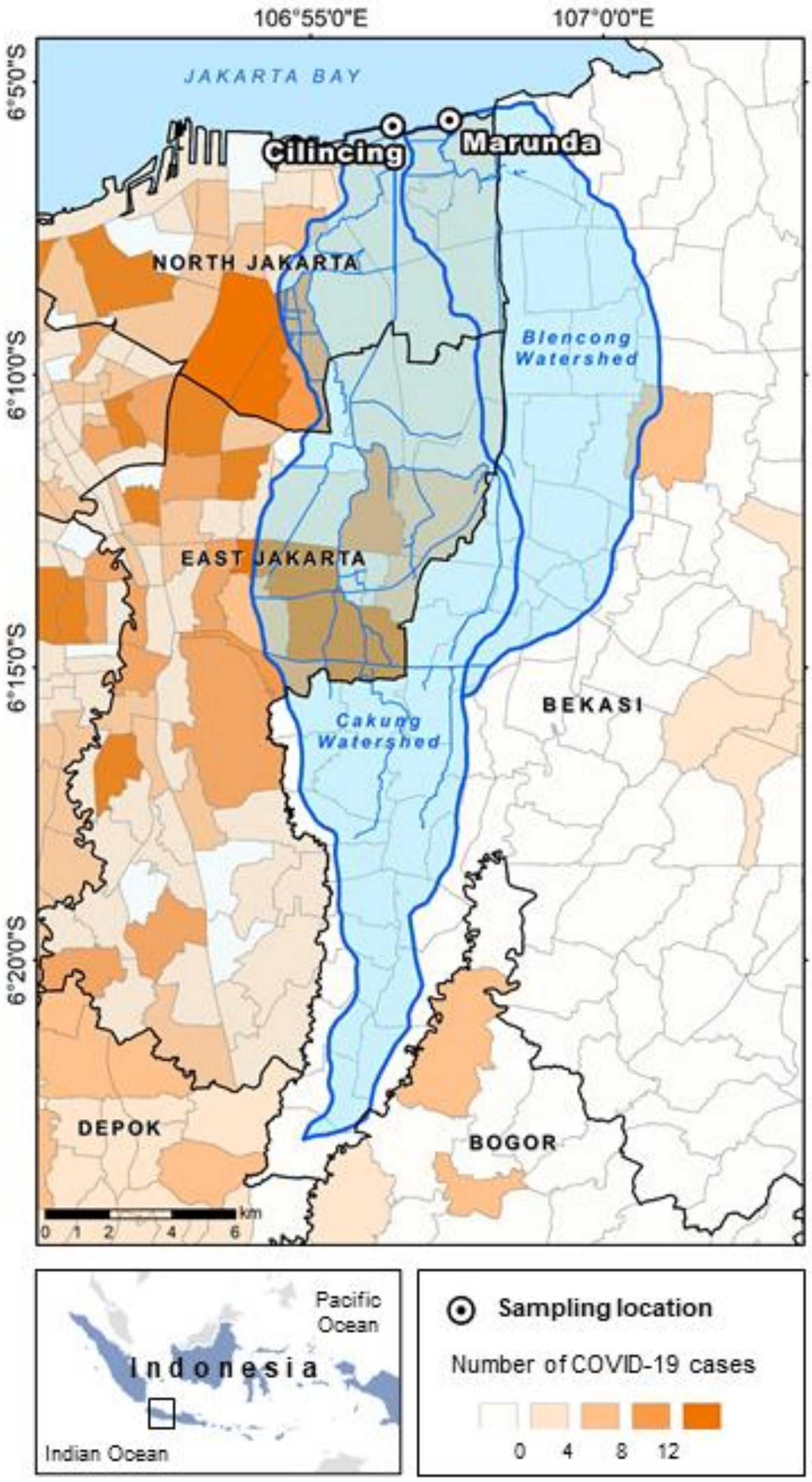

Figure 3. 1. Study sites at the Cilincing and Marunda river outlets into Jakarta Bay.

3.2 Sampling, Collection and Estimating Debris Release

Debris was collected from each river outlet using a 75 m-long and 1.5 m-deep net with a 5 cm mesh size. The river outlets have widths r

The debris was characterized every ~10 days (March 19, March 28, April 7 and April 15, 2020) at two river outlets into Jakarta Bay – the Cilincing and Marunda Rivers (Figure 3. 1). Following the method in Chapter 2, a 75 m-long, 1.5 m-deep net with a 5 cm mesh size were placed across each river during low tides for 15 minutes for four replicates. The debris was grouped into 7 types (plastic, metal, glass, wood/paper, cloth/fiber, PPE and others) and 47 categories (Table 2. 1). Cilincing River is 44.97 km long within the Cakung watershed of a 142.85 km^2 area with more than 2.75 million population. Marunda River is 28.88 km long within the Blencong watershed with an 80.81 km^2 area and more than 1.3 million population. The Cilincing and Marunda Rivers have river discharges of 6.84–13.91 m^3/s and 32.94–42.83 m^3/s, respectively (Cordova and Nurhati, 2019). The watersheds belong to Jakarta and Bekasi municipalities. As of April 15, 2020, there were 214 confirmed COVID-19 cases in the Cakung and Blencong watersheds (Pemprov DKI Jakarta, 2020).

The collected river debris was dried, quantified by abundance and weighted on-site using a Harnic Heles HL-340 digital scale with a maximum capacity of 5 kg and an 0.1 g accuracy. Daily debris releases were estimated following:

$$D = N \times \frac{1}{t} \times \frac{60\ minutes}{1\ hour} \times \frac{24\ hour}{1\ day}$$

where D is land-derived debris accumulation (items or ton per day); n is item (number) or weight (ton) of debris observed, and t is observation time (debris per day).

3.3 Debris Release Before and During Pandemic

This present study monitoring data showed slight increases in the abundance of river debris and a decreased debris weight compared to the 2016 baseline data of the same months and locations, hinting at the shifted composition of river debris towards lighter debris (Figure 3.2). The abundance of daily debris releases increased by 5% at both sites, from 9,312 items in March 2016 to 9,768 items in March 2020 and from 9,696 items in April 2016 to 10,176 items per in April 2020. At both sites, daily debris releases by weight decreased by 23% in March from 2.30 to 1.78 tons daily, and by 28% in April from 2.19 to 1.58 tons daily. More specifically, the observed increased abundance but decreased weight of river debris was more pronounced at Marunda. The abundance of daily debris releases increased by 2% (March) and 4% (April) at Cilincing, and by 9% (March) and 6% (April) at Marunda. The weight of daily debris releases decreased by 9% (March) and 21% (April) at Cilincing, and by 32% (March) and 34% (April) at Marunda. It is worth noting the consistent observations of reduced plastic debris by weight at the Bantar Gebang landfill and riverine environments in the Greater Jakarta area.

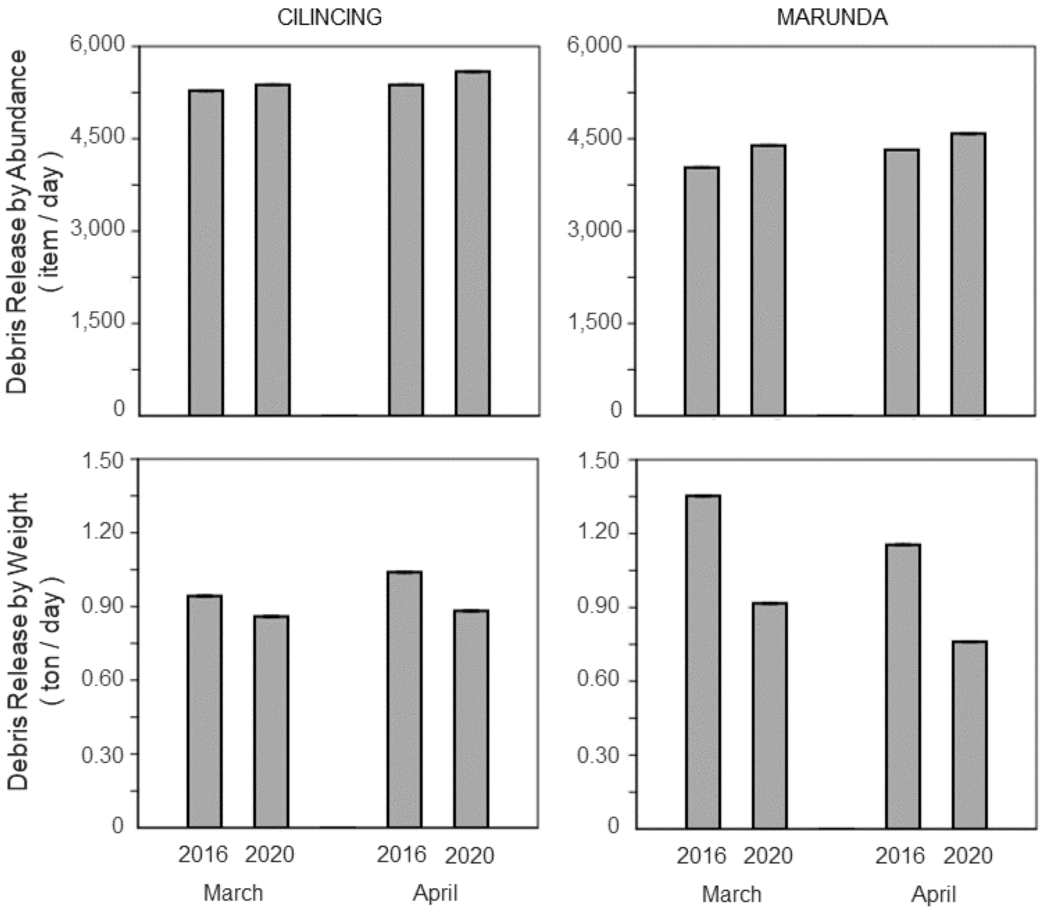

Figure 3. 2. Debris releases from the Cilincing and Marunda Rivers to Jakarta Bay before (March-April 2016) and during the COVID-19 pandemic (March-April 2020).

Plastics remained the dominant debris entering the Jakarta Bay (Figure 3.3). Plastics accounted for 43-47% by abundance or 50-62% by weight of the collected river debris in March−April 2020. Debris under the wood/paper category represented the second most abundant (16-19%) river debris after plastics. In terms of weight, this research result data showed increased glass waste at Cilincing that accounted for 9-12% of the river debris during the study period. Within plastics, styrofoam was dominant at Cilincing (8-15% by abundance), while rope and fishing rod were prevalent (22-34% by weight) at Marunda (Table 3. 1). Meanwhile, policymakers have devised regulations to reduce plastic waste, their implementation and enforcement face challenges (Cordova et al., 2020). For instance, Jakarta has banned single-use plastic bags since July 2020. While many supermarkets and chain restaurants have complied, the use of plastic bags is still commonly by small businesses. At the national level, the Ministry of Environment and Forestry has outlined a waste reduction roadmap by manufacturers that includes the prohibition on using single-use plastic from polystyrene, polypropylene, and high-density and low-density polyethylene by 2030 through the ministerial regulation number 75/2019 (Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia, 2019). Local programs and economic incentives to reduce land-to-sea leakage of styrofoam waste with no value to the waste collector community are still needed.

Table 3. 1. Percentages of river debris by abundance and weight at Cilincing and Marunda River mouths before (March–April 2016) and during pandemic (March–April 2020) under the 7 types and 47 categories. The highest values are shown in bold.

	CILINCING								MARUNDA							
	By Abundance (%)				By Weight (%)				By Abundance (%)				By Weight (%)			
	Mar 2016	Mar 2020	Apr 2016	Apr 2020	Mar 2016	Mar 2020	Apr 2016	Apr 2020	Mar 2016	Mar 2020	Apr 2016	Apr 2020	Mar 2016	Mar 2020	Apr 2016	Apr 2020
A. PLASTIC																
Ball, tire, balloon	0.45	0.45	0.89	0.43	0.50	0.29	0.16	0.3	1.19	1.09	0.56	1.05	1.40	1.08	0.10	0.62
Plastic bottle	7.27	5.36	3.57	3.43	2.48	2.27	2.27	1.69	5.36	3.28	1.67	3.14	1.60	1.73	1.51	2.22
Plastic cup	7.27	3.57	3.57	3.43	0.72	0.53	0.38	0.5	5.36	2.73	1.67	2.62	0.58	0.68	0.91	1.23
Plastic cover	0.91	0.89	1.79	0.86	6.18	4.19	1.98	1.56	1.19	1.09	1.11	1.57	1.25	1.14	1.80	2.33
Plastic match, tip, cigarette	0.91	2.68	0.89	6.87	0.01	0.18	0.01	0.28	1.79	3.28	1.11	4.71	0.64	3.62	1.89	4.02
Thin plastic wrap	4.55	2.68	4.46	3.43	2.92	8.24	2.72	**8.24**	1.79	3.28	2.78	2.62	0.25	0.61	0.61	0.58
Thick plastic wrap, sack	0.91	1.79	2.68	1.72	6.62	3.05	3.11	7.21	2.98	3.28	3.33	2.62	0.94	2.12	2.04	2.29
Rubber band, rubber piece	–	–	1.79	0.86	–	–	0.05	–	1.19	–	1.11	1.57	0.07	–	0.15	0.04
Masking tape, duct tape, plastic piece	0.91	0.89	0.89	0.86	0.30	0.51	0.06	0.87	1.19	1.09	1.11	1.05	0.03	0.03	0.08	0.04
Medicine wrap	1.82	3.57	1.79	6.87	0.24	0.04	0.04	0.25	–	4.92	1.11	**7.33**	–	0.15	0.02	0.30
Straw	4.55	1.79	6.25	2.58	0.06	0.04	0.07	0.03	3.57	1.64	4.44	1.05	0.11	0.09	0.15	0.06
Food boxes, plastic utensil	2.73	–	2.68	2.58	6.55	–	5.76	1.54	1.19	1.64	1.67	1.57	0.42	0.14	0.31	1.22
Shoes, sandal, glove	2.73	2.68	2.68	1.72	10.31	6.14	2.14	5.00	2.98	1.09	3.33	1.05	5.83	4.05	7.45	3.11
Styrofoam	**14.55**	**10.71**	**12.50**	**8.15**	1.31	0.94	0.46	0.55	**10.12**	**6.56**	**13.33**	**6.28**	0.22	0.34	0.51	0.60
Rope, fishing line, fishing rod	6.36	1.79	3.57	0.86	**15.03**	4.64	**9.77**	1.44	4.76	2.73	6.67	1.57	**33.83**	**28.92**	**25.25**	**22.36**
Plastic rope/small net piece	1.82	0.89	0.89	0.86	6.69	4.35	7.97	3.06	1.79	1.09	2.78	1.05	15.50	14.4	17.25	4.36
Pipe, hose, piece	0.91	0.89	0.89	0.86	3.63	3.57	2.90	4.48	1.19	1.09	–	–	2.35	2.90	5.25	3.36
Other plastic fault	–	0.89	4.46	0.86	–	**8.54**	7.03	4.24	1.79	1.09	–	1.05	6.13	11.09	5.61	5.87
Wrap cosmetic, toiletry, etc.	0.91	0.89	0.89	2.58	1.81	0.36	0.26	2.57	1.19	1.64	2.78	2.62	1.76	1.28	1.16	1.65
B. METAL																
Can	1.82	4.46	0.89	2.58	1.85	5.82	2.39	4.05	1.79	3.28	2.78	4.19	0.42	1.44	0.72	1.98
Iron, nail, similar iron fracture	1.82	0.89	1.79	–	0.74	0.49	1.83	–	1.79	–	2.78	1.05	0.24	–	1.53	0.19
Metal bottle cap	0.91	1.79	0.89	2.58	0.82	0.76	0.63	1.82	1.19	3.28	1.11	3.14	0.21	0.72	0.36	1.09

	CILINCING								MARUNDA							
	By Abundance (%)				By Weight (%)				By Abundance (%)				By Weight (%)			
	Mar 2016	Mar 2020	Apr 2016	Apr 2020	Mar 2016	Mar 2020	Apr 2016	Apr 2020	Mar 2016	Mar 2020	Apr 2016	Apr 2020	Mar 2016	Mar 2020	Apr 2016	Apr 2020
Other iron material	0.91	0.89	2.68	–	1.21	2.33	1.57	–	1.19	–	1.67	–	0.48	–	3.59	–
C. GLASS																
Glass bottle	0.91	2.68	0.89	1.72	0.76	6.16	1.69	5.67	1.79	1.09	1.67	1.57	2.22	1.69	1.16	0.97
Glass, broken glass	0.91	1.79	0.89	1.72	3.97	3.56	1.66	3.56	1.79	4.37	1.67	1.57	3.24	1.26	2.41	2.48
Lamp	1.82	2.68	0.89	1.72	0.79	2.82	2.55	5.00	1.79	1.09	1.67	1.05	0.88	0.12	0.40	1.19
Other glass material	0.91	0.89	0.89	0.86	2.85	1.87	0.85	4.22	2.98	1.64	2.78	1.05	0.38	0.11	0.20	0.26
D. WOOD / PAPER																
Pack of cigarette	0.91	1.79	0.89	0.86	0.35	1.50	0.44	0.36	–	1.09	1.11	1.05	–	0.33	0.22	0.29
Processed or broken wood	10.00	4.46	11.61	5.15	10.26	3.71	12.86	3.90	**12.50**	**8.20**	**16.11**	4.19	7.20	2.83	6.65	3.95
Wooden lighter	0.91	0.89	1.79	0.86	0.01	0.02	–	–	1.19	–	1.11	–	0.02	–	0.01	–
Clove cigarette butt	4.55	4.46	3.57	6.01	0.04	0.04	0.02	0.04	4.76	7.65	2.78	6.28	0.03	0.06	0.04	0.11
Cardboard, paper, newspaper, tissue, other pieces of paper	3.64	6.25	2.68	3.43	0.52	0.98	0.67	2.23	1.79	3.28	1.11	3.14	0.66	0.93	0.12	2.79
E. CLOTH / FIBER																
Clothes	1.82	0.89	1.79	0.86	4.63	3.89	**15.89**	2.16	1.79	–	2.78	2.62	1.68	–	3.91	2.43
Diapers and sanitary pads	3.64	2.68	2.68	0.86	1.93	1.54	3.20	1.32	6.55	1.09	1.11	1.57	2.65	1.21	0.70	2.08
Clothing / fabric material	1.82	2.68	1.79	–	0.20	0.83	0.58	–	1.79	2.73	1.67	–	3.38	–	1.70	1.27
F. PERSONAL PROTECTION EQUIPMENT																
Cotton mask	–	0.89	–	0.86	–	0.97	–	1.96	–	1.09	–	1.05	–	0.84	–	1.38
Sponge mask	–	2.68	–	3.43	–	1.36	–	2.03	–	2.73	–	3.14	–	1.28	–	0.74
Medical mask (surgical, N95)	–	5.36	–	6.87	–	1.94	–	2.16	–	4.92	–	6.28	–	2.29	–	2.28
Medical glove	–	2.68	–	1.72	–	1.40	–	0.70	–	2.73	–	1.57	–	1.22	–	2.79
Hazard suit material	–	0.89	–	0.86	–	4.01	–	3.70	–	1.09	–	1.05	–	4.63	–	5.40
Raincoat (used as hazard suit)	–	1.79	–	2.58	–	5.55	–	6.48	–	1.64	–	2.62	–	3.13	–	3.23
Face shield	–	–	–	0.86	–	–	–	0.56	–	–	–	1.05	–	1.49	–	0.52
G. OTHERS																

	CILINCING								MARUNDA							
	By Abundance (%)				By Weight (%)				By Abundance (%)				By Weight (%)			
	Mar 2016	Mar 2020	Apr 2016	Apr 2020	Mar 2016	Mar 2020	Apr 2016	Apr 2020	Mar 2016	Mar 2020	Apr 2016	Apr 2020	Mar 2016	Mar 2020	Apr 2016	Apr 2020
Leftover food	0.91	0.45	2.68	0.43	0.27	0.01	1.17	2.26	1.19	1.09	1.11	2.62	0.58	0.05	0.45	3.07
Dead animal	0.45	–	0.89	0.86	2.55	–	3.79	1.49	1.19	–	1.11	1.05	1.98	–	3.26	3.10
Contraception	0.91	0.89	0.89	1.72	0.06	0.01	0.09	0.10	1.19	1.09	1.11	1.57	–	–	0.07	–
Battery	–	0.89	0.89	0.86	0.25	0.32	0.40	0.40	–	1.09	1.11	1.05	0.84	–	0.22	0.15
Other waste	0.91	0.89	0.89	–	0.56	0.27	0.54	–	1.19	1.09	1.11	–	–	–	0.24	–

3.4 Unprecedented Presences of Personal Protection Equipment

This study data confirmed an unprecedented presence and variety of PPEs during the pandemic. PPEs, which were not present before the pandemic, represented 16% of the collected river debris or 780 ± 138 items (696 ± 102 items daily in March and 864 ± 136 items daily in April 2020). Medical waste found in the river outlets has become more diverse during the pandemic, adding to the types of medical waste previously found (i.e., medical wrap, contraception). In March−April 2020, seven more types of medical waste were found, which were cotton mask, sponge mask, medical mask (surgical, N95), medical gloves, hazard suit material, face shield and raincoat as a substitute for hazard suit (Table 3. 1).

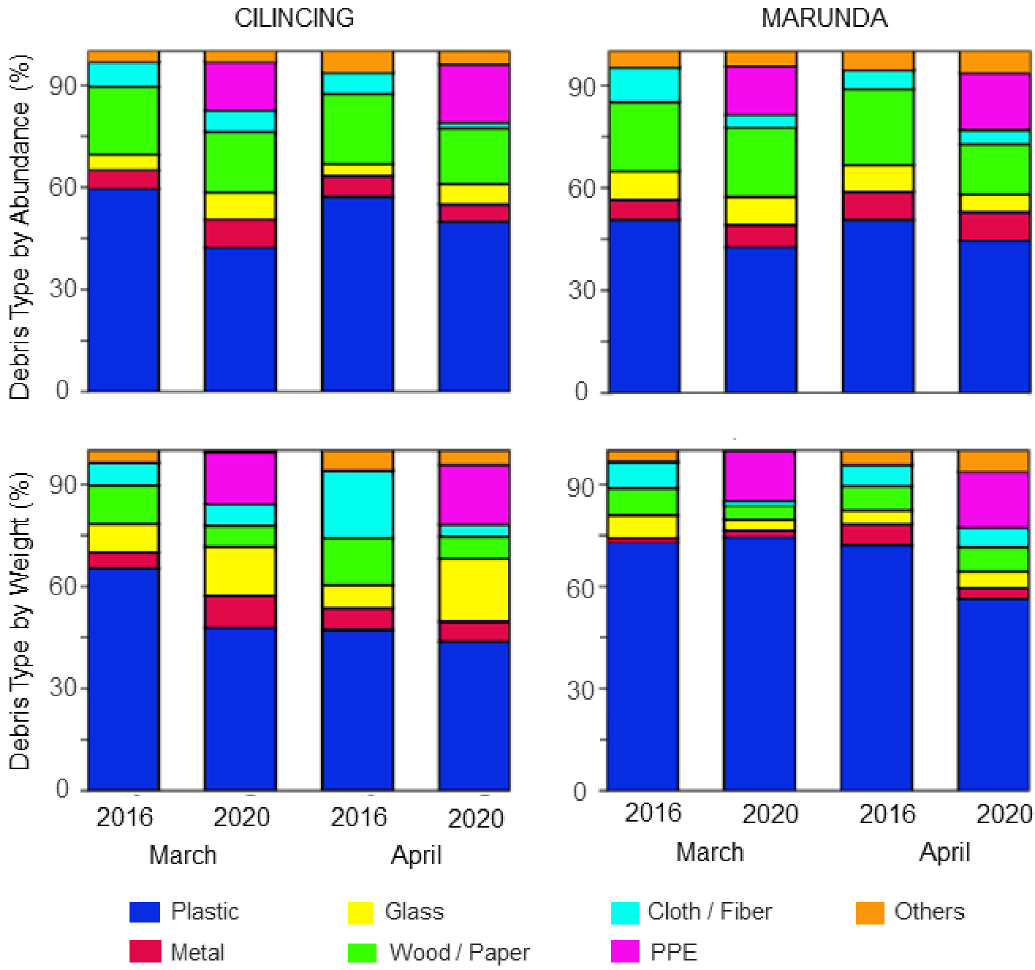

Figure 3. 3. Percentages of debris type by abundance (top) and weight (bottom) from the Cilincing (left panel) and Marunda (right panel) Rivers before (March-April 2016) and during the COVID-19 pandemic (March-April 2020).

This present study indicated that masks (cotton, sponge and medical), which represented 9.83% of the total debris or 492 ± 99 items daily, dominated the PPEs. During this monitoring period, there was an increase in the abundance of mask debris at the two river mouths from 432 ± 68 items per day in March to 552 ± 102 items per day in April 2020. Furthermore, the relationship between the number of COVID-19 cases in the watersheds and the unprecedented presence of PPEs at the river outlets was assessed and found moderate correlations ($R^2 = 0.50$ in Marunda and $R^2 = 0.49$ in Cilincing, statistically insignificant at a 90% confidence interval).

Increased lightweight plastic-made PPEs that could travel the distance in the environments with health and environmental concerns highlight the need for managing domestic PPE wastes, which differs from sources from regulated medical facilities (Vanapalli et al., 2021). The chemical composition of plastic-made PPEs may consist of polypropylene, polyurethane, polyacrylonitrile, polystyrene, polycarbonate, polyethylene or polyester (Potluri and Needham, 2005). Prior to the pandemic, the Indonesian Health Research and Development Agency (Badan Penelitian dan Pengembangan Kesehatan, 2019) reported an increase in managed medical waste that resulted in reduced medical waste leakages into the environments from 3.9% to 1.5%. Nevertheless, the surge of waste generated from medical facilities during the pandemic would require adapting to the current waste level (Klemeš et al., 2020). The Indonesian Ministry of Environment and Forestry has provided guidance for managing medical waste from hospitals and domestic sources (Kementerian Lingkungan Hidup dan Kehutanan, 2020b, 2020c; World Health Organization, 2020b), and the use of reusable cloth masks for non-medical personnel have been encouraged to ensure the availability of medical-grade PPEs for medical workers.

Moving forward, the pandemic could serve as a foundation for improved waste management and minimize leakages to environments in the long-term. Plastics, including styrofoam and PPE, are sources of microplastics into the environments as they degrade by mechanical and photodegradation processes (Aragaw, 2020; Yousif and Haddad, 2013) and carriers of toxic dan carcinogenic pollutants within ecosystems (Graca et al., 2014; National Research Council, 2014; Thaysen et al., 2018).

Upon the end of the COVID-19 pandemic, there will be time to consider the suitability of existing systems and the possibility of examining alternatives. Substitute single-use PPEs with reusable would reduce the amount of waste, although new problems will arise due to the use of chemicals for cleaning and sterilization. River cleanups using floating net booms and by the public facility worker force have been fruitful but unsustainable as they are remedial solutions. Moreover, reinforcing critical research thinking to provide environmentally friendly alternative solutions while enhancing an efficient waste management system can help find a sustainable solution to PPEs and plastic pollution. More than ever, active community participation is key in reducing single-use plastics and reducing leakages into the environments during the pandemic.

3.5 Remarks of Chapter 3

Global health concerns associated with exposure to the COVID-19 virus and the increased reliance on plastic-made PPEs are among the most relevant environmental issues facing our societies today. This study presents data on riverine debris releases into Jakarta Bay in March and April 2020 during the COVID-19 pandemic when the stay at home and lockdown policies were in place. This monitoring data suggest a slight 5% increase in the number of debris releases with changes in the composition of riverine debris towards lighter debris, thus the 23-28% decrease in the weight of debris releases during the pandemic relative to 2016. The observed PPEs, including medical masks, gloves, hazard suits, raincoats and face shields, are unprecedented and accounted for 16% of the collected riverine debris during the study period by abundance and weight. Plastics remain as the dominant riverine debris at 46% by abundance and 57% by weight. Altogether, the study provides evidence of increased PPEs in riverine debris as resulted from the COVID-19 pandemic by taking advantage of available *in situ* monitoring data before and during the pandemic in Jakarta, Indonesia.

Future works are needed to monitor plastic waste during and after the pandemic to identify effective waste solutions. It is uncertain how the medical waste level would change as the world enters the current phase of “new normal” when the use of reusable cloth mask for non-medical workers would help reduce single-use plastics in the environment. One critical question is how the emergency measures introduced to contain the outbreak could lead to long-term waste management solutions. The pandemic could serve as a foundation for improved waste management and minimize leakages to environments considering the compounded health and ecological risks.

Chapter 4 Abundance and Characteristics of Floating Microplastics in the Northern Coastal Waters of Surabaya, Indonesia

4.1 Introduction

Microplastic is a fragment of plastic waste with a size of 300 µm to 5 mm. The presence of microplastics in water is due to the high use of plastics or materials containing plastics by humans. Boucher and Friot (2017) categorized microplastics into two types: primary and secondary microplastics. Primary microplastics are micron-sized plastics that come from microbeads (<1 mm) commonly used in cleaning agents and cosmetics and are obtained as fragments by washing clothes (Wu et al., 2016). Secondary microplastics are the ones originating from fragmentation and plastic size reduction in marine environments (Boucher and Friot, 2017). Costa and Barletta (2015) also explained that microplastics were discovered in water in the 1970s, which indicates their existence since several years. Therefore, the researchers paid special attention to the presence of microplastic in waters because microplastic is rapidly consumed by organisms such as zooplankton(Cole et al., 2013), which is then transferred to the higher trophic level (Setälä et al., 2014). Microplastic distribution is scattered and has been found in both waters and sediments, with diverse types and abundances. Cincinelli et al. (2017) found microplastics ranging from 0.0032 to 1.18 particles/m^3 in seawater of the Ross Sea, Antarctica. The study found 18,405-38,790 particles in one kg dry weight sediment in Jakarta Bay, Indonesia, with predominantly fragment type and a size range of 100-500 µm (Manalu et al., 2017), and 0-3,146 particles in one kg of dry weight sediment in Northeast Atlantic (Maes et al., 2017). Microplastics are found in deep-sea sediments (Cordova and Wahyudi, 2016; Van Cauwenberghe et al., 2013), on coral reef ecosystems (Cordova et al., 2018), and even in Sumba waters, which has relatively low anthropogenic activity (Cordova and Hernawan, 2018). Murphy et al. (2016) suggested that microplastic abundance is associated with population density. The more densely populated an area, the higher is the presence of microplastics from wastewater treatment plants as a potential point source, and hence, the microplastic abundance becomes higher. This suspicion also applies in the northern coastal waters of Surabaya, East Java, Indonesia. PPGL (2016) states that northern coastal waters of Surabaya are one of the waters in East Java Province, Indonesia, which act as a center for marine transportation, marine aquaculture, tourism, and fisherman residence. These waters have a low topography and land elevation that is almost the same as the mean sea level (MSL). Coastal areas also have quite dense population activities. This dense activity has caused the northern coastal waters to be potentially large enough to experience erosion and receive anthropogenic waste including microplastics. This study aimed to analyze abundance, distribution, and characteristics of microplastics in the northern coastal waters of Surabaya, East Java Province, Indonesia.

4.2 Study Location

The study was conducted on the North Coast of Surabaya, East Java, Indonesia, in March 2017. The study area was divided into three stations: Lamong Bay, Kenjeran Beach, and Wonorejo coastal area (Figure 4. 1). Lamong Bay is a small bay in the north of Surabaya that faces directly to the Madura Strait. This bay is the estuary of 6 rivers: Lamong, Sememi, Brembung, Manukan, Krembangan, and Mas Rivers. In Lamong Bay, there is also reclamation activity due to loading and unloading cargo and containers, multiuse terminals, and depot containers, as well as waterfront city (Pujiraharjo et al., 2013). Kenjeran Beach is a muddy beach that also faces directly to the Madura Strait, and on land, it is dominated by tourism activities, fisherman residence, and mangrove ecosystems. Kenjeran Beach waters are also widely used for fishing, marine tourism activities, and military training (Kurnia, 2017). The coastal area of Wonorejo is one of the marine protected areas in East Java with the highest level of damage. Pradana (2014) in Rachmatullah and Idajati (2016) stated that during 2003-2013, mangrove forests on the coast of Wonorejo decreased by 0.44 ha peryear. From 2004 to 2009, the mangrove forests were converted into ponds (3.85%),whereas from 2009 to 2014, this conversion showed a decrease of up to 12.55% and a change of function of 0.01% due to the presence of residential areas (Rachmatullah and Idajati, 2016).

4.3 Microplastics Sampling and Laboratory Analysis

This study used adaptation procedures reported in previous studies (Masura et al., 2015; Suaria et al., 2017; Thompson et al., 2004; Zhang et al., 2015; Zhao et al., 2014). Water samples (20 L) were collected (triplicate) using a sterile HDPE (Nalgene™) bottle at each station. These samples were filtered using a 3-inch diameter stainless steel filter with a mesh (of sizes 5 mm and 200 µm). The filtered water samples were then transferred to a sterile petri dish, closed using a ParaFilm® sealing film, and then stored at 4 ± 2°C. To control the potential release of microplastics due to the use of the plastic bottle and sealing film, the container and the film rinsed thrice with double-distilled deionized water (DDDW). Under sterile conditions, the sample was transferred to a test tube and dried at 80-90 °C for 24 hours in an oven. H_2O_2 (30%, 3-5 ml; Merck Millipore, Emprove® Essential Medical) was added to the test tube then heated in a water bath (Shibata waterbath WB-6C) at 80 °C for 24-48 hours. The purpose of this treatment was to degrade the organic material and retain the microplastic. The microplastic analysis was categorized on the basis of shape, size, and type of polymer. The sample was transferred to a filter paper (sterile cellulose nitrate Whatman filter paper Ø47 mm, pore size 0.45 µm), and the morphology was observed using a Leica M205C stereo microscope by adapting procedures and criteria given in Cole et al. (2013), Hidalgo-Ruz et al. (2012),and Mohamed Nor and Obbard (2014). The particles were observed to have the following features: particle size of less than 5 mm, homogeneous color, no cellular network, and unsegmented and unbranched. Microplastic particles were categorized on the basis of forms as fiber, granule, fragment, and foam and on the basis of size as<30 0µm, 300-500 µm, 500-1000 µm, and >100 0µm. Microplastic polymer types were identified using a Nicolet™ iS5 FT-IR spectrometer equipped with attenuated total reflection (ATR) diamond crystal material. FT-IR was used for polymer analysis because of the ability to analyze samples directly (Käppler et al., 2015). FT-IR was operated using the experimental setup described in Käppler et al. (2015), Löder et al. (2015),and Löder and Gerdts (2015), on single reflection mode with 8 cm resolution, in the range of 600 and 3800 cm^{-1} and 16 scans per analysis. Microplastic particles were tested by FT-IR after cleaning the surface using sterile ethanol (96%). The process of identifying polymer types from microplastic with ATR FT-IR was carried out by analyzing the presence of a prominent peak, based on a study from Käppler et al. (2015) and Löder et al. (2015). Scheme identification of microplastic was performed by band regions 2780-2980 cm^{-1} (stretching vibrations of $CH/CH_2/CH_3$ groups), 1740-1800 cm^{-1} (C=O stretching vibration), 1670-1760 cm^{-1} (C=O stretching vibration), 1400–1480 cm^{-1} (CH_2 bending vibration), and 1174–1087 cm^{-1} (CF_2 stretching vibration) (Käppler et al., 2015; Löder et al., 2015). To avoid contamination, the procedures in the field and laboratory analysis, as well as all tools, were sterilized and kept closed, adopting a study from Nuelle et al. (2014) and applied procedural blank. DDDW water was used throughout the study procedures.

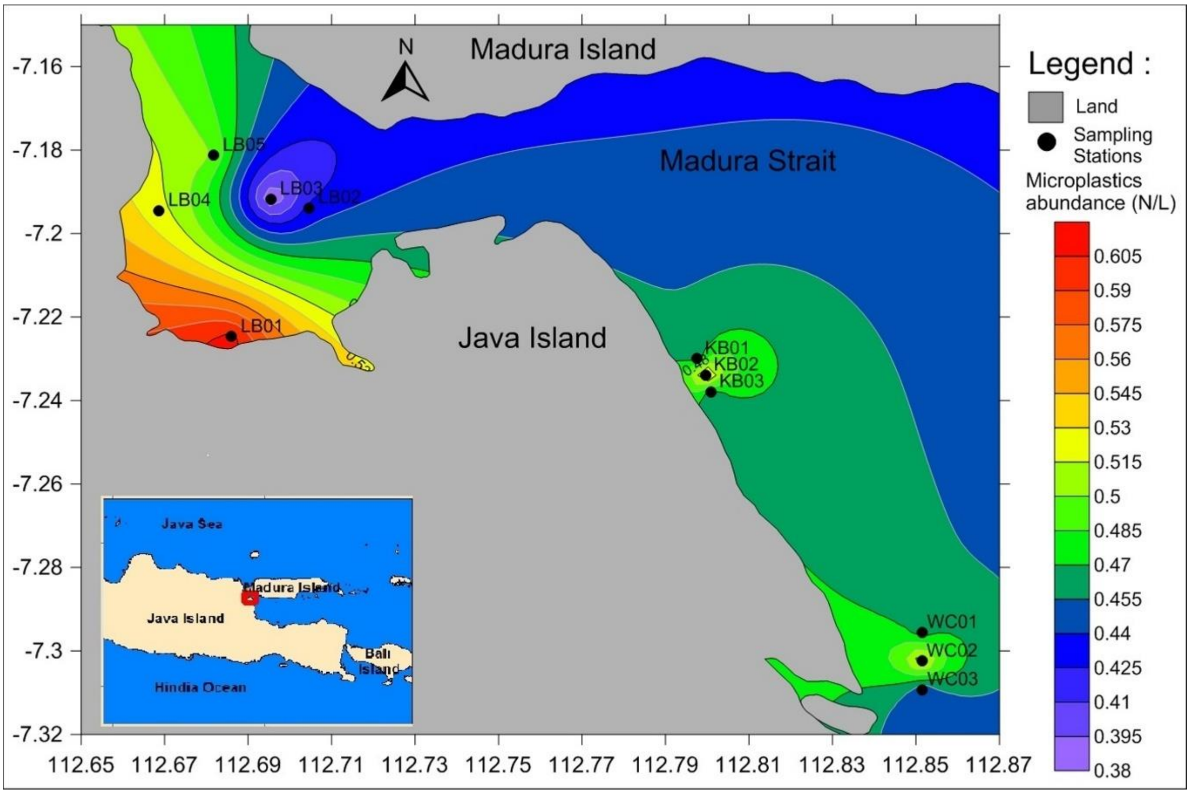

Figure 4. 1. Map Research location, abundance (N/L), and distribution of microplastics

4.4 Floating Microplastics Abundance

The microplastic abundance in the northern coastal waters of Surabaya ranged from 0.38 to 0.61 N/L, with an average of 0.49 N/L. The highest (0.61 N/L) and the lowest (0.38 N/L) microplastic abundances were obtained in Lamong Bay waters (Figure 4. 1). The highest abundance was obtained in LB01, which means that it is closest to the land and, in turn, close to the microplastic pollutant point source. The lowest abundance was found in the middle of Lamong Bay waters. This location is the farthest station from the mainland. Pawar et al. (2016) and Pedrotti et al. (2016) explained that land and beaches could be a source of plastic debris. Hardesty and Wilcox (2011) also emphasized that rivers and highly populated residences are the primary sources of marine debris.

Microplastic abundance in Kenjeran Beach (0.46-0.55 N/L) and Wonorejo Beach (0.44-0.53 N/L) was of lower range than that in Lamong Bay (Figure 4. 1). This is thought to be related to land activities at each research station. Lamong Bay is surrounded by harbor activities and settlements. Additionally, the number of rivers that flow into these waters makes Lamong Bay highly susceptible to pollutants including microplastics. High population activities on the upstream river and high shipping activities lead to the entry of microplastics into the waters. Boucher and Friot (2017) explained that 98% of microplastics in waters are a result of onshore activities. The lowest microplastic abundance was found in Wonorejo Beach, which was allegedly caused by low community activity. Rachmatullah and Idajati (2016)explained that the development of settlements in Wonorejo Beach was started during 2009-2014 with a deviation in the slow category (0.01%). Microplastic abundance in Kenjeran Beach was suspected because the activity on this beach was dominated by the population activities related to plastic use. Many people in Kenjeran Beach dispose their household waste directly into the sea because of no temporary landfill (Mega, 2017). Browne et al. (2011) also explained that pollution levels through septic tanks and wastewater drainages increase along with increasing urbanization.

The average microplastic abundance in the northern coastal waters of Surabaya (0.485 N/L) was lower than that found in Pelabuhan Ratu Beach, West Java (average 0.525 N/L), Indonesia (Hapitasari, 2016). However, this abundance was higher than that in Pantai Ancol, Jakarta (average 0.406 N/L), and Labuan Beach, Banten (average 0.207 N/L) (Hapitasari, 2016). Microplastic abundance in the northern coastal waters of Surabaya was also lower than that in the Yellow Sea, China (average 130 N/L)(Sun et al., 2018), Têt Waters, Mediterranean Sea (average 180 N/L), and the Rhône Waters, Mediterranean Sea (average 190 N/L) (Constant et al., 2018).

4.5 Characteristic of Floating Microplastics

Microplastic characteristics were evaluated according to forms of microplastic, types of polymer, and size ranges of microplastic. The results of identification showed that microplastics in the northern coastal waters of Surabaya have four forms, four size ranges, and seven polymer types (Table 4. 1). The microplastic forms are fibers (3.324%), fragments (34.513%), granules (3.727%), and foams (58.436%). Size ranges obtained were <300 µm (0.122%), 300-500 µm (45.478%), 500-1000 µm (48.539%), and >1000 µm (5.861%). The types of polymers obtained were polystyrene (58.436%), polyethylene (18.418%), polypropylene (18.801%), polyurethane (0.665%), PE terephthalate (1.133%), polybutadiene (0.150%), and polyester (2.397%).

Among the form types, foams were the dominant form in all stations, followed by fragments, then granules, and then fibers (Table 4. 1). Foams were the result of fragments or pieces of Styrofoam (Tanaka and Takada, 2016) or sponge and foam floats (Zhou et al., 2018). Fragments are pieces of plastic products with strong plastic polymers, such as beverage bottles and plastic gallons (Tanaka and Takada, 2016). Fibers were derived from broken fishing lines, plastic ropes, and synthetic fabrics (textile materials) (Kingfisher, 2011; Zhou et al., 2018). Granules were formed because of the pre-reproduction of plastic polymers to become cosmetic ingredients (Cole et al., 2011).

The domination of foams and fragments in the northern coastal waters of Surabaya indicated that the microplastics in waters are the result of waste of the population activities. A contrasting result was found in the Rhône and Têt Water in the Mediterranean Sea, which was dominated by fibers (60-70%) and a small number of foams and films (3-5%) (Constant et al., 2018). However, a similar result of microplastic type was found in the Northern Ionian Sea, Mediterranean Sea, which was dominated by fragments (99.7-100%) in the form of pellets, pieces of Styrofoam, and films (Digka et al., 2018). The high abundance of microplastics in the northern coastal waters of Surabaya needs more attention because of the high risk of aquatic or terrestrial organisms consuming these microplastics. A study by Güven et al. (2017) proved that the intestine and stomach of some Mediterranean Sea fish contain microplastics. Boerger et al. (2010) also found that fish in North Pacific Central Gyre consume microplastics of an average size of 1-2.79 mm. This microplastic size increases as the fish's size increases. Eerkes-Medrano et al. (2015) and Rochman et al. (2013) found that *Oryzias latipes* (Japanese medaka fish) eats small (less than 0.5 mm) polyethylene fragments. Similarly, Avio et al. (2017) also observed microplastics of size 100-1000 µm in fish in Giglio Island. In Indonesia, Cordova et al (2020) stated that 75% lead-head fish (*Aplocheilus* sp.) from the Ciliwung River had consumed microplastics mostly of the size 300-500 µm.

Table 4. 1. Frequency abundance of microplastic in percentage (N/L) according to form types, size range, and polymer types

		Microplastic abundance (N/L)														
		Form				**Polymer type**							**Size**			
No.	**Station**	**Fiber**	**Fragment**	**Granule**	**Foam**	**Polystyrene**	**Polyethylene**	**Polypropylene**	**Polyurethane**	**PE Terephthalate**	**Polybutadiene**	**Polyester**	**<300µm**	**300-500µm**	**500-1000µm**	**>1000µm**
1	LB01	0.89	4.78	0.57	5.96	5.96	4.12	1.77	0.01	0.03	0.00	0.31	0.04	5.84	6.02	0.30
2	LB02	0.40	2.35	0.35	5.50	5.50	2.18	0.80	0.00	0.00	0.00	0.12	0.02	4.57	3.26	0.75
3	LB03	0.53	2.36	0.26	4.45	4.45	1.55	1.02	0.00	0.07	0.00	0.51	0.00	2.47	4.53	0.60
4	LB04	0.44	3.45	0.70	5.81	5.81	2.47	1.58	0.00	0.10	0.00	0.44	0.04	5.57	4.12	0.67
5	LB05	0.35	4.29	0.50	4.86	4.86	2.41	2.46	0.00	0.02	0.00	0.25	0.01	6.04	3.19	0.76
6	KB01	0.13	3.40	0.50	5.17	5.17	1.77	1.57	0.56	0.00	0.00	0.13	0.00	3.95	4.81	0.44
7	KB02	0.25	4.87	0.50	5.38	5.38	1.50	3.61	0.03	0.22	0.02	0.24	0.02	4.29	5.88	0.81
8	KB03	0.14	2.13	0.20	6.73	6.73	0.73	1.11	0.03	0.32	0.14	0.14	0.00	4.52	4.29	0.39
9	WC01	0.14	2.36	0.18	6.52	6.52	0.99	1.36	0.05	0.14	0.00	0.14	0.00	3.97	4.81	0.42
10	WC02	0.14	3.86	0.20	6.40	6.40	0.56	3.45	0.02	0.03	0.00	0.14	0.00	4.03	6.17	0.40
11	WC03	0.14	3.01	0.02	5.63	5.63	1.39	1.35	0.01	0.28	0.00	0.14	0.00	3.32	4.76	0.72
Total (N/L)		**3.55**	**36.86**	**3.98**	**62.41**	**62.41**	**19.67**	**20.08**	**0.71**	**1.21**	**0.16**	**2.56**	**0.13**	**48.57**	**51.84**	**6.26**
	%	**3.32**	**34.51**	**3.73**	**58.44**	**58.44**	**18.42**	**18.80**	**0.67**	**1.13**	**0.15**	**2.40**	**0.12**	**45.48**	**48.54**	**5.86**

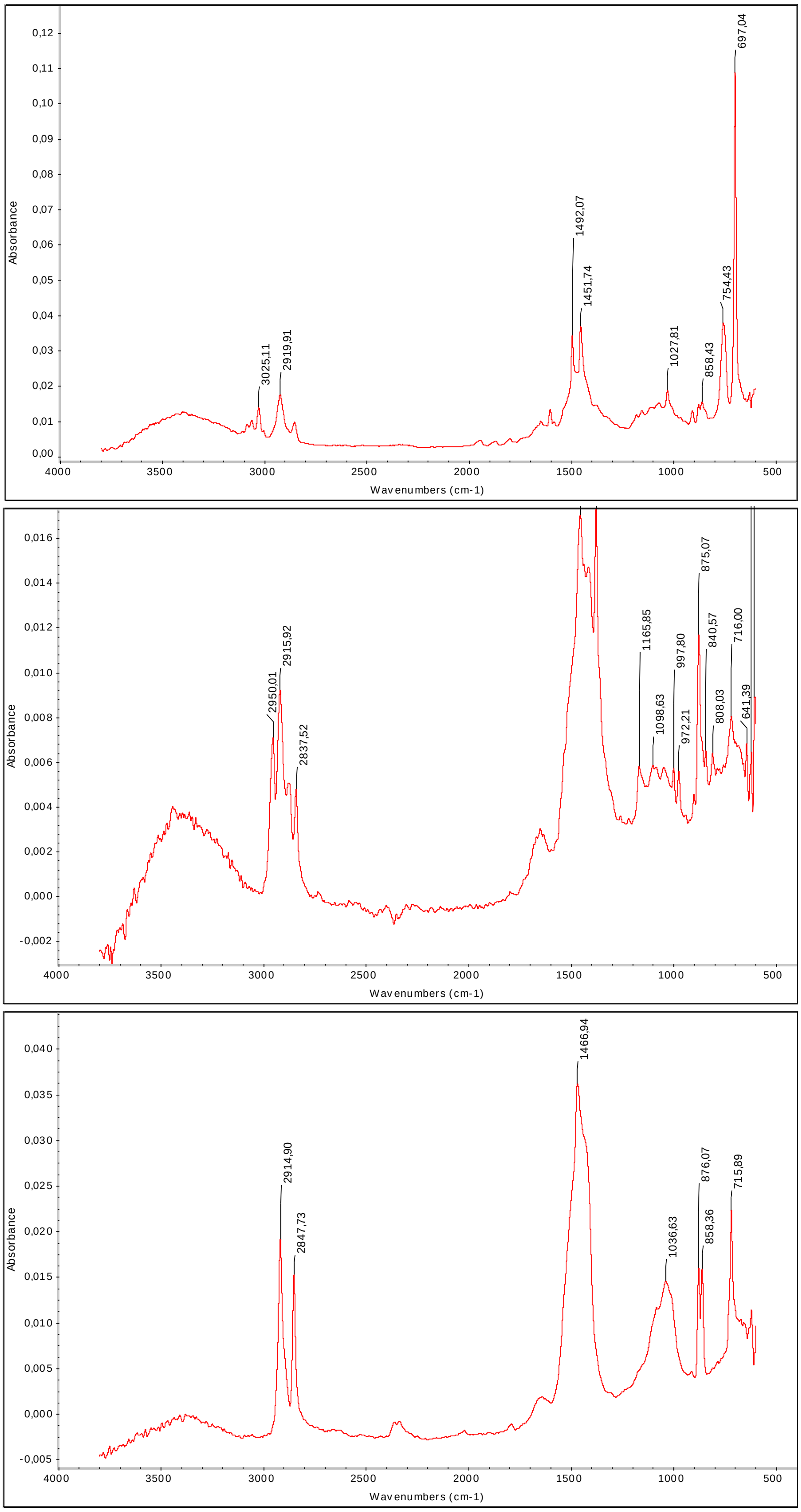

Figure 4. 2. FTIR spectra show the presence of a prominent peak of microplastics collected from the northern coastal waters of Surabaya

The domination of microplastics in this size range indicates the condition of microplastic particles that have not been degraded for a long time. Microplastics of size ranges 500-1000 μm (48.54%) and 300-500 μm (45.48%) were found dominant in all stations (Table 4. 1). This result is confirmed by Troyer (2015) who also found differences in microplastic size distributions, which indicate that large-sized microplastics have not deteriorated enough. The difference in microplastic size distribution is because of the influence of the hydrodynamic conditions (Troyer, 2015), wind speed (Kukulka et al., 2012), and the presence of bio-fouling (Pedrotti et al., 2016).

The microplastic size range found in this study is greater than that along the Belgian Scheldt River (15-320 μm) (Troyer, 2015), but it is almost similar to that found in the Ligurian Sea, North West Mediterranean Sea, which is 300-2000 μm (Pedrotti et al., 2016). Pedrotti et al. (2016) also showed that abundance of small-sized microplastic was higher closer to the mainland. This result was suspected because large microplastics can be preferably exported onto beaches through collision (Digka et al., 2018). The gap between microplastic sizes (less than 300 μm and more than 300 μm) was studied by Cózar et al. (2015) and Pedrotti et al. (2016). This gap occurs because changes in the microplastic size are the result of an accumulation of gradual plastic losses, which progressively transferred by fragmentation toward the small-sized category (Cózar et al., 2015).

4.5 Synthetic Polymer Identification of Floating Microplastics

Figure 4. 2 shows three examples of the FTIR spectra from the dominant polymer (polystyrene/PS, polypropylene/PP, and polyethylene/PE) of microplastics found in the northern coastal waters of Surabaya. PS sample showed a prominent peak at wavenumber3025cm^{-1} corresponding to aromatic C-H stretching vibrations (Syakti et al., 2017); at wavenumber 2919 cm^{-1} indicating C-H stretching, symmetrical vibrations, and asymmetrical stretching (Fotopoulou and Karapanagioti, 2015; Käppler et al., 2015; Löder et al., 2015); and at wavenumbers 1451 and 1492 cm^{-1}indicatingaromatic C-H bond stretching vibrations (Fotopoulou and Karapanagioti, 2015; Syakti et al., 2017). In the PP sample, significant peak appeared at wavenumbers 2837, 2867, 2915, and 2950 cm^{-1}, indicating stretching vibrations of CH_2 and asymmetrical vibration (Fotopoulou and Karapanagioti, 2015; Käppler et al., 2015; Löder and Gerdts, 2015); peak at wavenumber 1452 cm^{-1}, indicating symmetrical and symmetrical deformation vibrations of CH_3 (Fotopoulou and Karapanagioti, 2015) and CH_2 bending vibration (Käppler et al., 2015).The prominent peak at 1098 and 1165 cm^{-1}from the PP sample corresponded to CF_2 stretching vibration (Käppler et al., 2015; Löder et al., 2015). IR spectrum from the PE sample in the study showed a prominent peak at wavenumbers 1466, 2847, and 2914 cm^{-1}. Absorption at wavelength 2847 and 2914 cm^{-1} corresponded to stretching vibrations of $CH/CH_2/CH_3$ groups cm^{-1}, and absorption at wavelength 1466 cm^{-1} corresponded to methylene scissoring or asymmetrical methyl C-H bending (Fotopoulou and Karapanagioti, 2015; Käppler et al., 2015; Löder et al., 2015; Syakti et al., 2017).

This study found that polystyrene, which is generally found in Styrofoam products, is the most dominant polymer type (58.44%) in all stations (Table 4. 1) Polystyrene was dominant compared to other polymer types presumably because the microplastics in the study area are the result of the degradation of the community's large waste activities (secondary microplastics). This condition describes the dominance of foams compared to granules (primary microplastics). Moreover, polystyrene is a type of polymer plastic that is most widely used in everyday products (Garrigós et al., 2004; Halland, 2017). The density of polystyrene, which is higher than water density, also resulted in the presence of more polystyrene in waters (Halland, 2017; Oladejo, 2017).

4.6 Remarks of Chapter 4

This research was established that microplastics are present in the northern coastal waters of Surabaya. The abundance of microplastics in the northern coastal waters of Surabaya was0.38 to 0.61 N/L, with an average of 0.49 N/L. The highest and the lowest abundances of microplastics were found in Lamong Bay waters. In general, analysis of the microplastic characteristics showed that foams (58.44%) were the dominant form with size ranges of 500-1000 µm (48.54%) and 300-500 µm (45.48%), and polystyrene was the dominant type of polymer in all stations (58.44%). This result could be used to deduce the amount of microplastics present in the seafood and human intake. Further comprehensive assessments as effect studies are suggested to conduct.

Chapter 5 Characterization of Microplastics in Mangrove Sediment of Muara Angke Wildlife Reserve, Indonesia

5.1 Introduction

Plastics have been widely used almost for everything in the modern world (i.e., cosmetics, food packaging, equipment, transportations, building). This is due to its low cost of production, lightweight, and durability. However, discarded plastics in various forms and sizes enter the environment, including water, sediments, and biota. Moreover, plastics have been accumulated on the land, in rivers, lakes, and the ocean due to its material longevity characteristic. Therefore, this plastic debris has become an emerging problem. Photos of stranded whales with tons of plastic and debris entangled whales and sea turtles, as well as died seabirds choking on plastic debris spreading on social media have haunted us in recent years. It has raised awareness of the marine environmental issue of the plastic debris. This debris, mostly from land, enter to the ocean through river and waterways. It has been estimated that there are about 4.8–12.7 million MT per year entering the ocean (Agamuthu et al., 2019; Jambeck et al., 2015b) and it may continue to increase as the human population is projected to increase (Häder et al., 2020) and plastic production would be double in 2035 or almost quadruple in 2050 (Mrowiec, 2018). Floating plastics were considered to be the dominant accumulation in the ocean (Barnes et al., 2009), but Koelmans *et al.* (2017) argued that an ocean surface layer is only a temporary place for plastic debris accumulation, and then it sinks to the sea bottom. Plastic debris is also frequently deposited on beaches that close in proximity to population centers (Agamuthu et al., 2019). Either in the ocean surface layer or on beaches, plastic debris continues to be fragmented by a combination of photodegradation with UV light and physical abrasion (Barnes et al., 2009; Song et al., 2017), becoming so-called microplastics or nano-plastics. This small size of plastic debris is argued to have a more harmful effect on marine wildlife, from gene to community levels (Alimba and Faggio, 2019; Barboza and Gimenez, 2015; Cordova et al., 2020; Guzzetti et al., 2018; Ma et al., 2020). Accordingly, because of the high intake of seafood, there would be a potential effect of microplastic on human health (Barboza et al., 2018; Purwiyanto et al., 2020; Walkinshaw et al., 2020).

Occurring between land and ocean, mangrove ecosystems, to some extent, act as traps for marine plastic debris. Experimentation with tagged plastic items (i.e., bottles, bottle caps, plastic bags, polystyrene blocks, and margarine tubes) showed that mangrove forests retained macro-plastic debris for months to years (Ivar do Sul et al., 2014). A survey in Red Sea mangroves showed this trapping function, particularly when the mangrove forests are geographically close to the major maritime traffic routes; and have a dense tree stand with pneumatophores (Martin et al., 2019). The same story was found for microplastics, trapped, and retained in mangrove forests (Garcés-Ordóñez et al., 2019; Li et al., 2018; Naji et al., 2019).

As mentioned before, microplastics have a potential risk to human health when seafoods are contaminated with microplastics through bioaccumulation and bio-magnificent in food chains. This contaminant in fish products from mangrove ecosystems may occur either in wild stock or aquaculture fisheries (Harmesa and Cordova, 2020). Several studies have reported that microplastics were found in the gut of fishes inhabiting mangrove swamps (Garcés-Ordóñez et al., 2020; Naidoo et al., 2020). In an aquaculture stock, Priscilla and Patria (2019) found microplastics in the digestive system of milkfishes (*Chanos chanos)*. As deposit feeders, some benthic biota were found consuming microplastics, for example, snails (viz. *Cheritidia obtusa* and *Ellobium chinensis*) (Fitri and Patria, 2019;

Ruilong Li et al., 2020). If commercial crabs (e.g., *Scylla* spp.) prey on the snails, microplastics would also enter the digestive tract of the crabs. Then, these delicious but contaminated kinds of seafood may have an implication on our food safety.

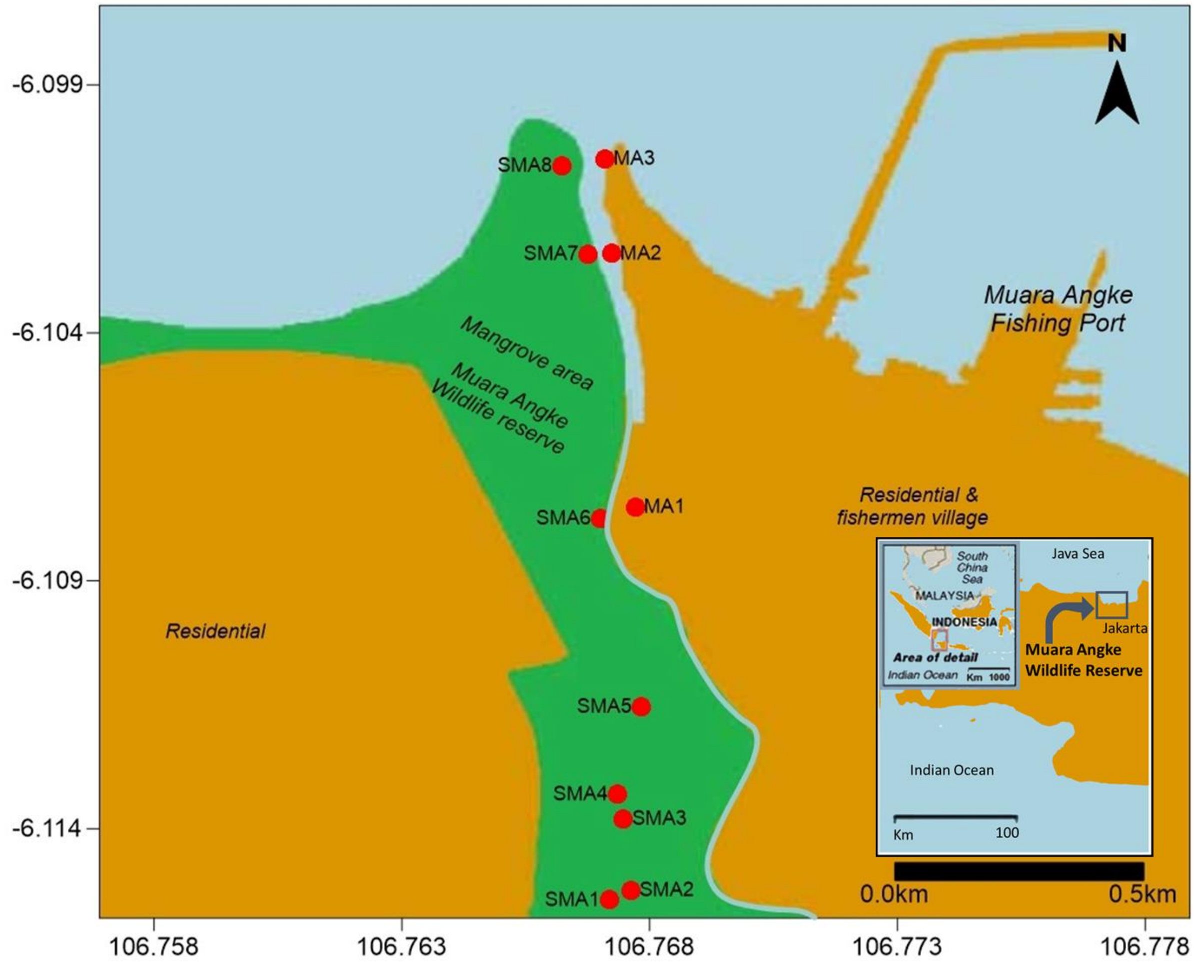

Figure 5. 1. Study area geographical location and sampling stations in mangrove ecosystem on Muara Angke Wildlife Reserve

With a combination of the first largest mangrove area (Giri et al., 2011; Richards and Friess, 2016) and poor plastic waste collections (Purba et al., 2019), Indonesia may be a hot spot for microplastics accumulation in its mangrove forests. More importantly, coastal fisheries (i.e., aquaculture ponds/tambak and wild stock) are of the essential food and economic resources of the country (Phillips et al., 2015). Thus, the plastic waste problem in the mangrove area should be a concern for the government and the people of Indonesia. Most studies in plastic debris in Indonesia have been conducted on macro-debris, as reviewed by Purba *et al.* (2019) from publications between 1986 and 2018; they recorded only three local literature reporting microplastic studies in mangroves. Therefore, an assessment of microplastics in Indonesia's mangroves is urgently needed.

This present study documented a microplastic study conducted in Muara Angke Wildlife Reserve, a remnant of extensive mangrove forests in Jakarta Bay, with the area of 25.02 Ha. This is the downstream of Angke River, frequently receiving huge quantities of solid waste, including plastic debris (Cordova and Nurhati, 2019). The upstream of the river is Jakarta metropolitan and its hinterland belongs to two other different provinces; thus, solid waste management becomes a tremendous work. Accordingly, this study site offered a unique opportunity to have the worst conditioned benchmark for microplastics in Indonesia's mangroves. Lessons from literature highlighted that microplastic characterization and distribution in mangrove forests are the basic topics to be covered (Garcés-Ordóñez et al., 2019; Li et al., 2018, 2019; Naji et al., 2019), then moving further to, for example, retention time, ecological risks, bioaccumulation, bio-magnificent, and toxicology (Alimba and Faggio, 2019; Bucci et al., 2020; Karbalaei et al., 2018). Thus, in this early step of the study, a survey to investigate the distribution and characteristics of microplastics in mangrove sediments of Muara Angke Wildlife Reserve was conducted.

5.2 Sampling Area and Sample Collection

Samples were collected in October 2015 from 11 stations in the Muara Angke Wildlife Reserve area. The five stations were inside the mangrove area (SMA1, SMA2, SMA3, SMA4, SMA5) and six stations were in the river mouth (SMA6, SMA7, SMA8, MA1, MA2, MA3). Then, the first group of stations is called as the inner layer of mangroves, and the second is the outer layer. The locations of the sampling area are shown in Figure 5.1. The sampling method was adapted from Mohamed Nor and Obbard (2014), obtaining from 1.5x1.5m^2 transect, 2-3 m apart in undisturbed areas, in an oxygenated zone (Ferreira et al., 2007; Marchand et al., 2004) at the top layer (4-8 cm) using a clean stainless-steel spatula. The samples were then stored in a freezer (4°C) prior to analysis.

5.3 Sediment Preparation and Microplastic extraction

Wet sediment was dried in the oven overnight at 60°C (Lin et al., 2021; Mohamed Nor and Obbard, 2014; Qiu et al., 2016). The selection of temperature of 60°C, which is lower than 70°C (Liebezeit and Dubaish, 2012) and 90°C (Vianello et al., 2013), was an adaptation of previous research (Daniel et al., 2021; Duan et al., 2020; Mathalon and Hill, 2014; Mohamed Nor and Obbard, 2014; Munno et al., 2018), aimed to prevent microplastic damage due to deformation after heating at high temperature (Lares et al., 2018; Lusher et al., 2017b; Qiu et al., 2016). Nevertheless, a treatment on temperature lower than 60°C (30-50°C), although it takes longer, will reduce the possibility of chemical structural damage to some types of polymers (Osswald, 2006; Qiu et al., 2016; Troitzsch et al., 1983). Microplastic extraction from dry sediment (~250 g) was performed using a concentrated saline solution (500 ml, ρ=1.2 g/ml) based on a modified flotation method (Claessens et al., 2011; Falahudin et al., 2020; Mohamed Nor and Obbard, 2014; Thompson et al., 2004). Under sterile conditions, the supernatant particles were transferred to a test tube (Pyrex, 50 ml), dried in an oven at 60°C (Lin et al., 2021; Mohamed Nor and Obbard, 2014; Qiu et al., 2016) for 24 hours. H_2O_2 (30%, 3-5 ml; Merck Millipore, Emprove® Essential Medical) was added to the test tube for 24-48 hours in a water bath (Shibata water bath WB-6C). This treatment aimed to degrade organic material and retain microplastic. The sample was transferred to a filter paper (sterile cellulose nitrate Whatman filter paper Ø47 mm, size 0.45 μm). A filter paper with the sample was covered by a sterile petri dish at room temperature prior to shape, size, and polymer analysis.

5.4 Observation, Identification, and Analysis of Microplastics

Shape and size identification was observed using a stereomicroscope (Leica M205C) with a camera (Leica IC90 E) by adapting procedures and criteria given in previous research (Cole et al., 2013; Hidalgo-Ruz et al., 2012; Mohamed Nor and Obbard, 2014). To distinguish MPs from other particles, some criteria from Cole *et al*. (2013) were considered during the investigation with a microscope: (a) particle has no organic or cellular structure, (b) particle has a homogenous color and is not sparkling or shiny, and (c) plastic fibers are unbranched and have no segments. The number of MPs recovered from the samples was expressed in particles/kg dry weight (dw).

Munno (2018) confirmed that H_2O_2 and temperature treatment at 60°C has a minimal structure alteration in the recovered polymer identified by Fourier Transform Infrared (FT-IR) spectrometer. A representative group of sediment microplastics (n=65, round up to 21% of recovered microplastic particles) was isolated for polymer identification using a FT-IR. FTIR used to evaluate polymers due to the capacity to analyze samples effectively (Käppler et al., 2015). FTIR-tested microplastic particles were washed using sterile ethanol (96%). Given the ability to analyze samples directly, FT-IR was used for polymer analysis (Käppler et al., 2015). Thermo Scientific Nicolet™ iS5 FT-IR spectrometer equipped with ATR diamond crystal was used in this research, using experimental setup an 8 cm single-reflection resolution mode of 600 and 3800 cm^{-1} and 16 scans per analysis (Cordova et al., 2019; Käppler et al., 2015; Löder et al., 2015; Löder and Gerdts, 2015). To identify the polymers, the presence of a prominent peak at a specific band was analyzed based on Käppler et al. (2015) and Löder et al. (2015).

The method of defining microplastic polymer categories with ATR FT-IR was performed by analyzing the prominent presence peak (Käppler et al., 2015, Löder et al., 2015); and comparing the spectrum of each sample with the Hummel Polymer and Additives library. Microplastic identification scheme based on a research from Käppler et al. (2015) and Löder et al. (2015) by band region 1174–1087 cm^{-1} (CF_2 stretching vibration), 1400–1480 cm^{-1} (CH_2 bending vibration), 1670-1760 cm^{-1} (C=O stretching vibration), 1740-1800 cm^{-1} (C=O stretching vibration) and at band region 2780-2980 cm^{-1} (stretching vibrations of $CH/CH_2/CH_3$ groups).

The abundance of microplastics inside and outside the mangrove area was compared using the Kruskal-Wallis and Mann-Whitney pairwise tests. Additionally, significant tests were performed between the microplastic shape category; and between the microplastic size category.

5.5 Precaution and Procedural Blanks

A method from Nuelle et al. (2014) and Lusher et al. (2017) was adopted to avoid contamination by microplastic sampling and laboratory analysis by using 100% cotton clothing, sterilized all field and laboratory analysis tools, used all non-plastic equipment (glass and stainless steel) and applied procedural blank. Briefly, a sterile filter paper was placed during laboratory analysis, and a blank control was then examined under a microscope. No plastic was found on the filter paper for a blank procedure, implying that there were no airborne microplastics contamination during laboratory processes. DDDW (double distilled deionized water) was used to rinse all equipment (3-5 times).

Standards polymer from Shimadzu, Thermo Scientific, and the University of Bayreuth, Germany, were used for quality assurance to ensure that FTIR performed well.

5.6 Concentration and Spatial Distribution of Microplastics

Microplastics were detected in all sediment samples collected from all 11 stations in the Muara Angke Wildlife Reserve area (Figure 5. 2). The average microplastic concentration for the 11 stations was 28.09 ± 10.28 particles per kg dry sediment (n/kg). Microplastic concentration was higher in the river mouth or outside mangrove area (35.01 ± 8.13 n/kg) than inside mangrove area (19.80 ± 4.90 n/kg). The Kruskal–Wallis (p = 0.01) and Mann-Whitney pairwise test (p = 0.01) revealed significant differences between the microplastics inside and outside the mangrove area.

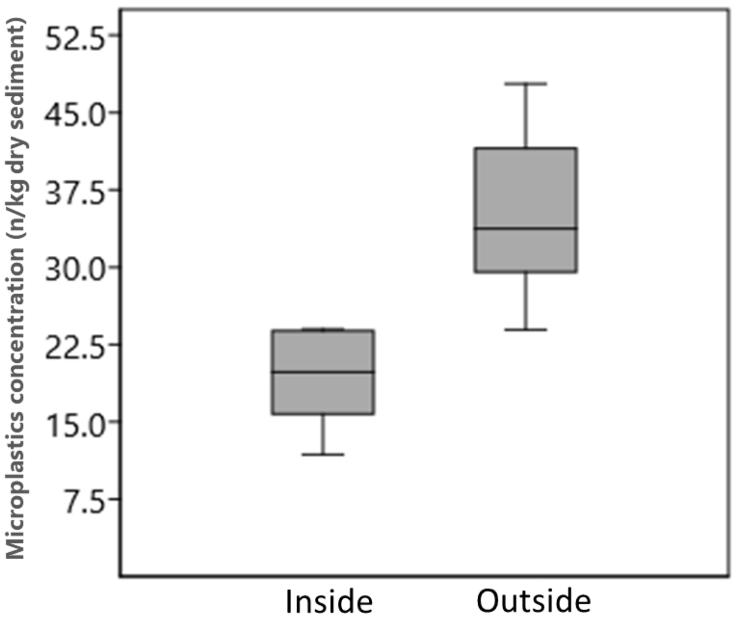

Figure 5. 2. Microplastic concentration in mangrove ecosystem on Muara Angke Wildlife Reserve

The average concentrations (Table 5. 1) reported in this study were on the same magnitude as reported in the mangrove area on the North Coast of the Persian Gulf (Naji et al., 2019) and Singapore Coastal (Mohamed Nor and Obbard, 2014). The variability of microplastics in this study was lower than that reported in the Colombian Caribbean (Garcés-Ordóñez et al., 2019) and China (Li et al., 2018, 2019; Ruili Li et al., 2020; Ruilong Li et al., 2020; Zhou et al., 2020; Zuo et al., 2020) mangrove sediments. Higher microplastic concentration was found in outside mangrove area than in inside the mangrove area, similar to research in Qinzhou Bay, China (Li et al., 2018).

There are at least two possible explanations for the lower microplastic abundance in Muara Angke Wildlife Reserve. First, the effect of temperature treatment during drying oven and biological digestion process may degrade or eliminate the substances of polymers (Rios Mendoza et al., 2017). Some polymers are more vulnerable than others to high temperature (e.g. High-density polyethylene and low-density polyethylene with heat deflection temperatures of 50°C and 35°C, respectively, Qiu et al., 2016) and highly alkaline or acidic chemical solutions (e.g. H_2SO_4 or KOH, Lusher et al., 2017).

Thus, performing temperature treatment at a relatively lower temperature (≤50°C) to minimize the sample losses was suggested. Second, the lower microplastic abundance in the study site might be due to the improved river and coastal cleanup programs in Jakarta, that had started before this research was conducted in October 2015 (Cordova et al., 2021; Cordova and Nurhati, 2019). However, this explanation should be confirmed by long-term coastal microplastic monitoring using a harmonization method. If affirmed, the cleanup and monitoring program can be repeated and replicated in waterfront cities, particularly in the developing world to provide policymakers with scientific knowledge to tackle the issue of marine debris.

Table 5. 1. Microplastics concentration and range in the mangrove ecosystem

No	Mangrove Location	Concentration	Range	Mean value	
			(n/kg)		References
1	Pearl River Estuary, South China	851 ± 177	100 - 7900		(Zuo et al., 2020)
2	South-eastern coastal zones, China		8.3 - 5738.3		(Zhou et al., 2020)
	Guangxi			875.3	
	Fujian			198.4	
	Hainan			146	
	Zhejiang			116.7	
	Guangdong			98.7	
3	Ciénaga Grande de Santa Marta, Colombian Caribbean	2,745 ± 1,978	31 - 2863		(Garcés-Ordóñez et al., 2019)
4	Southern China				(Ruili Li et al., 2020)
	Futian	2249 ± 747	980 - 3100		
	Zhanjiang	736 ± 269	460–1280		
	Dongfang	649 ± 443	160–2600		
	Dongzhaigang	431 ± 170	260–700		
	Yunxiao	424 ± 127	260 - 580		
	Fangchenggang	227 ± 173	120–640		
5	Maowei Sea Coastal, South China Sea		520–940		(Li et al., 2019)
6	Beibu Gulf, China		640 - 6360		(Ruilong Li et al., 2020)
7	Northern coast of the Persian Gulf	125 ± 25			(Naji et al., 2019)
8	Bandar Lengeh	34.5 ± 0.71			
	Bandar Angur	34.0 ± 4.24			
	Lashtaghan	26.5 ± 6.36			
	Mardoo	21.5 ± 10.61			
	Bandar Gelkan	19.5 ± 6.36			
9	Coast of Singapore	36.8 ± 23.6	12–62		(Mohamed Nor and Obbard, 2014)
10	Qinzhou Bay, China		15 – 6168		(Li et al., 2018)
	inside mangrove Qinzhou Bay	42.9 ± 26.8	15 - 80		
	outside mangrove Qinzhou Bay	2174.5 ± 2206.8	306 - 6168		
11	Muara Angke Wildlife Reserve	28.09 ± 10.28	11.83 - 47.79		This Research
	inside mangrove area	19.80 ± 4.90	11.83 - 23.98		
	outside mangrove area	35.01 ± 8.13	23.93 - 47.79		

5.7 Shapes and Sizes of Microplastics

The features of microplastics in the Muara Angke Wildlife Reserve mangrove sediments are presented in Figure 5. 3. Different types of microplastics, including foams, fibers, fragments, and granules, were found in mangrove sediments, with the most commonly identified types as foams (13.33 ± 8.54 n/kg) and fragments (10.08 ± 4.79 n/kg). This study results are similar to those of Li et al. (2018) who demonstrated >93% microplastics were fragmented at the sediments outside of the mangrove. Fragment and foam were found in sediments within the mangrove. This study found a significant difference between microplastic forms (p = 0.002). Overall, the foam form, the most dominant, was found to be significantly different from the fiber (p = 0.005), fragments (p = 0.04) and granules (p = 0.02). Based on the location where it was found, microplastics with foam type (significantly different from other types, p <0.05) were found more in the area outside the mangrove, while the fragment shape was mostly found in the area inside the mangrove but not significantly different from other forms (p = 0.26).

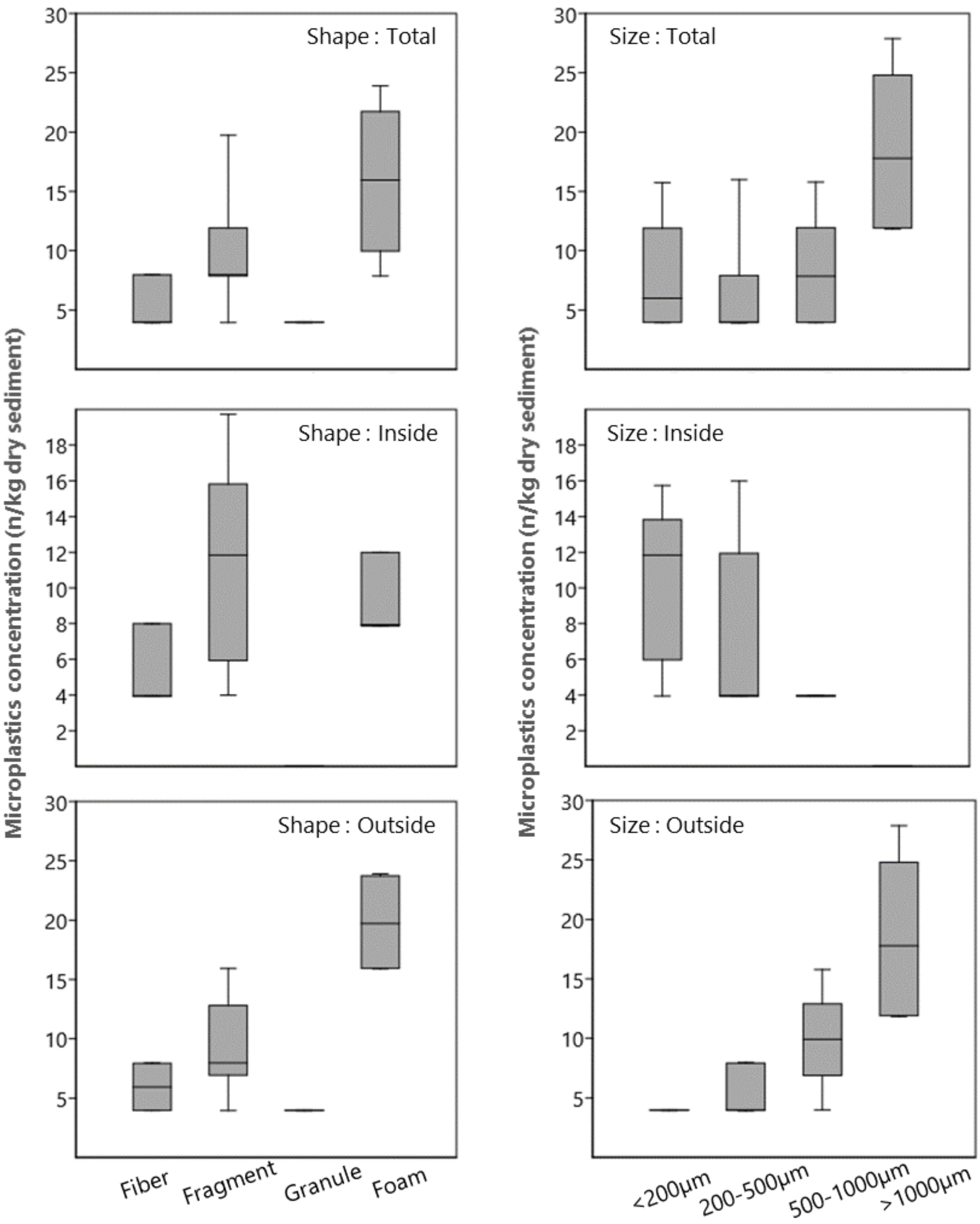

Figure 5. 3. Microplastic concentration (n/kg dry sediment) of various forms (left) and size (right) classes in mangrove sediment on Muara Angke Wildlife Reserve

Because of various pollutant sources and environmental processes such as solar radiation and biodegradation (Shah *et al.*, 2008; Singh and Sharma, 2008; O'Brine and Thompson, 2010; Gigault *et al.*, 2016), regular and irregular forms of the microplastics detected in the coastal environment may occur (Li et al., 2018). Li et al. (2018) explained regular forms generate from primary microplastics include granule, pellets, beads, or spherules. Irregular forms are mostly caused by the degradation of larger plastic debris (secondary microplastics) containing fragments, foam, and fiber type (Khatmullina and Isachenko, 2017). High temperatures and intense tropical climate-related solar ultraviolet light can accelerate the degradation of large plastic litter (Lambert et al., 2013).

Microplastics in the mangrove sediments are mainly affected by the following factors, intensive human activities, mangrove forest density, and texture of mangrove sediment (Zhou et al., 2020). In this research, Muara Angke River flowed 91.25 km through three dense provinces and derived plastic debris, including microplastics, to Jakarta Bay (Cordova and Nurhati, 2019). Mangrove stands could indeed retain floating microplastics (Li et al., 2018; Sutton et al., 2016), but here, the relationship between stand density and the abundance of microplastics could not be assessed since there was no measurement of this parameter during the sampling. Nevertheless, YKAN and BKSDA Jakarta (2019) reported that the stand density in the inner layer of mangrove forests in Muara Angke Wildlife Reserve ranged between 267 and 1100 trees Ha^{-1}. Thus, it remains unclear why the outer layer of mangroves was higher in microplastic concentrations than the inner layer, which also reported by Li *et al.* (2018). One possible explanation is a hydrodynamical model of sedimentation in mangrove forests showing the sedimentation rate was greater in the outer than inner layer of mangroves (Furukawa et al., 1997). These findings also showed that microplastics inside mangrove areas that had muddy sediments with fiber and fragments dominated, whereas foams type dominated outside mangrove areas with mainly muddy sand sediments. This result, consistent with previous studies (Eo et al., 2018; Maes et al., 2017; Vermaire et al., 2017), indicated that larger MP particles tend to collect in the same area as larger sand particles. This is due to sedimentation of both clastic and plastic particles is controlled by the same environmental law (Enders et al., 2019).

Microplastics collected from mangrove sediments in this research ranged from 186 to 4769 µm. Overall, more than half of microplastics (64.1%) in mangrove sediments were <1000 µm (6.00 ± 4.76 n/kg), whereas microplastics existed in size range of 1000–5000 µm has average 10.09 ± 10.70 n/kg. A higher number of microplastics with size <1 mm in the mangrove sediments is in accordance with studies in other areas such as in China and Singapore (Li et al., 2018; Mohamed Nor and Obbard, 2014; Zuo et al., 2020). The various size distributions of microplastics on different study fields can explain different sources, the extent of degradation, environmental factors (e.g., solar radiation and temperature), types of polymer, and different methods of sampling, and the consequent detection limits (Li et al., 2018).

There are differences in microplastic concentrations based on the size found outside the mangrove area and inside the mangrove area. Microplastics with a size> 1000 µm were more often found and significantly different ($p < 0.05$) outside the mangrove area (18.50 ± 6.49 n/kg), whereas in the mangrove area there were no similar size microplastics. Within the mangrove area were dominated with sizes <200µm and 200-500µm, as many as 5.76 ± 5.40 n/kg and 5.77 ± 4.14 n/kg, respectively. Higher small-sized microplastic concentrations in the Muara Angke Wildlife Reserve mangrove area occurred because smaller particles are more difficult to remove by water flow (Yan et al., 2019). The high proportion of small microplastics could promote the adverse effects on organisms in mangrove wetlands (Zuo et al., 2020), because the organism was misidentified as microplastics as food (Lehtiniemi et al., 2018; Tanaka and Takada, 2016) and easily captured (Bour et al., 2018).

5.8 Composition of Microplastics Polymer

In terms of polymer composition (Table 5. 2), the FTIR results showed a total of 6 types of synthetic polymers were found in the mangrove sediment of Muara Angke Wildlife Reserve, with an overall predominance of polystyrene (44.62%), followed by polypropylene (29.23%) and polyethylene (15.38%) and other polymers (10.77%). The dominant discovery of polystyrene polymer is in accordance with the results of the study from Cordova and Nurhati (2019) and Cordova et al. (2021), which stated that Styrofoam was the most abundant debris entering Jakarta Bay. Styrofoam (polystyrene) is widely used for packaging foods that will quickly degrade into microplastics (Jang et al., 2016). The two main groups in plastic processing are polypropylene and polyethylene worldwide, and their copolymers are also widely used for packaging, textiles, and fishery equipment (Cai et al., 2018; Geyer et al., 2017). Three dominant polymers found in this research are, therefore, commonly found in the marine environment.

Table 5. 2. Main chemical composition of microplastics detected in the mangrove sediment of Muara Angke Wildlife Reserve

Polymer composition	Inside Mangrove					Outside Mangrove						Total	%
	SMA1	SMA2	SMA3	SMA4	SMA5	SMA6	SMA7	SMA8	MA1	MA2	MA3		
Polystyrene	3	1	2		1	4	3	4	5	3	3	29	44.62
Polyethylene		1	1	1	1		1	2	1	1	1	10	15.38
Polypropylene	2	2	2	1	2	1	2	3	2	1	1	19	29.23
Nylon-6								1			1	2	3.08
Polyester					1							1	1.54
Polybutadiene	1						1			1	1	4	6.15
Total	6	4	5	2	5	5	7	10	8	6	7	65	100.00
%	9.23	6.15	7.69	3.08	7.69	7.69	10.77	15.38	12.31	9.23	10.77	100.00	

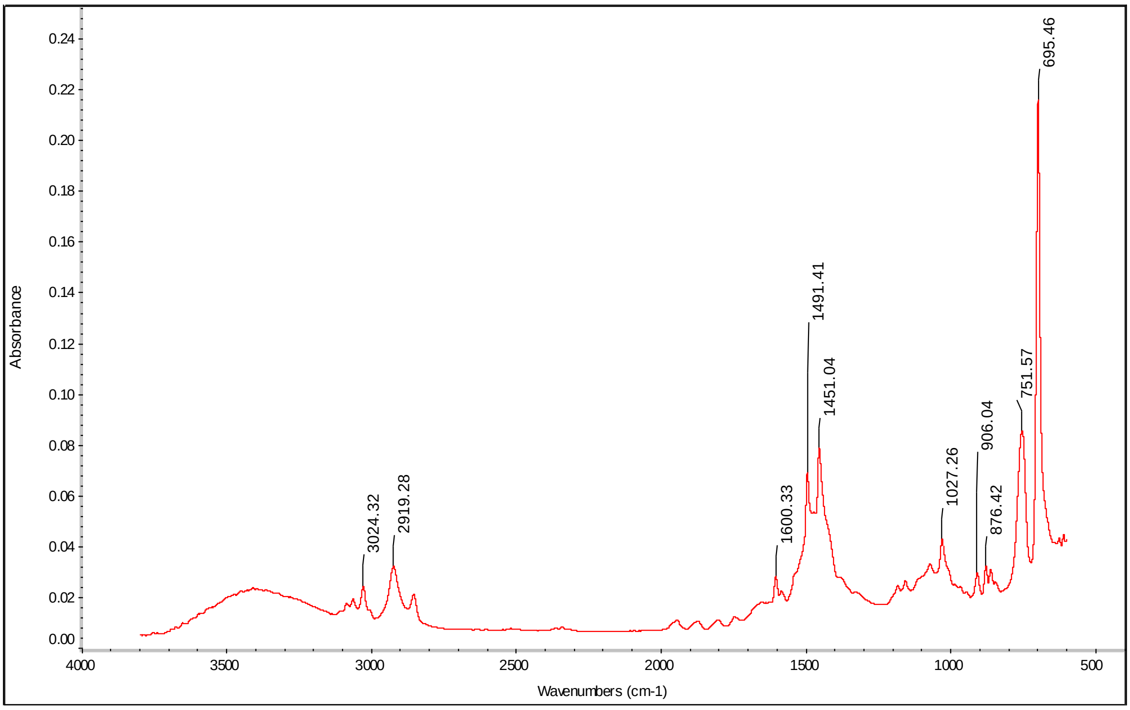

Figure 5. 4. Identification of recovered polystyrene from Muara Angke Sediment using FT-IR

Sample of polystyrene particle from Muara Angke (Figure 5. 4) shows prominent peak at 1451.04 and 1491.41 cm^{-1} symbolize aromatic C-H bond stretching vibrations (Fotopoulou and Karapanagioti, 2015); at wavenumber 2919.28 cm^{-1} indicate C-H stretching, symmetrical vibrations, and asymmetrical stretching (Fotopoulou and Karapanagioti, 2015, Käppler et al., 2016, Löder et al., 2015); and peak at wavenumber 3024.32 cm^{-1} correspond aromatic C-H stretching vibrations.

5.9 Remarks of Chapter 5

Mangrove sediment in Muara Angke Wildlife Reserve was a sink for microplastics in Jakarta Bay, with an average of 28.09 ± 10.28 particles per kg dry sediment (n/kg). This figure is surprisingly similar to that reported in Singapore, where the country has better solid waste management than Indonesia. The abundance of microplastics in this study was far lower than that in China as the first largest contributor to the world marine debris. Microplastics were significantly more abundant in the outer layer of mangroves than the inner. However, further studies should be conducted to resolve the mechanisms of microplastic distribution across mangrove forests. In terms of characteristics of microplastics, the foam form is the most dominant, also found more abundantly in the outer layer of mangrove forests. The size of microplastics ranged between 186 and 4769 µm, which the size <1000 µm reached 64.1%. These microplastics comprise predominantly of three polymers commonly found in the marine environment, i.e., polystyrene (44.62%), polypropylene (29.23%) and polyethylene (15.38%). The dataset of microplastics in Muara Angke Wildlife Reserve could be a benchmark for a national data inventory of microplastics in Indonesia's mangrove. If the proximity to the population center is the main factor for microplastic accumulation in mangroves, this study may expect that the abundance of microplastics in other mangrove forests would be lower than that reported here. However, there may be additional factors that could fail to meet that expectation. Then, after completing that inventory, conducting further studies on the ecological risks of microplastics, toxicology, and food safety were suggested, which would be essential for humans.

Chapter 6 Microplastic Pollution Distribution in Coral Reefs Sediment, Case Study Sekotong, West Nusa Tenggara

6.1 Introduction

Plastic production has been increasing rapidly and became a potential threat to the marine environment. Plastic production in a wide variety of products reached 335 million tons worldwide and is estimated to have an upward trend of 1.5-2.5% on 2017 and 2018 (PlasticsEurope, 2018). High consumption of plastics exceeds the recycle rates. Most of the plastic packages are not recycled, only 14% plastics package collected for recycling, 40% of which go to landfill, 32% leaks to the environment including marine ecosystem and the other 14% plastics wastes incinerated and/or used as energy recovery (Ellen MacArthur Foundation, 2016). Recent studies indicate that plastic debris in the ocean are between 7,000 and 250,000 metric tons (Cozar et al., 2014; Eriksen et al., 2014). This prevailing condition is enough to notice that plastics have been a new potential threat to the environment. Based on the size, plastic particles in the marine environment are categorized into megaplastics (≥ 1 m), macroplastics (≥ 2.5 cm - 1 m), mesoplastics (≥ 1 mm - 2.5 cm), microplastics (≥ 1 µm - 1 mm) and nanoplastics (≤ 1 µm) (GESAMP, 2015). However, < 5 mm sized plastics are categorized as microplastics. Large sized plastics (mega and macro sized plastics) have direct external effects, such as entanglement and swallowing, not only cause damage for marine organisms (Cole et al., 2011; Gall and Thompson, 2015; Laist, 1997), but also impact the death of large marine organisms, like marine mammals, seabirds and sea turtles (Coppock et al., 2017).The effects of small sized plastic pollution (microplastics) are not apparent due to lack of research. However potential environmental risks are known, but real consequences are mostly unknown. Marine organisms are discovered accumulating microplastics (Boerger et al., 2010; Browne et al., 2008; Farrell and Nelson, 2013; Van Cauwenberghe et al., 2015; Van Cauwenberghe and Janssen, 2014). Microplastics could leach additive substances and also transfer high concentration of pollutants (Avio et al., 2015a; Paul-Pont et al., 2016).

Coral reefs, one of the richest marine habitat, have biotic ecological services as important spawning, nursery, breeding and feeding areas for a multitude of organisms (Moberg and Folke, 1999). The entry of microplastic into coral reefs ecosystem potentially threatens the living organisms. Small sized microplastics vary in colors, making marine organism (e.g., fish) mistaken it to plankton (Jovanović, 2017). Lombok is located in Indonesia which is well known as part of coral triangle regions and one of the out flow locations of the Indonesian Through Flow (ITF). In this ITF area, shipping activity is really active, that pass through the center Indonesian archipelagic. There is a possibility of microplastics flowing across the ITF and to the coral reef ecosystems in the region, especially West Lombok area. Sekotong is one district in West Lombok that has developed economic activities such as fisheries and tourism (Wildan et al., 2016). The anthropogenic activities, along with ITF effects, could be potential sources for microplastic pollution in this area. This study aims to analyze occurrence, distribution, and characteristics of microplastics in the coral reef sediment in Sekotong, Lombok, Indonesia.

6.2 Study Location, sample collection and microplastics extraction

Sediment samples were taken on east monsoon season on December 2015 by diving in coral reef habitats (depth range between 3 and 5 m) in Sekotong, Lombok Island, Indonesia (Figure 6.1). There were 10 stations spreading in the bay of Sekotong. Sediment samples (1000 g) were taken using a stainless shovel within the sediment surface (5-10 cm). The samples then were stored in the room temperature. A modified flotation methods to extract microplastic from sediment was conducted (Claessens et al., 2011; Mohamed Nor and Obbard, 2014; Thompson et al., 2004).

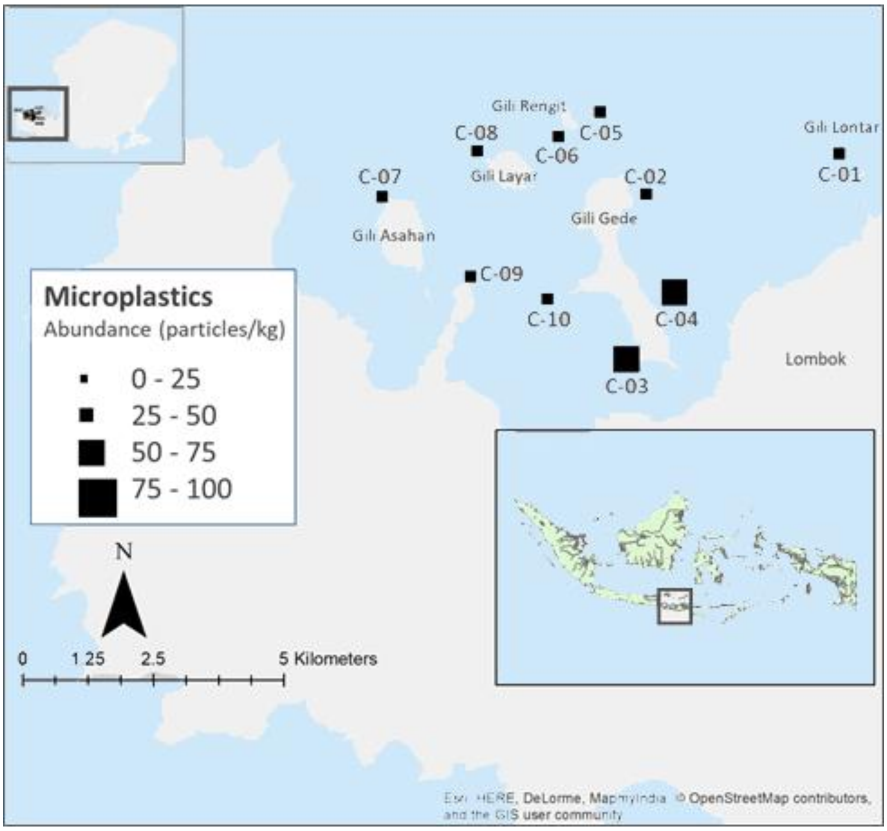

Figure 6. 1. Sampling location and microplastics abundance.

Sediment samples were dried in the oven at temperature of 75°C for 24 hours. The wet peroxide oxidation process (Masura et al., 2015) was applied to eliminate the organic matter. Samples were added with 30% H_2O_2 and heated on a hot plate (80-90°C), and then the visible froths were removed. The sediment was put on Erlenmeyer bottle with 250 mL concentrated saline solution (1.18 kg/L NaCl on double-distilled deionized water), and then was stirred using mechanical shaker (1000 rpm, 10 minutes). After 6 hours, the supernatant was extracted from the mixture, and then was filtered into Whatman cellulose filter paper (dØ: 47 mm; pore size 0.45 µm). Vacuum filtration unit was used to accelerate the filtration process. To prevent airborne contamination, filter paper were stored in petri-disk, covered with Parafilm®, within a vacuum desiccator.

6.3 Quantitative analysis and Polymer Identification

Sample observation and quantitative analysis were conducted using microscope Nikon Eclipse E600. The criteria for identifying microplastic follows Cole et al. (2013); Hidalgo-Ruz et al. (2012); Mohamed Nor and Obbard (2014), namely: (a) organic or cellular structure is absent, (b) homogenous color, it is not shiny or sparkling, (c) plastic fiber are unbranched and not tapered at the ends, (d) there is no segmented fibers. The particles which are identified as microplastic were counted and measured. Plastic polymer identification was applied using Nicolet™ iS5 FT-IR Spectrometer with diamond crystal attenuated total reflectance (ATR) based on report from Löder and Gerdts (2015), on wavenumber spectral range 650-4000 cm^{-1} at resolution 8 cm^{-1} 16 scans and an aperture 100 µm.

6.4 Microplastics Concentration in the Coral Reefs Sediment

Figure 6. 1 and Table 6. 1 show microplastics abundance in the coral reef sediment in all stations, averaging at 48.3±13.98 particles per-kg. The highest microplastic concentration was found in the C-03 at south west of Gili Gede (77 particles/kg), followed by sediment from C-04 at south east of Gili Gede Island (69 particles/kg). On the other hand, the lowest concentrations were found in two stations C-06 (Gili Rengit) and C-08 (Gili Layar), by 35 particles/kg.

Table 6. 1. Microplastics abundance and characteristic in every sites

Code	Area name	Depth (m)	Microplastics abundance (particles/kg)											
			Form				Polymer type			Size				Total
			Fb	Fr	Gr	Fm	PS	PE	PP	A	B	C	D	
C-01	Gili Lontar	3	1	10	13	23	23	10	14	2	9	12	24	47
C-02	NE Gili Gede	4	2	18	12	17	17	20	12	2	13	12	22	49
C-03	SW Gili Gede	4	1	32	18	26	26	32	19	4	15	21	37	77
C-04	SE Gili Gede	3-4	2	30	15	22	22	27	20	4	13	24	28	69
C-05	Gili Anyaran	5	3	9	23	12	12	12	23	1	13	15	18	47
C-06	Gili Rengit	5	2	11	4	18	18	11	6	2	14	15	4	35
C-07	Gili Asahan	4-5	2	16	8	17	17	16	10	1	13	9	20	43
C-08	Gili Layar	4-5	1	7	5	22	22	7	6	1	11	13	10	35
C-09	Siong	4-5	2	13	7	18	18	12	10	1	7	8	24	40
C-10	W Gili Gede	4-5	1	11	5	24	24	9	8	1	13	13	14	41
Total			17	157	110	199	199	156	128	19	121	142	201	483
Percentage (%)			3.52	32.51	22.77	41.20	41.20	32.30	26.50	3.93	25.05	29.40	41.61	100

Mark: Form category [Fb: Fiber, Fr: Fragment, Gr: Granule, Fm: Foam]; Polymer type [PS: Polystyrene, PE: Polyethylene, PP: Polypropylene]; size category [A: < 200 µm, B: 200-500 µm, C: 500-1000 µm, D: > 1000 µm].

6.5 Type of Microplastics in the Coral Reefs Sediment

Microplastic was found in four different forms, including fiber, fragment, granules, and foam (Table 6. 1). The most common form is foam, by 199 particles (41.20%), then followed by plastic fragment (157 particles, 32.51%). The south west of Gili Gede holds the highest concentration of foam form (26 particles/kg), followed by the sediment in Gili Lontar (23 foam particles/kg). In the south west of Gili Gede, the highest concentration of plastic fragment was also found (32 foam particles/kg), followed by sediment from the south east of Gili Gede (30 foam particles/kg). Based on the size of microplastics in this study, the most abundant size is more than 1000 µm (201 particles). Subsequently, 142 particles were found in size range of 500-1000 µm, then size between 200-500 µm (121 particles). Least of all, 19 particles are in the size less than 200 µm. In the south west of Gili Gede and the south east of Gili Gede, the highest size of plastic particles found is more than 1000 µm, respectively by 37 and 28 particles per-kg, and plastics particles size between 500-1000 µm (21 and 24 particles per-kg). The polymer types found was polystyrene (199 particles, 41.20%), followed by polyethylene (156 particles, 32.30%) and polypropylene (128 particles, 26.50%). In the southwest of Gili Gede, the highest polymer type was polyethylene (26 particles per-kg) and polystyrene (32 particles per-kg).

6.6 Comparison of Microplastics with Global Coastal Sediment

Microplastics comparison in coastal sediment presented in Table 6. 2. Compared to other locations, the concentration of microplastics in this study was similar to study of microplastics in mangrove area in Singapore (Mohamed Nor and Obbard, 2014) and higher from beach sediment from Norderney, Germany (Dekiff et al., 2014). Coral reef sediment in this study was less polluted than other sediment from other coastal habitats, for instance sediment in harbor, sublittoral area and beach in Belgian coast (Claessens et al., 2011), subtidal sediment from Venice Lagoon, Italy (Vianello et al., 2013), beach sediment from Slovenia (Laglbauer et al., 2014) and intertidal sediment from Halifax harbor in Nova Scotia, Canada (Mathalon and Hill, 2014).

Table 6. 2. Microplastic concentrations in coastal sediments

Location	**Origin**	**Size range (µm)**	**Microplastics concentration (particles/kg)**	**References**
Belgian coast	Harbor	> 63	167 ± 92	Claessens et al (2011)
Belgian coast	Sublittoral	> 63	97 ± 19	Claessens et al (2011)
Belgian coast	Beach	> 63	93 ± 38	Claessens et al (2011)
Singapore	Mangrove	< 20-5000 <	37 ± 24	Mohamed Nor & Obbard (2014)
Venice Lagoon, Italy	Subtidal	30-5000	1445 ± 460	Vianello et al (2013)
Norderney, Germany	Beach	100-1000	4	Dekiff et al (2014)
Slovenia	Beach	250-5000	156	Laglbauer et al (2014)
Nova Scotia, Canada	Harbor	> 50	200-800	Mathalon & Hill (2014)
Sekotong, Indonesia	Coral reefs	< 200-5000 <	48.3 ± 13.98	This study

Microplastic particles found in all study sites are presumably derived from anthropogenic activities on main land of Lombok, such as tourism and fisheries. (Wildan et al., 2016) reported tourism sector is the second biggest contributor to the West Lombok's Regional Gross of Domestic Product and it has an ascending trend from 2012 to 2013, increase by 43.07%. Furthermore, this condition might be likely attributable to ocean current-driven microplastic that contains plastic waste (Mohamed Nor and Obbard, 2014). Hence, ITF in this area could be possibly as a source of microplastics.

Shipping is suspected as a source of plastics debris in this area. There are about 3900 ships (~140 million metric tons) that pass through the center Indonesian archipelagic, crossing from Sulawesi Sea, Makassar Strait, Flores Sea, Lombok Strait; and transit in Lombok Strait annually (Shicun and Keyuan, 2009). This result is consistent with a statement that indicates the area near the port or vessel traffic has high presence of microplastic (Claessens et al., 2011). In general, microplastics in Sekotong coral reef sediment were on lower magnitude from other sediment from coastal area, except from Singapore and Norderney, Germany. Plastics' sources were predicted in shoreline come from local resident activities and tourism. Generally, fishermen use polystyrene block to float their nets. Whereas, tourism and local residents often discard plastic bags and trash on the recreational beaches. Plastic waste could also be discharged from the mainland through the river system as found in Cilacap (Indonesia) coastal area (Syakti et al., 2017). Andrady (2011) and Cole et al. (2011) estimated fishing and aquaculture activities contribute a small portion (18%), while land-based activities take the bulk of main source of microplastics in the ocean (~80%). Passing ships also discard macroplastics in the ocean. Although there are some national and international regulations controlling this prevailing issue, this issue is still difficult to address globally and locally (Čulin and Bielić, 2016).

6.7 Polymer Composition of Microplastics

Three polymer types were found in this area. Highest microplastic forms were foam which is fully polystyrene. Polystyrene (styrofoam) is one of the most widely used plastics. Polystyrene usage includes food, beverage and fish containers, protective packaging, lids, bottles, trays, tumblers, and disposable cutlery (Wünsch and Rapra Technology Limited., 2000). Other forms of microplastics found were fragment, granule and fiber; these are categorized as polypropylene and polyethylene. Polypropylene has the highest melting point, the lowest density and excellent chemical resistance. Furthermore, it has an important use as fiber (textiles), also packaging and labeling, stationery, plastic parts and reusable containers of various types, laboratory equipment, loudspeakers, automotive components, and polymer banknotes (Allahvaisi, 2017; Arutchelvi et al., 2008; Miller, 1990). Polyethylene is the most common plastic, used in packaging such as plastics bottle, plastics container, plastic bags, and plastic films (Arutchelvi et al., 2008; Roy et al., 2011). Microplastics found in coral reef sediment in Sekotong, Lombok were assumed mainly derived from anthropogenic activities as the most present microplastics found were more than 1000 µm (41.61%) and 41.20% of which were styrofoam.

6.8 Potential threats plastic pollution to coral reefs

Although covering less than 1% of the ocean surface, coral reef ecosystems have an essential role in the ocean because it has a high complexity, high biodiversity, and high productivity. (Moberg and Folke, 1999). The coral reef ecosystem's role is marine biodiversity preservation, global climate mitigation, and human harvesting of natural resources and livelihoods of more than 500 million people whose lives are directly or indirectly associated with coral reefs (Hoegh-Guldberg et al., 2017; Hughes et al., 2018; Spalding and Brown, 2015). Besides, millions of dollars in industries (including fisheries and tourism) rely on healthy coral reef ecosystems (Cesar, 2002). However, coral reefs are vulnerable to the combination of natural disasters and human activities. Different influences affect coral reefs, including climate change, ocean acidification, marine pollution, diseases, and plastic pollution (Abu-Hilal and Al-Najjar, 2009; Halpern et al., 2007; Hughes et al., 2018; Moberg and Folke, 1999).

Owing to its diverse interactions, plastic contamination can be considered an emerging threat to coral reefs (Yoshikawa and Asoh, 2004). An estimated 11,1 billion plastic debris had been "trapped" in coral reefs, with a projected 40% increase by 2025 (Lamb et al., 2018). Plastic litter may lead to physical abrasions and coral tissue injuries (Feng et al., 2020; Lamb et al., 2016). Plastic pollution is able to promote pathogens and ciliated protozoa invasion, which causes coral disease (Chapron et al., 2018; Feng et al., 2020; Goldstein et al., 2014). Moreover, the main interactions between microplastics and corals have been demonstrated by laboratory evidence as microplastic active ingestion and passive surface adhesion (Hall et al., 2015; Mouchi et al., 2019; Reichert et al., 2018; Rotjan et al., 2019; Syakti et al., 2019). Plastics may also cause foreign microbial communities (e.g., coral opportunist pathogens) and may disturb the host-symbiont's relationships (Feng et al., 2020; Okubo et al., 2020, 2018). In addition, microplastics' combined effects with related chemicals and coupled climate change impacts on the coral reef environment are increasingly gaining attention (Aminot et al., 2020; Su et al., 2020).

Plastic pollution affects the economic productivity of coral reefs and preserves and protects reefs will provide the local populations that utilize the coral reef's ecosystem, high economic benefits. Degraded coral reef habitats decrease species structure, composition and, richness (Thushari and Senevirathna, 2020). This finding's economic impact can be linked to reducing fishery productivity because plastic debris can interfere with seafood sources' feeding and nursery grounds (Global Environment Facility, 2012). In addition, the presence of plastic in the coral reef environment and damaged ecosystems may reduce the number of tourists due to loss of aesthetic value and attraction (Thushari and Senevirathna, 2020). Marine plastic debris can also cause navigational hazards for fisheries and shipping to result in a direct loss of income and a high cleanup cost (UNEP, 2016). However, the potential societal and economic impacts of plastics on coral reefs is still an open topic. Thus, it is imperative to invest in monitoring and research to address knowledge gaps, such as understanding human exposure and health impact of consuming microplastics in coral reef organisms, and the economic impacts of marine plastic litter and microplastics on reef dependent businesses and societies.

6.9 Remarks of Chapter 6

The frequent and high use of plastics in daily activities is inevitable and thus may result in highly microplastic-contaminated water. Furthermore, water current may exacerbate the negative impact by driving and accumulating the microplastics in the areas in which the current pass through. Although the adverse effects on human are not yet studied, the effects can be utterly lethal to marine organisms which are parts of our food chains.

This evidence can be a marker of additional pollution risk to organisms living in this region. It is necessary to undertake additional studies of microplastic emissions on coral reefs in more detail, on water and sediments over a period of time, to see the potential of microplastic contamination in coral reef areas. In this case, management of plastic waste is strongly suggested to be improved, particularly plastics debris from polystyrene, polypropylene, and polyethylene-based. It is essential to develop an environmentally friendly substance to replace plastics in near future.

Chapter 7 Microplastics Ingestion by Blue Panchax Fish (*Aplocheilus* sp.) from Ciliwung Estuary, Jakarta, Indonesia

7.1 Introduction

The imbalance between recycling management and the production of plastics has negative consequences. Meanwhile, an estimated 348 million tons of plastics was produced worldwide (PlasticsEurope, 2018), and only approximately 14% of that quantity was recycled. The Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2016) reported that most of the plastic (40%) ended up in landfills and 32% entered the environment, with the highest quantity being mostly in the marine environment. A study estimated that 4.8-12.7 million metric tons of plastic waste are dumped into oceans across the world annually (Jambeck et al., 2015a), which adds to an estimated 5 trillion metric tons previously reported (Cozar et al., 2014; Eriksen et al., 2014). The accumulated plastic in the ocean is degraded into smaller pieces due to physical, mechanical, chemical, and biological processes (Andrady, 2011), and its debris are mistaken as food by marine biota (Browne et al., 2008). Furthermore, microplastics (microscopic size of plastic) are currently a complex issue that must be tackled as their indirect consumption results in digestive system disease. Moreover, hazardous pollutants such as POPs and heavy metals are transferred to the organs of biota (Brennecke et al., 2016; Hirai et al., 2011; Purwiyanto et al., 2020; Rochman et al., 2014), and this is hazardous to both fish and humans. Furthermore, the estuary of Ciliwung River and the North Jakarta coastal area are waters that are prone to contamination by microplastics.

The Ciliwung River flows along a length of 120 km, with a watershed area of 438.25 km^2, and starting from the upstream point to the Jakarta Bay, it passes the residential, industrial, and domestic activities areas (Pemerintah Provinsi Daerah Khusus Ibukota Jakarta, 2016). Unfortunately, Ciliwung received the most pollutants in Jakarta due to the high anthropogenic effect in the area (Riani et al., 2018). Furthermore, the northern part of Jakarta is a coastal area, where the land is directly adjacent to the sea. This part consists of 6 sub-districts and 31 villages (kelurahan) with a length of 35 km and a total area of approximately 146.6 km^2. The Northern coastal area, which includes 12 tourist destinations is vital for Jakarta's economic growth (Rahayu et al., 2016). The area that represents this region is the Ancol coast, which is an integrated tourist center with more than 17 million excursionists annually. (BPS Provinsi DKI Jakarta, 2019). In addition, Ancol is located close to Tanjung Priok Port, which is the busiest Indonesian seaport. It serves as a local port for a trip to Seribu Island and fishing port such as Cilincing, Marina Ancol, Muara Baru, and Muara Angke. Furthermore, tourism-based practices and effluent disposal from hotels and restaurants along the tourist destinations constitute the source of plastic waste, including microplastics (Retama et al., 2016). In addition to inadequate waste management (Satmoko, 2016), the damage is also compounded by plastic waste disposal. Cordova and Nurhati (2019) and Mani et al. (2015) reported that a large number of activities in the watershed increases microplastics in the river estuary and coastal area, which is carried to the sea. Therefore, microplastics pollution in Jakarta Bay, which is derived from the waste entering Ciliwung river-estuary and its coastal area, negatively affects the biota living in this ecosystem. Furthermore, one of the most common fish in Ciliwung and Ancol coast is Blue panchax fish (*Aplocheilus* sp.) (Hadiaty, 2011).

The *Aplocheilus* sp. is a type of euryhaline that survives in a salinity range of freshwater to estuary (Chakraborty et al., 2008; Gupta and Banerjee, 2013). In terms of its ecological role, it feeds on plankton and mosquito larvae. Unfortunately, microplastics are often mistaken as food by planktivorous fish (Holmes et al., 2014; Zbyszewski and Corcoran, 2011). Therefore, there is a high potential for the consumption of microplastics by *Aplocheilus* sp. that live in Ciliwung. Additionally, *Aplocheilus* sp. is a type of carnivorous fish (Madhavi, 1980) which tends to be omnivorous (Fernando et al., 2015; Jacob and Nair, 1982). In the river and coastal ecosystems, *Aplocheilus* sp. is at the second or third trophic level of the food chain (Hadiaty, 2011) and it has a high potential risk of microplastics bioaccumulation due to its omnivorous feeding behavior (McNeish et al., 2018; Mizraji et al., 2017) as well as biomagnification for the highest-level consumers (Akhbarizadeh et al., 2019; Au et al., 2017; Van der Oost et al., 2003). However, there is limited information regarding this issue. Consequently, it is necessary to conduct research concerning microplastic ingestion in *Aplocheilus* sp. in Ciliwung Estuary. Therefore, this study aimed to confirm the accumulation of microplastic by small-size consumers, such as *Aplocheilus* sp., and to estimate the number of microplastics ingested by *Aplocheilus* sp.

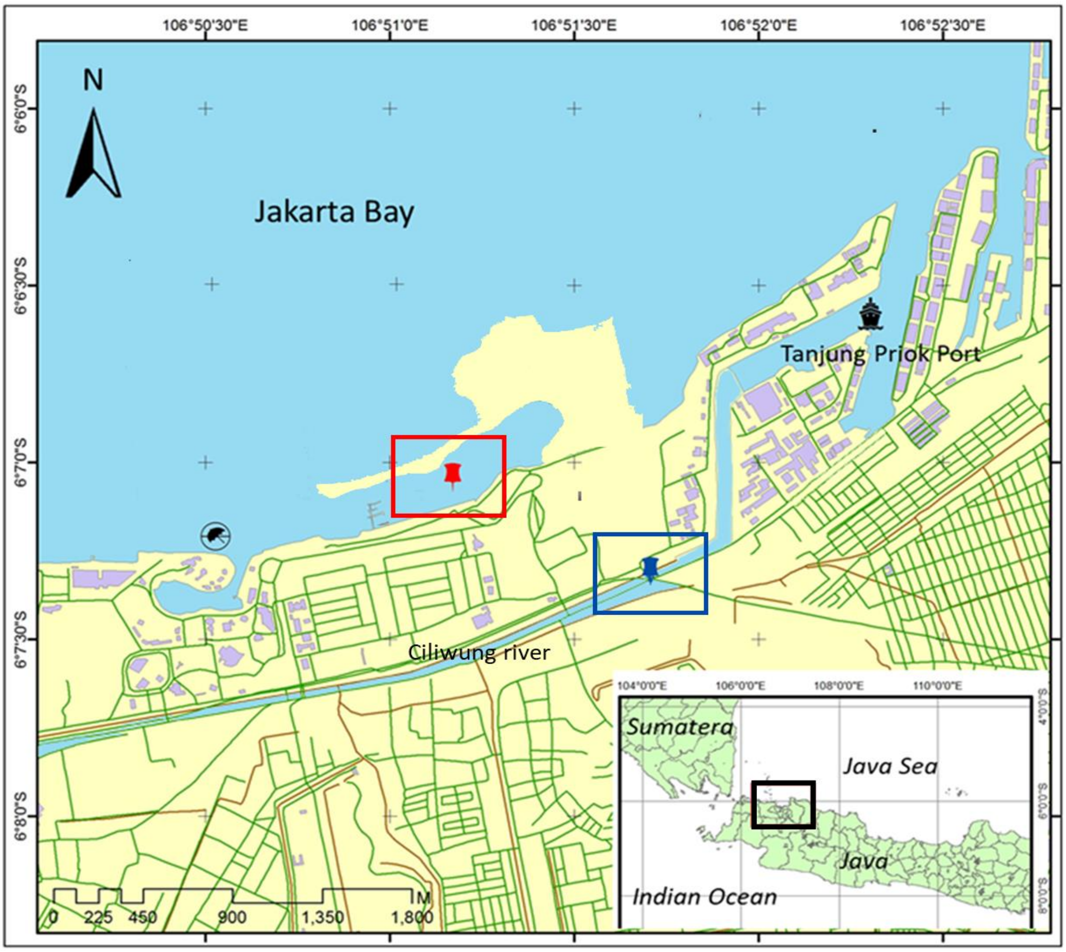

Figure 7. 1. Study location. Bluepoint and box indicate sampling area in the estuary of Ciliwung, and redpoint and box indicate sampling area in the coast of North Jakarta.

7.2 Water and fish sampling

In April 2018 (transition season from west to east monsoon), samples of water and *Aplocheilus* sp. were obtained to estimate the level of plastic accumulation. The water samples were collected from the fish habitat in the river-estuary of Ciliwung and the coastal area of North Jakarta (Ancol coast) using a manta trawl net with 450 cm^2 opening and 80 µm mesh size (Figure 7. 1). The manta trawl was installed in the opposite direction of the river flow at low tide with trawling involving five repetitions (Michida et al., 2019). Additionally, the water samples in the coastal area were obtained using a manta trawl net installed on the side of the boat with 3 knots speed for 5-6 minutes per sampling session and repeated three times. Subsequently, water samples were placed in sterile glass bottles and tightly sealed using Parafilm®. Furthermore, *Aplocheilus* sp. samples were collected randomly in the Ciliwung river estuary and coastal area of North Jakarta using 2.5 mm mesh size of larva nets (Collard et al., 2017). They were preserved in the sterile glass bottles containing 90% filtered ethanol, which were closed immediately to prevent microplastic airborne contamination (Barrows et al., 2017). In addition, the standard body length (cm) of each fish was recorded in the laboratory and the body size of 60 ranges from 0.7-2.5 (average = 1.75 cm).

7.3 Laboratory analysis: extraction and identification

The microplastic extraction procedures in the water and fish sample were adopted from the method proposed by Masura et al. (2015), Mathalon and Hill (2014), and Lusher et al. (2017b). The water sample was filtered using a Ø300 µm pore of sieve shaker and was subjected to a wet peroxide oxidation digestion procedure (Cordova et al., 2019; Gewert et al., 2017; Masura et al., 2015) in a test tube with a screw cap (Iwaki Pyrex). Furthermore, 5-10 ml of 30% H_2O_2 (Merck Millipore Emprove®) were added to the sample and left overnight for the incubation process. Further, the fish samples were rinsed using purified water (reverse osmosis water with a sterile filter paper; Sartorius A.C.N., 0.45 µm pore size, Ø47 mm, Cat 11406) to eliminate any possible particles attached to the fish body surface as in Karami et al. (2017). Subsequently, the entire body of the fish was transferred into a test tube with a screw cap. This was to include in the study all microplastics in its organs such as its gills, gastrointestinal tract, muscle, and tissue (Barboza et al., 2020; Lusher et al., 2017b). Afterwards, the sample was dried in an oven for 24 hours at 80°C, and then 5-10 ml of 30% H_2O_2 was added as an oxidizing agent to digest the body (Avio et al., 2015b). The samples were left overnight, and then the incubation processes was carried out. Additionally, both samples in the test tube were incubated in a fume hood with a water bath (B-One DWBC-30L-6H) at 60°C for 36-48 hours or until the sample became clear. The samples were then filtered using sterile filter paper with the help of a vacuum pump (Vacuubrand ME 2C) at a pressure setting of 30 mbar. Before the next stage of microplastics identification, the filtered sample was moved to a sterile petri dish (Chazuru CLW E09) and sealed using Parafilm®.

Furthermore, a filtered sample was observed using a Nikon DF-12 stereo microscope at 4-40x magnification with a camera connected to the computer. The identification procedure was based on Cole et al. (2013) and Noren (2011) protocol, wherein no organic structures were tapered towards the end with specific particles and homogeneously colored. The result was then categorized into form including fragments, fibers, foam, and granules (Figure 7. 2), as well as size ranges including 300-500 µm, 500-1000 µm, and >1000 µm (Cordova et al., 2019; Sutton et al., 2016). Fragments have a rigid, often irregular form e.g., circular, subround, angular, or subangular, can be any color combination (Figure 7. 2a). The fragments are in a form of break-apart plastic/debris. The foams included the Styrofoam category, which has characteristics cloud-like, compressible and soft, regularly white but can be another color (Figure 7. 2b). The fibers are thread-like materials. Fibers are versatile, with equal thickness, clean-cut, pointing, or fraying ends, available in various colors that, due to bleaching, can be inconsistent in one particle (Figure 7. 2c). Granules known as spheres or pellets or nurdles have characteristics that can be any color, round, cylindrical, or half fraction, in shape with smooth surfaces (Figure 7. 2d).

7.4 Precaution on contamination

The Precautions were set up to minimize the airborne microplastic contamination, according to previous research (Lusher et al., 2017; Nuelle et al., 2014; Purwiyanto et al., 2020). Latex masks and gloves were worn (Sensi Gloves® sterile, non-polymer) during the sampling and analysis. All the sampled bottles and glassware were washed and rinsed with liquid water purified by Reverse Osmosis Liquid with sterile filter paper and parafilm®-covered glassware and sample equipment. Furthermore, procedural blank (Van Cauwenberghe and Janssen, 2014) was made by placing uncovered sterile Petri dishes close to the sample during the extraction process until the end of identification. The results were contamination-free, especially from fibers (a material commonly used in clothing) and other types of microplastic particles. The particles were randomized (n=30) to identify the polymer type and to ensure that they were microplastics. In addition, the identification used Nicolet™ iS5 FT-IR Spectrometer with the diamond crystal of Thermo Scientific™ iD5 attenuated total reflectance (ATR) accessory and then passed through Omnic™ Software correction. FT-IR was operated referring to Löder dan Gerdts (2015) in a mode of single reflection, with 8 cm^{-1} resolution, 32 scans per analysis, and ranging from 600 to 3800 cm^{-1}. Additionally, quality control for the polymeric material of plastic was done by comparing the spectrum of particles found with polymer standard of Thermo-scientific, Shimadzu, and plastic standard from Research Centre for Geosciences, University of Bayreuth, Germany.

7.5 Statistical analysis

The abundance of microplastics in the river estuary, coastal area, and *Aplocheilus* sp. were analyzed using descriptive statistics. Surface water microplastic concentration among sites compared using one-way ANOVA. Moreover, linear regression analyses were conducted between fish microplastic concentration and surface water microplastic concentration; and between fish microplastic concentration and fish body length. All statistical analyses were performed with PAST 3 (version 3.14, Hammer et al., 2001).

7.6 Microplastic in river-estuary and coastal water

Microplastics (Figure 7. 1) were found in estuary and coastal water (Table 7. 1), as well as *Aplocheilus* sp. (Table 7. 3). All categories of forms and sizes were also found in water and *Aplocheilus* sp. (Figure 7. 2). The average microplastic concentration in Ciliwung estuary was 9.37 $\pm$ 1.37 particles/m^3, while in the coastal water of North Jakarta, it was 8.48 $\pm$ 9.43 particles/m^3. In addition, the dominant forms surveyed both in the estuary and coastal water were fragments of 53.31% and 44.20%, respectively. Fiber (34.3%) was the second dominant form in the estuary, similar to foam (21.48%) in the coastal water (Table 7. 1). Furthermore, based on the size variation (Table 7. 2), microplastics greater than 1000 µm were dominant in both estuary (47.34%) and coastal water (55.80%).

Table 7. 1 showed the microplastic composition in various forms in the estuary, which include fragments (53.31%), fibers (34.30%), granules (7.25%), and foam (5.14%). The highest concentration was fragments with 5.04 particle/m^3, while the lowest was foam with 0.47 particle/m^3. Further, the composition result looks similar in coastal water; this includes fragments (45.80%), foam (21.48%), granules (19.01%), and fibers (15.31%). The highest concentration in coastal water was of fragments with 3.29 particle/m^3, while the lowest was of granules with 0.72 particle/m^3. In addition, the high result of fragments and fibers in Ciliwung estuary is related to the anthropogenic activities around the area and the watershed, which is actively flooded by plastic waste. It is also due to the discharged or stored wastes along the banks of the river, which ultimately fall or are drained with rainwater into the river (Riani and Cordova, 2018). This hypothesis is also supported by the result of polymers' analysis at the study location using FT-IR. The identification of microplastic scheme based on studies from Käppler et al. (2015) and Löder et al. (2015) by five band region (Figure 7. 3), i.e. 2780-2980 cm^{-1} (stretching vibrations of $CH/CH_2/CH_3$ groups), 1740-1800 cm^{-1} (C=O stretching vibration), 1670-1760 cm^{-1} (C=O stretching vibration), 1400–1480 cm^{-1} (CH_2 bending vibration), 1174–1087 cm^{-1} (CF_2 stretching vibration). The result showed the dominant materials found which include polyethylene (n=10, 33.3%), polypropylene (n=9, 30%), polystyrene (n=7, 23.3), polyester (n=3, 10%), and cellophane (n=1, 3.3%). These types of polymer materials characterized the plastic waste in the river as resulting from anthropogenic activity (Cordova et al., 2019; Cordova and Nurhati, 2019; Falahudin et al., 2020; Purwiyanto et al., 2020; Syakti et al., 2018, 2017).

Table 7. 1. The abundance of microplastics in various shapes and sizes in the estuary and coastal water

Shape	**Concentration (particles/m^3)**		**Size (µm)**	**Concentration (particles/m^3)**	
	Estuary	**Coastal water**		**Estuary**	**Coastal water**
Foam	0.47 ± 0.41	2.50 ± 3.40	300-500	2.77 ± 1.14	1.79 ± 2.18
Fragment	5.04 ± 1.99	3.29 ± 3.36	500-1000	2.01 ± 0.72	2.15 ± 2.47
Fiber	3.19 ± 1.66	1.97 ± 1.97	>1000	4.60 ± 2.65	4.54 ± 4.80
Granule	0.68 ± 0.32	0.72 ± 0.72			
Average	9.37 ± 1.37	8.48 ± 9.43		9.37 ± 1.37	8.48 ± 9.43

The size composition in the estuary was predominantly 1000 µm and above (47.34%), followed by 300-500 µm (30.22%) and 500-1000 µm (22.44%). Furthermore, the size >1000 µm was predominant with a concentration of 4.6 particles/m^3, while the lowest range was 500-1000 µm with 2.01 particles/m^3. In addition, the sizes of microplastics in coastal water were similar to the estuary, where 1000 µm and above was dominant by 55.80%, followed by 500-1000 µm by 26.42%, and 300-500 µm by 17.78%. The microplastic concentration of the size >1000 µm was 4.6 particles/m^3, while the lowest was 300-500µm with 1.79 particles/m^3. In this study, it was assumed that the high concentration of microplastics with a size >1000 µm is due to the limited time taken by the waste entering Ciliwung to degrade into smaller pieces.

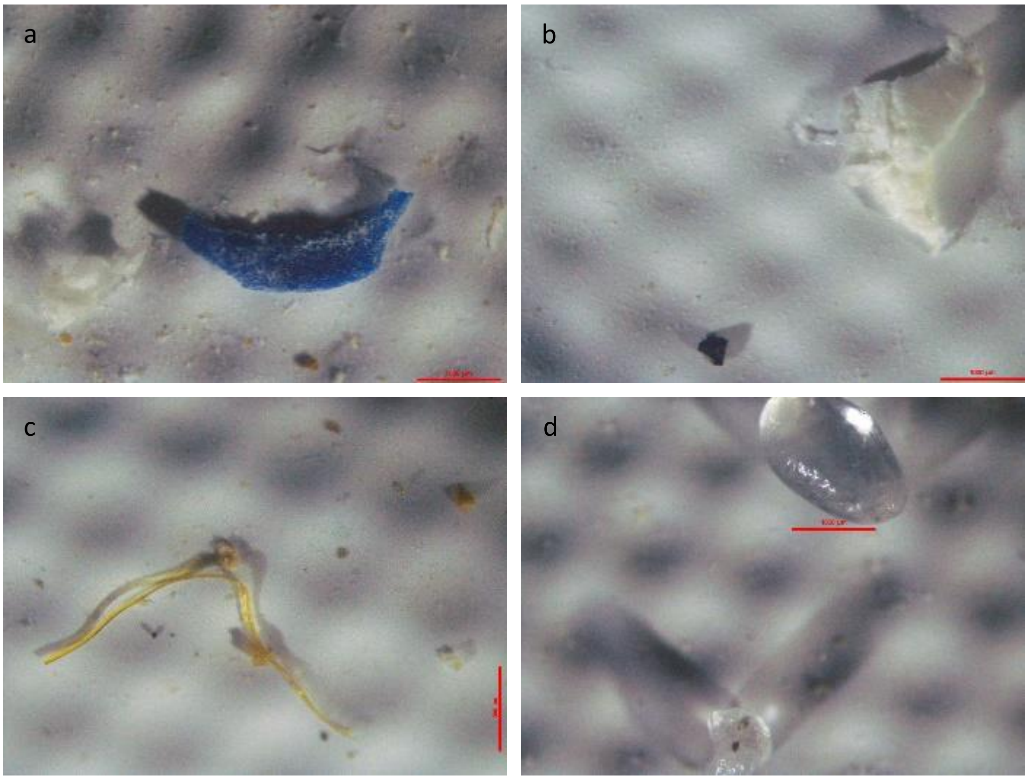

Figure 7. 2. Microplastic in Ciliwung estuary, coastal of North Jakarta, and *Aplocheilus* sp. Scale: 1000 µm

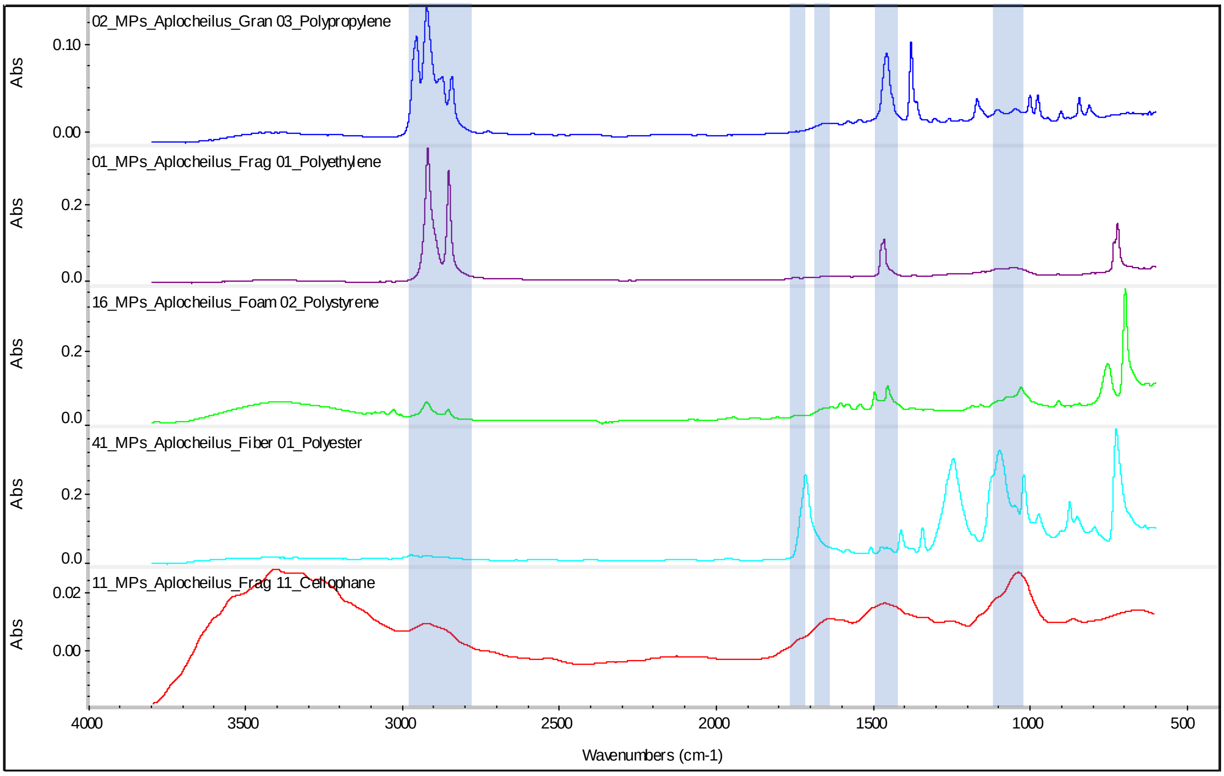

Figure 7. 3. Five types of microplastic particles FTIR spectra result.

The result of microplastic abundance at the estuary of the Ciliwung River and the coastal area of Northern Jakarta was still relatively lower compared to other countries and relatively higher in comparison to other Indonesian areas (Table 7. 2). In this case, the average in Ciliwung estuary was lower than Saigon River (Lahens et al., 2018) and Yangtze estuary (Zhao et al., 2014); however, it was higher than Isipingo estuary (Naidoo et al., 2015) and Seine River (Dris et al., 2018). Additionally, when compared to Indonesian river-estuaries, Ciliwung was higher than the downstream area of the Citarum river (Sembiring et al., 2020). However, microplastic concentration in the study location was lower than the downstream area of Surabaya river (Lestari et al., 2020). Furthermore, microplastic abundance in the coastal area of North Jakarta was higher than that of Israel (van der Hal et al., 2017), Stockholm Island (Gewert et al., 2017), Southern California (Lattin et al., 2004), and Victoria Harbour (Tsang et al., 2017). Further, when compared to the Indonesian coastal area, North Jakarta has a higher concentration of microplastic in the Cilacap (Syakti et al., 2017) and Bintan coastal areas (Syakti et al., 2018).

Table 7. 2. The abundance of microplastic in several estuaries and coastal waters

Area	**Site Location**	**Average concentration (particles/m^3)**	**Reference**
Estuarine/ mouth of the river	Saigon, Vietnam	295,500	Lahens et al. (2018)
	Yangtze, China	4137.3	Zhao et al. (2014)
	Isipingo, South Africa	3.1	Naidoo et al. (2015)
	Seine, France	0.35	Dris et al. (2015)
	Surabaya, Indonesia	16.03	Lestari et al. (2020)
	Citarum, Bekasi, Indonesia	0.06	Sembiring et al. (2020)
	Ciliwung, Jakarta, Indonesia	9.37	This study
Coastal water	Israel	7.68	van der Hal et al. (2017)
	Stockholm Islands, Sweden	5.26	Gewert et al. (2017)
	Southern California, US	3.92	Lattin et al. (2004)
	Victoria Harbor, Hong Kong	0.35	Tsang et al. (2017)
	Cilacap, Indonesia	0.54	Syakti et al. (2017)
	Bintan, Indonesia	0.45	Syakti et al. (2018)
	North Jakarta, Indonesia	8.48	This study

7.7 Microplastic ingestion in blue panchax fish

The results showed that microplastics were detected in the body of 75% of the total samples of *Aplocheilus* sp. Meanwhile, the average microplastic concentration of all fish samples collected was 1.97 particles/individual (Table 7. 3). The microplastics were in the form of fragments and fibers. Fibers were the dominant form with a composition of 46.61% and presence of 0.92 $\pm$ 1.03 particles/individual. Fragments were the second, with a composition of 39.83% and a concentration of 0.78 $\pm$ 1.75 particles/individual. The sizes of the dominant microplastics found in *Aplocheilus* sp. were 300-500 µm and >1000 µm with concentrations of 0.8 $\pm$ 1.23 (40.68%) and 0.65 $\pm$ 0.76 particles/individual (33.05%), respectively. Furthermore, linear regression analyses were conducted between microplastic concentration in fish and surface water. Additionally, analyses between microplastic concentration in the fish and fish body length were also conducted, and the analyses showed a weak positive correlation between both variables (r^2=0.05; p = 0.16 in river-estuary and r^2=0.05; p = 0.18 in the coastal area). A weak positive correlation indicates that there is a low link between surface water and microplastic concentration in fish, even though both variables appear to increase in response to each other. Additionally, the abundance of microplastics in fish showed a low positive correlation with an increase in body size, although the model explained a small portion of the variation in the data (r^2 = 0.04; ρ=0.21). In this case, the trend of increased concentrations with body size is not very strong.

Table 7. 3. The abundance of microplastic in *Aplocheilus* sp.

Shape	**Concentration (particles/individual)**	**Composition (%)**	**Size (µm)**	**Concentration (particles/ individual)**	**Composition (%)**
Foam	0.15 ± 0.55	7.63	300-500	0.8 ± 1.23	40.68
Fragment	0.78 ± 1.75	39.83	500-1000	0.52 ± 1.20	26.27
Fiber	0.92 ± 1.03	46.61	>1000	0.65 ± 0.76	33.05
Granule	0.12 ± 0.37	5.93			
Average	1.97	100		1.97	100

Table 7. 4. The abundance of microplastics in fish with relatively similar size and habitat with other studies

Location	**Sample (species)**	**Average concentration ± standard deviation (particles/individual)**	**% sample containing microplastic**	**Reference**
River Thames, UK	*Rutilus rutilus*	0.69 ± 1.25	32.8%	Horton et al. (2018)
French Rivers, France	*Gobio gobio*	n.a	12%	Sanchez et al. (2014)
Flemish rivers, Belgium	*Gobio gobio*	n.a	9%	Slootmaekers et al. (2019)
Río de la Plata, Argentina	*Astyanax rutilus*	n.a	100%	Pazos et al. (2017)
Pajeu River, Brazil	*Hoplosternum littorale*	3.6	83%	Silva-Cavalcanti et al. (2017)
Yangtze estuary, China	*Pseudorasbora parva*	2.5	n.a	Jabeen et al. (2017)
Ciliwung estuary	*Aplocheilus* sp.	1.96	75%	This study

Furthermore, the abundance of microplastics in *Aplocheilus* sp. was relatively high compared to other fish living in similar length and living habitat (estuary and coastal water) in other locations (Table 7. 4). The percentage of *Aplocheilus* sp. samples containing microplastics (75%) was lower than *Hoplosternum littorale* from Pajeu River, Brazil (83%), and *Astyanax rutilus* from Río de la Plata estuary in South America. However, it is higher than *Rutilus Rutilus* from Thames River (32.8%) and *Gobio gobio* from French (12%) and Flemish rivers (9%). Furthermore, in comparison to the larger body size of *Pseudorasbora parva* with an average body length of 14.5 cm (2.5 particles/individual), the microplastic in the *Aplocheilus* sp. was still relatively lower. However, it was subjected to higher contamination pressures due to larger microplastic contamination in the surface water of its habitat. Therefore, a more in-depth study and periodic monitoring are needed to assess the impact.

7.8 Microplastic implication in the marine coastal ecosystem and in the fish

The discovery of waterborne microplastics in Ciliwung river-estuary and coastal water in North Jakarta resulted in *Aplocheilus* sp. being exposed by microplastic. This finding is due to plastic waste disposal from land activity. The Ciliwung watershed passes through residential and industrial areas and is the site of domestic activities (Costa et al., 2016; Dsikowitzky et al., 2018; Satmoko, 2016). Therefore, without proper waste management, it will be a direct route of plastic disposal into the river and coast. This is in accordance with Lahens et al. (2018) and Medrano et al. (2015) who reported that the primary microplastics in the ocean came from the rivers that pass through cities and industrial areas. Furthermore, primary microplastic includes small-sized manufactured plastic such as microbeads (GESAMP, 2015). The term "Microbead" is used to describe microplastic particles that are present as additional ingredients in cosmetic products and synthetic fabrics (Cole et al., 2011; Mohamed Nor and Obbard, 2014; Sutton et al., 2016). Other sources of microplastics include the plastics which are directly discharged to the environment and then degraded by solar radiation, wave action, and bacterial activity (Arutchelvi et al., 2008; Horton et al., 2017; Muthukumar and Veerappapillai, 2015; Rånby, 1989; Zettler et al., 2013).

Furthermore, the average of the abundance of microplastics in the river-estuary is higher than in coastal water. Additionally, the results of this research are in accordance with Xu et al. (2020), who reported that the accumulation of microplastics in a river estuary was higher than in coastal areas. In addition, the increased deposition of microplastics in Ciliwung river estuary is caused by different factors, which include turbulence and salinity (Xu et al., 2020). In addition, an estuary is the convergence of fresh and saltwater which accumulates various materials and contaminants (McLusky, 1989). Microplastic accumulates in estuary sediments due to the continuous flow of freshwater in rivers containing microplastics (Simon-Sánchez et al., 2019).

The concentration of microplastics in the Northern Jakarta coastal area is relatively higher than the Ciliwung river estuarine region. However, there is no significant difference between the two locations ($\rho>0.05$). It was possibly linked to the sampling site on the Ancol coast, which was semi-isolated and blocked by the land reclamation project (Figure 7. 1). Furthermore, the potential sources of microplastics in the coastal area of the North Jakarta area are activities in the tourism sites and ports (Cordova, 2020; Laglbauer et al., 2014; Retama et al., 2016), as well as industrial operation in and around the port environments (Hitchcock and Mitrovic, 2019; Jahan et al., 2019).

Furthermore, the various forms and sizes of microplastics (Figure 7. 2) found are an indication of various anthropogenic sources (McCormick et al., 2016). These forms were classified into four categories with a relatively similar result on average. The fragment is the dominant category in both estuary and coastal areas. It was suspected that the source of the microplastic fragment is the degradation of large plastic. During the investigation, large plastics were discovered in both locations; these include bags, containers, food wrappers, waste from tourism activity, and pieces of fishing nets.

Furthermore, due to natural weathering, biological deterioration, and physical stress, the large plastic wastes become brittle and are easily divided into smaller pieces (Baldwin et al., 2016; Pichel et al., 2012; Ryan et al., 2009; Teuten et al., 2009). Additionally, fibers, as the second dominant form in Ciliwung estuary, generally come from clothing material, ropes, and fishing lines (Gallagher et al., 2016; Mohamed Nor and Obbard, 2014). In Ciliwung estuary, it is assumed to come from household waste from washing activity (Eerkes-Medrano et al., 2015). Foam is the second dominant form in the coastal area of Northern Jakarta and is related to waste generated from boat trips taken by tourists including buoy boat, food containers, fish storage/box, handicrafts, ornaments, and single-use Styrofoam (Cordova et al., 2018; Čulin and Bielić, 2016; Jang et al., 2016).

Furthermore, microplastics with sizes >1000 µm were predominant, while the remaining were in the ranges of 300-500 and 500-1000 µm. According to Mohamed Nor and Obbard (2014), the sizes of microplastics can illustrate the potential effect on biota. Additionally, the occurrence of the ingestion of microplastics increased as the size of microplastics decreased. Meanwhile, the variation in size of microplastics in both locations is caused by solar radiation. However, in the coastal region and ocean, variation in size is also caused by wave action. This is in accordance with Horton et al. (2017), who state that the primary factors affecting plastic degradation in the waters are solar radiation and wave action. Moreover, ultraviolet at 400-2900 nm in solar radiation loosen the chemical bond in polymers, reduce molecular weight, and change its physical composition (Rånby, 1989; Shah et al., 2008), and then the wave breaks the polymer bond into smaller sizes (Shah et al., 2008). The effectiveness of plastic degradation is also affected by other factors such as the intensity of solar radiation, season, and geographical condition (Crawford and Quinn, 2017a; Shah et al., 2008; Singh and Sharma, 2008). Nevertheless, the plastic degradation rate is not understood in the marine environment (Crawford and Quinn, 2017b), and therefore a comprehensive study is required.

The microplastics ingested by *Aplocheilus* sp. were relatively high (75%), with the dominant form being fibers (46.61%, an average of 2.75 particles/individual) and dominant size of 300-500 µm. This fiber is relatively smooth and flexible compared to fragments or granules (Silva-Cavalcanti et al., 2017). Furthermore, the results are consistent with Bessa et al. (2018) and Horton et al. (2018), who described the domination of fibers among microplastics that are ingested by fish. Further, microplastics of the size range 300-500 µm were dominantly present (40.68%) in the body of *Aplocheilus* sp., illustrating the difficulty of the fish in distinguishing plastic from food (Cole et al., 2011). The small size causes the plastic to potentially accumulate in the body of the biota (Schuyler et al., 2012). Schuyler et al. (2012) stated that the body size of an organism affects the characterization of plastic found in their bodies. Furthermore, Gupta and Banerjee (2013) stated that feed preferences should be higher with increased body size. However, based on the result in this study, microplastic abundance within fish had a weak positive relationship with its body length. This result is consistent with McNeish et al. (2018) and Pazos et al. (2017), who reported a low relationship between microplastic abundance in fish and body length. However, in the research of McNeish et al. (2018), specifically on the invasive, voracious, and opportunistic round goby fish (*Neogobius melanostomus*), the abundance of microplastic increased with the length of fish. He also suggested that microplastic accumulates with age in such fish. Meanwhile, in the river-estuarine and coastal regions of Northern Jakarta, the abundance of microplastic in *Aplocheilus* sp. was similar, indicating that the water's waste concentrations were not a reliable predictor of the abundance of microplastics in *Aplocheilus* sp. Most studies focused on analyzing microplastic abundance in marine organisms. Therefore, the research related to exposure, trophic transfer, as well as the effect and retention time of microplastics that lead to blockage irritation in the digestive system, need further investigation. Particularly, a comprehensive and holistic microplastics study is needed in the estuary of Ciliwung River and Northern Jakarta coastal waters.

7.9 The impact of microplastic on fisheries

The production and mass consumption of plastics contributed to plastics accumulation in marine environments and detrimental effects on marine organism and the socio-economy aspects. Marine plastic debris has the tendency to reduce the profitability of commercial fisheries and aquaculture production by physical obstruction and damages (Mouat et al., 2010; Newman et al., 2015). Simultaneously, the food source from fisheries activities is the primary source of animal protein (20% of dietary intake) for 19% of the global population (Golden et al., 2016). Plastic debris is also consumed by many marine organisms, including those directly crucial for food supply at complete lifecycle stages (Lusher et al., 2013; Rochman et al., 2015; Steer et al., 2017). Fish that ingest plastic directly from the environment or indirectly consumed via the food chain, typically rich in additives (Setälä et al., 2014). Once in the marine environment, persistent organic pollutants (POPS), heavy metals, and microbial pathogens can easily accumulate in plastic (Andrady, 2011; Avio et al., 2017b; Bakir et al., 2014; Brennecke et al., 2016; Purwiyanto et al., 2020; Zettler et al., 2013). Toxic pollutants can accumulate in marine organisms and biomagnified in predators' bodies (Teuten et al., 2009). Plastic pollution on the food chain and the associated pollutants puts the fish product at risk of reduced reproductive success and development (Galloway et al., 2017; Paul-Pont et al., 2016; Sussarellu et al., 2016), which threatening fish stock.

Consumption of marine plastic by humans occurs when the whole body, including the gut, is consumed, e.g., shellfish, sea snails, anchovies. Marine plastic debris could also intensify toxic pollutant concentrations in fish tissue, posing an additional threat to consumers (Bouhroum et al., 2019; Rochman et al., 2015). Microplastics in aquatic ecosystems, species, and marine foods are basic knowledge. Although more controlled studies are needed to better understand human risk, current research concludes that marine plastic debris's health risks are minimal (Daniel et al., 2021; Lusher et al., 2017a). Based on the 2011 ecosystem service prices and marine plastic stocks study, marine plastic debris's economic costs attributable to marine natural resources (e.g. providing healthy and safe commercial fisheries and aquaculture, leisure, and heritage values) are conservatively assumed to be between $3300 and $33,000 per ton of marine plastic debris per year (Beaumont et al., 2019). The full economic cost is likely to be much higher, given the economic value only includes marine natural capital impacts.

Overall, the sustainability, competitiveness, profitability, and safety of the commercial fisheries and aquaculture industry is highly vulnerable to marine plastic's effects, particularly in combination with broader factors such as climate change and overfishing. The high reliance on seafood for nutrition leaves a large proportion of the world population highly vulnerable to changes in the amount, quality, safety, and security of seafood sources (Golden et al., 2016).

7.10 Remarks of Chapter 7

Conclusively, microplastic were detected in the blue panchax fish (*Aplocheilus* sp.), as well as in its habitat. In both study locations, the dominant forms are fragments, fibers, and foam, with a size >1000 µm. Furthermore, in the body of *Aplocheilus* sp., microplastics are mostly in the form of fibers in a small size category (300-500 µm). This finding proved that biota in the estuary and coastal waters have difficulty in distinguishing between degraded plastic and prey. Additionally, the ingestion of microplastics by fish is likely the cause of biomagnification in higher consumers. The plastic transferred into food webs potentially facilitate the route of hazardous and toxic pollutants absorbed, particularly to humans. Therefore, an in-depth study on the effect, biomagnification, exposure, chemical toxicity, and socio-economic effects of plastics on marine organisms is needed.

Chapter 8 Conclusions and Perspectives

8.1 Concluding Remarks

In the synthesis of the two Research Lines, information about the sources, inflow, occurrence, and distribution of macro and microplastics in the Indonesian marine ecosystem was gained. The first research line is the first study on debris quantification in the Indonesian river mouth. A result from research line two illustrates the abundance and distribution of microplastic in Indonesian water.

The first marine debris monitoring data from Indonesia's capital, the Greater Jakarta area was presented by characterizing major sources and monthly variations of debris release at nine river outlets into Jakarta Bay between June 2015-June 2016. Plastics was the most common debris entering Jakarta Bay representing 59% (abundance) or 37% (weight) of the total collected debris. Styrofoam was dominating among plastic debris, highlighting the urgency of reducing plastic and styrofoam uses. Higher debris releases during the rainy season (December-February) highlight the need to intensify river clean-up activities. In this case, waste management entering during a different season and different area needs a different approach. An average daily debris release was estimated at 97,098 ± 28,932 items or 23 ± 7.10 tons into Jakarta Bay with considerably lower inputs from the capital compared to its neighboring municipalities. Within the plastics category, field monitoring data yield a daily plastic debris release of 8.32 ± 2.44 tons from the Greater Jakarta area, which is 8–16 times less than global-scale model estimates.

River debris, during COVID-19 pandemic at two river outlets – the Cilincing and Marunda Rivers, revealed a 5% increase in the abundance of debris and a 23-28% decrease in the weight of debris releases in March–April 2020 compared to March–April 2016, suggesting a compositional shift towards lighter debris. Plastics continued to dominate river debris at 46% (abundance) or 57% (weight). Unique to the pandemic, an unprecedented presence of PPE (medical masks, gloves, hazard suits, face shields, raincoats) were observed that accounted for 15-16% of the collected river debris of 780 ± 138 items (abundance) or 0.13 ± 0.02 tons (weight) daily. The observed increased plastic-made PPE in river outlets urges for improved medical waste management of domestic sources during the prolonged pandemic.

Microplastics was found in all sampling area, namely in surface water, sediment, and in the organism. Microplastics observed, might not only come from anthropogenic activities around, but also other parts of the oceans. The highest abundance was obtained in the closest station to the land and, in turn, close to the microplastic pollutant point source. The lowest abundance was found in the farthest station from the mainland.

The highest abundance of microplastics obtained in the closest area to the land. The microplastic abundance in the northern coastal waters of Surabaya ranged from 0.38 to 0.61 N/L, with an average of 0.49 N/L. The highest (0.61 N/L) and the lowest (0.38 N/L) microplastic abundances were obtained in Lamong Bay waters. Microplastics were found in all the stations, with an average of 28.09±10.28 particles per kg of dry sediment (n/kg). Sediments in the outside mangrove area contained more microplastics than the inside area. Foam form was the most dominant in all the samples and was found more abundant on the outside. More than half of microplastics were of size <1000 µm, and nearly 50% were polystyrenes. This polymer is widely used for food packaging, which is prone to be fragmented. Polypropylene and polyethylene form another 50% of microplastics, which are widely used for textiles and fishing gears. As Jakarta is the largest city in Indonesia, this microplastic dataset may be the benchmark for other mangroves around the country. Average of microplastics in the coral reef sediment is 48.3±13.98 particles per-kg. The highest microplastic concentration was found at the southwest of Gili Gede (77 particles per-kg), followed by sediment at the southeast of Gili Gede Island (69 particles per-kg), which also close to the anthropogenic activity namely tourism and fisheries. On the other hand, the lowest concentrations were found in Gili Rengit and Gili Layar, by 35 particles per-kg. Microplastic were found in various forms and sizes in Ciliwung river flow (9.37±1.37 particles/m^3), Northern Jakarta coastal waters (8.48±9.43 particles/m^3), and in 75% samples of *Aplocheilus* sp. (1.97 particles/individual). The microplastic size which was of highest concentration in *Aplocheilus* sp. was relatively small, ranging from 300-500 µm. This small size indicates that the fish has difficulty in distinguishing between their food and the microplastics.

The results of this study indicate that the microplastics particles found in the Indonesian marine ecosystem are present at relatively low concentrations compared to the levels found other regions. Furthermore, the high abundance of microplastics particles in the sediment confirmed the aggregation and biofouling mechanism in the water column that made the low-density MPs sink to the seafloor

A plastic pattern that found on research line one dominated by single-use plastics, such as styrofoam, thin and thick plastic wrap, food boxes, plastics utensil, and shoe/sandals. On the second research line, the domination type was also found of fragments, foams, fiber, and granules, with polystyrene, polypropylene, and polyethylene as a dominant polymer in all sampling areas. The composition of macro and microplastic litter found in the Indonesian marine ecosystem is assumed correlated to local behavior and lifestyles in Indonesia. Polystyrene is a styrofoam, one of a plastic type that widely used in Indonesia for packaging. Local lifestyles believed to use thin or thick plastic to wrap everything and reduce used food boxes used plastic utensils and used shoes/sandals by throwing it directly into the river, particularly on rainy season. Majority of single-use or disposable plastic is polypropylene and polyethylene. The primary use of polyethylene is packaging materials, e.g., food and beverage containers, geomembrane plastic bags, and film (Arutchelvi et al., 2008). Polypropylene is widely used in food and beverage containers, clothing industry, ropes, and reusable containers (Allahvaisi, 2017; Arutchelvi et al., 2008; Miller, 1990). The correlation of waste in Indonesian water, in terms of the weight of garbage and geometric, also microplastics, affirms Indonesian perform poorly of managing waste, has a paradigm "out of sight, out of mind" and to reduce visible litter is achieved by burning or burying it or by throwing it directly into the environment (Syakti et al., 2017).

Based on studies from two research lines, plastic consumption and land-based waste management will influence the amount of plastic (macro and micro) waste entering the ocean. These research results showed the importance of providing data and model verification and validity to calculate littering on the ocean. River cleanups using floating net booms and by the public facility worker force have been fruitful but unsustainable as they are remedial solutions. Microplastics are present in the water surface, sediment, and organism and have pervaded relatively pristine environments, namely in coral reef and mangrove ecosystem. The dominant macro and microplastic types found are those derived from single-use plastic. Moreover, reinforcing critical research thinking to provide environmentally friendly alternative solutions while enhancing an efficient waste management system can help find a sustainable plastic pollution solution.

Marine plastic debris has the tendency to reduce the profitability of commercial fisheries and aquaculture production by physical obstruction and damages. Plastic pollution on the food chain puts the fish product at risk of reduced reproductive success and development, which threatening fish stock. Sustainability, competitiveness, profitability, and safety of the commercial fisheries industry is highly vulnerable to marine plastic's effects, particularly with climate change and overfishing.

8.2 Recommendation and Future Subject

Recommendation

The Indonesian government showed serious commitment by creating National Action Plan, a strategy action for combating marine plastic debris (United Nation #OceanAction14387, 2017). Moreover, the new commitment from Indonesian Government stated by the Coordinating Minister for the Ministry of Maritime Affairs during the 2017 World Ocean Summit that the Government of Indonesia until 2025 would allocate up to 1 billion USD (13 trillion Rupiah) per year to reduce around 70% of plastics waste in the sea (Langenheim, 2017; United Nation #OceanAction14387, 2017). A more accurate estimate of marine debris amount is a step towards achieving the indicator Sustainable Development Goal 14.1 in order to prevent and significantly reduce marine pollution including marine debris in particular from land-based activities by 2030.

The United Nations estimates that 80% of all global marine pollution originates from land-based sources, predominantly from rivers. To reduce marine debris originating from rivers in Indonesia, it is recommended to replicate river cleanup programs in Indonesia's capital city, Jakarta, such as institutional and city cleaner strengthening and the installation of river floating net booms that could reduce debris releases to the marine environment. Furthermore, government policy on protecting the environment from plastics pollution also arise at the local administration level. Banjarmasin Government has banned the use of plastic bags in stores and modern markets since June 2016 and in 2019, will gradually ban the use of plastic bags on traditional markets. The plastic bag prohibition policy contained in the Banjarmasin Mayor's Regulation number 18/2016 has managed to reduce plastic waste by 55%. However, other sources of plastics waste still lack control from government of Indonesia. Comprehensive studies including large-scale, long-term and extensive monitoring processes are needed to address the existing knowledge gap to quantify the effects of debris along Indonesian marine ecosystem.

Future subjects

In this study, several issues remain a future subject

1. Further works are needed to understand the sources, pathways and ecological impacts of marine debris using long-term field monitoring data
   These further works includes comprehensive assessment macro and microplastics present in the seafood and human intake, seasonal and temporal variation of microplastics with effect studies.
2. To investigate the abundance and impact of microplastic from selected fish and invertebrate macrobenthic species in the Indonesian marine ecosystem
   The impact of microplastic on the marine ecosystem will be addressed by analyzing the ingestion of microplastic by selected marine organisms. The selected species will represent important fishery resources in the Indonesian marine ecosystem. The fish and macroinvertebrate species will be sampled in a different type of coastal area, namely high, medium, and low anthropogenic activity. The impact of microplastics also obtained by evaluating microplastics effects on selected biota (bioassay experiment) has become an urgent research priority.
3. To provide advice related to the management of plastic pollution in Indonesia
   The research results will highlight risk in Indonesia coastal areas and facilitate the definition of measures to start tackling the issue together with all involved stakeholders on a local scale

4. To understand societal and economic impacts of plastics on in Indonesian marine ecosystem
   The study's results would demonstrate the awareness of human exposure and health effects of consuming microplastics in marine organisms and the economic impact of marine plastic debris and microplastics on marine ecosystem dependent corporations and communities.

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Summary

1. BACKGROUND AND OBJECTIVE

Chapter 1. Introduction and overview of the study

Since the early 1950s, plastic production has risen exponentially and reached 368 million metric tons in 2019, and this does not include synthetic fibers, which accounted for 61 million tons in 2015. Plastics demand is projected to continue to grow in the near future, with production levels likely to double by 2025. Inadequate plastic waste disposal has contributed to increased freshwater, estuarine, and marine pollution. Around 19 million to 23 million tons of plastic waste reached the oceans in 2016, and marine plastic debris is forecasted could reach 53 million tons by 2030. Indonesia's vast coastline, huge population, and a high percentage of unmanaged waste are recipes that add substantial quantities of land-derived debris to oceans. Indonesia is considered the world's second-largest contributor to oceans after China. In response, Indonesia developed a national action plan to tackle marine plastic debris between 2017-2025 through several measures. The Indonesian government has pledged to allocate up to $1 billion annually to reduce 70% of plastic waste in the Indonesian seas by 2025, to preserve the environment. The middle and long-term fate of macro and microplastics in the environment is unknown, as is its abundance and distribution in coastal ecosystems, particularly in Indonesia. Science is the key to getting the right alternative for managing plastic debris. Thus, monitoring data is key in formulating effective strategies to reduce land-derived debris. The aim of this research is to provide baseline data of plastics debris in Indonesian Sea, particularly to macro and microplastics. This data will be useful for the management of marine litter as has been stated in Indonesia's Presidential Decree No. 83 on Marine Debris Management. The study will address the following objectives (1) to provide in situ monitoring data on sources and inflow of debris from major Indonesian cities with high population density and river discharge as a baseline to better formulate environmental policies in reducing marine debris; and (2) to investigate the abundance and distribution of microplastic from Indonesian marine ecosystem (in the water, sediment, and the marine organism)

To achieve the study's objectives, two studies were conducted to answer the first research lines and four studies to the second research lines. The first two studies are spatially, and temporally comprehensive marine debris monitoring in major Indonesian rivers carried out at river outlets leading to Jakarta Bay. Furthermore, four studies related to microplastics were carried out on the coast of Surabaya, mangrove areas in Muara Angke Wildlife Reserve, Sekotong coral reef area, and microplastic ingestion in blue panchax fish (*Aplocheilus* sp.).

2. RIVERINE PLASTIC DEBRIS TRANSPORT

Chapter 2. Marine Debris inflow from the Greater Jakarta Area, Indonesia

The first land-derived debris monitoring was performed between June 2015 and June 2016, characterizing major sources and monthly variation of marine debris at nine river outlets in Jakarta Bay, Indonesia. The nine river outlets are from west to east: Dadap River in Tangerang, Angke, Pluit, Ciliwung, Kali Item, Koja, Cilincing, and Marunda Rivers in the capital city of Jakarta, and Bekasi River in Bekasi. Land-derived debris was collected using a 75 m-long and 1.5 m-deep net with a 5 cm mesh scale. River outlets have widths between 18-64.9 m or below our sampling net range. The net was

installed 15 minutes along the river width and repeated 3-6 times depending on the river discharge. The debris then quantified by abundance, using a modified list of the NOAA Marine Debris Program datasheet, was classified into six types of debris (plastics, metal, glass, wood/paper, cloth/fiber, and others) and 19 categories of plastics.

From first monitoring land-derived debris, it is found that plastics are the most common debris entering Jakarta Bay, comprising 59% (abundance) or 37% (weight) of total debris. Styrofoam dominated plastic debris, demonstrating the importance of plastic and styrofoam elimination. Higher debris releases during the rainy season (December-February) reinforce the need to intensify clean-up activities. An average daily release of 97,098 ± 28,932 products or 23 ± 7.10 tons in Jakarta Bay was measured with slightly lower capital inputs than neighboring municipalities. Field monitoring data in the plastics group yields a daily plastic debris release of 8.32 ± 2.44 tons from the Greater Jakarta area, 8-16 times less than global model estimates. A simple explanation is that rivers in the study area (in Jakarta) have floating net booms in place that reduce debris releases, one of the factors that are not captured in the global-scale models. However, there is a possibility of higher debris release in the field relative to global projections in other cities, given varying levels of local commitment to minimize land-derived debris. Plastics are the most common debris entering Jakarta Bay combined with global marine debris models, field sampling at river sources serves as ground-truth evidence to refine global forecasts by taking local strategies in place to minimize marine debris.

Chapter 3. Marine Debris inflow From Two Rivers Outlet Into Jakarta Bay during COVID-19 Pandemic

In March–April 2020, the measurements from the first monitoring were repeated in two out of nine river outlets (Cilincing and Marunda Rivers) in Jakarta Bay to determine the amount of debris entering the river's marine environment outlet in Jakarta as a result of the COVID-19 pandemic. Due to the lockdown situation, the analysis could not be repeated in all nine river outlets. During the COVID-19 pandemic, the abundance of daily debris releases at two sampling sites increased by 5%. At both locations, daily debris releases decreased by 23% in March from 2.30 to 1.78 tons per day and by 28% in April from 2.19 to 1.58 tons per day. Plastics, accounted for 43-47% by abundance or 50-62% by weight, remained the dominant debris entering the Bay of Jakarta in March-April 2020. The study data demonstrated the unprecedented presence and prevalence of personal protection equipments (PPEs) during the pandemic. The PPEs accounted for 16% of the river debris collected, were not present before the pandemic. Increased lightweight plastic-made PPEs that could move distances in environments with health and environmental issues underline the need for domestic PPE waste management, which varies from regulated and controlled medical facilities sources. Overall, monitoring data on major sources and monthly variations in land-derived debris release to Jakarta Bay advise stakeholders and policymakers to prioritize various forms of debris, plastics groups, and months of the year to eliminate land-derived debris from the Greater Jakarta area more effectively. Furthermore, data could help to evaluate efforts over recent years to minimize land-derived debris across riverine channels.

3. QUANTIFICATION AND IDENTIFICATION OF MICROPLASTICS IN MARINE ECOSYSTEM

Microplastic (small plastic particle < 5mm) is recognized as an emerging problem in oceans and must be tackled through an intergovernmental process. It is important to develop comprehensive microplastic pollution data at different locations and environmental matrices, particularly in

Indonesia's marine ecosystem. Various effects in marine environments and coastal fisheries, aquaculture, and human health will occur through microplastic contaminated seafood consumption. However, data on plastic pollution, particularly microplastic, is still inadequate, and research remains challenging due to limited equipment and a wide marine environment in the Indonesian Seas.

The sediment, water, and fish sample microplastic extraction procedures were adapted from the Guidelines for Harmonizing Ocean Surface Microplastic Monitoring Methods by implementing a modified flotation method and wet peroxide oxidation procedures. Possible particles had the following characteristics: particle size less than 5mm, homogeneous color, no cellular network, and unsegmented and unbranched. The shape composition, the counted microplastic, was divided into four categories: fragments, fibers, granules, and foam. The samples were categorized into different size classes. The recovered microplastic polymer forms were then described using an ATR FT-IR (Attenuated Total Reflection Fourier Transform Infrared) spectrometer.

Chapter 4. Abundance and Characteristics of Floating Microplastics in the Northern Coastal Waters of Surabaya, Indonesia

Floating microplastic in northern coastal waters of Surabaya was taken using a sterile HDPE bottle. Microplastic concentration in Surabaya's northern coastal waters ranged from 0.38 to 0.61 N/L, averaging 0.49 N/L. The highest microplastic abundance was obtained at the nearest ground station and, in turn, near the source of microplastic pollutant point. The lowest abundance was found in the mainland's farthest station. The dominance of foams and fragments in Surabaya's northern coastal waters showed that water microplastics result from a waste of population activity. The size ranges of microplastics 500-1000 µm (48.54%) and 300-500 µm (45.48%) indicate the state of microplastic particles that have not been deteriorated for a long time. Polystyrene was dominant relative to other forms of polymers, possibly due to the deterioration of the group's extensive waste activities (secondary microplastics).

Chapter 5. Characterization of Microplastics in Mangrove Sediment of Muara Angke Wildlife Reserve, Indonesia

Sediment samples in Muara Angke Wildlife Reserve were taken in the mangroves' inner and outer layers. Microplastics were found in all the stations in mangrove sediment of Muara Angke Wildlife Reserve, with an average of 28.09±10.28 particles per kg of dry sediment (n/kg). Sediments in the outside mangrove area contained more microplastics than the inside area. Foam form was the most dominant in all the samples and was found more abundant on the outside. More than half of microplastics were of size <1000 µm, and nearly 50% were polystyrenes. This polymer is widely used for food packaging, which is prone to be fragmented. Polypropylene and polyethylene form another 50% of microplastics, widely used for textiles and fishing gears. As Jakarta is the largest city in Indonesia, this microplastic dataset may be the benchmark for other mangroves around the country.

Chapter 6. Microplastic Pollution Distribution in Coral Reefs Sediment, Case Study Sekotong, West Nusa Tenggara

Sediment samples in Sekotong by diving in the coral reef area. Microplastics concentration in coral reefs sediment in Sekotong ranged from 35 to 77 particles/kg, with an average of 48.3±13.98 particles/kg. The highest concentration was located in Gili Island's southwest (77 particles/kg). The microplastic types found were foam (41.20%), fragment (32.51%), granule (22.77%), and fiber (3.52%). The most frequent microplastics size ranged from more than 1000 µm and was followed by a size range of 500-1000 µm. Polymer analysis showed that microplastic found were composed of polystyrene, polyethylene, and polypropylene. This type of polymers indicates that the primary source of microplastics in the Sekotong coral reef sediment was styrofoam, food and beverage packages, and fishing devices.

Chapter 7. Microplastics Ingestion by Blue Panchax Fish (*Aplocheilus* sp.) from Ciliwung Estuary, Jakarta, Indonesia

Aplocheilus sp. samples were collected randomly in North Jakarta's Ciliwung estuary and coastal region using a larva net. Moreover, floating microplastic in *Aplocheilus* sp. habitat (Ciliwung River Estuary and North Jakarta Coast) was taken using sterile manta trawl net. Different forms and sizes of microplastic were contained in the river flow of Ciliwung River Estuary (9.37±1.37 particles/m^3), North Jakarta coastal waters (8.48±9.43 particles/m^3), and 75% of *Aplocheilus* sp. (1.97 particles/individual). The microplastic size in *Aplocheilus* sp. was relatively small, ranging from 300 to 500 µm. This small size suggests that fish have trouble distinguishing between their food and microplastics. Furthermore, the plastics were able to contain other contaminants.

4. CONCLUSIONS AND PERSPECTIVES

Chapter 8. Conclusion and Recommendation

The importance of long-term marine debris monitoring in major Indonesian cities provides critical information to minimize land-derived debris in Oceans. Plastics originating from land activities are predicted to become microplastic because the dominant macro- and microplastic forms found are plastic single-use types. Microplastic was found in all areas, in water, sediment, and selected marine organisms. Microplastics have pervaded relatively pristine habitats, including coral reef and mangrove areas, which may conflict with commercial fishing and aquaculture. Marine plastic debris, including microplastic, tends to reduce commercial fisheries and aquaculture production profitability through physical obstruction and destruction. Many marine species, including those critical to the food supply, ingest microplastic. Humans eat marine plastic when the entire body, including the gut, is eaten, e.g., shellfish, sea snails, and anchovies. Food chain plastic contamination puts the fish product at risk of reduced reproductive success and growth, threatening fish stocks. Commercial fisheries industry sustainability, competitiveness, profitability, and safety are highly vulnerable to the effects of marine plastics, particularly with climate change and overfishing. Detailed research on the impact of plastic consumption on marine organisms, biomagnification, exposure, chemical toxicity, and socio-economy is recommended. Plastic pollution impacts coral reefs and mangrove economic viability, and thus preserving and protecting these areas will offer high economic benefits to local people using the marine and coastal ecosystem. However, plastics' possible social and economic effects on the marine and coastal ecosystem remains an open question. Investing in testing and analysis to resolve information gaps is, therefore, crucial. It is strongly suggested that plastic waste management be strengthened and that an environmentally friendly material be invented to replace synthetic plastics in the near future. A more reliable estimation of marine debris is a step towards achieving the Sustainable Development Goals 14.1 indicator to prevent and substantially reduce marine pollution, including marine debris, especially from land-based activities, by 2030. Accordingly, Indonesia's government has developed a National Action Plan, a policy action to tackle marine plastic debris. Until 2025, Indonesia's government will allocate up to $1 billion per year to eliminate about 70 percent of plastic waste at sea. Other plastics waste sources, however, also lack Indonesia's government regulation. In order to quantify the effects of debris along with the Indonesian marine ecosystem, comprehensive studies, including large-scale, long-term, and detailed monitoring processes, are required.

It is imperative to invest in monitoring and research to address knowledge gaps and future subjects, e.g., (1) to understand the sources, pathways, and ecological impacts of marine debris using long-term field monitoring data; (2) to investigate the abundance and impact of microplastic from selected fish and invertebrate macrobenthic species in the Indonesian marine ecosystem; (3) to provide advice related to the management of plastic pollution in Indonesia; and (4) to understand societal and economic impacts of plastics on in Indonesian marine ecosystem.