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Seasonal distribution of microplastics in Hamilton Harbor's water

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Abstract. Microplastics (MPs) are plastic particles smaller than 5 mm and known to have prolong negative impacts on ecosystem and human health. MPs often are transported to freshwater and marine systems, and it is important to track their occurrence in water bodies. The distribution of these contaminants in water is affected by various parameters including particles' buoyancy, surface composition, biofilm formation, and flow hydrodynamics. One hydrodynamic parameter that can affect the MPs vertical distribution is lake stratification during hot months. Temperature-induced Lake stratification is shown to be an important factor in the depth wise distribution of organic matter and oxygen on water column. This study focuses on the impact of lake stratification and thermocline formation on the vertical distribution of MPs in Hamilton Harbor. Thermocline formation in a lake could cause a dramatic difference in the temperature, which changes the density of water between top and bottom layer where it calls metalimnion, and thermocline is a part of this stratified section. As a result of thermocline formation, hydrodynamic behavior of MPs could be affected, where the distribution can be affected by partitioned mixing. To conduct this research, large-scale water samples were taken from July and October at different depths, and pretreatment methods prior to microscopy were done to extract maximum MPs from the water samples. Finally, microscopy was carried out and water residues on filters from near-surface layer (1 m), thermocline layer (6.5 to 9 m), and near-bottom samples (1 m above the bottom layer) were counted based on their size and shape. The thermocline zone had a higher MP concentration during the warm season than either the surface or bottom layers, according to initial findings, indicating the important impact of thermal stratification on MP distribution. Fibers were the most dominant particles in all layers of water during both warm and cold months. Particles were divided into four categories based on their size, and large-size particles (larger than 300 µm) outnumbered smaller particles from different categories. Findings of this research prove that thermocline could entrap particles in the middle layer during hot months.

Keywords: Microplastics; Thermocline; Lake Stratification, Contaminant Transport

1 Introduction

Particles of plastic known as microplastics (MPs), defined as being less than 5 mm in size(Andrady, 2011), have been identified as environmental pollutants stemming from a variety of sources such as city expansion, discharge from water treatment facilities, and the improper disposal of waste (Wong et al., 2020). These tiny particles can absorb a range of pollutants due to their large surface area relative to their volume, including but not limited to, pharmaceutical substances and metals that pose a threat to the well-being of wildlife (Atugoda et al., 2021; Brennecke et al., 2016). While the direct impact of MPs on human health remains uncertain, their presence in the human circulatory system suggests a potential significant health risk (Leslie et al., 2022).

MPs are found across various segments of the environment such as in water bodies, soil sediment, and within living organisms. Oceans are recognized as the final depository for these MPs (Jambeck et al., 2015), yet they frequently enter marine ecosystems through freshwater systems like rivers and lakes (Wang et al., 2022). This underscores the importance of understanding how various factors influence the distribution of MPs in freshwater environments. Despite the prevalence of MPs, research has predominantly focused on their presence in saltwater rather than freshwater settings. In terms of research methodologies, the majority of studies employ surface net sampling techniques to collect MPs (De-la-Torre et al., 2022), which leaves the distribution of MPs in different strata of water largely unexplored.

The aim of our study was to evaluate how the seasonal layering of water in a lake, a phenomenon known as stratification, affects the concentration of microplastics (MPs) within a freshwater system, with a particular focus on Hamilton Harbor. Stratification is the process where water in a lake separates into distinct layers, with warmer, less dense water sitting atop cooler, denser, and deeper water layers. The occurrence of thermal stratification is determined by a variety of elements, including differences in water density, the amount of heat the water absorbs, the depth of the lake, and the degree of movement in the water (Elçi, 2008). During the period when the lake is stratified, the middle layer known as the metalimnion, or thermocline, can act as a barrier which restricts the flow of water between layers. This restricted movement may result in the metalimnion becoming a collection point for various particles, MPs included (Elçi, 2008).

The development of thermocline, which occurs during warmer periods, plays a crucial role in altering water density and the vertical circulation of water bodies, ultimately impacting the descent of microplastics (MPs) through the water. The rate at which MPs sink, or their settling velocity, is determined by several attributes, including the MPs' density, size, shape, the presence of biofilms on their surface, and water dynamics such as turbulence. For instance, it has been shown that spherical particles of a larger size generally descend faster than smaller, fibrous ones (Khatmullina & Isachenko, 2017). Typically, heavier particles will drop to the sediment. Yet, studies have indicated that with petite particles, especially those sized between 100 to 200 micrometers, the churning movements of water are the dominant factor influencing their movement rather than their density (Shamskhany & Karimpour, 2022). Furthermore, the formation of biofilms on MPs can alter their density, consequently reducing their buoyancy and potentially changing their distribution across water layers (Rummel et al., 2017).

Taking into account the critical role of environmental dynamics such as biofilm accumulation and the movement of water, the stratification of lakes is likely to have an impact on how microplastics (MPs) settle. There is a gap in research regarding how the creation of thermocline affects the distribution of MPs across various strata in freshwater environments. Few studies have delved into this phenomenon. For instance, a study concerning the formation of both a thermocline and halocline in the Baltic Sea identified a more substantial concentration of MPs within the thermocline zone than on the water's surface (Uurasjärvi et al., 2021). Similarly, research conducted in the Bay of Marseille considered the influence of seasonal shifts and lake stratification, suggesting that in the absence of stratification, lighter particles predominantly remain near the surface, subject to wind movement, thereby underscoring the importance of the thermocline (Chevalier et al., 2023). Our research intends to fill this void by examining the seasonal stratification effects in Lake Ontario, with a specific focus on Hamilton Harbour, and how it relates to the transport dynamics of MPs.

2 Method

2.1 Study Area

Hamilton Harbor (HH), separated from Lake Ontario by a natural sandbar, is connected to Cootes Paradise, a wetland at the western end of the lake, through a narrow channel, once part of the Desjardins Canal (Aristone et al., 2022). Spanning an area of 21 km^2 and reaching depths of up to 25 meters, Hamilton Harbor has demonstrated layers of water stratification in past research. Temperature studies have shown that while surface temperatures can climb to 25°C, they may plummet to 10°C at depths beyond 10 meters (Gertzen et al., n.d.; Yerubandi et al., 2016), potentially leading to the establishment of a thermocline zone. This zone can extend down to 10 meters with a temperature decline rate of 2°C per meter (Yerubandi et al., 2016). Historically industrial, particularly in steel and iron, and impacted by the effluent from three wastewater treatment facilities and a hospital, Hamilton Harbor is a repository for numerous pollutants, including microplastics (MPs). The harbor is near a variety of industries, such as paper and construction. Due to a notable deterioration in water quality over recent years, the harbor has been recognized as one of Canada's Areas of Concern (AOC) by the government, prompting increased vigilance and assessment of its water and sediment conditions (Hall et al., 2006).

2.2 Sampling

Sampling activities were carried out with water samples collected at three varying depths as determined by the depth measurements of the sampling boat's probes. These depths included the near-surface (0.5 m below), the middle layer where the thermocline is anticipated to form, and the near-bottom layer, which matches the station's maximum depth. A stainless steel Niskin bottle was utilized for sample collection, chosen specifically for its ability to collect water from distinct layers and accommodate very small-sized samples, aligning with the study's objectives (Bagaev et al., 2018). After collection, the water was placed into stainless steel containers with tightly sealed lids to eliminate the risk of external contamination. These samples were then transported to the laboratory and kept at a temperature of 4°C until they were further analyzed. Fig 1 illustrates the Niskin bottle that was used for the sampling process.

Fig. 1. Niskin bottle was applied to collect samples from different layers of Hamilton Harbor water

2.3 Sample Processing and Analysis

Once the samples arrived at the laboratory, they underwent several preparatory steps before analysis. Initially, the volume of the samples was reduced by using 8 μm polycarbonate filters, a decision based on the need to capture fiber particles effectively, as larger pore sizes have been noted to potentially lead to underestimation of fibers. After filtration, the samples were transferred to glass Petri dishes for storage pending further examination. The next step involved the application of the Fenton process, adapted from the methodology recommended by the National Oceanic and Atmospheric Administration (NOAA) for the oxidation of organic material (Masura et al., 2015). This process involved adding 20 ml of a 0.05 M solution of $FeSO_4.7H_2O$ (sourced from Fisher Scientific, USA) to the filter residues, followed by the gradual addition of H_2O_2 (also from Fisher Scientific, USA) in three separate 20 ml increments. The reaction's temperature was carefully monitored with a thermometer to ensure controlled conditions. After this digestion phase, the samples were again filtered through polycarbonate filters and stored in glass Petri dishes awaiting further analysis. The final examination of the filters was conducted using a Leica D1500 microscope (Leica, Germany) at 100x magnification, allowing for the classification of particles by size, color, and shape. This analysis was guided by a microscopy protocol from the Marine and Environment Research Institute (MERI), ensuring a standardized approach to categorizing the samples.

2.4 Quality Assurance and Quality Control (QA/QC)

A variety of strategies were put in place to reduce the possibility of external contamination. The use of plastic materials was avoided during the initial treatment stages. Protective gear, including gloves and cotton lab coats, was mandatory for all experimental activities. Before being utilized, every piece of field sampling equipment and laboratory glassware underwent a rigorous cleaning process with Milli-Q water and was then air-dried. Green cotton lab coats were specifically chosen to lessen the risk of airborne particles contaminating the experiments during both the preparation stages and while conducting microscopy. Before starting the experiments, every surface was cleaned using Milli-Q water followed by a 70% ethanol solution. The microscopy analysis was performed in an environment controlled by a fume hood, with a blank filter positioned under the microscope to identify any ambient contamination. Notably, during these blank tests, a total of five fibers (three black and two transparent) were observed. For validation purposes, a predetermined quantity of microplastics (MPs) was intentionally added to the samples, allowing for the calculation of the recovery efficiency at each procedural step.

3 Results and Discussion

3.1 Lake Stratification Effect

To assess the effect of lake stratification on the distribution of MPs, particles presence in July and October samples were compared. These two months are the representatives of warm and cold seasons, and as it has been mentioned earlier, it is hypothesized that thermocline and lake stratification should be formed in warm months, which is July in this study. The abundance of MPs in different layers of the lake is depicted in Fig 2.

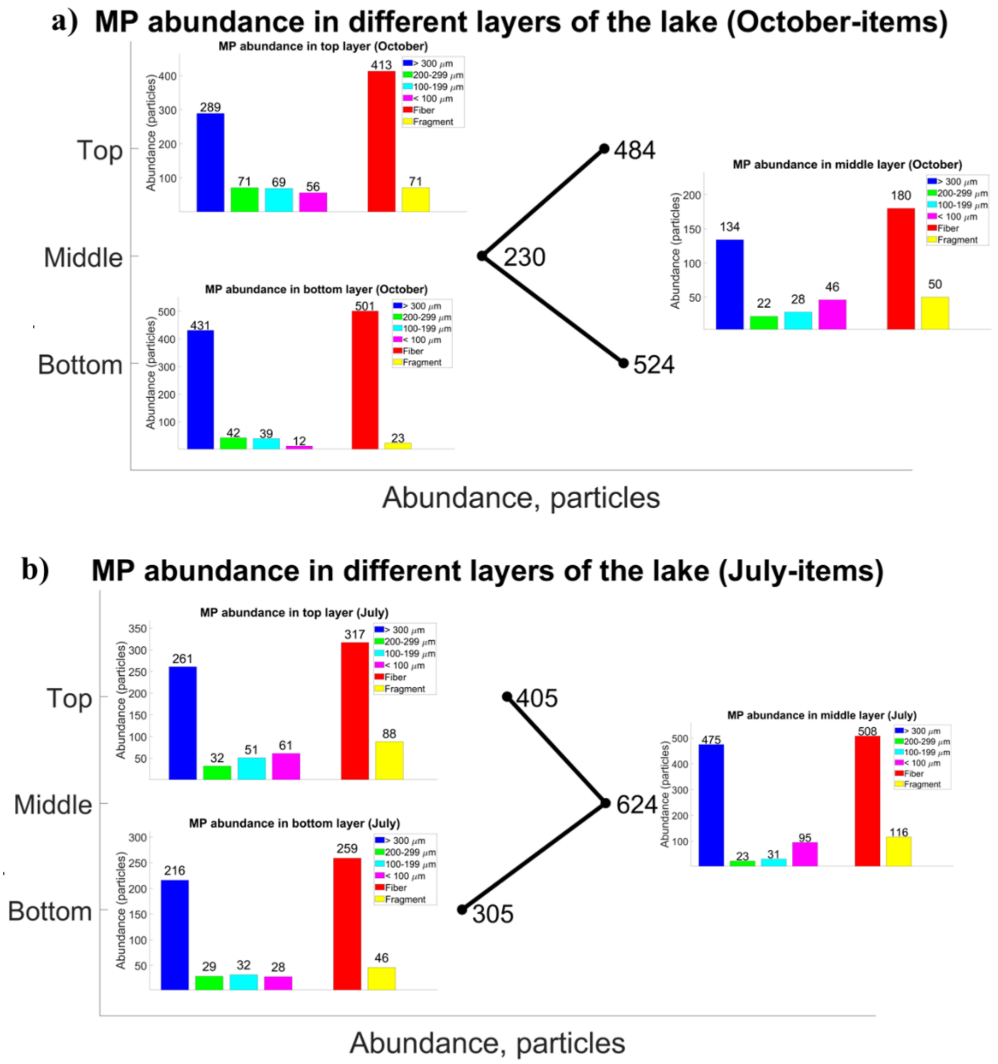

Fig. 2. The presence of MPs in different layers of Hamilton Harbour's water in a) October and b) July

In the month of July, the greatest density of microplastics (MPs), at 39.0 particles per liter, is observed in the middle layer of the water. The surface layer contains a slightly reduced count, with 25.31 particles per liter, while the lowest density is found at the bottom layer, registering 19.06 particles per liter. This could suggest a lesser degree of microplastic deposition at the lake's deepest part, or it might reflect environmental factors at the bottom that promote the disintegration or sedimentation of these particles (Ge et al., 2024). According to the obtained results from July sampling, the effect of thermocline on MP presence is evident as the stratified lake and metalimnion layer formation caused the entrapment of MPs in the middle layer. The distribution of MPs in top and bottom layers has been affected by factors such as density of particles and hydrodynamic currents (Uurasjärvi et al., 2021).

In October, the top layer now shows the highest concentration of MPs with 34.64 particles per liter, which is an increase from July. The middle layer has a significant decrease to 17.69 particles per liter. The bottom layer's MP concentration increases to 32.75 particles per liter, almost reaching the concentration of the top layer and significantly higher than in July. These results indicate that in October, which has a lower average temperature than July, thermocline has not formed, and the particles have been floated or sunk based on factors other than lake stratification.

The concentration of larger particles in the top layer in October could be due to buoyancy, where larger, lighter items may be more likely to float or remain suspended (Kye et al., 2023). The middle layer having fewer MPs might be a result of settling dynamics or middle-water column currents that transport MPs away. The abundance of smaller particles and fibers in the bottom layer suggests that these may be more prone to sinking or that currents within the lake are depositing these MPs in the lower depths (Li et al., 2023). Fibers often result from the breakdown of larger items or may originate from activities such as fishing or washing of synthetic clothing, which can introduce fibers directly into waterways (Rebelein et al., 2021).

The middle layer in July had a significantly higher concentration of MPs than in October, indicating a seasonal variation in MP distribution due to lake stratification phenomenon. In both months, the bottom layer had a high count of smaller particles, which may be due to settling dynamics that favor smaller particles and fibers (Pan et al., 2023). The top layer in July had fewer large particles compared to October, suggesting potential differences in inputs or physical conditions such as water temperature and stratification.

The decrease in MP abundance from July to October in the middle layer could be associated with changes in water column temperature and lake stratification occurrence or biological activity that alters during the transition from summer to fall. Increased recreational activity in summer could introduce more MPs, particularly near the surface and middle layers. Weather conditions like wind and rain (Kye et al., 2023) could affect the distribution patterns, especially since summer storms may stir the water column differently compared to those in fall.

4 Conclusion

The variation in microplastic abundance and size distribution across different layers of the lake between July and October illustrates the dynamic nature of aquatic ecosystems. Seasonal changes in water properties, biological activity, and human-related factors are likely influencing the observed patterns of microplastic distribution. According to the results of this study, lake stratification showed a significant role in the seasonal and vertical distribution of MPs in different water layers. Stratified lake in July entrapped the MPs in the middle layer, metalimnion, showing the significance of thermocline formation on MPs presence. In October, on the other hand, the lake did not experience stratification and particles have not been trapped in the middle layer.

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