Spatial and Seasonal Distributions and Characteristics of Microplastics in Narragansett Bay Surface Water

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Background, study system, and methods

Narragansett Bay (NB) is a 147 square-mile estuarine system and New England's largest estuary. Plastic pollution is a critical but absent metric in the majority of water quality analyses conducted in NB, with only one published study currently in existence which surveyed plastic in limited NB sediment samples. Here we present a multi-year, seasonal analysis of microplastics (MPs) in NB surface water across six locations using manta trawl sampling methodology. Sampling sites in NB were selected for their spatial distribution across NB, relative to surrounding land use, potential MP sources including freshwater inputs and stormwater vulnerable areas, and circulation patterns (Figure 1). Each site was sampled twice per season to produce two replicates, with each replicate consisting of a trawl using a manta trawl net (330 µm mesh size) towed by a 20 ft motorized Maritime Skiff traveling at a consistent speed of approximately 2-3 kts for 10 minutes. A total of 72 unique trawls were completed.

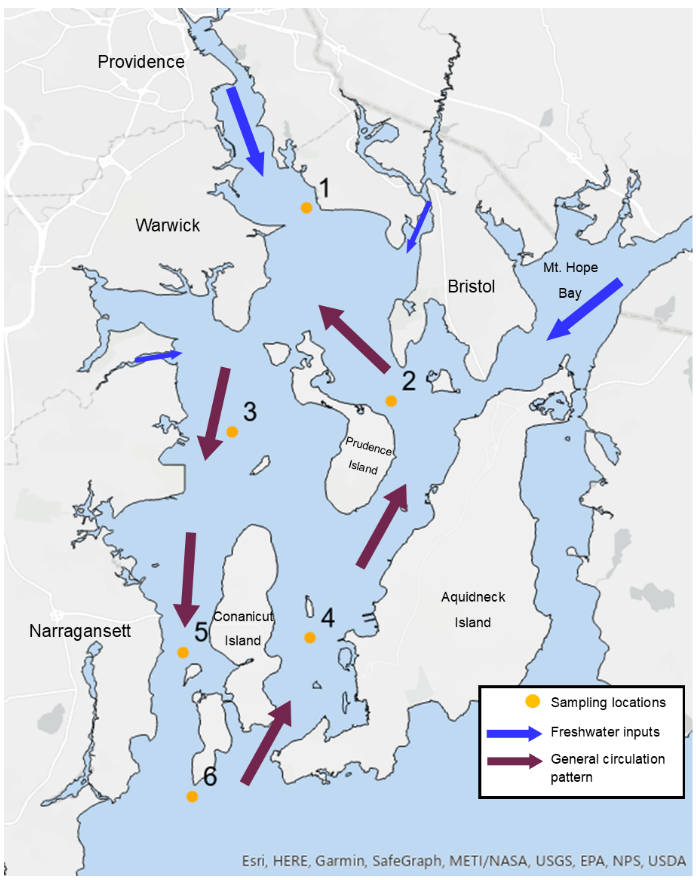


Figure 1. Manta trawl sampling sites in Narragansett Bay. Sampling sites are numbered 1-6 along a north-to-south gradient to indicate their distance relative to the hypothesized strongest drivers of MP

pollution in NB (stormwater runoff, freshwater river inputs, population density, and impervious surface cover).

Results

Plastic particle concentrations

The overall average concentration of microplastic particles in Narragansett Bay surface water across seasons and locations was observed to be 0.396 ± 0.428 particles/m^3. When considering cumulative averages for individual sampling locations across the entire sampling period, samples collected from Site 1 contained the highest average plastic particle concentrations at 1.04 ± 0.55 particles/m^3, followed by Site 5 with 0.93 ± 0.59 particles/m^3, Site 2 with 0.89 ± 0.34 particles/m^3, Site 3 with 0.40 ± 0.29 particles/m^3, Site 4 with 0.33 ± 0.13 particles/m^3, and Site 6 containing the fewest average particles with 0.27 ± 0.11 particles/m^3. Seasonally, particle concentrations (Figure 2) exhibited high variability within and between sites.

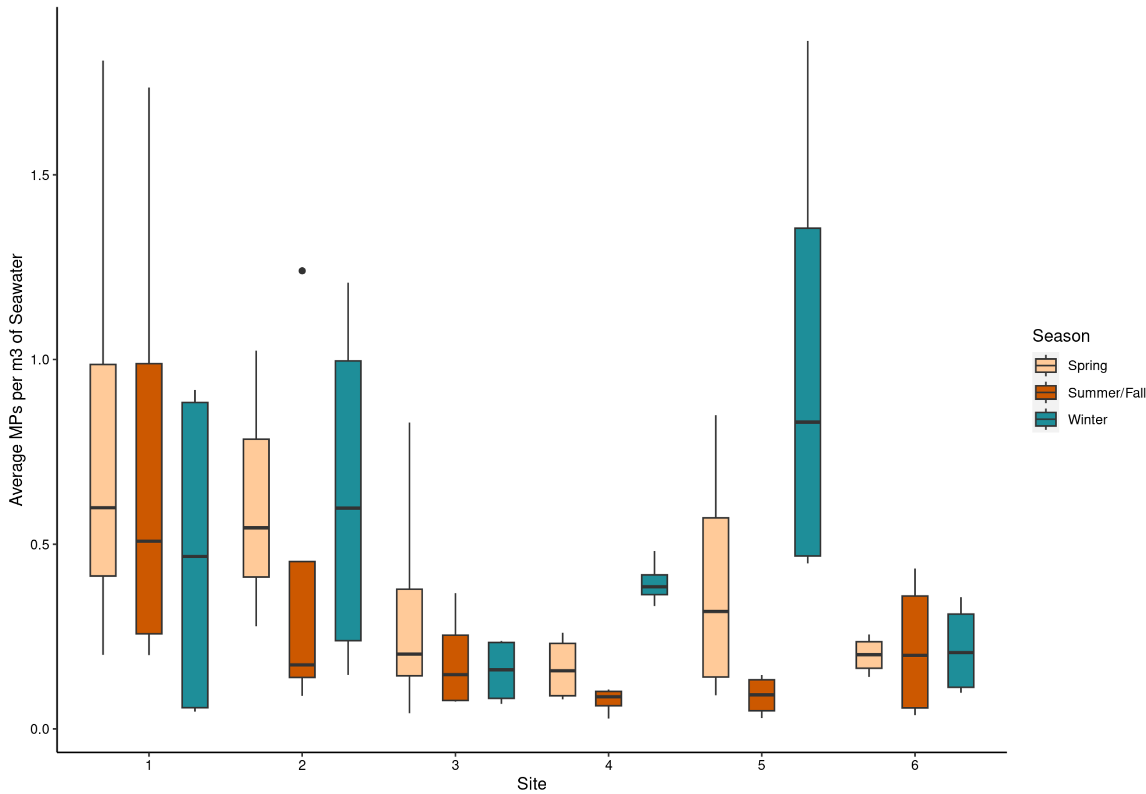
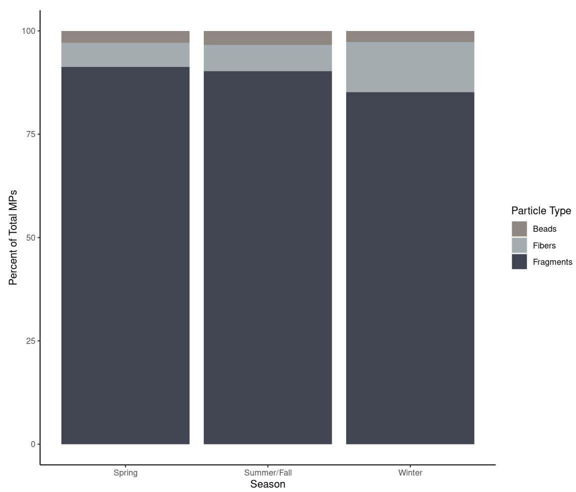
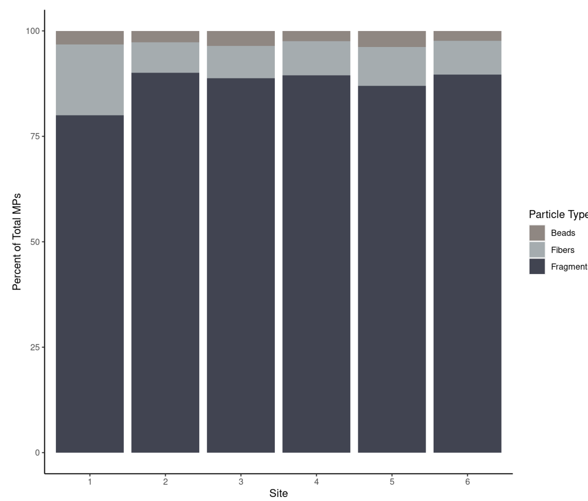


Figure 2. Average concentration of MPs observed at NB sampling sites across the Spring, Summer/Fall, and Winter seasons. When considering seasonal variation, particle concentrations were consistently highest in the northern portion of NB throughout all seasons (Sites 1, 2, and 3), with high variability across seasons in the southern portion of NB (Sites 4, 5, 6). Site 5 exhibited a major spike in MP yield during the Winter season that was not observed consistently at other sampling sites. These findings highlight the spatial and seasonal dynamics of microplastic pollution in Narragansett Bay, emphasizing the importance of improved targeted monitoring and management strategies in mitigating MP pollution.

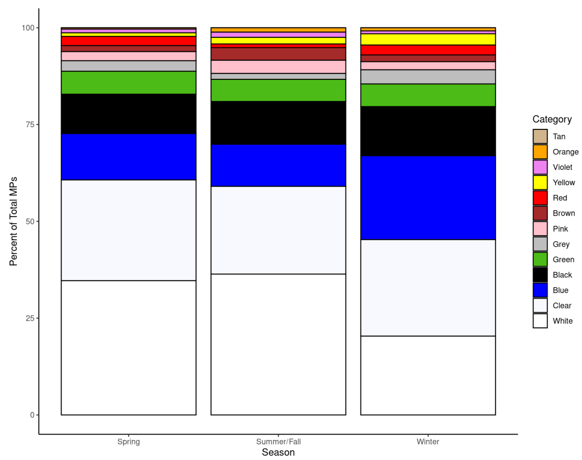
Morphology, color, and size

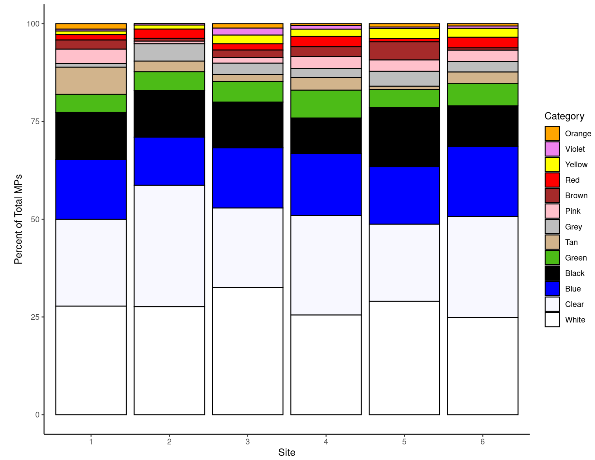
A total of n = 2548 MPs were analyzed for characteristics. Morphology, size, and color were determined based on observation of high-resolution imagery of particles captured by an Olympus BX63 automated light microscope. The dominant shape of recovered particles was fragments, and morphology did not vary significantly between sites or seasons (Figures 3 and 4). A wide range of colors were observed (Figures 5 and 6), with four dominant colors (white, clear, blue, and black) comprising approximately 75% of all particles. The proportion of observed colors was not variable between sites or seasons. The average length of particles tended to increase throughout the year from Spring (shortest) to Summer/Fall to Winter (longest) (Figure 7).





Figures 3 and 4. Morphology of MPs across seasons and sites. Morphology was not significantly variable across seasons or sites sampled, with fragments comprising the majority of particles recovered. Fibers and beads were also present but in relatively lower quantities. These results suggest that the assemblage of microplastics in Narragansett Bay remains consistent across seasons and sites, with fragmented particles being the dominant form. Understanding the morphology of MPs provides insights into potential sources and pathways of pollution in the bay.





Figures 5 and 6. Proportion of MP particle colors observed across seasons and sites. A diverse range of particle colors was identified, with white, clear, blue, and black being the dominant colors, collectively comprising a significant proportion of the observed MPs. Importantly, the proportions of different colors did not show significant variation across different sites or seasons, suggesting a consistent color distribution pattern in the microplastics present in Narragansett Bay.

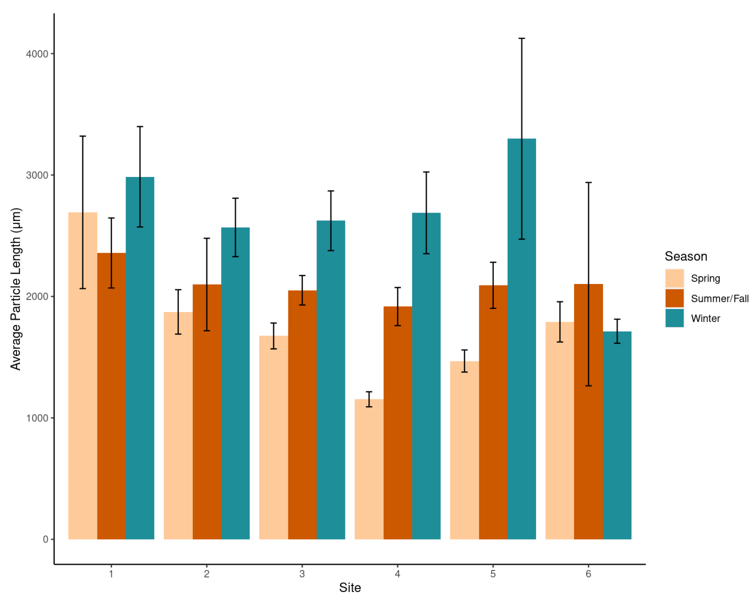
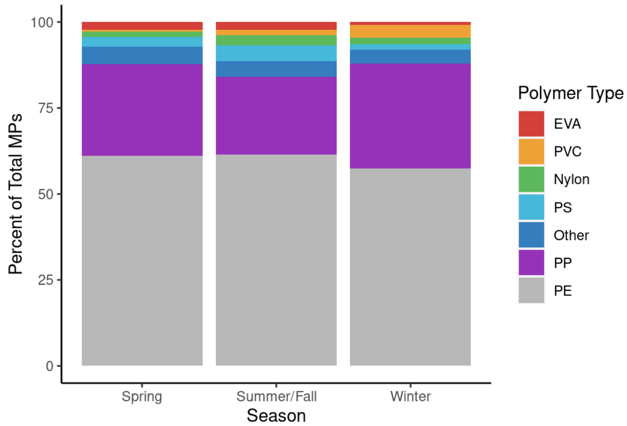
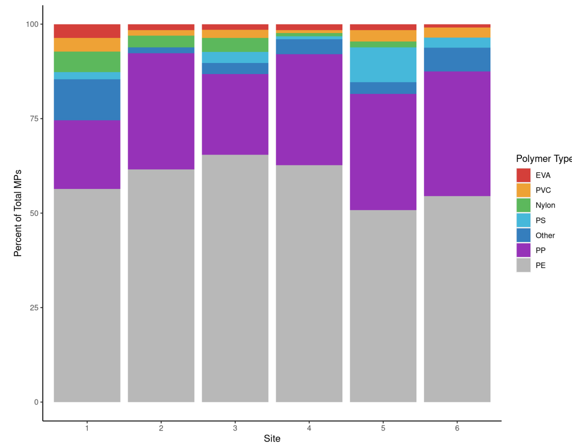


Figure 7. Average MP length at each site by season. In Spring, Sites 2, 3, 4, and 5 displayed the shortest particle length, indicating a prevalence of smaller-sized microplastics during this season. However, in Winter, these same sites exhibited the longest particle length, suggesting an increase in the proportion of larger-sized microplastics. These findings suggest that seasonal dynamics are a stronger driver of differences in particle length than site location.

Polymer type

A random 20% subset of all particles (n = 616) were analyzed for polymer and plastic material type using Raman spectroscopy (Figures 8 and 9). Spectra matches higher than 70% were accepted, with an average match percentage of all analyzed particles of 84%. Two dominant polymer types, polypropylene (PP) and polyethylene (PE), comprised 87% of particles tested. The remaining analyzed particles were other low-density plastics, including polystyrene (PS), ethylene vinyl acetate (EVA), and polyvinyl chloride (PVC), as well as textile fibers (nylon).





Figures 8 and 9. Proportions of identified MP polymer types by season and site. Polyethylene (PE) and polypropylene (PP) were found to be the predominant polymer types, comprising over 87% of all recovered MPs. The proportions of polymer types did not exhibit significant variation among different sites or seasons. It is important to acknowledge that the surface trawl sampling method used in this study is more likely to capture low-density floating particles, which may explain the higher representation of PE, PP, and polystyrene (PS) in the recovered samples.

Discussion

The highly similar assemblages of MPs by observable characteristics (morphology, color, polymer type, and size) across all sites and seasons suggests that MPs in surface water in NB are well-mixed, and unique types of particles do not tend to accumulate in any specific area of the bay. However, the average MP yields (particles/m^3 of seawater) observed in surface water suggest that the northern portion of NB is generally the most consistently polluted, with MP load decreasing as sampling moved south. By using latitude as a proxy variable to represent the hypothesized north-to-south gradient of MP pollution in NB surface water, we observe a significant linear relationship between our sampling event latitudes and our resulting particle yields ($p = 0.00927$) (Figure 10).

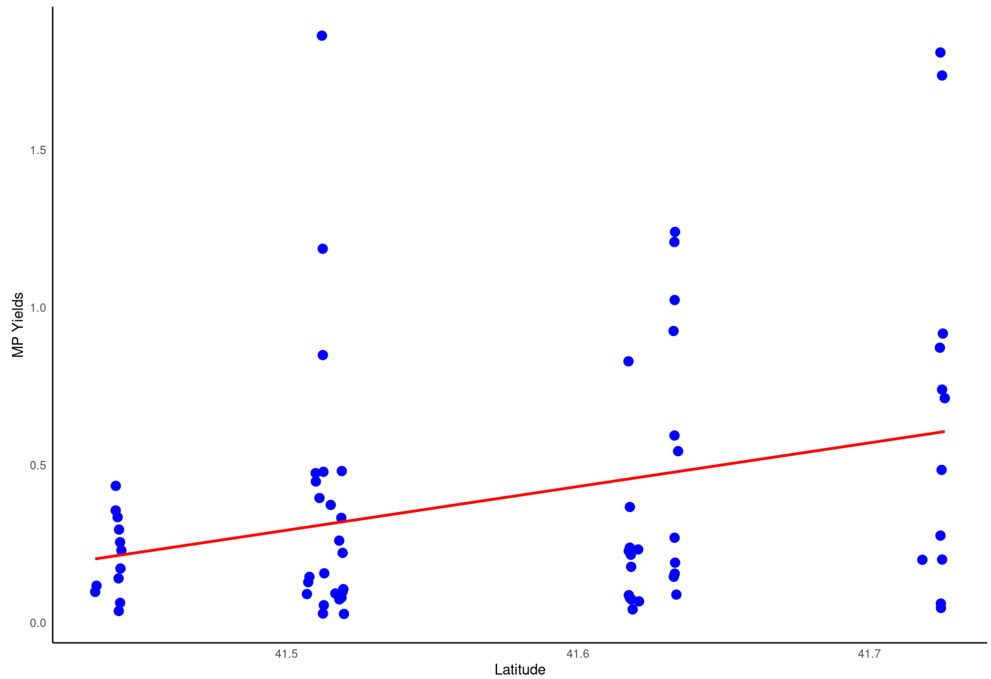


Figure 10. Relationship between latitude and MP concentrations in Narragansett Bay surface water. Scatter plot showing the distribution of particle yields (Particles/meter^3) across different latitudes in Narragansett Bay. The red regression line represents the linear relationship between latitude and particle yields.. Blue data points represent individual sample event observations. The plot demonstrates a significant positive relationship ($p = 0.00927$), indicating that particle yields tend to increase as latitude increases in Narragansett Bay. The plot provides insights into the spatial distribution of microplastics in the bay and highlights the potential influence of predictors (freshwater inputs, population density, stormwater runoff) on microplastic pollution patterns.

There are several possible drivers for the northern portion of NB exhibiting higher MP surface water concentrations than the southern portion Land use around the northern end of NB is heavily urbanized with a large industrial presence from the cities and towns of Providence, Cranston, Warwick, and Bristol. Impervious surface intensity, a metric for built surfaces that requires stormwater management, is high in the north, covers a greater proportion of the NB coastline than in the south, and represents a likely pathway for urbanized stormwater runoff into NB. Multiple studies have also observed several other gradients that extend north to south in NB, for example, Pilson (1985) estimated freshwater inputs to be 104.8 $m^3 s^{-1}$ into NB, with approximately 89% of this being derived from rivers that drain into northern NB. The strong counterclockwise circulation in NB (Pilson 1985; Pfeiffer-Herbert et al., 2015) further establishes a north to south environmental gradient that influences several other variables including physical parameters such as temperature and biological variables such as primary production (Oviatt et al., 2017).Wastewater treatment facilities are also concentrated in the north of NB and likely to be major sources for MPs into freshwater and marine environments (Mason et al., 2016; Conley et al., 2019). Future studies should focus on additional sampling efforts to more thoroughly capture spatial and seasonal trends in NB, and emphasis should be placed on examining potential sources of MPs (freshwater inputs, stormwater runoff, etc.) individually to assess their potentiality as predictor variables for MP yield and to better understand the variation among sites and seasons.