Atmospheric Deposition of Microplastics and Anthropogenic Cellulose in an Inland Suburban Florida Town

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Introduction

Global plastic production has increased exponentially since 1950, and in 2023 alone, approximately 413.8 million tons of plastic were produced (Plastics Europe, 2024). Because many plastic products manufactured are intended for single-use applications, most accumulate in landfills or the natural environment, and an estimated only 9% has been recycled and 12% incinerated as of 2015 (Geyer et al., 2015). Once in the natural environment, plastic debris can make its way into soil, aquifers, rivers, lakes, streams, then eventually end up in oceans (Jambeck et al., 2015; Rillig, 2012; Wagner et al., 2014). Plastic pollution has become ubiquitous in the natural environment, having been found in all corners of the planet, from the Mariana Trench (Chiba et al. 2018) to remote mountain ranges (Allen et al., 2019).

In 2004, when the term "microplastic" (less than 5 mm) was first used (Thompson, 2004), the concern for plastic pollution grew with the introduction of a possible new threat to the environment, animals, and human health. Microplastics can be categorized as primary, which are intentionally manufactured as preproduction pellets or microbeads, or secondary, which derive from the degradation and natural weathering of plastic products such as textiles, packaging, and fishing gear. Publications on the sources, abundances, life cycles, and fates of these pollutants in water systems are rapidly being produced to fill in key knowledge gaps, as the potential harmful effects of these pollutants gain global attention (Barboza et al., 2018; Horton et al., 2017; Machado et al., 2018). Negative impacts such as metabolic disorders, oxidative stress, and even mortality have been documented in marine vertebrates and invertebrates (Lei et al., 2018; Tallec et al., 2018), mice (Jin et al., 2019), plants (Pignattelli et al., 2020), and humans (Dong et al., 2020).

Synthetic plastics are made from fossil fuels that undergo polymerization to create long hydrocarbon chains, which give the material its flexibility and strength (Plastics Europe, 2024). Because synthetic polymers are incapable of fully biodegrading due to complex chemical structures, there is a growing demand for natural-based, biodegradable packaging and textile materials (Ahmed et al., 2018; Shah et al., 2008). Cellulose, the most abundant organic polymer on Earth, can be unmodified or chemically modified, often with dyes and additives to produce compounds suitable for textile production (Felgueiras et al., 2021). Textile materials such as viscose, lyocell, modal, and rayon are examples of modified cellulose polymers used in clothing, often marketed as "environmentally friendly" alternatives to fully synthetic materials such as polyester and nylon. While cellulose itself is naturally harmless, the dyes and fillers added into natural polymers affect the ability to biodegrade (Aziz et al., 2022). Additionally, it is unknown whether the dyes and additives in modified cellulose leech toxins through natural weathering, leaving modified cellulose's true environmental impact questionable.

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The presence of microplastics and cellulosic material in urban waterways is well documented (Cho et al., 2023; Li et al., 2023; Stovall & Bratton, 2022), but the sources and transportation pathways remain largely unknown. Effluents of wastewater treatment plants and sewage sludge have been suggested to be important pathways of microplastics (Habib et al., 1998; Mintenig et al., 2017; Zubris & Richards, 2005). More recently, evidence of atmospheric transport and deposition as one mechanism for the pollution of airborne microplastics and cellulosic particles has emerged. This research examines atmospheric deposition as a potential vector for pollution of microplastics (MPs) and anthropogenic (man-made) cellulose particles (ACPs) in a central Florida urban environment.

Methods

Sample Collection

Samples of atmospheric particle fallout (MPs and ACPs) from wind and rain were collected at a residence in the suburban city of Oviedo, FL, USA, which has an estimated population density of about 41,900 (US Census Bureau, 2024). Oviedo is bordered by Lake Jesup to the north and additional suburban areas to the east, west, and south (Figure 1). The study site was a 0.75-acre lot with one single-family house. The adjacent houses are also single-family homes with lots ranging from 0.25-1 acre.

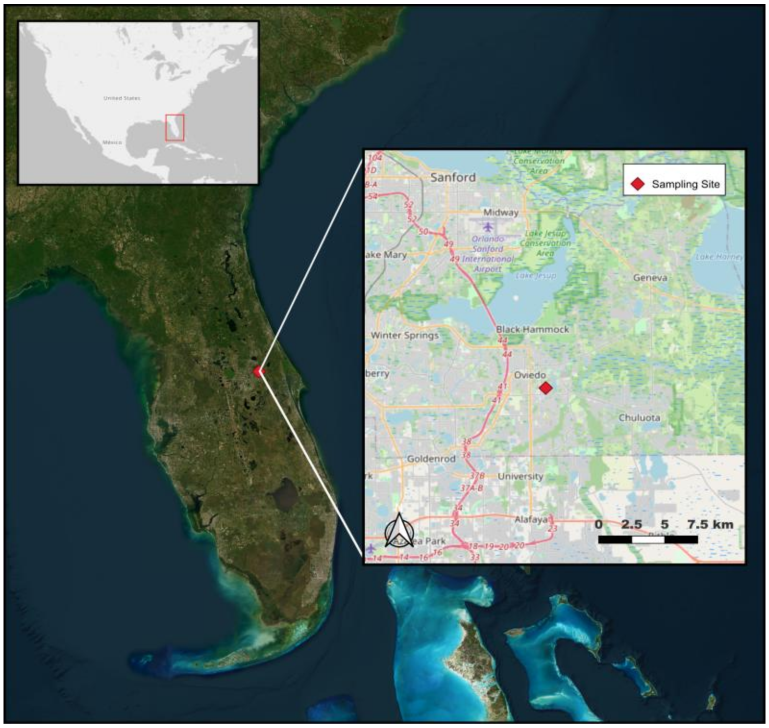

Figure 1. Map of Sampling Site : *The study was conducted in Oviedo — an inland, suburban town located in central Florida.*

From 23 September 2023 to 4 February 2024, suspended particulate matter was collected in passive deposition collectors elevated 15 cm above the ground using non-plastic materials (cement bricks, wood platform). Over the course of this data collection, jars were deployed 59 times. For each collection time, three replicate passive collection devices were placed in the center of the property where they were not obstructed by trees, nor did the house's clothes dryer vent face in the direction of the jars. The collection devices were isolated, with no direct contact to roadways or foot traffic. Collectors were 0.95 L (32 oz) Ball® wide-mouth glass mason jars (Height: 16.8 cm; Diameter of opening: 7.6 cm) (Figure 2). To collect deposits, all jars had 10 mL of 0.45 µm filtered deionized water and were deployed for 4-hour periods. If during the 4-hour window rain occurred, then the sample would be labeled as a "wet" sample. A sample taken during a period with no precipitation was labeled as "dry." The timing and dates of deployment were haphazard. All jars were sealed with metal lids and held in the laboratory at the University of Central Florida at room temperature until processing.

Figure 2. Experimental Setup*: Three 32 oz passive deposition jars were elevated 15 cm off the ground using non-plastic materials to collect atmospheric fallout. The setup was unobstructed by trees or buildings, with no contact with heavy foot or vehicle traffic.*

Quality Control and Quality Assurance

All glassware, dishes, and vacuum filter equipment used in sample collection and analysis were prerinsed three times each with 0.45 µm filtered deionized (DI) water prior to use and in between samples. The filtering membrane used during processing was composed of mixed cellulose ester that includes cellulose nitrate and cellulose acetate. All student researchers were instructed to wear 100% natural fiber clothing to reduce contamination. To verify the rate of indoor contamination during examination of samples, laboratory "blanks" were prepared with 0.45 µm filter papers in laboratory grade polystyrene Petri dishes that had 2 mL of 0.45 µm DI. Each instance a new deposition sample was examined, five new "blanks" were set out around the microscope for the duration of the session to monitor cross-contamination.

Laboratory Processing

For all samples, 200 mL of 0.45 µm filtered DI water was added to the collectors, closed, and shaken to dislodge particles adhered to the glass walls. The rinse water was then filtered through 0.45-µm filter paper using a GAST® vacuum pump. Each jar was rinsed three times, totaling 600 mL of DI water. The filter paper was then placed in a triple-rinsed Petri dish for microscopy. The volume (mL) of rainwater in each jar was recorded prior to filtration with a glass graduated cylinder. The volume of rainwater in "wet" collection devices was recorded using graduated cylinders to estimate rainfall amounts (Walters et al., 2025). This method was used instead of relying on local airport rainfall gauges as precipitation in this study area is patchy. However, it is acknowledged that visual inference may be an overestimation of rainfall amounts, considering all collectors started with 10 mL of filtered water.

Visual Observation and FTIR Analysis

Deposits on the filter papers were observed under a dissecting microscope at 30X magnification. Particles were visually identified based on the common microplastic morphology criteria presented in the literature (Hidalgo-Ruz et al., 2012). Suspected particle type was visually classified based on fragility upon application of pressure using tweezers, fraying or smooth ends, and color uniformity. Data recorded for each particle found on a filter paper were size (mm), color, shape (fiber, fragment, film, bead), and suspected composition (anthropogenic cellulosic particle or microplastic).

Attenuated Total Reflection Fourier Transform Infrared Spectroscopy (ATR-FTIR) was used to verify the identities of a randomly selected subsample of particles visually classified as anthropogenic cellulose particles (ACP) or microplastics (MP) during microscopy with a Shimadzu IRSpirit-T spectrometer (Shimadzu, Kyoto, Japan) and Bruker Alpha-II FTIR spectrometer (Bruker, MA, USA). Subsamples of particles were randomly selected from the processed wet and dry deposits (Wet: n = 11; Dry: n = 19) and compared against reference spectra (KnowItAll FTIR Spectral Database Collection™).

Statistical Analysis

All statistical analyses were conducted in R Studio version 4.4.1 and analyses were conducted separately for suspected ACPs and MPs. All generalized linear mixed models (GLMMs) were fitted using the glmmTMB package, and a negative binomial distribution was used to account for overdispersion (Brooks et al., 2017). Tukey method pairwise comparisons were made via the emmeans package (Lenth, 2025). In all GLMMS, the collection sample ID was included as a random intercept to account for the nested sampling design. A Spearman's rank correlation was conducted to assess the relationship between average rainfall volume collected and total particle deposition in rain samples. Model assumptions were assessed visually with diagnostic plots.

Results

Abundance of Deposits

Atmospheric deposits were present in all 59 sampling dates. Out of a total of 1,809 particles, 481 were suspected as MPs and 1,328 suspected as ACPs. ACPs significantly outnumbered MPs, in raw counts and model-estimated abundance (GLMM: $p < 0.0001$). The mean (± SD) MPs per sample was 8.15 (± 5.44) and the median was 7 (Range: 0-22). The mean (± SD) ACPs per sample was 22.51 (± 12.27) and the median was 21 (Range: 0-75). The distributions of deposited suspended particles were roughly the same across both methods of deposition (Figure 3). The mean (± SD) rates of particle deposition were calculated as particles per m^2 per minute, using the 4-hour deployment window (Table 1). The average (± SD) wet sample deposition rates were 2.50 ± 1.47 $MP/m^2/min$ and 7.42 ± 4.38 $ACP/m^2/min$; dry sample average (± SD) rates were 2.49 ± 1.86 $MP/m^2/min$ and 2.49 ± 1.86 $ACP/m^2/min$. The mean (± SD) volume of rainwater per sample was 72.7 (± 110.03) mL (Range: 0.3-496.0 mL). There were no significant differences in total deposits between wet and dry collectors (GLMM: $p = 0.341$). The correlation between rain volume and deposits per sample was weak and not statistically significant (Spearman's rank correlation: $\rho = 0.14$, $p = 0.46$), indicating no evidence of a consistent trend.

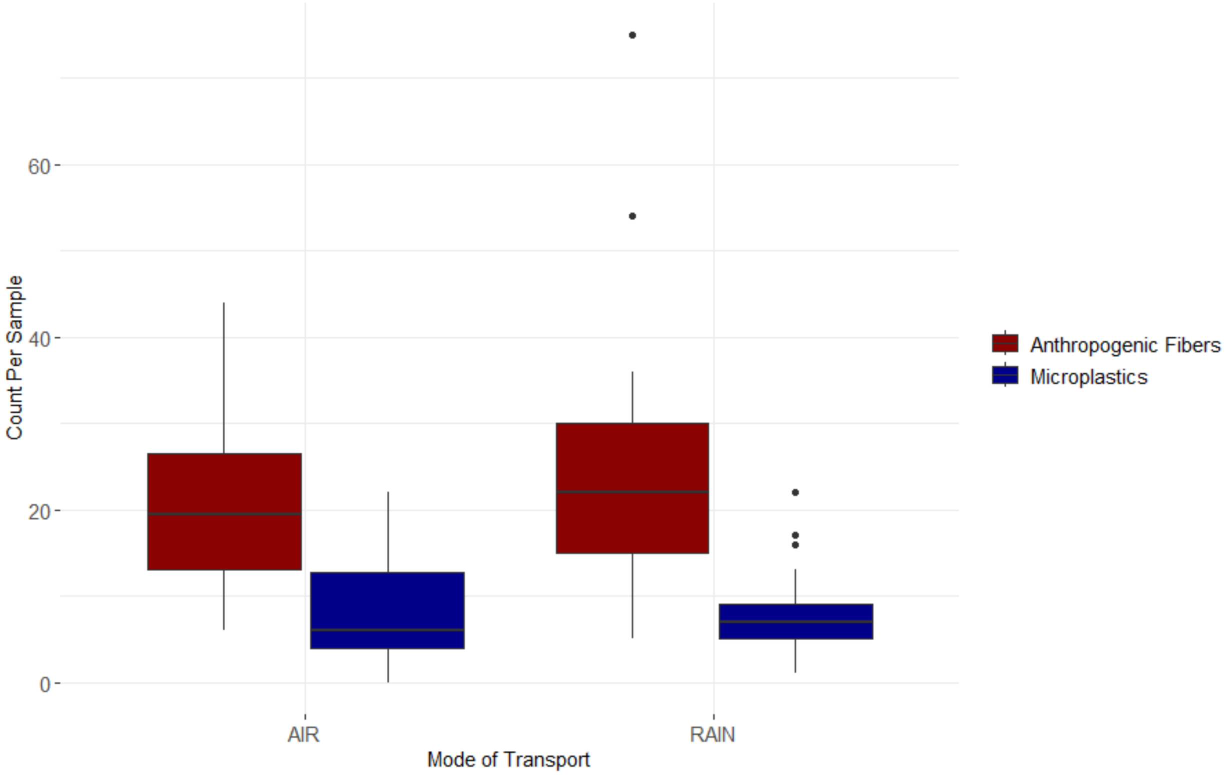

Figure 3. Abundance of Atmospheric Fallout Per Mode: *Box plots represent the minimum, maximum, and interquartile ranges of particles found in dry ("air") and wet ("rain") samples per sampling event. Dots represent data outliers. All samples were collected haphazardly during the collection period. Dry deposits were collected over 4-hour sample events, and wet samples were collected over the duration of precipitation events. The total area of collection was 136.09 cm^2.*

	MP m^{-2} min^{-1} (± SD)	ACP m^{-2} min^{-1} (± SD)
Wet	2.50 ± 1.47	7.42 ± 4.38
Dry	2.49 ± 1.86	6.38 ± 3.02

Table 1. Mean Wet and Dry Deposition Flux: *MP = Microplastics; ACP = Anthropogenic Cellulosic Particles. Mean ± SD of rainwater volume was 72.7 ± 110.03 mL.*

Shape, Size, and Color

The morphologies of the particles collected in this study included fibers, fragments, and pellets. 96.9% of MP observations were fibers, and 2.5% fragments (Table 2). Fibers made up 99.9% of ACPs (Table 3). The sizes of cellulose particles collected ranged from 0.1 mm to 18 mm, with a mean (± SD) of 1.71 ± 1.67 mm. Plastic particles ranged in size between 0.02 mm and 45 mm with a mean of 1.78 ± 2.56 mm (Table 4).

Shape	Count	Percentage
Fiber	467	96.89%
Fragment	12	2.49%
Foam	2	0.41%
Pellet	1	0.21%

Table 2. Morphology of Suspected Microplastics

Shape	Count	Percentage
Fiber	1321	99.85%
Fragment	2	0.15%

Table 3. Morphology of Suspected Anthropogenic Cellulosic Particles

	Mean length ± SD (mm)
MPs	1.78 ± 2.56
ACPs	1.71 ± 1.67

Table 4. Mean Length of Particle Deposits

Approximately 30% of the MPs collected fell in the size range of 500 – 1000 μm, and 18% fell in the 100 – 500 μm size range (Figure 4). The size distribution of ACPs was similar to that of MPs (Figure 5). The dominating size group for both material types was between 100 μm and 1000 μm.

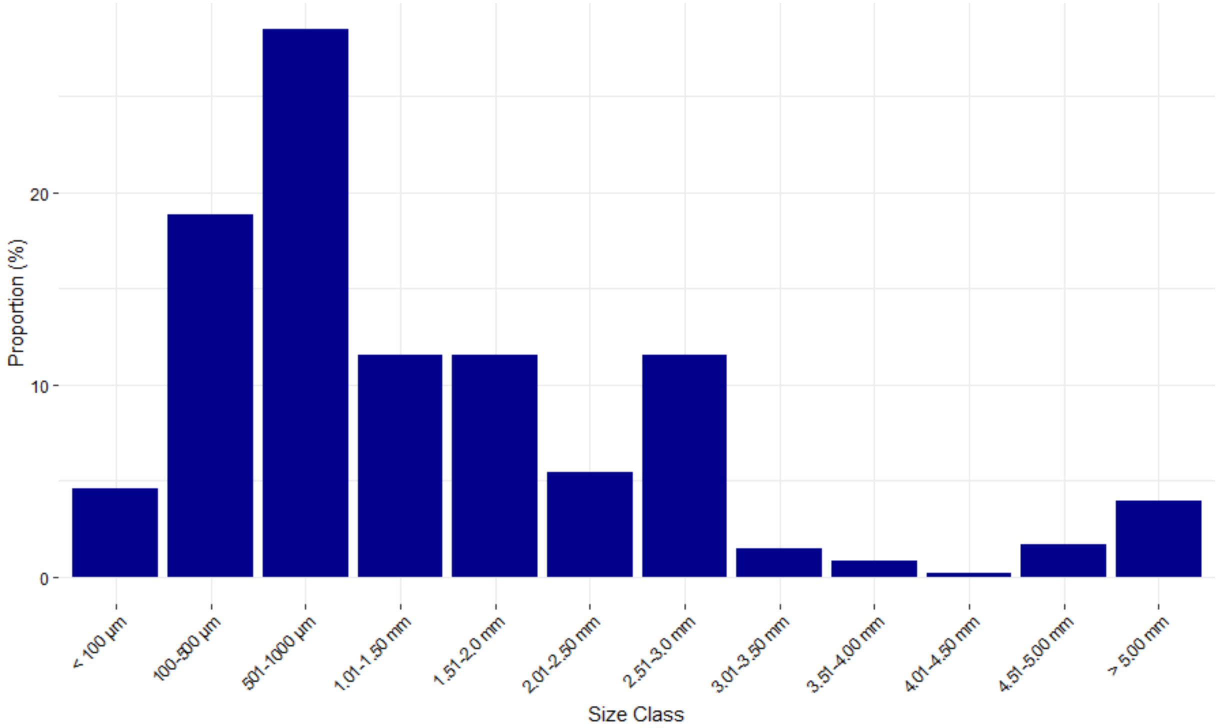

Figure 4. Size Class Distribution of MPs

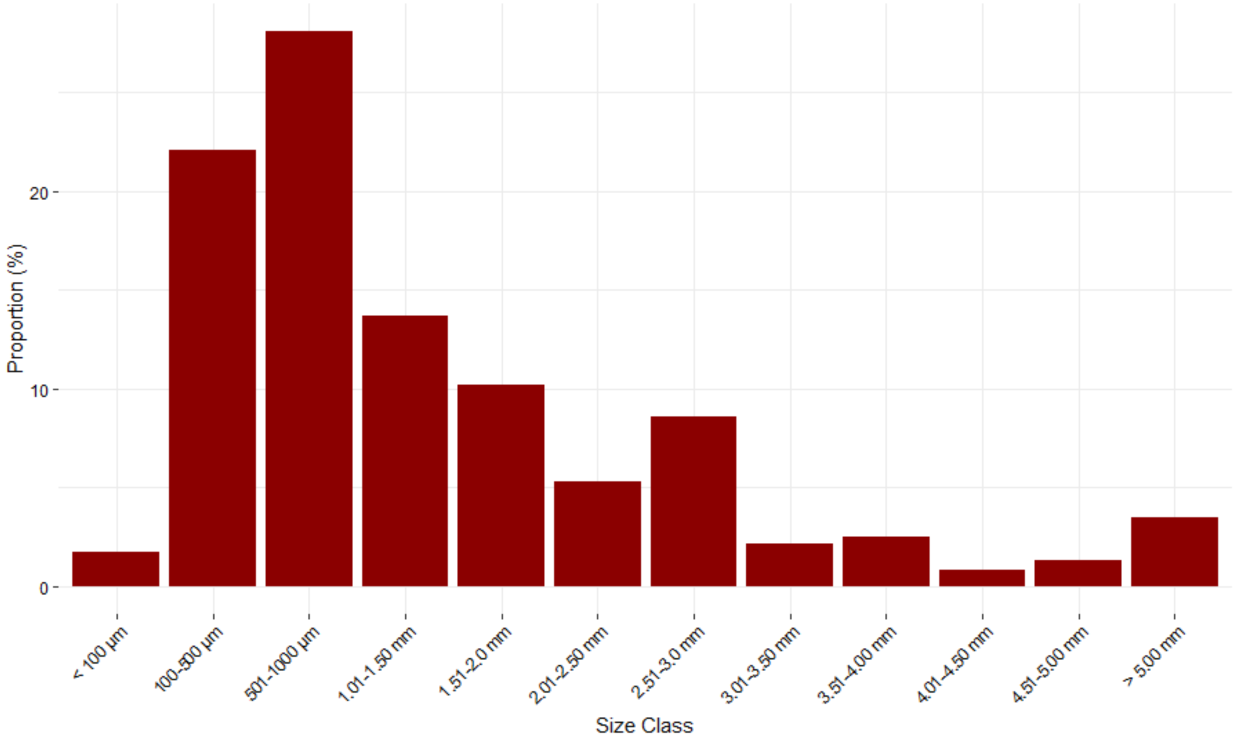

Figure 5. Size Class Distribution of ACPs

Clear was the most frequently observed color of MPs (40.5%), followed by navy blue (19.8%), and black (13.8%) (Figure 6). Navy blue was the most abundant color of ACPs (34.7%), followed by black (17.2%), and clear (16.7%) (Figure 7).

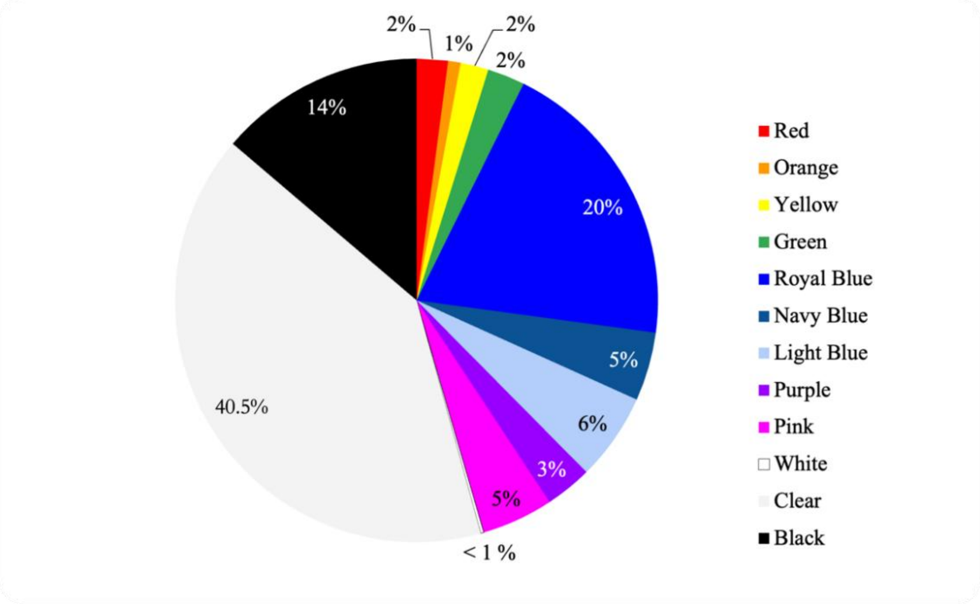

Figure 6. Color Distribution of MPs

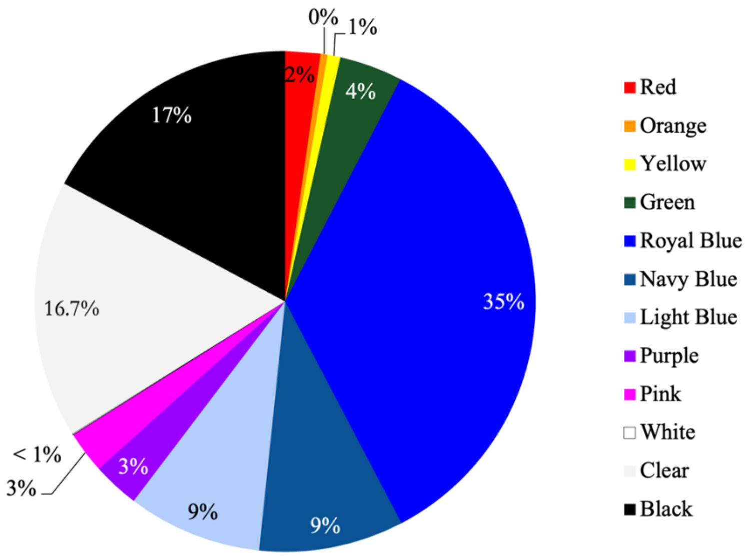

Figure 7. Color Distribution of ACPs

Chemical Composition of Atmospheric Deposits

Plastic polymers such as nylon and polystyrene were identified from both wet and dry subsamples. Polyethylene terephthalate (PET) and polyacrylamide were unique to the wet subsample (Figure 8), while polyvinyl chloride (PVC) was found only in the dry subsample (Figure 9). Wet and dry subsamples both included various anthropogenically modified cellulose polymers, including microcrystalline cellulose, microfibrillated cellulose, nitrocellulose, and Tencel (also known as lyocell). Within the dry deposit subsample, cellulose and protein were identified, which are naturally occurring.

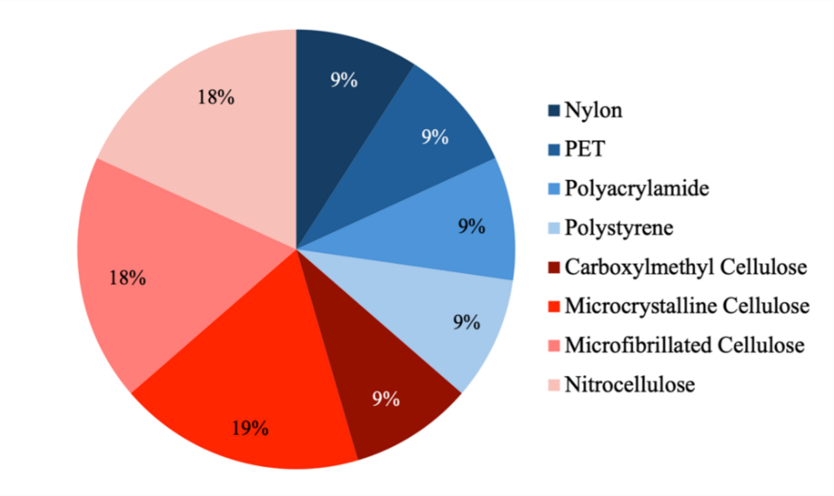

Figure 8. Chemical Compositions of Wet Deposits (n = 11)

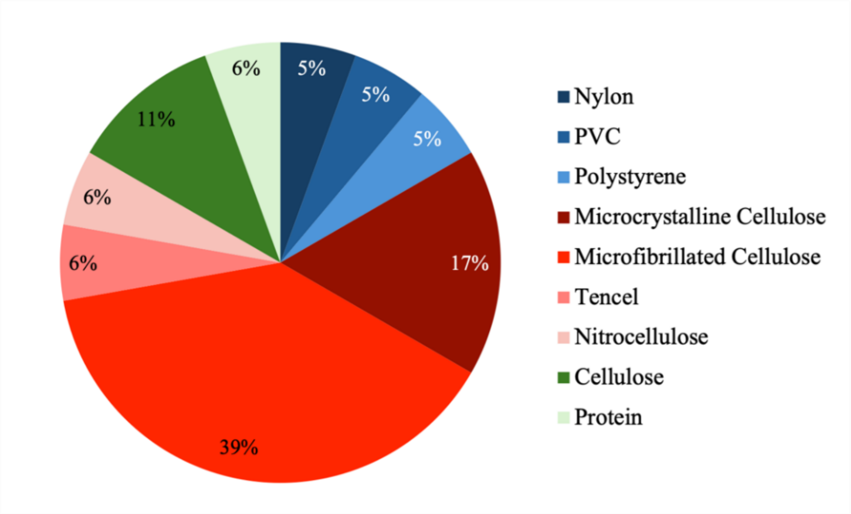

Figure 9. Chemical Compositions of Dry Deposits (n = 19): *17% of the selected particles from dry deposits were determined to be cellulose and protein, indicated by green shades.*

Contamination Rates

The mean rates of indoor aerial contamination for MPs and ACPs were calculated to be 0.007 (± 0.017 SD) and 0.035 particles (± 0.043 SD) per filter, respectively. Contamination was found to be minimal and thus not incorporated into the results (Walters et al., 2025).

Discussion

Microplastic pollution in Florida has been previously examined in waterways (Walters et al., 2022) and stormwater outfalls (Busch et al., 2023) but not yet examined through atmospheric deposition in inland, suburban areas. In this study, 59 sampling dates caught a total of 1809 suspended particles through dry and wet deposition. Plastic material accounted for less than half of the visually identified particles (26.6% MPs; 73.4% ACPs), which aligns with the current literature (Finnegan et al., 2022).

Multiple particle shapes were observed, but fibers accounted for nearly 100% of detections; this was comparable to the results of other atmospheric deposition studies. Fibers were the dominant shape of suspended MPs in other urban cities such as London (Wright et al., 2020), Guangzhou (Huang et al., 2021), and Dongguan (Cai et al., 2017). Analysis of atmospheric deposition samples over coastal and pelagic oceans found fibers dominated in abundance as well (Liu et al., 2019), suggesting the shape and density of fibers allow for longer suspension time and transportation through the atmosphere via wind. Opposingly, in Seoul, South Korea, and five megacities in China, fragments were found to be the dominant morphology of atmospheric deposits, at 87.4% and 88.2%, respectively (Chang et al., 2023; Zhu et al., 2021). It is important to note the variation in study sites between the present study and those studies where fragments were more abundant than fibers. Four out of five study sites in Chang et al. (2023) were areas with heavy foot and vehicle traffic, two sites of which were directly adjacent to busy roads. The proximity to anthropogenic activity may have contributed to the dominance of fragments, likely sourced from automotive parts and plastic packaging, as supported by 58.7% of fragments being identified as polypropylene (PP), which is a common polymer used for plastic packaging and car parts (Chang et al., 2023; Kozderka et al., 2016; Song et al., 2018). The present study was conducted in the backyard of a single-family residence, with limited vehicle and foot traffic, which may explain the low number of fragments identified.

There appears to be a commonality in the size of airborne micropollutants. Around 30% of the MPs in this study fell in the size range between 500-1000 µm, which is a nearly identical proportion to fibers in the same size range collected in Guangzhou, China (Huang et al., 2021). Smaller fibers in the 200-400µm and 400-500µm size ranges were the predominant sizes in Paris (Dris et al., 2016) and London (Wright et al., 2020), respectively. Global comparison of ACP fallout is difficult due to the lack of studies including such data. Most atmospheric deposition studies report only the deposition of petrochemical fibers, though one study conducted in rural coastal sites in Ireland reported approximately 85% of the total microfibers collected to be synthetic cellulose fibers (Roblin et al., 2020). This proportion is comparable to that of the present study, which is approximately 73% synthetic cellulose fibers.

When making comparisons between deposition data across studies, the climate, meteorological patterns, and sites should be taken into consideration. Strength and occurrence of precipitation events may positively influence atmospheric fallout (Dris et al., 2016; Allen et al., 2019), although strong evidence for such a correlation was not found in this study. Rates of microfiber fallout were higher in the Pyrenees mountains than those in Paris, potentially due to the higher occurrence of precipitation events in the mountains (Allen et al., 2019; Dris et al., 2016).

Anthropogenically modified particles were more abundant compared to microplastics, likely due to the long historical use of cellulose-based materials in textiles (Finnegan et al., 2022). ACPs outnumbered MPs in this study ~2:1. Within the last two decades, however, the production of petroleum-based, synthetic polymers has taken over the textile industry, and the use of natural fibers has declined (Textile Exchange, 2024). Projections indicate that a crossover will occur between 2025 and 2030, when plastics will become the dominant particles in the atmosphere (Finnegan et al., 2022).

The colors of the particles collected offer evidence of their possible sources. Forty percent of the suspected MPs in this study were transparent, which might indicate probable sources such as fishing line, food packaging, and previously colored textiles that have undergone natural UV-oxidation (Wu et al., 2021). Thirty-five percent of the suspected ACPs were blue, which may be attributed to blue denim, considering the textile's century-long history. Particles of other colors are very likely sourced from the shedding of dyed textiles via natural weathering or machine washing (Habib et al., 1998; Thompson, 2004; Zubris & Richards, 2005).

The subsamples of particles assessed under ATR-FTIR (Dry: n = 11; Wet: n = 19) posed limitations to the strength of statistical analysis due to small sample size; however, it provided insightful information on the types of polymers present in atmospheric fallout. For example, polyethylene terephthalate (PET), identified in the "wet" subsample, is a petrochemical polymer and dominates the synthetic textile market, with production exceeding 57 million tons in 2020 (Hayes et al., 2022). The most common applications of PET are fibers for textiles and plastic bottle packaging for drinks (Hayes et al., 2022). Microfibrillated cellulose, which accounted for 39% of the "wet" subsample and 18% of the "dry" subsample, is a mechanically modified cellulose often used for packaging, aerogels, and films due to its lightweight yet strong characteristics (Lavoine et al., 2012). It is impossible to identify the primary sources of atmospheric fallout based on chemical polymers alone, but FTIR provides hints into the common products deteriorating into airborne pollutants. Gathering data on the chemical polymers suspended in the air of suburban environments can assist policymakers to make informed decisions and pass legislation to mitigate potential human health risks from inhaling such chemicals.

Conclusions

Through this study, it can be confirmed that atmospheric deposition is a pathway for micropollutant movement and deposition in Oviedo, FL. We estimated atmospheric deposition of approximately 3,600 particles per m^2 per day (95% CI: $3.0 \times 10^3 - 4.2 \times 10^3$), based on 59 deposition events. It is important to acknowledge, though, this study is a preliminary examination, thus further research is necessary for substantial conclusions.

The potential adverse effects, such as toxicity and mortality, on vertebrates — especially humans, invertebrates, and the natural environment through the settling and inhalation of such airborne pollutants should be taken into consideration by environmental regulation agencies. There is currently limited knowledge on atmospheric deposition throughout Florida, including on movement patterns and primary sources, but the subject continues to gain traction in the scientific community. As the global burgeoning of plastic and modified cellulose material production continues, mitigation of additional airborne microplastics and modified cellulose particles should be prioritized.

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