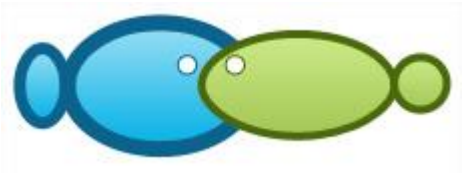

Floating microplastics on the sea surface of semi-closed and open bays of small islands

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Abstract. The lack of proper waste management systems leads to plastic pollution in marine waters, especially in semi-closed and open bays. Ambon Bay is located in a small island, comprising the Inner Ambon Bay (IAB) and the Outer Ambon Bay (OAB). The objective of this study was to assess floating microplastics (MPs) in both semi-closed bay (e.g. IAB) and open bay (e.g. OAB). The study showed that MPs concentration in the Ambon Bay had a mean value of 0.1632 n L^{-1}. The Kruskal-Wallis analysis ($\chi 2(1)=7.75$, $p=0.011$) showed that the concentration of MPs in the semi-closed bay (IAB) was significantly higher (58%, with a mean of 0.3292 n L^{-1}) than in the OAB (8%, with a mean of 0.0437 n L^{-1}). Fibers were the most common MPs (86%), followed by films (13%) and fragments (1%). Most fibers were distributed in the IAB (93%), while fragments were distributed mostly in the OAB (63%) and films were distributed equally in the IAB and OAB. The MPs concentration in Ambon Bay was higher than in other bays in the world. This is an alert signal of plastic pollution, especially in semi-closed bays. It was confirmed that plastic pollution negatively affects the ecosystem (e.g. mangrove), marine biota and health. This data and information is required for a better co-management of the waste and of the coastal area of bays.
Key Words: microplastic, sea surface, semi-closed, open bay, Ambon Bay.

Introduction. Plastics represent an important element of the scope of materials used in recent society. Plastics have a lot of advantages over other materials such as irons or metals. Owing to the advantages of plastic, such as being less expensive, strong, lightweight and adjustable, nearly all human needs are based on plastic. Plastics are widespread in industries such as: construction, transportation, electrical and electronic, packaging, automotive, sports, furniture, medicals and healthcare, etc. The largest usage of plastics worldwide is related to the numerous packaging applications, such as food packaging, containers, bottles, boxes, cups and vending packaging, baby products and protective packaging. The plastic used in packaging applications is mostly disposable (Thevenon & Carroll 2015).

The inadequate of waste management in the coastal nations led to million tons of plastic thrown in the ocean (Jambeck et al 2015; Meijer et al 2021; Geyer et al 2017; Napper & Thompson 2020; Ostle et al 2019). Marine plastic debris can enter the marine environment by riverine transport, sewage overflow, leisure activities on beach or at sea and by the wind (Veiga et al 2016). In the marine environment waters, plastics can slowly break down in smaller pieces, due to the physical, chemical and biological factors. The plastic with a size of less than 5 mm is called microplastic (Gesamp 2015).

The presence of microplastics (MPs) has been reported in sea water, sediment and marine biota from all types of marine ecosystems, like: coral reef (Hall et al 2015; Patti et al 2020), seagrass (Tahir et al 2019,2020; Jones et al 2020), mangrove (Patria et al 2020; Cordova et al 2021), bays (McEachern et al 2019), estuarines (Zhao et al 2014; Bikker et al 2020), beaches (Manullang 2019; Jeyasanta et al 2020), open ocean (Desforges et al 2015; Kanhai et al 2018) and deep-sea floor (Van Cauwenberghe et al 2013; Peng et al 2018). Microplastics are found close to urban and industrialized areas,

such as Hong Kong (Tsang et al 2017), but also in remote areas close to the Arctic (Lusher et al 2015).

This study was focused on Ambon Bay. The Ambon Bay is part of the Ambon Island, an urban area in the eastern part of Indonesia. Ambon Bay is divided into two parts, namely the Inner Ambon Bay (IAB) and the Outer Ambon Bay (OAB). The IAB is a semi-closed bay, relatively small (total area is 2.5 km^2), with shallow waters (average depth: 26 m) and low water currents (Anderson & Sapulette 1981). Meanwhile, the OAB is a relatively open water, connected to the Banda Sea, larger than the IAB, with deep waters (average: 100 m) and high water currents (0.19 m s^{-1}) (Fadli & Radjawane 2014). Furthermore, the IAB was separated by a narrow and shallow sill (Figure 1). The aim of this study was to provide the preliminary assessment of floating MPs in the sea surface of the Ambon Bay. There have been other studies on MPs around Ambon Bay (Manullang 2019; Tuhumury & Pellaupessy 2021), but they didn't provide data about concentrations in the sea surface around the Bay. The present research could be a comparative reference for the studies of marine MPs in the future.

Material and Method

Sea surface water samples were collected in September 2019. Six transect line samplings were conducted around the Ambon Bay: 2 in the IAB (Poka-Galala (PG) and Waiheru-Halong (WH)), 1 in the sill area (Merah Putih Brigde (MPB)) between the IAB and the OAB, and 3 in the OAB (Airport-Eri (AE), Hative Besar-Salobar (HBS) and Wayame-Mardika (WM)) using a manta net with a 15 x 25 cm^2 opening and a 200 µm mesh. The manta net was towed along the surface layer, at a nominal speed of 2-3 knots, for 10-15 minutes, in each transect. The towing off was performed on the port side of the boat, to avoid the disturbance by the bow wave. The net and cod end were rinsed thoroughly with clean seawater for any potential MPs. The geographical position of the start and end of each tow was recorded. A flow meter was attached to the subsurface net frame near the mouth of the net and the number of revolutions of the flow meter were recorded. The seawater volumes filtered through the net ranged from 1,746 to 21,829 per line transect. Once the towing was completed, the net was rinsed into the cod end. The content of the net was washed into a sample glass jar.

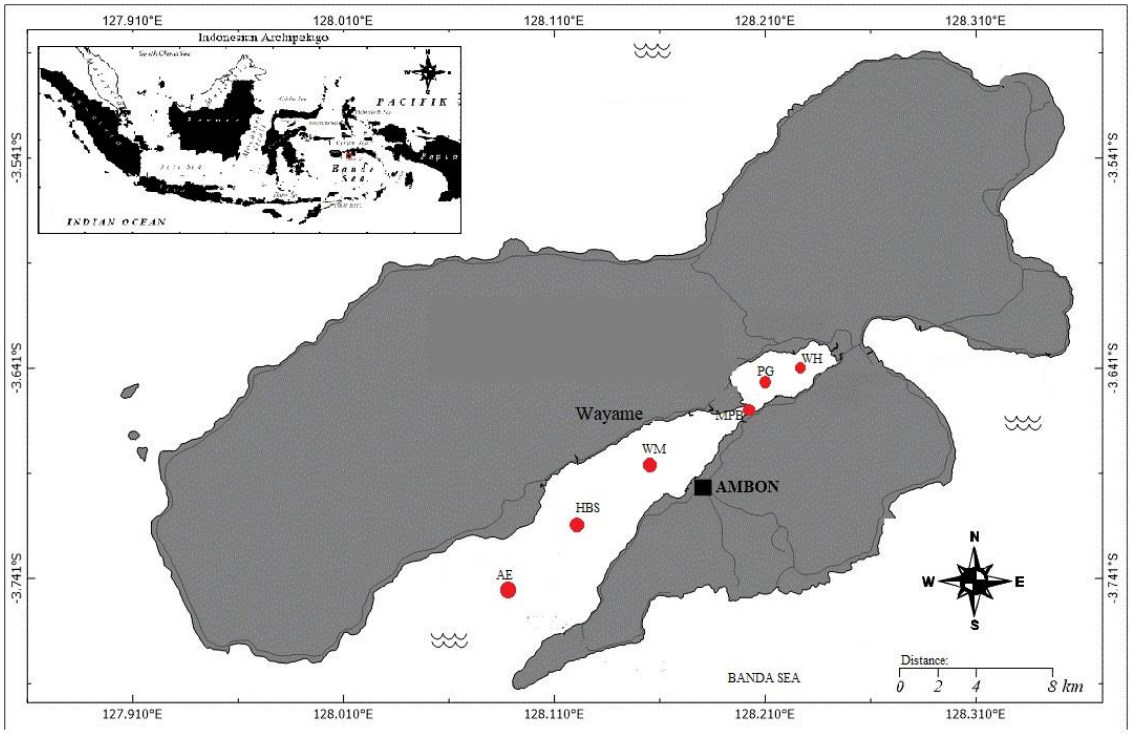

Figure 1. Sampling location sites.

Figure 2. Manta net with a 15 x 25 cm^2 opening and a 200 µm mesh (original photo).

In the laboratory, samples were left to dry at 40°C. To remove organic matter, 30 mL of 30% H_2O_2 solution were added and then heated at 40°C (Masura et al 2015). If any natural organic matter remained, an additional amount of 30% H_2O_2 was added to the samples, repeatedly. After no natural organic remained, the H_2O_2 solution was eliminated using a sieve with a mesh size of 0.037 µm. The samples were collected in a beaker and then NaCl solution was added. The sample was then moved to a density separator, covered with an aluminium foil and then left for 24 h. After 24 h, the floating MPs were extracted using a sieve mesh size of 0.037 µm. Thereafter, the contents of each sieve were analyzed under a dissecting microscope to count the MPs found. In this study, we counted all the MPs with a size <100 µm. Plastic particles were classed into fragments, fibers, films and pellets. The concentration of MPs found was performed in items per liter (n L^{-1}). A Kruskal-Wallis test, followed by a Bonferroni post-hoc test, were applied to determine if significant differences in MPs occurred between the IAB, sill area and OAB.

Results. The study confirmed that floating microplastic were found at all sites of study area: IAB, sill area, and OAB. A Kruskal-Wallis analysis $\chi^2(1)=7.75$, $p=0.011$) showed that concentration of MPs in the IAB (with a mean of 0.3292 n L^{-1}) was significantly higher than in the OAB (with a mean of 0.0437 n L^{-1}, $p=0.002$) and in the sill area (with a mean of 0.1901 n L^{-1}, $p=0.002$). About 58% of MPs were distributed in the IAB, 34% in the sill area and only 8% in the OAB. The MPs concentration in the IAB was ranging from 0.2252 to 0.4331 n L^{-1}, in the sill area it was of 0.1901 n L^{-1} and in OAB it was ranging from 0.0146 to 0.0821 n L^{-1} (Table 1). The largest abundance of MPs was in WH (0.4331 n L^{-1}), located in the IAB, followed by the MPB (sill area), and the lowest was in WM (0.0146 n L^{-1}), located in the OAB (Table 1).

Table 1

Floating MPs concentration on sea surface of Outer Ambon Bay (OAB), Sill area, and Inner Ambon Bay (IAB)

Site	*Location*	*Coordinates*				*Vol (L)*	*MPs concentration (n L^{-1})*			
		Start		*End*						
		Long	*Lat*	*Long*	*Lat*		*Fragment*	*Film*	*Fiber*	*Total*
AE	OAB	3.71	128.10	3.74	128.12	21,829	0.0022	0.0207	0.0115	0.0344
HBS	OAB	3.67	128.14	3.70	128.16	12,418	0.0039	0.0420	0.0362	0.0821
WM	OAB	3.68	128.17	3.69	128.18	11,323	0.0004	0.0059	0.0082	0.0146
MPB	sill area	3.66	128.20	3.66	128.20	1,746	0.0023	0.0412	0.1466	0.1901
PG	IAB	3.64	128.19	3.66	128.20	7,496	0.0005	0.0112	0.2134	0.2252
WH	IAB	3.65	128.22	3.63	128.22	13,578	0.0010	0.0102	0.4219	0.4331

Fibers (86%), films (13%) and fragments (1%), were found in all sites, but differently distributed among the bay (Figure 3). About 63% of the fragments were distributed in the OAB and 37% were distributed in the IAB. In contrast, the fibers were mainly distributed in the IAB (93%) and only 7% were distributed in the OAB. Films were distributed almost equally: 48% in the IAB and 52% in the OAB. The most common type of MPs, namely the fibers, come from the intensive fishing activities (Katsanevakis & Katsarou 2004). Fragments are the result of cutting plastic products with very strong synthetic polymers (Kingfisher 2011). Previous studies conducted in the Ambon Bay found a high abundance of fiber type plastics in the fish from the Ambon Bay and plastic film stranded on the beach and in the mangrove ecosystems (Tuhumury & Pellaupessy 2021; Manullang 2019; Suyadi & Manullang 2020a).

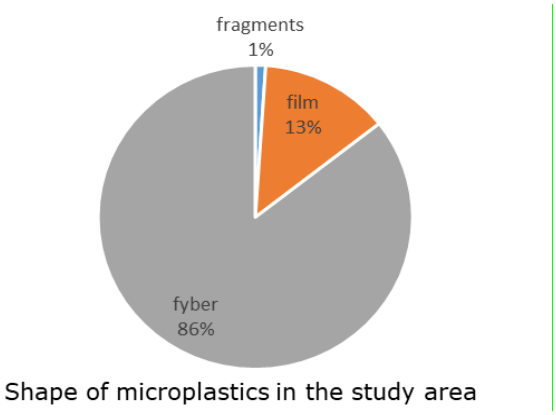

Figure 3. The shape of MPs in the Ambon Bay.

Discussion. The higher MPs concentration found in the IAB might be related to the difference in water currents and bathymetry between the IAB and OAB. The oceanography studies have been estimated that the water mass which enters the IAB from Banda Sea (OAB) will be trapped for about 17 hours in the IAB (Anderson & Sapulete 1981). It is also considered that MPs will remain longer in the IAB. A previous study in Ambon Bay also proved that MPs concentration on the beaches of the IAB was higher than on the beaches of the OAB (Manullang 2019).

Compared to other semi-closed bays in the world, Ambon Bay was the most polluted by MPs (Table 2). Mean MPs concentration in Ambon Bay (0.1632 n L^{-1}) was much higher than in the Chesapeake Bay in USA (0.00016 n L^{-1}) and Jiaozhou Bay in China (0.046 n L^{-1}) (Bikker et al 2020; Zheng et al 2019). The highest concentration of MPs was in the IAB. The MPs concentration in the OAB was lower than in the Jiaozhou Bay (China), but it was much higher than in the Chesapeake Bay (USA), Tokyo Bay (Japan), Tampa Bay (USA) and Xiangshan Bay (China) (Table 2).

The result of this study indicates that marine waters are being polluted by MPs at an alarming rate in semi-closed bays such as Ambon Bay. Plastic pollution also occurred in the coastal area, such as in the mangrove ecosystem of the Ambon Bay (Suyadi & Manulang 2020a). Plastic pollution has negative impacts on the mangrove health and seedlings survival (Suyadi & Manulang 2020a). It was confirmed that MPs pollution contaminated marine biota and caused outbreaks of diseases, due to microbial colonization by pathogens (Lamb et al 2018; Choy et al 2019). In turn, these affected the human health, for example, it was recorded that 30 people got diarrhea and 4 of them died after consuming mollusks collected from the bay (Sapulete et al 2007; Suyadi 2009).

The high MPs concentration in the Ambon Bay far exceeds the values measured in other semi-closed bays, due to poor waste management systems in the urban area, around the bay. About 150 tons day^{-1} of litter was produced in the Ambon Bay and 38% of it goes to the ocean, especially in the Ambon Bay (Suyadi & Manulang 2020b). Ambon Island is one of the most populated small islands in Indonesia, with a population density of over 647 people km^{-2} (BPS 2015). Most of the population is living in the coastal areas, especially around the Ambon Bay (Suyadi 2012). Many physical infrastructures are

located in the coastal areas, such as settlements, traditional and modern markets, harbor, oil and electrical infrastructures, and airport. These anthropogenic activities contribute to the high plastic pollution in the Ambon Bay.

Plastic pollution on the coastal ecosystem and in the marine waters of small islands, such as Ambon, may be higher than around large islands. This is due to a limited carrying capacity of the island and to a lack of facilities and of a waste management system. Plastic debris did not only pollute the urban area and its surrounding marine waters, but also the rural area (even uninhabited islands) and its surrounding marine waters (Suyadi et al 2021a,b). Based on data of the Ministry of Industry, for the year 2017, it is estimated that around 4.8 million tons of plastic pollution has been mismanaged in Indonesia (Republic of Indonesia-Indonesia's Plan of Action on Marine Plastic Debris (NPAP) 2017). 9% or about 620.000 tons of them were released into the water bodies (rivers, lakes and ocean). The latest report of the World Bank in 2021 has been updated to 4.9 million tons (World Bank 2021). Furthermore, it has to be mentioned that most of the mismanaged plastic pollution in Indonesia comes from the urban areas or small-medium cities (e.g. Ambon). Meanwhile, in the USA or Japan, where waste management system are more adequate, over 90% of their waste is already managed (Nakano et al 2021).

Table 2

Comparison MPs concentration found in the Ambon Bay and in other bays

Location	*Country*	*Mean MPs concentration (n L^{-1})*	*Reference*
Inner Ambon Bay (IAB)	Indonesia	0.3292	This study
Outer Ambon Bay (OAB)	Indonesia	0.0437	This study
Ambon Bay (IAB + OAB)	Indonesia	0.5630	This study
Tokyo Bay	Japan	0.00055	Nakano et al 2021
Chesapeake Bay	USA	0.00016	Bikker et al 2020
Tampa Bay, Florida	USA	0.0045	McEachern et al 2019
Jiaozhou Bay	China	0.046	Zheng et al 2019
Xiangshan Bay	China	0.0089	Chen et al 2018

Conclusions. The semi-closed bay (Inner Ambon Bay-IAB, with a mean of 0.3292 n L^{-1}) was more polluted by floating MPs than the open bay (OAB). About 58% of the MPs were distributed in the IAB. Semi-closed bays, especially in small islands, such as the IAB, are vulnerable, being characterized by shallow waters, narrow straits and slow water circulation. Consequently, MPs are trapped and remain in the bay for a longer time, with long-term negative impacts on ecosystems, marine biota and health. The MPs concentration in the Ambon Bay was much higher than in other semi-closed bays in the world. This is an alert signal of plastic pollution in marine waters and coastal ecosystems (bays). Given the high plastic pollution, dramatic decisions have to be taken and an effective co-management of waste and coastal (bay) is required to reduce plastic pollution and to improve the quality of marine waters.

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Conflict of interest. The authors declare no conflict of interest.

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