MICROPLASTIC IN THE DEEP-SEA SEDIMENT OF SOUTHWESTERN SUMATERA WATERS

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ABSTRACT

Indonesia is recently ranked second as the world's largest plastic wastes producer. Plastic is a very durable material that can be degraded by thermal oxidation with ultraviolet radiation and/or mechanically to smaller sizes. Degraded plastic with size less than 5mm is referred to as microplastic. Here, we investigate the pervasiveness of microplastic pollution by studying deep-sea sediments retrieved from western Sumatera in the eastern Indian Ocean during the Ekspedisi Widya Nusantara (EWIN) 2015 research cruise. The cruise, which took place between May 7-18, is part of Indonesia's contribution to the ongoing International Indian Ocean Expedition-2 (IIOE-2) campaign. Deep-sea sediments were taken at depths ranging from 66.8 to 2182m and microplastic characterization of the sediments was carried out following a modified flotation method. Our finding reveals that microplastics are present in 8 out of 10 sampling locations. We find 41 particles of microplastic in the forms of the granule (35 particles) and fiber (6 particles). Most or 20 microplastic particles are found at depths less than 500 m. Furthermore, the presence of microplastics in the western Sumatera sediments at more than 2000m deep confirms that plastics have pervaded marine environments including pristine areas despite being a relatively recent material that started being produced in the early 19th century.

Keywords: microplastic, sediment, pollution, Sumatera, eastern Indian Ocean

INTRODUCTION

The convenience of using plastics has resulted in its increased production throughout years with a negative consequence to marine environments. Being versatile, lightweight, strong, durable and inexpensive materials, plastics are used to make tools, clothing, transportation and building materials, and more. Global plastic production increased from about 0.5 million tons per year in 1950 to 288 million tons in 2012. This trend continued to increase at about 4% per year by 2016 (PlasticsEurope, 2010, 2013, 2015). In Indonesia, the production of plastics reached 1.9 million tons in 2013 with an average production rate of 1.65 million tons per year (Kementerian Perindustrian dan Perdagangan, 2013). As such, it has been estimated that Indonesia is indeed the world's second largest plastic producer and consumer (Jambeck & Johnsen, 2015). With an assumption that about 10% of plastics would end up in seas (Van Cauwenberghe *et al.*, 2015), we can estimate that about 165,000 tons of plastic waste pollute Indonesian seawaters every year. The increased plastic use unfortunately poses as one of the major environmental problems today. This phenomena would endanger marine organisms as have been observed elsewhere (Moore *et al.*, 2001).

One concerning issue related to plastic pollution is the existence of microplastic in the environment. Plastic can be degraded by UV thermal oxidation and/or mechanical processes forming microscopic sizes (Andrady, 2011; Wagner *et al.*, 2014). Plastic waste that is micrometer in size ahs been referred to as microplastic. Aside from being a mechanically degraded plastic, microplastic in the environment could also come from microbeads contained in cosmetics and fabrics (Browne *et al.*, 2011; Fendall & Sewell, 2009). Many studies categorize microplastic as plastic waste with size no more than 5mm (Arthur et ald, 2009; Wright et aly, 2013), while some categorize microplastic as plastic waste with size below 1mm (Browne *et al.*, 2011; Van Cauwenberghe *et al.*, 2013). Regardless, previous works have detected microplastics in coastal and mangrove ecosystems, the water column and even in deep-sea sediments (Claessens, *et al.*, 2011; Mohamed Nor & Obbard, 2014; Moore *et al.*, 2002; Thompson *et al.*, 2004; Van Cauwenberghe *et al.*, 2013). The small size would increase plastic bioavailability for digestion by marine organisms. Some laboratory studies show that detritivores organisms (e.g. amphipods), deposit feeders (e.g. lugworm), filter feeders (e.g. barnacles and bivalves), and deposit and suspension feeders (e.g. sea cucumber and copepods) consume microplastics (Graham & Thompson, 2009; Thompson *et al.*, 2004). Plastic consumption would irritate digestive system (Betts, 2008) and furthermore could cause other serious problems since the consumed plastics may also adsorb organic pollutant (Teuten *et al.*, 2009). Microplastic consumption by marine organisms could happen as the organisms falsely identify the microplastic as an edible food (Van Cauwenberghe *et al.*, 2012).

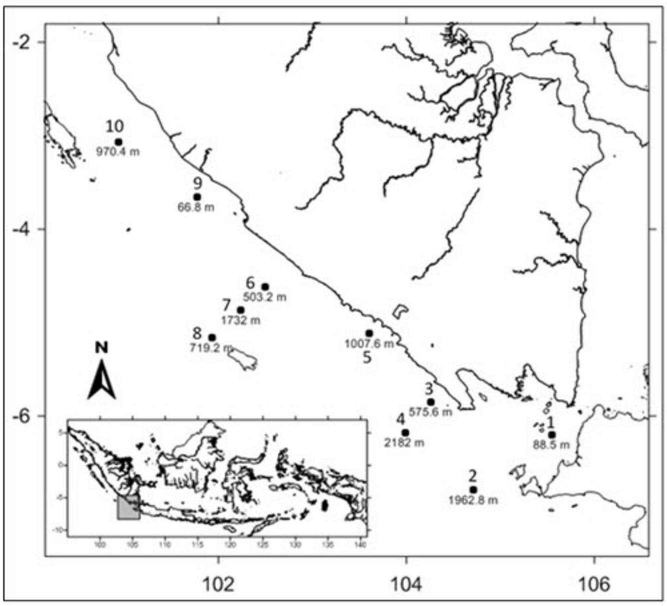


Figure 1. Study site and sampling stations.

The eastern Indian Ocean especially southwestern Sumatera waters is of an interest for studying microplastic due to the fact that it is a busy domestic and international shipping route. This condition increases the possibility for receiving pollution. Furthermore, scientific data particularly on marine pollution and microplastic from this area is rare. Therefore, it is important to characterize microplastic pollution in this area by analyzing its pervasiveness in deep-sea sediments.

MATERIALS AND METHODS

Deep-sea sediment sampling was conducted during the Ekspedisi Widya Nusantara (E-WIN) research cruise between May 7-18, 2015. Samples were retrieved using a 60 x 40 x 50cm boxcore from 10 stations with depths ranging from 66.8 to 2182m (Figure 1). Sub-samples were taken using a stainless steel shovel (20ml) from sediment surface within a 10cm x 5cm x 2cm section. Then, the samples were stored in a freezer (4°C) prior to analysis at the Chemical Oceanography Laboratory of the Research Center for Oceanography (Indonesian Institute of Sciences).

Microplastic extraction was conducted using a modified flotation method by using a concentrated saline solution at 1.18 g/l (Claessens *et al.*, 2011; Mohamed Nor & Obbard, 2014; Thompson *et al.*, 2004) and double-distilled deionized water.

The sediments were oven dried (60°C, 24h). To remove organic matters, the sediments were added with H_2O_2 and heated (90ºC), and then the visible froth was removed. Dried sediment samples weighted 62.5g was put on erlenmeyer bottle with 250 ml concentrated saline solution, and then stirred using a mechanical shaker (200 rpm, 10 minutes). After 6 hours, the supernatant was extracted from the mixture and filtered into Whatman cellulose filter paper (diameter 47mm; pore size 0.45µm). Vacuum filtration unit was used to accelerate the filtration process. Samples from the filter paper were stored in petri-disk within a vacuum desiccator.

We conducted sample observation and quantitative analysis using a Nikon Eclipse E600 microscope. The criteria for identifying microplastic follows (Cole et al, (2013), namely (a) organic or cellular structure is absent, (b) homogenous in color, not shiny or sparkling, (c) plastic fibers are unbranched and not tapered at the ends, and (d) there is no segmented fiber. Particles identified as microplastic were counted and measured. Microplastic samples were classified according to their sizes, which are <20µm, 20-60µm, 60-100µm, 100-500µm and >500µm. And, their types were identified as fiber or granule.

RESULT

General trend

A total of 41 microplastic particles were found from eight out of ten the sampling stations (Table 1). The highest number of microplastics (14 particles) was observed at a station located in the Sunda Strait at a depth of 88.5m (Station 2). Microplastic particles were found only in two types of sediments (i.e. sandy mud and mud), where 26 particles were found in the sandy mud type of sediment and 15 particles in the mud sediment. Whereas the two stations where microplastic is absent are made of muddy sand

Table 1. Number of microplastic particles according to location, depth and sediment volume.

Sampling Location	Latitude	Longitude	Depth (m)	Number of particles	Sediment Volume (cm^3)	References
South Atlantic Ocean	52.0°S	8.0°W	2749	1	25	Van Cauwenberghe *et al.* (2013)
Nile Deep Sea Fan	32.4°N	31.7°E	1176	1	25	Van Cauwenberghe *et al.* (2013)
North Atlantic Ocean	48.8°N	16.5°W	4842	3	25	Van Cauwenberghe *et al.* (2013)
South of Portugal	37.1°N	7.5°W	27.4	6	859.03	Frias *et al.* (2016)
South of Portugal	37.0°N	8.2°W	9.7	6	245.44	Frias *et al.* (2016)
South of Portugal	37.1°N	8.6°W	19.4	1	245.44	Frias *et al.* (2016)
South of Portugal	36.9°N	8.9°W	18.7	1	981.75	Frias *et al.* (2016)
South of Portugal	36.9°N	8.9°W	18.7	1	1043.11	Frias *et al.* (2016)
South of Portugal	37.0°N	8.9°W	7.9	1	981.75	Frias *et al.* (2016)
South of Portugal	37.0°N	8.9°W	7.9	5	981.75	Frias et al (2016)
South of Portugal	37.0°N	8.9°W	7.9	1	981.75	Frias *et al.* (2016)
South of Portugal	37.0°N	9.0°W	22	4	460.19	Frias *et al.* (2016)
Southwestern Sumatera	6.2°S	105.5°E	88.5	14	100	This study, Sandy mud
Southwestern Sumatera	6.7°S	104.7°E	1962.8	4	100	This study, Mud
Southwestern Sumatera	5.8°S	104.2°E	575.6	3	100	This study, Mud
Southwestern Sumatera	6.1°S	103.9°E	2182	1	100	This study, Mud
Southwestern Sumatera	5.1°S	103.6°E	1007.6	3	100	This study, Mud
Southwestern Sumatera	4.6°S	102.4°E	503.2	4	100	This study, Mud
Southwestern Sumatera	4.8°S	102.2°E	1732	0	100	This study, Muddy sand
Southwestern Sumatera	5.1°S	101.9°E	719.2	0	100	This study, Mud clay
Southwestern Sumatera	3.6°S	101.7°E	66.8	6	100	This study, Sandy mud
Southwestern Sumatera	3.0°S	100.9°E	970.4	6	100	This study, Sandy mud

and mud clay. Microplastics found in this study are mainly observed in sampling stations with depths <500m (20 particles of microplastic, see Figure 2).

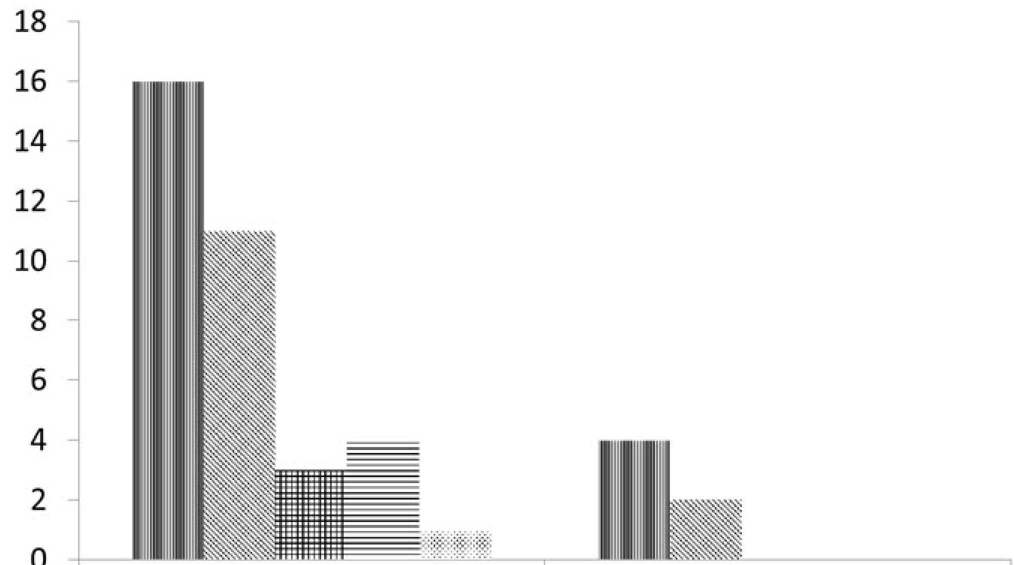
Our finding shows that microplastics found in southwestern Sumatera sediments are in the forms of granule and fiber (Figure 2). Most microplastics found in this study are granulates from depths of less than 500 m with a total of 16 particles. Fiber form is also most commonly found at the same depth range (<500m) with a total of 4 particles.

Based on the size classification of microplastic, most observed microplastic particles in the southwestern Sumatera sediments are those with the size range of 100-500µm with a total of 16 particles (Figure 3). This is followed by the size range of 60-100µm (13 particles) and less than 20µm (6 particles). While the least of all are the size range of 20-60µm and >500µm, each having 3 particles.

DISCUSSION

The suspected sources

Relatively higher amount of microplastics found in areas close to terrestrial input and along a busy shipping route is consistent with anthropogenic influence. The microplastic particles are found mostly from sediment samples taken from depths less than 500 m. These particles were likely derived from anthropogenic activities on the west coast of Sumatera then carried by ocean currents (Mohamed Nor & Obbard, 2014). As for sampling station, most or 14 particles of microplastic are found in the Sunda Strait (Station 2) at a depth of 88.5 m. This is a busy ocean shipping route with more than 100,000 passengers and 2,200 ships passing by per year (Rusli, 2012). Therefore, our study supports other works suggesting that areas near port or along shipping traffic have high presence of microplastic (Claessens *et al.*, 2011).



	Granule	Fiber
<500	16	4
500 - 1000	11	2
1000 - 1500	3	0
1500 - 2000	4	0
>2000	1	0

Figure 2. Microplastic classification based on form.

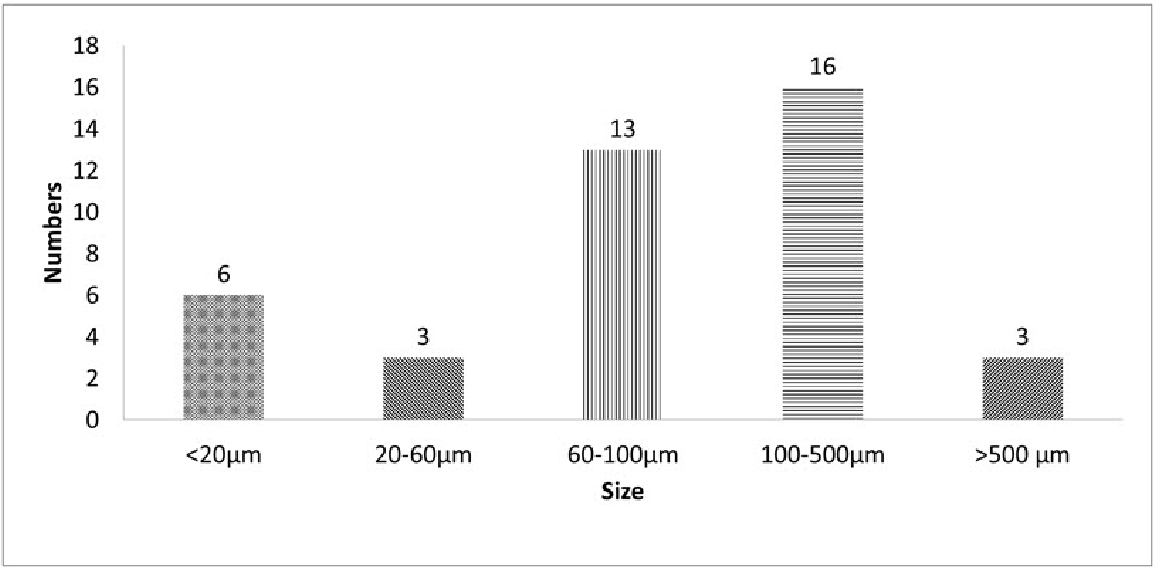


Figure 3. Microplastic classification based on size.

Other sampling sites with higher amount of microplastic are Station 1 (at a depth of 970.4m) and Station 10 (66.8m), each with 6 plastic particles. We suspect that the high microplastic abundance came from the east coast of Sumatera specifically near Bengkulu. This area has large rivers namely Bengkulu River, Jenggalu River and Babat River. In all, microplastic particles found from these three locations represent 63.4% plastic particles found from all sampling sites in this study. Indeed, the proximity to human activity causes higher exposure of microplastic (Frias *et al.*, 2016). We also found microplastic on the southwestern Sumatera deep-sea sediment sample taken at a depth of >2000m. This suggests that plastics which have been produced since 1910 (with its mass production since the 1950s), have pervaded marine environments even in pristine sites (Van Cauwenberghe *et al.*, 2013).

Eventually, microplastics would fall into seabed via a process called "marine snow" (discussed more in the next section) and be ingested by bottom-dwelling marine organisms that accumulate microplastics in their bodies (Goldberg, 1997). Plastics could reach sea bottom at depths of >2000m within a few days or a year, depending on ocean currents (Van Cauwenberghe *et al.*, 2013). Eventually, microplastic would reach the seabed and be covered with sand and mud (Ivar Do Sul & Costa, 2014).

The potential downward vector of microplastic

Marine snow is the downward export of organic matters that may also influence the transport of microplastic and other pollutant. Marine snow is a component in biogeochemical vector of biological pump (Turner, 2015). And as suggested by some studies, marine snow may also become a vector for microplastic downward transport (Goldberg, 1997; Van Cauwenberghe *et al.*, 2013). Furthermore, it has been widely known that the formation of marine snow is not merely composed of organic materials (e.g. fecal pellets, phytodetritus, transparent exopolymer, but also inorganic materials and others Graham *et al.*, 1999; Passow *et al.*, 2014; Passow *et al.*, 2012).

The downward transport of microplastic could occur in stages along the depth. Since plastic could adsorb organic pollutant (Teuten *et al.*, 2009), it is possible that other non-pollutant organic materials may also attach to plastic. This process may occur during the formation of transparent exopolymer (TEP) by microorganisms

(Turner, 2015). TEP itself attracts other materials such as fecal pellets, phytodetritus from planktonic organisms, and even dead materials to aggregate into bigger sizes (M. Graham *et al.*, 1999; Turner, 2015). This process would accelerate the downward export (Passow *et al.*, 2014). However, the crucial downward export process may happen in the twilight zone up to the upper aphotic zone (300-1000m) when the microbial process enhances biogeochemical processes. Within this zone, marine snow may be degraded by microbes (Sanders *et al.*, 2014), but the process may not affect the non-degradable microplastics. Then in the depth below 1000m, the microplastics would aggregate with freshly produced particulate matters (Liu *et al.*, 2007), the process that is affected by partial pressure of CO2 and particle size (Passow *et al.*, 2014).

The potential impacts of microplastic

Plastic pollution was initially seen as an aesthetic problem (Galgani, Hanke, Werner, & De Vrees, 2013; Gregory, 2009), but many researches in recent decades show how marine animals could be negatively affected by the presence of plastics (Boerger, Lattin, Moore, & Moore, 2010; Galgani *et al.*, 2013). Marine organisms could be affected mainly through the winding of plastic, getting trapped by plastic and plastic consumption (Gregory, 2009; Thompson, Moore *et al.*, 2009; Van Franeker *et al.*, 2011). Worse, the microscopic size allows the bioavailability of plastic through ingestion tract (Betts, 2008). A number of marine organisms have been observed to accumulate microplastics in their bodies, including crabs (Farrell & Nelson, 2013), copepods (Cole *et al.*, 2013), blue mussels (Browne *et al.*, 2008; Van Cauwenberghe & Janssen, 2014) and mussels (Van Cauwenberghe & Janssen, 2014). Microplastic ingested by marine organisms could disrupt the functioning of digestive tract (Cole *et al.*, 2013) and become a carrier for other organic contaminants adsorbed on microplastic such as brominated diphenyl ethers and polychlorinated biphenyls (Teuten *et al.*, 2009).

CONCLUSION

Microplastics found on the southwestern Sumatera deep-sea sediments tend to increase towards the main island, consistent with increased anthropogenic activities. Our finding also shows that microplastic pollution has pervaded relatively pristine environments. We project that the continuing increase of plastic production and consumption in Indonesia would lead to increased microplastic pollution that subsequently affects marine organisms.

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REFERENCES

Andrady, A. L. (2011). Microplastics in the marine environment. *Mar. Pol. Bul.* http://doi.org/10.1016/j.marpolbul. 2011.05.030

Arthur, C., Baker, J., & Bamford, H. (2009). Proceedings of the International Research Workshop on the Occurrence , Effects , and Fate of Microplastic Marine Debris. *Group*, (January), 530.

Betts, K. (2008). Why small plastic particles may pose a big problem in the oceans. *Envir. Sci. Tech.* http://doi.org/10.1021/es802970v

Boerger, C. M., Lattin, G. L., Moore, S. L., & Moore, C. J. (2010). Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. *Mar. Pol. Bul.*, 60(12), 2275–2278. http://doi.org/10.1016/j.marpolbul.2010.08.007

Browne, M. A., Crump, P., Niven, S. J., Teuten, E., Tonkin, A., Galloway, T., & Thompson, R. (2011). Accumulation of microplastic on shorelines woldwide: Sources and sinks. *Envir. Sci. Tech.*, 45(21), 9175–9179. http://doi.org/10.1021/es201811s

Browne, M. A., Dissanayake, A., Galloway, T. S., Lowe, D. M., & Thompson, R. C. (2008). Ingested microscopic plastic translocates to the circulatory system of the mussel, Mytilus edulis (L.). *Envir. Sci. Tech.*, 42(13), 5026–5031. http://doi.org/10.1021/es800249a

Claessens, M., Meester, S. De, Landuyt, L. Van, Clerck, K. De, & Janssen, C. R. (2011). Occurrence and distribution of microplastics in marine sediments along the Belgian coast. *Mar. Pol. Bul.*, 62(10), 2199–2204. http://doi.org/10.1016/j.marpolbul.2011.06.030

Cole, M., Lindeque, P., Fileman, E., Halsband, C., Goodhead, R., Moger, J., & Galloway, T. S. (2013). Microplastic ingestion by zooplankton. *Envir. Sci. Tech.,* 47(12), 6646–6655. http://doi.org/10.1021/es400663f

Farrell, P., & Nelson, K. (2013). Trophic level transfer of microplastic: Mytilus edulis (L.) to Carcinus maenas (L.). *Envir. Pol. (Barking, Essex : 1987)*, 177, 1–3. http://doi.org/10.1016/j.envpol.2013.01.046

Fendall, L. S., & Sewell, M. A. (2009). Contributing to marine pollution by washing your face: Microplastics in facial cleansers. *Mar. Pol. Bul.,* 58(8), 1225–1228. http://doi.org/10.1016/j.marpolbul.2009.04.025

Frias, J. P. G. L., Gago, J., Otero, V., & Sobral, P. (2016). Microplastics in coastal sediments from Southern Portuguese shelf waters. *Mar. Envir. Res.,* 114, 24–30. http://doi.org/10.1016/j.marenvres.2015.12.006

Galgani, F., Hanke, G., Werner, S., & De Vrees, L. (2013). Marine litter within the European Marine Strategy Framework Directive. *ICES J. Mar. Sci.* http://doi.org/10.1093/icesjms/fst122

Goldberg, E. D. (1997). Plasticizing the Seafloor: An Overview. *Envir. Tech.,* 18(2), 195–201. http://doi.org/10.1080/09593331808616527

Graham, E. R., & Thompson, J. T. (2009). Deposit- and suspension-feeding sea cucumbers (Echinodermata) ingest plastic fragments. *J. Exp. Mar. Biol. Ecol.*, 368(1), 22–29. http://doi.org/10.1016/j.jembe.2008.09.007

Gregory, M. R. (2009). Environmental implications of plastic debris in marine settings--entanglement, ingestion,smothering, hangers-on, hitch-hiking and alien invasions. *Philos. T. R. Soc. B.,* 364(1526), 2013–2025. http://doi.org/10.1098/rstb.2008.0265

Ivar Do Sul, J. A., & Costa, M. F. (2014). The present and future of microplastic pollution in the marine environment. *Envir. Poll.,* http://doi.org/10.1016/j.envpol.2013.10.036

Jambeck, J. R., & Johnsen, K. (2015). Citizen-Based Litter and Marine Debris Data Collection and Mapping. *Comput. Sci. Eng.*, 17(4), 20–26. http://doi.org/10.1109/MCSE.2015.67

Kementerian Perindustrian dan Perdagangan. (2013). Semester I, Konsumsi Plastik 1,9 Juta Ton. Retrieved December 8, 2015, from http://www.kemenperin.go.id/artikel/6262/Semester-I,-Konsumsi-Plastik-1,9- Juta-Ton

Liu, K. K., Kao, S. J., Hu, H. C., Chou, W. C., Hung, G. W., & Tseng, C. M. (2007). Carbon isotopic composition of suspended and sinking particulate organic matter in the northern South China Sea-From production to deposition. *Deep-Sea Research Part II: Topical Studies in Oceanography*, 54(14-15), 1504–1527. http://doi.org/10.1016/j.dsr2.2007.05.010

M. Graham, W., MacIntyre, S., & Alldredge, A. L. (1999). Diel variations of marine snow concentration in surface waters and implications for particle flux in the sea. *Deep-Sea Research Part I: Oceanographic Research Papers,* 47(3), 367–395. http://doi.org/10.1016/S0967-0637(99)00063-1

Mohamed Nor, N. H., & Obbard, J. P. (2014). Microplastics in Singapore's coastal mangrove ecosystems. Mar. Pol. Bul., 79(1-2), 278–283. http://doi.org/10.1016/j.marpolbul.2013.11.025

Moore, C. J., Moore, S. L., Leecaster, M. K., & Weisberg, S. B. (2001). A comparison of plastic and plankton in the North Pacific Central Gyre. *Mar. Pol. Bul.*, 42(12), 1297–1300. http://doi.org/10.1016/S0025-326X(01)00114-X

Moore, C. J., Moore, S. L., Weisberg, S. B., Lattin, G. L., & Zellers, A. F. (2002). A comparison of neustonic plastic and zooplankton abundance in southern California's coastal waters. *Mar. Pol. Bul.,* 44(10), 1035–1038. http://doi.org/10.1016/S0025-326X(02)00150-9

Passow, U., De La Rocha, C. L., Fairfield, C., & Schmidt, K. (2014). Aggregation as a function of PCO2 and mineral particles. *Limnol. Oceanogr.,* 59(2), 532–547. http://doi.org/10.4319/lo.2014.59.2.0532

Passow, U., Ziervogel, K., Asper, V., & Diercks, A. (2012). Marine snow formation in the aftermath of the Deepwater Horizon oil spill in the Gulf of Mexico. *Envir. Res. Lett.,* 7(3), 1–11. http://doi.org/10.1088/1748-9326/7/3/035301

PlasticsEurope. (2010). Plastics *– the Facts 2010. Plastics – the Facts* 2010.

PlasticsEurope. (2013). Plastics-The Facts 2013: An analysis of European latest plastics production, demand and waste data. *Octubre 2013*, 1–40. http://doi.org/10.1016/j.marpolbul.2013.01.015

PlasticsEurope. (2015). Plastics - the facts 2014/2015: An analysis of European plastics production, demand and waste data. *Plastics Europe*, 1–34. http://doi.org/10.1016/j.marpolbul.2013.01.015

Rocha-Santos, T., & Duarte, A. C. (2015). A critical overview of the analytical approaches to the occurrence, the fate and the behavior of microplastics in the environment. *TrAC - Trends in Analytical Chemistry*. http://doi.org/10.1016/j.trac.2014.10.011

Rusli, M. H. . (2012). Maritime Highways of Southeast Asia: Alternative Straits? Retrieved November 9, 2016, from http://www.rsis.edu.sg/publications/Perspective/RSIS0242012.pdf

Sanders, R., Henson, S. A., Koski, M., De La Rocha, C. L., Painter, S. C., Poulton, A. J., … Martin, A. P. (2014). The Biological Carbon Pump in the North Atlantic. *Prog. Oceanogr*, 129(PB), 200–218. http://doi.org/10.1016/j.pocean.2014.05.005

Teuten, E. L., Saquing, J. M., Knappe, D. R. U., Barlaz, M. A., Jonsson, S., Björn, A., … Takada, H. (2009). Transport and release of chemicals from plastics to the environment and to wildlife. *Philos. T. R. Soc. B.,* 364(1526), 2027–45. http://doi.org/10.1098/rstb.2008.0284

Thompson, R. C., Moore, C. J., vom Saal, F. S., & Swan, S. H. (2009). Plastics, the environment and human health: current consensus and future trends. *Philos. T. R. Soc. B.,* 364(1526), 2153–2166. http://doi.org/10.1098/rstb.2009.0053

Thompson, R. C., Olsen, Y., Mitchell, R. P., Davis, A., Rowland, S. J., John, A. W. G., … Russell, A. E. (2004). Lost at sea: where is all the plastic? *Science (New York, N.Y.)*, 304(5672), 838. http://doi.org/10.1126/science.1094559

Turner, J. T. (2015). Zooplankton fecal pellets, marine snow, phytodetritus and the ocean's biological pump. *Prog. Oceanogr*. http://doi.org/10.1016/j.pocean.2014.08.005

Van Cauwenberghe, L., Claessens, M., Vandegehuchte, M. B., & Janssen, C. R. (2015). Microplastics are taken up by mussels (Mytilus edulis) and lugworms (Arenicola marina) living in natural habitats. *Envir. Poll*, 199, 10–17. http://doi.org/10.1016/j.envpol.2015.01.008

Van Cauwenberghe, L., Claessens, M., Vandegehuchte, M., & Janssen, C. (2012). *Occurrence of microplastics in Mytilus edulis and Arenicola marina collected along the French-Belgian-Dutch coast*. Ghent. Retrieved from http://www.vliz.be/en/imis?module=ref&refid=213495

Van Cauwenberghe, L., & Janssen, C. R. (2014). Microplastics in bivalves cultured for human consumption. *Envir. Poll.*, 193, 65–70. http://doi.org/10.1016/j.envpol.2014.06.01

Van Cauwenberghe, L., Vanreusel, A., Mees, J., & Janssen, C. R. (2013). Microplastic pollution in deep-sea sediments. *Envir. Poll.* http://doi.org/10.1016/j.envpol.2013.08.013

Van Franeker, J. A., Blaize, C., Danielsen, J., Fairclough, K., Gollan, J., Guse, N., … Turner, D. M. (2011). Monitoring plastic ingestion by the northern fulmar Fulmarus glacialis in the North Sea. *Envir. Poll.,* 159(10), 2609–2615. http://doi.org/10.1016/j.envpol.2011.06.008

Wagner, M., Scherer, C., Alvarez-Muñoz, D., Brennholt, N., Bourrain, X., Buchinger, S., … Reifferscheid, G. (2014). Microplastics in freshwater ecosystems: what we know and what we need to know. *Envir. Sci. Europe.*, 26, 12. http://doi.org/10.1186/s12302-014-0012-7

Wright, S. L., Thompson, R. C., & Galloway, T. S. (2013). The physical impacts of microplastics on marine organisms: A review. *Envir. Poll.*. http://doi.org/10.1016/j.envpol.2013.02.031