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Release of Microplastic Fibers from Carpet-Washing Workshops Wastewater

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Abstract

Microplastics have raised many concerns because of their potential negative impacts on the environment. Identifying the sources of microplastics release to the environment is a challenging subject. Synthetic textiles, such as machine woven carpets, are highly capable to propagate and emit microplastics, especially fibers. While the carpet cleaning service has experienced a fast growth due to urbanization and its impact on life style, there is a lack of information on the number and the size of fibers, which are released during the washing process. In this study, we characterized the microplastic fibers in the wastewater of two carpet-washing workshops in the cities of Ahwaz and Sari in Iran. Three replicates of 10 L-samples were taken from the wastewater of washing and drying stages. All samples were passed through sieves of 500, 300 and 37 µm. The residues were washed with 1 L distilled water and poured into clean glass bottles. Then, the samples were passed through 25 µm filter paper. The remained materials on the filter were examined using a stereo microscope. Shapiro-Wilk and Levin tests were applied to test the normality and homogeneity of data. One-way ANOVA test was used to investigate the differences in size of microplastic fibers and independent t-test to determine the difference between the total number of the released microplastic fibers and the ones at each stage in the cities. More than 3097 and 1824 microplastic fibers per square meter of carpet (equal to 81 and 48 microplastic fibers per liter of wastewater) were counted in the workshops in Ahwaz and Sari, respectively. The shares of microplastic fibers in the size of ≥500, 300-500 and 37-300 µm were 18.4%, 24.6%, 57% in Ahwaz and 14.4%, 28.8%, 56.8% in Sari, respectively. The number of released microplastic fibers per liter of wastewater of carpet washing workshops is much higher than the number of fibers in the raw wastewater entering Sari WWTP, which was 4.9-12 microplastic fibers per liter. The washing of machine woven carpets is an important emission source of microplastic fibers especially with the size of less than 300 micron. The number of released microplastic fibers depends on the type of washing and drying practices. It is expected its emission load will sharply increase in future due to the booming growth in demand for these kinds of reasonably priced floor covers.

Keywords: Machine Woven Carpet, Microplastic Fiber, Washing, Wastewater.

1. Introduction

Microplastics[1] are an emerging anthropogenic contaminant which has been identified in different terrestrial and aquatic environments, such as oceans, rivers, lakes, estuaries, and soil, as well as in urban runoff and wastewater effluent (Michielssen et al., 2016, Rillig, 2012, Ziajahromi et al., 2017). They are non-degradable debris less than 5 mm and remain in the environment (Derraik, 2002, Gorycka, 2009, Browne et al., 2010), and can be divided into two primary and secondary MPs. Primary MPs are produced in microscopic sizes and used in manufacturing of larger plastic materials, face cleaners and cosmetics or in air blasting technology and equipment manufacturing. Secondary MPs are small plastic debris resulting from decomposition of larger plastic debris through biological, chemical, and physical processes in water or on soil (Zitko and Hanlon, 1991, Lee et al., 2013, Lassen et al., 2015).

MPs also are an environmental concern because of their potential to physically and chemically damage a variety of exposed organisms (Miranda and Carvalho-Souza, 2016). The properties of MPs play an important role in their environmental impacts. Researchers have shown that consumption of MPs, due to their small size and high surface-to-volume ratio, can damage marine organisms and provide a convenient route for transporting of pollutants such as industrial chemicals, drugs, hormones, pesticides and metal ions to living organisms (Rochman et al., 2013, Wright et al., 2013, Lassen et al., 2015). As a result, MPs have the potential to accumulate and transfer toxins to the food chain. They may also be a potential threat to human health through consumption of contaminated seafood (Teuten et al., 2009, Lassen et al., 2015, Rochman et al., 2015). Besides, the entry of MPs into the tissues of living organisms results in an increase in granulocytes (a group of white blood cells) and a decrease in the stability of the lysosomal membrane (Yamashita et al., 2011, Rochman et al., 2013).

Despite much research to identify microplastics in the environment, both in terms of number and morphology, identifying the sources of MPs release to the environment is a challenging subject (Ziajahromi et al., 2017). Decomposition of larger plastic debris, microbeads in cosmetics and synthetic fibers released from textiles have been identified as two major sources of MPs that can enter the aquatic ecosystem through wastewater, surface runoff and wind. Based on their physical features, MPs are classified as particles[2] (fragments, films, pellets, granules, lines, foams and beads) and fibers[3] (Lassen et al., 2015). Synthetic fibers are widely used in cloths, carpets and many other goods. Researchers have shown that wastewater from the laundry is one of the most important sources of fiber release into the environment, so that by washing clothes, a wide range of natural (such as cotton and wool) and synthetic fibers (such as nylon) can enter the sewage. (Browne et al., 2011, Lassen et al., 2015) and finally enter the environment so that they were found in a variety of environments, including sediments, water bodies, and organisms (Browne et al., 2011). Despite some research in the world on the amount of synthetic fibers released during the washing process, so far no research has been done on other products made from synthetic fibers such as carpets.

The machine woven carpets are often made from synthetic fibers such as acrylic, polyester, polypropylene and nylon fibers while the first two ones are more common in Iran. These carpets are widely used in Iran and many other countries, so that, total world production in 2016 was 3.9 billion square meters and it is expected to reach 4.3 billion square meters by 2025. Due to widespread use of carpets, carpet-washing workshops are being established and developing as a service job in Iran and many other countries. Like other synthetic textiles, machine woven carpet is made of polymer fibers. Fine fibers detached from these textiles often enter the environment through washing and drying processes.

Despite the importance of carpet washing workshops as a source of MPFs, so far no research has been performed on this industry. In this study, the number and the size of MPFs in the wastewater of two carpet washing workshops in the cities of Sari in the north and Ahwaz in the southwest of Iran were investigated.

2. Materials and methods

This study was conducted in two common carpet-washing workshops in Ahwaz and Sari. The number of carpet-washing workshops in each city and the capacity and an approximate number of carpets that are washed daily by carpet-washing workshops in each city are estimated based on information received from workshop owners to get an approximate picture of the state of microplastic diffusion in this industry. For this purpose, the number and size of released microplastics fibers in two carpet-washing workshops were investigated. The workshops are located in the cities of Ahwaz (the capital of Khuzestan province in the southwest of Iran) and Sari (the capital of Mazandaran province in the north of Iran) and release their wastewater into the Karun River and the absorption wells, respectively (fig. 1).

The samples of wastewaters were taken from the washing (contained detergent and disinfectant) and drying steps of both carpet washing workshops. To determine the number and size of MPFs, eight machine woven carpets with total area of 96 m^2 in Ahwaz and three machine woven carpets with total area of 36 m^2 in Sari were washed. At each washing and drying step, 10 L wastewater was taken in three replicates and the samples were transferred to the laboratory.

The samples were passed through stainless steel sieves of 500, 300 and 37 µm and the residues were washed with 1 L distilled water and were poured into clean glass bottles. Next, the contents of each bottle were passed through 25 µm filter paper (Filter Paper, Whatman 41) and were rinsed with ultrapure water (Brown et al., 2011, Napper & Thompson, 2016).

[1] Microplastics (MPs)
[2] Microplastic particle (MPP)
[3] Microplastic fiber (MPF)

To avoid overestimating of the number of MPs, non-plastic materials such as natural fibers like cotton,

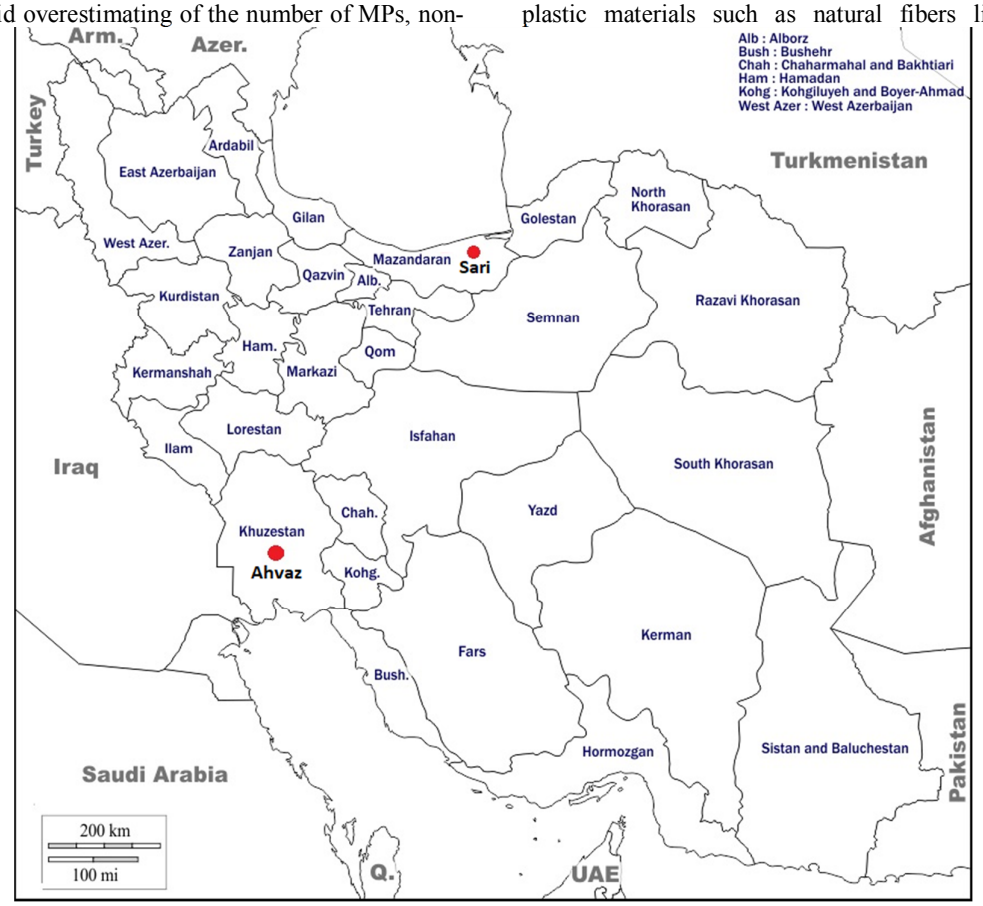


Fig. 1. Location of carpet washing workshops in the cities of Ahwaz and Sari

which are visually similar to synthetic fibers, were stained by adding 5 ml of 0.2 mg/ml Bengal Rose solution to each screen and allowed to react for 5 min at room temperature (Ziajahromi et al., 2017). The dye was washed off with ultrapure water. Then the samples were dried at 60 °C for 15 min.

The remained materials on the filter paper were examined using a search KERN stereo microscope equipped with a 10 MP KECAM digital camera (fig. 2) and all fibers were extracted from each sample (except the pink fibers) and counted. Pink stained fibers, suspected to be natural matter and very small in number, were removed from the samples after confirming their natural origin.

Shapiro-Wilk and Levin tests were applied to test the normality and homogeneity of the data. One-way ANOVA[1] test was used to investigate the presence or absence of differences in size of MPFs and independent t-test to determine the difference between the total number of MPFs released between the two carpet washing workshops and also to compare different stages between cities in terms of the number of fibers.

[1] Analysis of Variance (ANOVA)

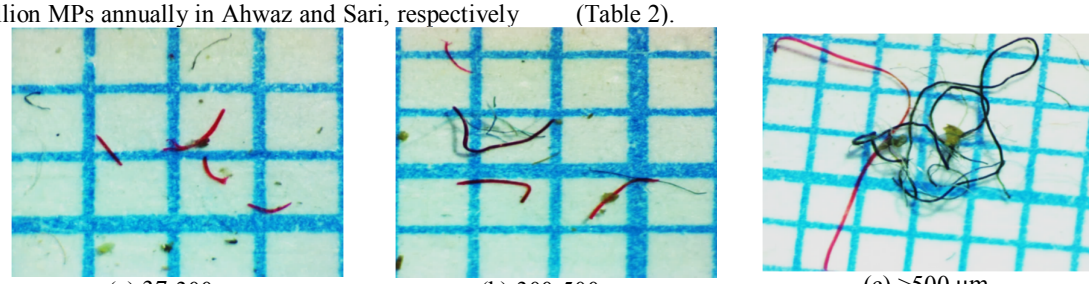
3. Results and Discussion

3.1. Abundance of MPFs

The number of MPFs caused by washing and drying steps were counted and reported as of number per square meter of carpet (Table 1). All extracted microplastics from the wastewater were fiber. In total, 3097.38±69.16 and 1824.76±180.12 MPFs per square meter of carpet were counted in Ahwaz and Sari, respectively. The total number of MPFs/m^2 in Ahwaz was higher than in Sari where the majority of MPFs in both workshops belong to the washing stage (Table 1).

Based on information obtained from this industry's owners, on average, in the cities of Ahwaz and Sari, from April to January, each carpet washing workshop washes 180 and 360 square meters per day, and during February and March, these numbers reach 600 and 1200 square meters, respectively, due to the proximity to the New Year. The average consumed water for washing one square meter of carpet in both carpet-washing workshops was 38 L. On the other hand, according to information provided by the union of carpet washing workshops, there are 50 workshops in Ahwaz and 30 workshops in Sari. Thus, they release more than 13 and

31 billion MPs annually in Ahwaz and Sari, respectively (Table 2).



(a) 37-300 µm (b) 300-500 µm (c) >500 µm

Fig. 2. The MPFs from washing stage (×7.5)

Table 1. The number of observed MPFs in the wastewater of carpet washing workshops in the cities of Ahwaz and Sari

Size of MPs (µm)	Ahwaz		Sari	
	Washing step (MFi/m^2)	Drying step (MFi/m^2)	Washing step (MFi/m^2)	Drying step (MFi/m^2)
>500	340.86±11.02	106.4±16.72	278.54±33.44	57±4.56
300-500	817±101.08	74.86±6.46	384.94±29.26	64.6±5.7
37-300	1579.66±88.54	178.6±16.72	916.94±134.52	122.74±15.2
Sum	2737.52±53.2	359.86±15.96	1580.42±162.64	244.34±19
Total	3097.38±69.16		1824.76±180.12	

Table 2. Examination of MPFs in carpet washing in Ahwaz and Sari

Size (µm)	Ahwaz			Sari		
	MPs/m^2	Released MPs by one workshop (10□/ yr)	Released MPs by all workshops (10^6/ yr)	MPs/m^2	Released MPs by one workshop (10□/ yr)	Released MPs by all workshops (10^6/ yr)
>500	447.26	38	1900	335.54	190	5721
300-500	891.86	77	3850	449.54	255	7665
37-300	1758.26	152	7600	1039.68	590	17729
Sum	3097.38	267	13350	1824.76	1035	31115

3.2. Comparison of released MPFs between the workshops

Shapiro-Wilk and Levene statistical tests indicate that the data are normal and homogeneous. Besides, the results of independent t-test shows there is a significant difference between the total number of the released MPFs per square meter by the two workshops (T: 4.5, p-value <0.05). The difference is also significant for the washing and drying stages in the two cities (T: 6.76-4.93, p-value <0.05). Similarly, statistical analysis of the sizes shows there is a significant difference between the size of released MPFs in both cities and the size of 37-300 microns has the most significant difference with the other two sizes (p-value <0.05 F = 47.5-26.39). This indicates that a large number of MPFs released into the environment are in the range of 37-300 microns (fig. 3).

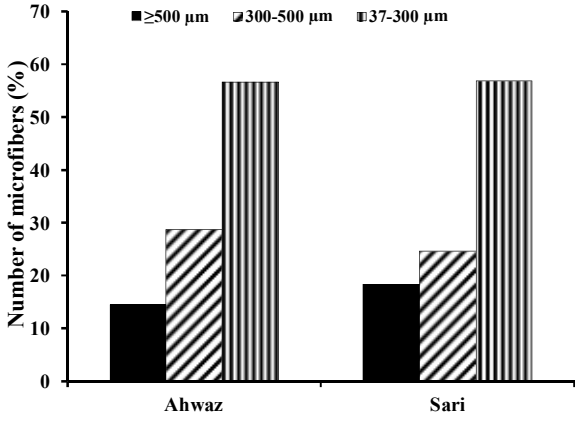


Fig. 3. The size distribution of MPFs in the wastewater of the carpet washing workshops in Ahwaz and Sari (%)

3.3. Discussion

The environmental consequences of the presence of MPs are not yet fully understood. Given the increasing consumption of plastics, it is expected that the number of MPs in the environment will increase in the future. This, despite the fact that, if the use of plastics is stopped, the number of MPs will increase due to the fragmentation of plastics in the environment (Law and Thompson, 2014). There are many concerns about the use of MPs by organisms and their harmful effects on them and a lot of research has been done in this area. Therefore, considering the long-term stability of plastics in the environment and their harmful effects, it is necessary to identify the different sources of their production and to manage them. This is especially important for the resources that release plastics with a size of less than 5 mm such as micro-particles used in cosmetics and fibers used in the textile structure. According to this, in addition to laundry, one of the industries that will be directly involved in the production of MPFs is carpet washing workshops. The result of this study showed that carpet washing workshops consume a high volume of water and produce wastewater that contains large amounts of MPFs, which often enter the environment without any treatment. Investigation of two carpet washing workshops in the cities of Ahwaz and Sari revealed that washing and drying of one square meter of machine-woven carpet generates more than 3097 and 1824 MPFs respectively which are mostly less than 300 microns where the wastewater is usually discharged to water resources without any effective treatment to remove MPFs. These fibers often have a high ability to absorb environmental pollutants due to their small size and high surface-to-volume ratio (Rios et al., 2007).

There was a significant difference between the released MPFs in carpet washing workshops in Ahwaz and Sari, and the number of fibers released by washing each square meter of carpet in Ahwaz was higher than Sari; but due to the large number of carpets that are washed daily and annually in Sari carpet washing, much more fiber from this carpet washing workshop enters the environment compared to Ahwaz. The carpet washing workshop Sari releases 1035×10^6 MPFs into the environment annually, which is about 3.8 times more than Ahwaz, considering the number of carpet washing workshops in Ahwaz and Sari, this number is estimated at $31,115\times10^6$ MPFs for Sari and $13,350\times10^6$ MPFs for Ahwaz in one year. These estimated results suggest that the industry could be considered as a significant source of microplastic diffusion into the environment, but generalizing this data to a wider range or more accurately estimating the amount of release requires additional research.

According to this research, the volume of water used to wash each square meter of carpet is about 38 liters. Thus, about 81 and 48 fibers were produced per liter of wastewater produced by washing one square meter of carpet in Ahwaz and Sari, respectively such that the number of released MPFs per liter of wastewater of carpet washing workshops is much higher than the number of fibers in the wastewater entering Sari WWTP, which was 4.9 and 12 fibers per liter, respectively, in winter and spring (Alavian & Hashemi, 2019). This indicates the importance of carpet washing workshops in releasing large amounts of MPFs per liter of wastewater and if the wastewater of carpet washing workshops is connected to the municipal sewage collection system in the future, and it eventually enters the treatment plant, it will bring a high number of fibers into the treatment plant.

Since no studies have been conducted on the amount of MPFs released from carpet washing workshops, it is not scientifically acceptable to compare these results with other research. However, a review of studies on the amount of fiber released from the laundry process suggests that one cloth can produce more than 1900 fibers per wash (Browne et al., 2011, Napper and Thompson, 2016). It was also shown that on average, for 6 kg of acrylic fabric, more than 700,000 fibers were found in the washing machine wastewater. Also, a fleece dress (Almroth et al., 2018) and 5 kg of polyester textile (Falco et al., 2018) respectively, can discharge about 110,000 and 6,000,000 MPFs into wastewater. Although the number of MPFs released by washing a square meter of carpet is less than the amount provided above, it can be said that carpet washing workshop with laundry is one of the most important sources of fiber production and release. A comparison of two carpet washing workshops to investigate the cause of the difference in the number of released fibers showed that both carpet washing workshops used drinkable water with a temperature of 24-25 °C, powdered detergent, similar disinfectants (liquid calcium hypochlorite, 5g/L) and similar washing and drying processes. However, in Ahwaz, due to its warm weather condition, large open space and platforms with higher capacity and more manpower are used for carpet washing. As a result, more carpets are washed per day, whereas in Sari, due to its high humidity and rainfall, a small covered space with a lower capacity and less manpower are used for each carpet. Thus, during washing stage, carpet erosion is less in Sari than Ahwaz, and therefore fewer fibers are released. On the other hand, in Ahwaz, a carpet dryer with a speed of 1500 rpm and 3 minutes drying time is used while in Sari the dryer has a speed of 1200 rpm and 5 minutes drying time. It seems although the higher spin has shortened the drying time in the workshop in Ahwaz, it has resulted in more carpet erosion and an increase in the number of fibers in the wastewater of drying stage.

4. Conclusion

The presence of large amounts of MPFs in the wastewater of the carpet washing workshops studied indicates that the industry could be a significant source of the release of the MPFs to the environment, most of which is less than 300 microns in size. These small fibers have a high surface-to-volume ratio and therefore have a very high ability to absorb stable organic pollutants and heavy metals in the environment, and therefore are known as an environmental concern, especially for the city of Ahwaz, which directly discharges the wastewater caused by their carpet washing workshops into the Karun River. Given the importance of this industry in the production and release

of MPFs, it is important to create new washing and drying methods that reduce carpet erosion and thus reduce fiber diffusion. Also, the study of more carpet washing workshops in Iran in order to better understand and recognize this activity in a more accurate estimation of fiber emission to the environment requires additional research. In addition, it is necessary to create protocols for better management of their wastewater.

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References

Alavian Petroody, S. S. & Hashemi, S. H. 2019. Occurrence and characterization of microplastics in urban wastewater, a case study: Sari wastewater treatment plant. *Journal of Civil Engineering of Modares,* 19 (6)**,** 145-154 (In Persian).

Almroth, B. M. C., Åström, L., Roslund, S., Petersson, H., Johansson, M., & Persson, N. K. 2018. Quantifying shedding of synthetic fibers from textiles; a source of microplastics released into the environment. *Environmental Science and Pollution Research,* 25(2)**,** 1191-1199.

Browne, M. A., Crump, P., Niven, S. J., Teuten, E., Tonkin, A. & Galloway, T., et al. 2011. Accumulation of microplastic on shorelines woldwide: sources and sinks. *Environmental Science and Technology,* 45**,** 9175-9179.

Browne, M. A., Galloway, T. S. & Thompson, R. C. 2010. Spatial patterns of plastic debris along estuarine shorelines. *Environmental Science and Technology,* 44**,** 3404-3409.

Derraik, J. G. 2002. The pollution of the marine environment by plastic debris: a review. *Marine Pollution Bulletin,* 44**,** 842-852.

De Falco, F., Gullo, M. P., Gentile, G., Di Pace, E., Cocca, M., Gelabert, L., et al. 2018. Evaluation of microplastic release caused by textile washing processes of synthetic fabrics. *Environmental Pollution,* 236, 916-925.

Gorycka, M. 2009. Environmental risks of microplastics. *Faculteit der Aard-en Levenswetenschappen.* Vrije Uniersiteit Amesterdam, Amesterdam, Netherlands.

Lassen, C., Hansen, S. F., Magnusson, K., Hartmann, N. B., Jensen, P. R., Nielsen, T. G., et al., 2015. *Microplastics: occurrence, effects and sources of releases to the environment in Denmark*, The Danish Environmental Protection Agency, Strandgade, Denmark.

Law, K. L., Thompson, R. C. 2014. Microplastics in the seas. *Science*, 345, 144-145.

Lee, J., Hong, S., Song, Y. K., Hong, S. H., Jang, Y. C., Jang, M., et al. 2013. Relationships among the abundances of plastic debris in different size classes on beaches in South Korea. *Marine Pollution Bulletin,* 77**,** 349-354.

Michielssen, M. R., Michielssen, E. R., NI, J. & Duhaime, M. B. 2016. Fate of microplastics and other small anthropogenic litter (SAL) in wastewater treatment plants depends on unit processes employed. *Environmental Science Water Research and Technology*, 2**,** 1064.

Miranda, D. D. A. & De Carvalho-Souza, G. F. 2016. Are we eating plastic-ingesting fish?, *Marine Pollution Bulletin*, 103(1)**,** 109.

Napper, I. E. & Thompson, R. C. 2016. Release of synthetic microplastic plastic fibers from domestic washing machines: effects of fabric type and washing conditions. *Marine Pollution Bulletin,* 112**,** 39-45.

Rillig, M. C. 2012. Microplastic in terrestrial ecosystems and the soil?, *Environmental Science and Technology*, 46**,** 6453-6454.

Rios, L. M., Moore, C. & Jones, P. R. 2007. Persistent organic pollutants carried by synthetic polymers in the ocean environment. *Marine Pollution Bulletin,* 54**,** 1230-1237.

Rochman, C. M., Hoh, E., Kurobe, T. & Teh, S. J. 2013. Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. *Scientific Reports,* 3**,** 3263.

Rochman, C. M., Tahir, A., Williams, S. L., Baxa, D. V., Lam, R., Miller, J. T., et al. 2015. Anthropogenic debris in seafood: plastic debris and fibers from textiles in fish and bivalves sold for human consumption. *Scientific Reports,* 5**,** 14340.

Teuten, E. L., Saquing, J. M., Knappe, D. R., Barlaz, M. A., Jonsson, S., Björn, A., et al. 2009. Transport and release of chemicals from plastics to the environment and to wildlife. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 364**,** 2027-2045.

Wright, S. L., Thompson, R. C. & Galloway, T. S. 2013. The physical impacts of microplastics on marine organisms: a review. *Environmental Pollution,* 178**,** 483-492.

Yamashita, R., Takada, H., Fukuwaka, M. A. & Watanuki, Y. 2011. Physical and chemical effects of ingested plastic debris on short-tailed shearwaters, puffinus tenuirostris, in the North Pacific Ocean. *Marine Pollution Bulletin,* 62**,** 2845-2849.

Ziajahromi, S., Neale, P. A., Rintoul, L. & Leusch, F. D. 2017. Wastewater treatment plants as a pathway for microplastics: development of a new approach to sample wastewater-based microplastics, *Water Research*, 112(1)**,** 93-99.

Zitko, V. & Hanlon, M. 1991. Another source of pollution by plastics: skin cleaners with plastic scrubbers. *Marine Pollution Bulletin,* 22**,** 41-42.