Marine Pollution Bulletin 161 (2020) 111702

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

The presence and significance of microplastics in surface water in the Lower Hudson River Estuary 2016–2019: A research note

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ARTICLE INFO

Keywords:
Microplastics
Hudson River
New York City
Combined sewer overflows

ABSTRACT

Microplastics are a major environmental issue of concern. Since 2016, Hudson River Park has collaborated with Brooklyn College to survey microplastics within Park waters between Chambers and 59th Streets in Manhattan. It was hypothesized that microplastic concentration is influenced by proximity to combined sewer overflow (CSO) points, precipitation, and tides. Samples were collected at channel and near-shore locations at downtown and midtown sites. Microplastics were analyzed following NOAA methods via stereo microscope. Concentrations in 2018 were higher than in 2016, 2017 and 2019 ((ANOVA F (1,70) = 5.2, $p < 0.03$*; post hoc Tukey test $p < 0.009$*)), and near-shore sites tended to exhibit higher concentrations than channel sites (ANOVA and post-hoc Tukey: $p < 0.03$*). Microfibers were not fully accounted for and fragments were highly prevalent in all samples (~70%). Additional data will improve the understanding of the presence of microplastics in the Lower Hudson and elucidate the effects of wet weather on plastic concentrations.

1. Introduction

Microplastics are pieces of plastic less than or equal to 5 mm in size. Microplastics can result from the breakdown of larger plastics and are also intentionally manufactured, such as microfibers, microbeads, and nurdles that are especially common byproducts of the textile and cosmetic industries (Rochman et al., 2019).

Microplastic pollution is an environmental issue that has gained increasing attention by the scientific community due to the global impact of plastics in the ocean (Borrelle et al., 2017). A report by the MacArthur Foundation projected that by 2050, plastic pieces will outnumber fish (MacArthur et al., 2016). Today, microplastics have been identified in some of our world's most isolated environments from remote lakes in Mongolia, to the mountaintops of the French Pyrenees, to the deepest points in the ocean (Free et al., 2014; Allen et al., 2019).

Estimates from global models assessing the accumulated number of microplastic particles in the ocean range from 15 to 51 trillion particles, weighing between 93 and 236 thousand metric tons (Van Sebille et al., 2015). A survey of microplastics in the North Atlantic Gyre found concentrations of 1.60 mg/m^3 and a similar survey in the East Asian seas discovered quantities of 3.70 pieces/m^3 (Reisser et al., 2014; Isobe et al., 2015). All studies emphasize the prominence of the world's plastic problem; these numbers are only growing as the global consumption of plastic increases and plastics persist in the environment.

Plastic contamination is a pervasive issue that affects all waterways, especially urban environments (Hitchcock, 2020) and estuaries (Harris, 2020), however, limited research has been conducted to determine the quantity of microplastics in the Lower Hudson River Estuary (LHRE).

At the inception of this survey in 2015–16, there was a dearth of local literature on the subject. In one of the few available reports, NY-NJ Baykeeper found an average of 256,322 microplastic particles/km^2 across a dozen sites in NY harbor (NY-NJ Baykeeper, 2016) using NOAA's recommended methods (Masura et al., 2015). In the years following, a survey of microplastics in the Mohawk River – the Hudson River's largest tributary – found a concentration of up to 0.743 particles/m^2 (743,000 particles/km^2) (Smith et al., 2017). Using a different methodology incorporating 45 μm filter paper, researchers from Rozalia Project quantified microfiber pollution throughout the length of the Hudson River, finding microfiber contamination in all sample sites with an average of 0.98 particles/L (Miller et al., 2017). Columbia University's Lamont-Doherty Earth Observatory along with Riverkeeper additionally studied microbead pollution in the New York harbor and Newton Creek (Krajick, 2017; Lim et al., 2018).

These studies employed a variety of collection techniques and used different metrics, making comparisons difficult. The concentration

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https://doi.org/10.1016/j.marpolbul.2020.111702
Received 19 May 2020; Received in revised form 19 September 2020; Accepted 19 September 2020
Available online 03 November 2020
0025-326X/ Published by Elsevier Ltd.

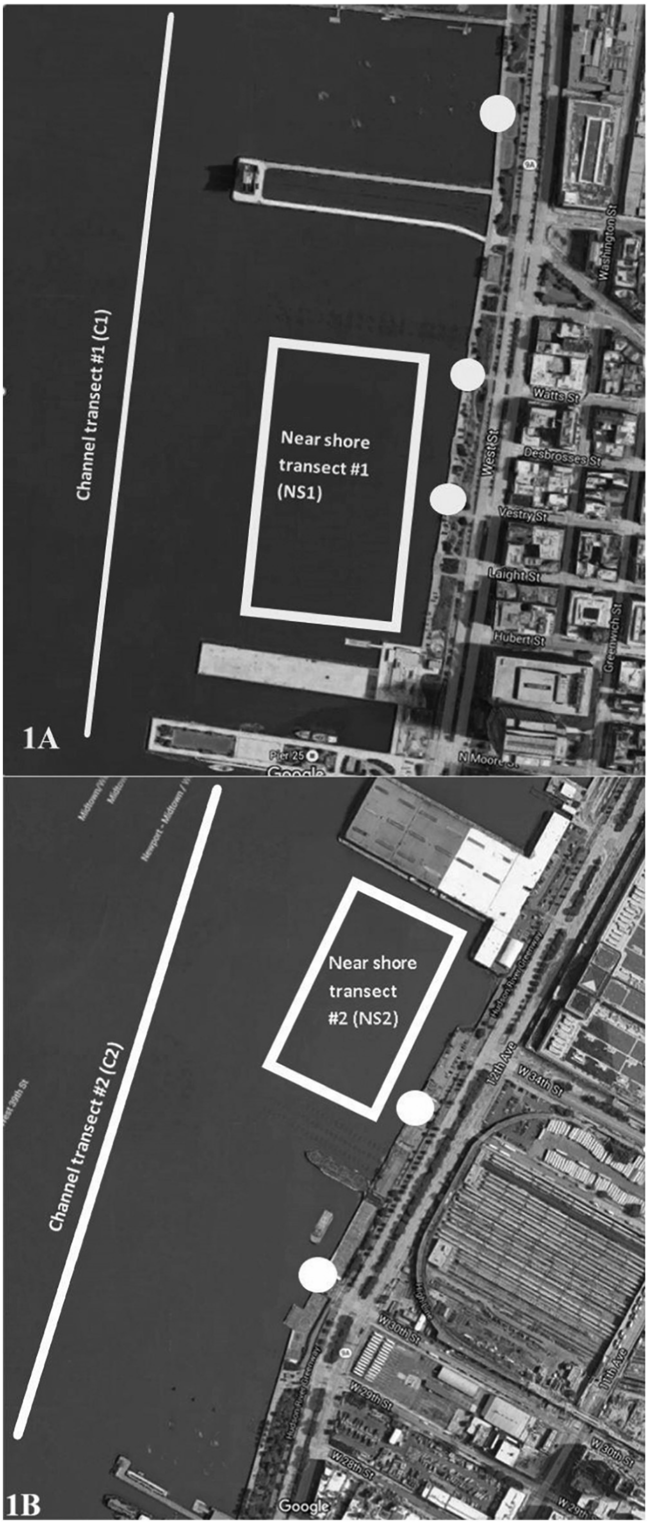

Fig. 1. Panels A and B | Map of microplastics sampling and CSO locations in Hudson River Park. NS1 and C1, near Vestry Street (downtown). NS2 and C2 midtown near 34th Street (midtown). CSO location denoted by circles.

metric of microplastics "particles/km^2" was chosen to align with other, contemporaneous monitoring efforts such as those by NY-NJ Baykeeper and NOAA to standardize reporting of data. The Park's present work is the first multi-year study to quantify and categorize the diversity of microplastics in the LHRE to assess inter-annual variability in this dynamic and urbanized system.

This study aimed to investigate how microplastic concentrations are influenced by sampling year, sample location, sample site, precipitation, and tide cycle. We hypothesized that near-shore sites (especially those in inter-pier areas) would exhibit higher concentrations than channel sites due to proximity to CSOs (Fig. 1) (Estahbanati and Fahrenfeld, 2016; Dris et al., 2018) and reduced flow rates (Able and Duffy-Anderson, 2005).

2. Methodology

2.1. Field sampling

The survey was conducted by collecting surface water samples at near-shore and channel locations in midtown and downtown sites within the Park's Estuarine Sanctuary. The Sanctuary includes 400 acres of protected, brackish waters along a 4-mile, 150-acre stretch of the West side of Manhattan from Chambers St. to 59th St. The submerged topography is characterized by 2 to 4 m deep mud flats between piers and pier remnants, tapering to a maximum depth of 15 to 20 m in the center of the channel. Sites were chosen to compare different areas within the Park, and to observe if and how microplastics vary in relation to potential pollution sources, especially CSOs (Fig. 1). Over 30 CSO pipes are located within the Park and are hypothesized to be a dominant source of microplastics in the Park's estuarine waters (Open Sewer Atlas, 2019).

Field sampling was conducted according to NOAA's recommended methods (Masura et al., 2015) available when the project commenced. Sampling occurred monthly from June to October from 2016 to 2019. Samples were collected using a 0.3 mm (333 μm) mesh, 1 m wide, 3 m long Sea-Gear® Neuston net with a 1 L plastic bottle attachment. For each transect, the Neuston net was trawled along the surface of the water for 15 min at an average speed of 4 knots. This time and distance were chosen to ensure that ~1.8 ± 0.052 km was consistently traveled at both downtown and midtown sites and at nearshore and channel sampling locations, for a total of 4 transects (Fig. 1A, B). Near-shore transects were rectangular due to spatial constraints imposed by nearby pier infrastructure. Transect lengths were confirmed using coordinates obtained in the field by a castable conductivity, temperature, and depth instrument (CASTAWAY®-CTD), and these water quality parameters were also recorded each sampling day as metadata.

The distance between the coordinates recorded by the CTD was then confirmed with Google Maps. A near-shore sample and a channel sample were collected monthly at both midtown and downtown sites, producing 4 samples per month. Samples were transferred into 1 L glass mason jars. Excess material caught on the net's threaded ring was washed into the jars with tap water.

Throughout the summer field seasons of 2016 to 2019, 72 samples were collected in total, with 16 taken in both 2016 and 2019, and 20 in both 2017 and 2018. The samples were then delivered to Brooklyn College for laboratory processing.

2.2. Laboratory processing and analysis

All samples processed were subjected to NOAA's methods when the program started in 2016 (Masura et al., 2015). Methods remained unchanged in order to provide congruous data. The samples were first rinsed with distilled water through a stack of sieves with mesh sizes of 5.6 mm and 0.3 mm to separate large pieces of organic material and larger plastic debris. The material collected on the 0.3 mm sieve was transferred to a 500 mL beaker and dried at 90 °C overnight. Then, organic matter was degraded using a Fe (II) wet peroxide oxidation (WPO) process. To degrade as much organic matter as possible, the WPO was repeated up to four times. Approximately 6 g of NaCl per 20 mL of sample was then added to increase the density of the aqueous solution to ~5 M NaCl in order to perform density separation. Samples were transferred to glass funnels and allowed to cool and separate overnight. The contents of the funnel were then drained via rubber hose and pinch clamp attached to the funnels through 0.3 mm sieves made from Nitex mesh, with the settled and floating fractions separated onto two different sieves. The resulting “sink” and “float” samples were air-dried for at least 24 h before both being counted and categorized. Both sink and float counts were combined to provide total sample microplastic concentration, but tallied separately to assess the ratio of floating to sinking plastics in each sample.

2.3. Counting and categorizing

Processed samples were counted and categorized using stereo microscopic analysis at 40 times magnification, identifying plastics from 0.333 mm to 5.6 mm in size. While observing particles under a stereo microscope, size, color, shape, texture, and heat reactivity were all used to distinguish plastic from non-plastic based on NOAA's guidelines (Masura et al., 2015). Exposure to a heated metal probe allowed for distinction of microplastic pieces from organic marine debris since the former melts and the latter burns or remains inert when exposed to heat (Masura et al., 2015). In the future, polymer identity will be confirmed using spectroscopic analysis in collaboration with partner laboratories.

Microplastics were identified as belonging to one of six categories outlined by Masura et al. (2015): fragments, foam, line, pellets, film, and nurdles (Fig. 2A–F). Fragments are hard and amorphous pieces of plastics that have degraded from larger pieces of plastics. Foam pieces are soft, porous, irregular plastics. Line refers to any thin, flexible plastic, such as fishing line or large fibers. Film is thin and flat, often translucent/transparent. Nurdles are hard with a more uniform, cylindrical shape.

2.4. Calculations and statistical methods

The areal concentration (C) of surface microplastics (microplastic particles/km^2) for each transect (i) was calculated using the following formula:

$$C_i = \frac{ni}{WL_i}$$

where n_i is the number of microplastic pieces found at that transect, W is the width of the Neuston net (0.0009144 km), and L_i is the length of the transect (~1.8 ± 0.052 km). Height of the net was not included in this calculation due to inconsistency in net submersion and alignment with Masura et al. (2015). Excel 2016, SPSS v25, and R (3.5.1) were used to assess the data and compare the effects of variables. Data were analyzed using ANOVA statistical tests with both post hoc *t*-tests and Tukey tests. Variables of interest for these tests included sampling year, sampling site (downtown vs. midtown), and sampling location (nearshore vs. channel).

The relationship between microplastic concentration and precipitation was analyzed using Spearman's rank correlation and Kendall's tau-b method.

3. Results

We found microplastics in all samples and consistent average surface concentrations between years in the Estuarine Sanctuary, except for higher concentrations in 2018 (830,762 microplastics particles/km^2). Average (mean) concentration in 2018 was three times greater than both 2016 (243,772) and 2019 (244,142), and six times greater than 2017 (143,204) (Fig. 4). Fragments made up 67% of all microplastic pieces observed in 2016, 44% in 2017, 77% in 2018, and 64% in 2019, for an average of 70% across all years (Fig. 3).

In 2016, 2018 and 2019, the second most common type of microplastic found was foam (13%). This is consistent with the Park's 2019 macroplastic, shoreline survey where foam is the dominant marine debris found in cleanups (50%), followed by beverage bottles (29%) and food packaging (5%) (Hudson River Park, 2019).

Significant differences in microplastic concentrations were observed between 2018 and every other year (ANOVA $F(1,70) = 5.2, p < 0.03^*$; post hoc Tukey test $p < 0.009^*$). No significant difference was found between 2016, 2017, and 2019. Significant difference was also observed between near-shore (NS) and channel (C) locations over all four years (ANOVA $F(1,70) = 5.1$, $p < 0.03^*$), with Tukey tests showing that 2018 near-shore concentrations were significantly higher than both channel concentrations in 2016, 2017, and 2019 ($p < 0.002^*$) and near-shore concentrations in 2016 and 2017 ($p < 0.03^*$).

In general, the concentration data were found to be heavily right-skewed. The normality of the distribution of plastic concentration data was assessed using Kolmogorov-Smirnov and Shapiro-Wilk test ($p < 0.05$) in SPSS v25, with 72% of samples at or under 416,000

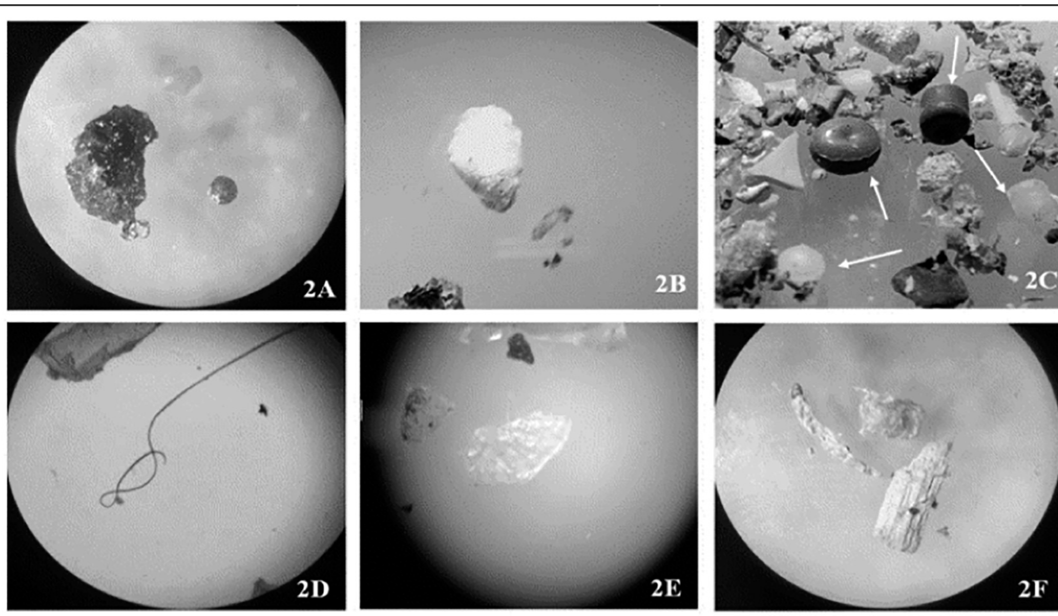

Fig. 2. Panel A | Fragment (*left*). Pellet (*right*). Panel B | Foam (*center left*). Panel C | Various nurdles. Panel D | Line. Panel E | Film (*center*). Panel F | Organic debris (e.g. wood and arthropod remains).

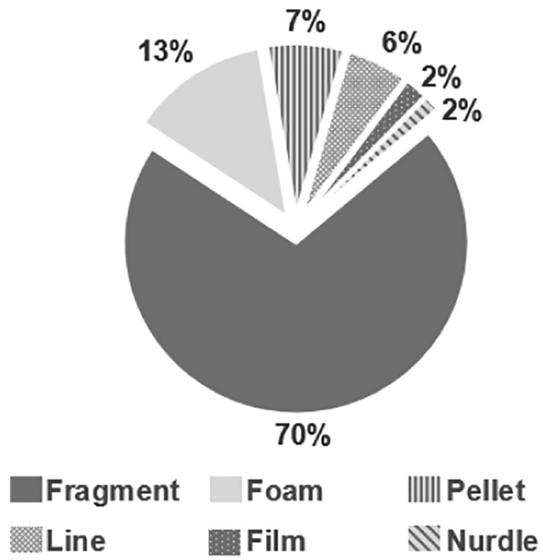

Fig. 3. Combined proportion of plastic types found from 2016 to 2019. Where total pieces of plastics = 46,158.

particles/km^2, and a median of 198,000 particles/km^2 across all four years. Therefore, statistical tests for non-parametric data were used such as Spearman's rank correlation and Kendall's Tau-b correlation, where no significant relationship between rainfall either within one week prior to sampling or overall, throughout the season were found. Logarithmic transformation to account for skew did not yield significantly different outcomes in analysis.

There was no observed difference between either sampling sites (midtown or downtown) or months (Fig. 5). To analyze concentrations at various stages of the tidal cycle, an ANOVA with Tukey multiple comparisons of means with a 95% family-wise confidence level was conducted. The results of this test showed no significant difference in samples collected during ebb and flood tides.

3.1. Discussion

The results of this study show that microplastics are present in the Hudson River in amounts comparable to other local studies (NY-NJ Baykeeper, 2016; Smith et al., 2017); the majority of the 72 samples taken from 2016 to 2019 contained hundreds of pieces of microplastics, and some samples had as many as 6000 pieces.

The significantly higher concentrations in 2018 illustrate high annual variability in the complex LHRE, but the source of that variability is not apparent from the available data. More information is needed to fully discern sources of microplastics in the LHRE.

Variance analysis revealed that while concentrations in near-shore and channel locations are often comparable, in a year of significantly higher concentrations (2018), near-shore sites seem to display significantly higher concentrations than both channel sites and the same near-shore sites in other years (Table 1). This was expected, as it was hypothesized that proximity to CSOs (Estahbanati and Fahrenfeld, 2016; Dris et al., 2018) and reduced flow rate of near-shore, inter-pier areas (Able and Duffy-Anderson, 2005) would cause increased concentrations of particles.

The high prevalence of fragments suggests that a significant source of microplastics may be via the degradation of larger plastics, possibly in connection to heavy rainfall, CSO events, and/or litter. In similarly conducted microplastics studies, researchers found that both the San Francisco Bay and the Great Lakes Tributaries had larger quantities of fragments than any other non-fiber microplastic category (Sutton et al., 2016; Baldwin et al., 2016), while NY Harbor exhibited a higher proportion of foam (38%), with fragments a close second (31%) (NY-NJ Baykeeper, 2016). Both this Baykeeper study and Smith et al. (2017) found similar average concentrations to the present work in NY-NJ Harbor, the Hudson, and its tributaries: a range of < 100,000–700,000 microplastic particles/km^2. A local study found fibers to comprise ~1% of plastics observed in/around NYC (Lim et al., 2018), while an international study found that tide-dominated systems tended to exhibit lower relative fiber counts (Harris, 2020).

Table 1
Mean microplastic concentration (particles/km^2) by site (Downtown & Midtown) and location 2016–2019.

	Site	Location	M	SD
2016	Down	Channel	118,701	172,004
		Near-shore	314,961	486,842
	Mid	Channel	90,208	69,520
		Near-shore	256,201	335,148
2017	Down	Channel	748,386	118,094
		Near-shore	354,685	58,635
	Mid	Channel	543,851	98,573
		Near-shore	1,217,162	204,674
2018	Down	Channel	2,600,435	752,722
		Near-shore	3,945,875	1,101,256
	Mid	Channel	3,221,726	928,668
		Near-shore	6,847,202	2,225,202
2019	Down	Channel	457,544	143,598
		Near-shore	2,202,596	519,323
	Mid	Channel	768,485	173,347
		Near-shore	477,643	119,476

On average, a higher microplastic concentration was observed in years with higher rainfall (Fig. 4) (National Centers for Environmental Information, 2020), in accordance with Hitchcock's (2020) findings that antecedent rainfall increased plastic concentrations. The summer of 2018 notably experienced high rainfall (11 in of rain more than the previous year) (Fig. 4) and exhibited the highest concentrations measured. It is possible that the season's rain events contributed an elevated amount of microplastics to the estuarine system. However, the relationship between annual rainfall and microplastic concentration was not significant, which suggests confounding factors and/or not enough data, highlighting the importance of long-term data collection.

Though the sites and locations chosen for this study are comparable to each other, they may not be reflective of the Estuarine Sanctuary as a whole due to the widely variable and complex hydrology of the area, as well as varying pier structures.

Other studies, both local and international, have identified CSOs & Wastewater Treatment Plants (WWTPs) as a major point-source of microplastics in urban river settings. In Paris, researchers found fragments and fibers in water collected from CSOs in quantities of up to 3100 fragments/L and up to 190,898 fibers/L (Dris et al., 2018). Dixon et al., 2017, included wastewater treatment plants and CSOs as prominent sources of microplastic pollution in their NYC report. Estahbanati and Fahrenfeld (2016) also found significantly more plastics downstream of WWTPs compared to upstream in the nearby Raritan River (NJ) using near-identical methods to this study. Based on this literature, it is likely that CSOs following heavy rain events contribute to microplastic pollution in the Hudson River, though the complex hydrodynamics of the system and additional non-point sources of pollution could confound the direct correlation over short timescales. The continued collection of samples and factoring in of tidal forces and hydrodynamics could elucidate the relationship between microplastics, rain and CSOs.

Our findings further corroborate that the use and improper disposal of plastic items have and will continue to litter waterways by breaking down into fragments that are nearly impossible to remove. In future Hudson River microplastic surveys, a decrease in foam microplastics is expected due to the New York City Styrofoam ban passed in January of 2019 (City of New York, 2018). A decrease in pellets is also expected in connection to the 2018 and 2019 summer implementation of the FDA Microbead-Free Waters Act of 2015 (U.S. Food & Drug Administration, 2020). If microplastics including nurdles, pellets, and foam do decrease with time, such observations will speak to the effectiveness of recent legislation.

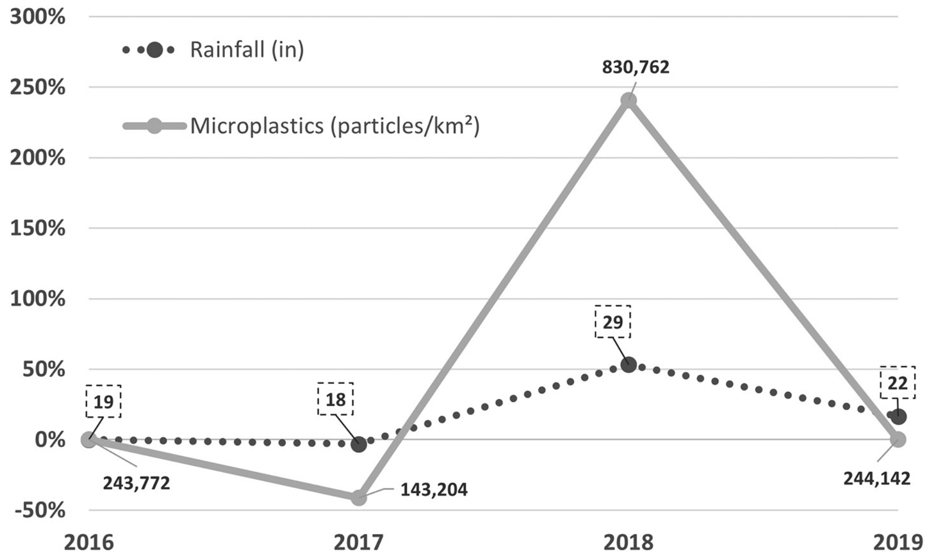

Fig. 4. Percent change of mean seasonal microplastics concentration versus mean seasonal rainfall in inches, 2016–2019. Sampling season is defined as June–October.

3.2. Microfibers

The Park's quantification of microplastics in the Hudson Estuary does not fully account for line/fibers, a common category of microplastics that includes synthetic fibers from clothing. The Park's data on these plastics are incomplete due to a variety of factors: many fibers are prohibitively small for visual analysis (Dixon et al., 2017; Ravandi and Valizadeh, 2011), they are found in 81% of global tap water (Koelmans et al., 2019; Kosuth et al., 2018) which was used during field sampling, and chiefly, are absent in the methods that this survey was based on (Masura et al., 2015).

When the Park's data collection started in 2016, the prevalence of microfibers was unknown and not accounted for. To standardize the data across 2016–2019, NOAA's methods were adhered to strictly, even as the importance of microfibers became apparent in the literature. While the category termed "line" may account for the largest microfibers, there is no way to account for < 300 μm fibers using stereoscopic analysis.

Additionally, because tap water was used in the field and potentially carries fibers (Koelmans et al., 2019; Kosuth et al., 2018) it would have been impossible to distinguish the larger microplastic fibers that were originally present in the Hudson River, even if large enough to be visually inspected. Future sampling years will use distilled water in the field to circumvent this confounding factor.

From stereoscope observation of the samples, relatively large fibers were present in all survey samples which were subsequently categorized as "line". These observed fibers likely constitute an incomplete image of those present in the system due to the limitations of the present work's methodology.

3.3. Gas chromatography and IR spectroscopy

In 2018, the Park collaborated with NOAA to conduct chemical analysis on microplastics previously categorized through stereo microscope analysis in this study. Chemical analysis using pyrolysis, gas chromatography- mass spectrometry (GC–MS) was conducted on archived samples from August and October of 2018, where pieces exhibited several of the common chemical compositions of various plastics. The results of these analyses will be presented in a separate communication.

Though it was not possible to include the results of these tests in the present work, the Park is working toward the inclusion of this type of chemical analysis in future years' analysis to strengthen the study.

4. Conclusion

From 2016 to 2019, Hudson River Park found substantial surface concentrations of microplastics along the west side of Manhattan in the LHRE. These concentrations are comparable to those gathered in other surveys performed nearby (NY-NJ Baykeeper, 2016; Smith et al., 2017), and in other areas of the continental United States (Sutton et al., 2016;

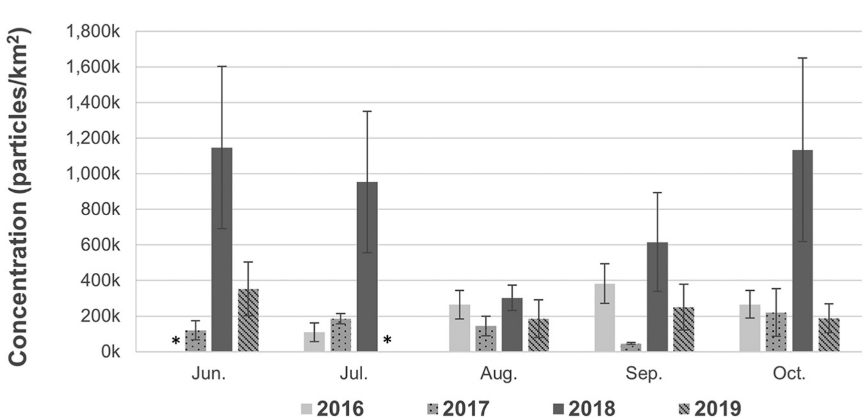

Fig. 5. Microplastics concentration 2016–2019, combined monthly means. Error bars are standard error of mean (SEM). Asterisks (*) indicate no data. June 2016 was the pilot and therefore not included. July 2019 saw unscheduled maintenance of sampling vessel.

Baldwin et al., 2016). Concentrations in 2018 were significantly and inexplicably higher than all other years, belying the need for the continuation of sampling and expanded analysis to determine the causal relationship of environmental factors and plastic pollution.

It should be reiterated that the Park conducted surface net trawls which do not collect plastics throughout the water column. While the majority of microplastics do float at the surface level (Morét-Ferguson et al., 2010), the concentrations of microplastics quantified by this study – and any using surface trawl protocols – are likely some degree lower than the actual totals present in the LHRE, due to the exclusion of plastics that may be found below the surface, and the exclusion of < 0.3 mm microfibers and other plastics.

It is hypothesized that rainfall and CSOs have an impact on microplastics concentration, but that more data is required and that more factors are considered to clarify the relationship. Continuing to collect information on microplastics in the LHRE creates a deeper understanding of how policies and behaviors affecting plastic use and disposal in New York City impact the estuarine system. This information is valuable in creating an overarching understanding of the health of the River. By monitoring the annual fluctuations in plastic concentration in the system, the Park can track how sample location, rain, and other environmental fluctuations may alter the plastic concentrations. The Park intends to continue this survey and proactively reduce plastic consumption within its boundaries. The Park hopes to create strong records of microplastic concentrations in the Estuarine Sanctuary and aims to distinguish sources of contamination to mitigate marine debris pollution.

CRediT authorship contribution statement

Ph.D Brett Branco: Supervision, Conceptualization, Methodology, Implementation, Writing – Reviewing and Editing, **Carrie Roble:** Supervision, Conceptualization; Methodology; Implementation; Writing – Reviewing and Editing, **Justin Siddhartha Hayes:** Conceptualization, Methodology, Formal Analysis, Investigation, Resources, Writing - Review & Editing, and Visualization. **Helen Polanco:** Writing original draft, Data curation, investigation, Formal analysis. **Krupitsky Marika:** Investigation, Writing review and editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors acknowledge National Fish and Wildlife Foundation, Hudson River Park and Brooklyn College for funding this research. Special thanks to Captain Jim Gill, Andy Zheng, Nadia Noori, Emma Samstein, Eliana Green, Theresa Trelles, Jailene Hidalgo, Elena Davis, Jessica Rose,Natalie Monterrosa, Christiana Hooker and Dr. Ashok Deshpande for their field and lab support.

Funding

This work was supported by the National Fish and Wildlife Foundation [Grant number 55745, Date 2017].

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