Vertical distribution of microplastics in Hood Canal and Main Basin, Puget Sound, Washington

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June 2nd, 2019

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Keywords: microplastics; distribution; vertical; depth; Puget Sound; marine debris; pollution;

Abstract

Microplastics have been an increasingly important pollutant and area of research over the past 50 years. Although microplastics threaten marine ecosystems in various ways, little is known about their sink, vertical distribution or role in estuaries. To address the lack of knowledge of the vertical distribution of microplastics in estuarine systems, this study collects and analyzes observational data across the water column in Puget Sound using a series of net tows. Microplastics were visually observed in all samples collected and the samples were quantified to concentrations at each depth. The highest microplastic concentration - 1.88×10^{-4} g/m^3 - was found in Possession Sound while the most consistent vertical profile was found at Seabeck in Hood Canal, suggesting residence time is more likely a driving factor to vertical distribution than proximity to population centers. This study uses a novel approach to researching the vertical distribution of microplastics and therefore highlights the need for further research and awareness on the increasingly important issue of microplastics.

Introduction

Microplastics are most commonly defined as pieces of plastic marine debris that are smaller than 5.0 millimeters (Auther et al., 2009). Primary microplastics are manufactured to be smaller than 5 millimeters, where secondary microplastics begin as larger marine debris and are broken down through physical, chemical and biological weathering (Cole et al., 2011). When discussing microplastics it is important to note that there are many different types of plastics that comprise marine debris - the three most common being: polypropylene; polyethylene; and poly(vinyl chloride) - which are commonly used in packaging and fishing equipment (Andrady, 2011). Rivers are a major source for both primary and secondary microplastics in the marine environment (Lebreton et al., 2017) while larger marine debris - that become secondary microplastics - can enter the marine system directly from litter in coastal communities.

Of the global sinks that have been proposed for microplastics, only pelagic sediments are considered probable. Observations show that microplastic concentrations are higher in subtidal sediments (Thompson et al., 2004) and that microfibers are ubiquitous in pelagic sediment cores and coral reefs (Woodall et al., 2014). Although it is still unclear how long it takes microplastics to reach the sediment, or how long they stay there, it is widely agreed that benthic sediments are a likely sink for microplastics (Wright et al., 2013). It is important to recognize that most circulation models used to determine the global reservoir of microplastics do not take this proposed sink into account as there is insufficient data on settling rates to guarantee accuracy in the models (van Sebille et al., 2015).

Vertical distribution of microplastics

Once in the marine environment, microplastics pose a variety of threats to marine ecosystems. Most microplastics are bioavailable because of their size, density, and abundance (Wright et al. 2013); therefore they have the potential to bioaccumulate in all trophic levels. This is evident as organisms such as zooplankton, benthic sea cucumbers, and seabirds have been documented to have ingested microplastics (Collignon et al., 2012; Graham et al., 2009; Blight et al., 1997). Furthermore, there have been observations of microplastics ingested by shellfish that are cultured for human consumption (Van Cauwenberghe et al., 2014). Finally, microplastics have the potential to transport invasive species long distances (Lin, 2016), leech toxic chemicals into the environment (Teuten et al., 2009) and have been found in sea salts intended for human consumption produced in China (Yang et al., 2015).

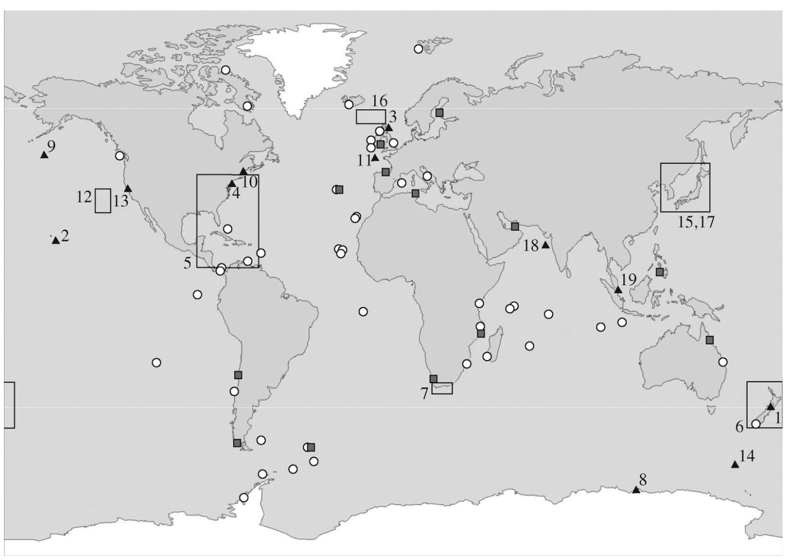

Figure 1. Original figure from Barnes et al., 2009 This figure illustrates the presence of plastic marine debris globally since 1960. Taken from a variety of sample types, this is a comprehensive look at the expanse of plastic in global marine environments.

Microplastics have become an increasingly important research topic over the past 50 years as they have become more ubiquitous in the marine environment, with global observations since the mid-1960s (Figure 1; Barnes et al., 2009). This issue has been addressed by the United States government with the creation of the NOAA Marine Debris Program in 2006 (120 Stat. 3333) and through the Microbead-Free Waters Act of 2015, an amendment to the Federal Food, Drug, and Cosmetic Act that banned microplastics as exfoliants in cosmetic products (129 Stat. 3129). Even with this increased attention to the issue, it has been difficult to quantify the quantity and spatial distribution of microplastics in the marine environment because of the vast gaps in our knowledge of the sinks and vertical and temporal distributions of microplastics. Of the estimates made of global microplastic reservoirs, many of them use combinations of observational data and circulation models. One recent survey estimated the weight of the global microplastic reservoir is 2689.4×10^2 tons, mostly found in the Northern Hemisphere subtropical gyres (Eriksen et al., 2014), commonly dubbed the 'Pacific Garbage Patch.' Although there is a general understanding of the global spatial distribution of microplastics, less is known about the distribution of microplastics global vertical distribution and their reservoirs in estuaries.

Little is known about how microplastics accumulate and interact with ecosystems in estuarine environments, even though estuaries often host complex ecosystems and large human populations. Therefore, estuaries are subject to concentrated plastic pollution from land-based sources and water exchange with an already polluted ocean. It has been found that in estuaries, microplastics accumulate near areas of high urbanization and sewage outflows (Pazos et al., 2018) and are dependant on the residence time of the body of water (Mahoney, 2017). In the Puget Sound region, microplastics have been observed in water samples taken from the Strait of Juan de Fuca and in the Salish Sea where higher concentrations were found closer to shore, indicating land-based sources (Desforges et al., 2014). It stands to reason that higher concentrations will be found in the Puget Sound when compared to adjacent bodies of water as there are more concentrated population centers, a high river input, constant exchange with the Salish Sea and longer residence times than in the Strait of Juan de Fuca and the northeast Pacific Ocean.

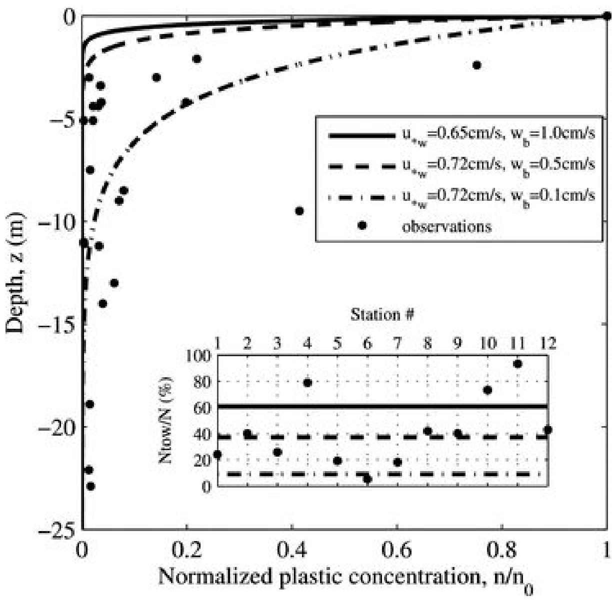

Figure 2. Original figure from Kukulka et al., 2012: This figure indicates that as the shear stress of a wind increases, there is increased vertical mixing of microplastics. The inset shows estimates of relative concentrations of surface plastics relative to total plastic concentrations from observations (dots) and model results (lines).

Some studies have begun to explore the vertical distribution of microplastics in the open ocean. It is important to look at the vertical distribution of microplastics as these buoyant pieces of marine debris are susceptible to wind-driven mixing (Figure 2; Kukulka et al., 2012). This mixing and neutral buoyancy have been shown in one field study to cause a size gradient of microplastics resulting in larger pieces at the surface and smaller pieces further down in the mixed layer (Figure 3; Enders et al., 2015). This is significant not only because it poses an additional challenge in studying microplastics, but because it offers new insight into the potential for a deep-sea reservoir of microplastics and their proposed sink in pelagic sediments.

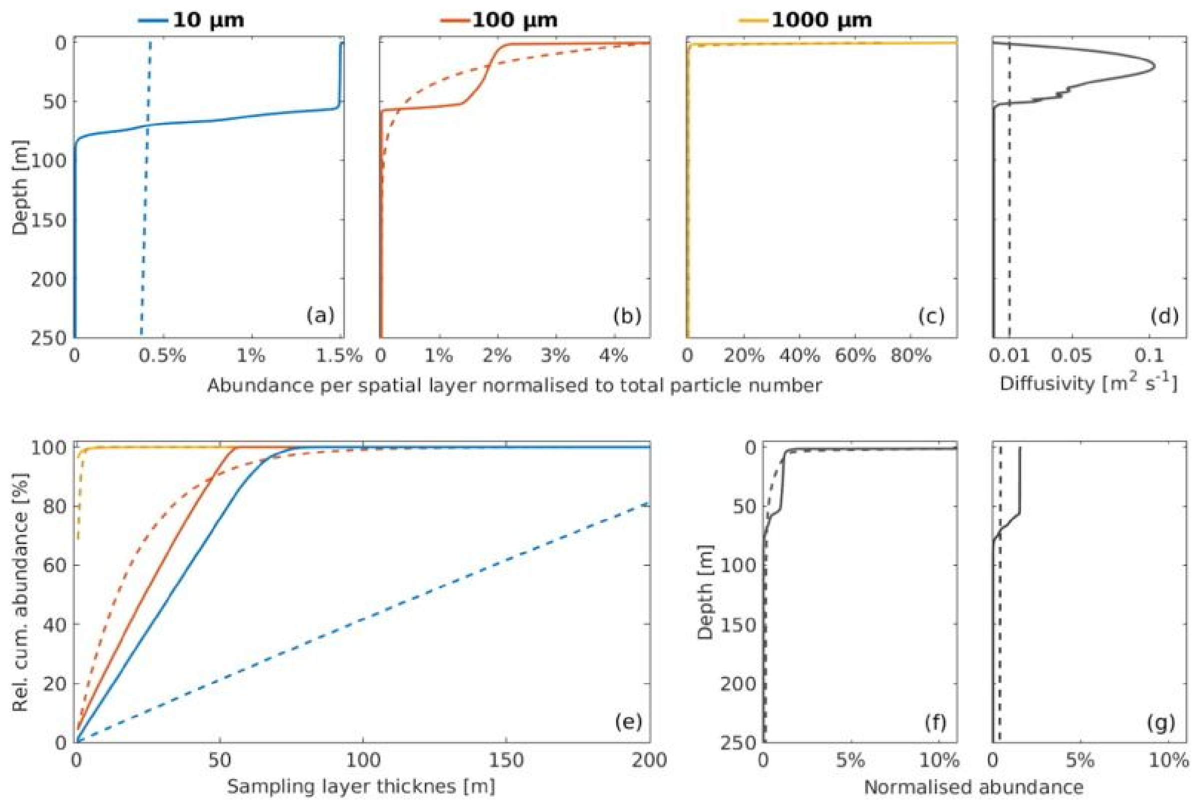

Figure 3. Original figure from Enders et al., 2015: This figure illustrates that larger plastic marine debris are more frequently found higher in the water column and smaller plastic marine debris can settle lower into the water column.

Observational studies of microplastics at different depths in the water column have been limited, although studies using surface sampling, single depth trawls and multi-level net tows of the mixed layer have been conducted (Mahoney, 2017; Cole et al., 2011; Reisser et al., 2015). This study analyzes the observed microplastic vertical distribution in the Puget Sound in Washington through multi-depth net tows. Information about the vertical distribution of microplastics has yet to be collected using this method. Based on the modeled depth profiles and proposed sink, this observational information will be a powerful tool in working towards a better understanding of the microplastic reservoir and distribution in an estuarine system. This study has broad applications ranging from more focused, local microplastic research to more informative global studies on microplastic distribution.

Methods

To analyze the microplastic concentrations in the vertical water column in Hood Canal and the Main Basin of Puget Sound, water samples were collected using a Manta Net with 330-micron mesh and a multinet tow with 333-micron mesh, both performed on the R/V Rachel Carson during the UW Oceanography senior cruise from January 18th to 21st, 2019. Samples were then transported to the lab and processed according to the NOAA Marine Debris Program lab manual (Masura et al., 2015).

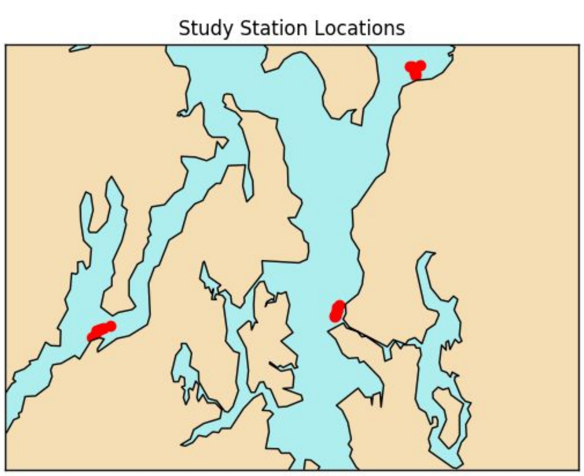

Figure 4. Locations of transects sampled shown by red dots. This figure will be recreated to include lat, lon, scale bar and other navigation tools.

Sample Collection

Vertical distribution of microplastics

Samples were collected from the R/V Rachel Carson from one transect in Hood Canal; one transect in Possession Sound off of the city of Everett, Washington; and one transect in the Main Basin of Puget Sound in Shilshole Bay (Figure 4). The Hood Canal location was selected for its long residence times (Mahoney, 2017) - between 8 and 16 days - and low population density. The Possession Sound location was selected for its proximity to the city of Everett, which has a population of approximately 110,000 people (U.S. Census Bureau, 2017). Finally, the Shilshole Bay location was selected for its proximity to a marina and popular public beach.

Each transect was sampled at four depths: one water sample within 10 meters of the seafloor; one water sample 5 meters below the bottom of the mixed layer; one water sample 5 meters above the bottom of the mixed layer; and one water sample at the surface. Each sample filtered an average of 181.04 m^3 (Table 1) with a maximum towing speed of 4 knots (Hydro-Bios Apparatebau GmbH., 2009).

When collecting water samples, a Seabird SBE-9 CTD was first used to identify the depth of the mixed layer on the day of sampling. Then, the R/V Carson towed a Hydro-Bios MultiNet type Midi - a phytoplankton sampler that has a total of 5 net bags of 333-micron mesh - for the collection of samples at depth and a 330-micron Manta Net for the collection of surface samples. The MultiNet was lowered to each depth and a different net bag was opened at the desired depth, towed at that depth and closed once a target of 150 cubic meters of water had been sampled, allowing for two discrete samples to be taken from one deployment of the instrument. 150 cubic meters was selected for the time it took to filter that volume. Additionally, the R/V Rachel

Carson towed a Manta Net at the surface along the same transect to collect the surface sample. For each station, the Manta Net was deployed once and the MultiNet was deployed twice. Finally, there were three samples of convenience collected using only the Manta Net.

On the back deck of the R/V Rachel Carson, each net was sprayed down with seawater to concentrate the sample and ensure none of the sample was left on the net as contamination for the following samples. Once concentrated, the samples were passed through two sieves: one 550-micron mesh sieve and one 330-micron mesh sieve. The sieves were then rinsed with sea water to consolidate the sample that was collected on the sieve into the sample jars. The samples were then transported back to the lab for further processing

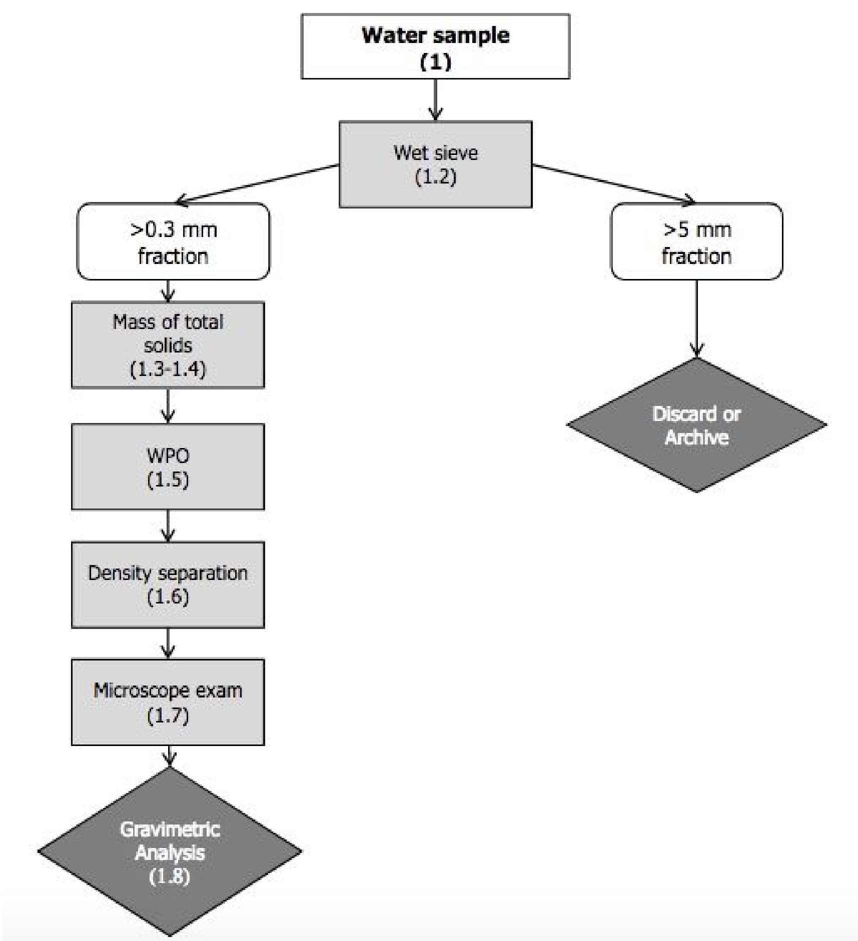

Figure 5. Original figure from Masura et al., 2015. This flow diagram provides an overview of the steps taken to process water samples. These standards were set by NOAA and are held as the standard for microplastic processing by in the United States.

Lab Processing

The samples were transported to and processed in Kathy Newell's lab at the University of Washington in the School of Oceanography. Each water sample was subjected to: wet sieving; wet peroxide oxidation using iron and hydrogen peroxide to remove organic matter; density separation; and a microscope exam where microplastics were removed from the sample by hand (Figure 5; Masura et al., 2015). For further details on how to process water samples, please refer to the laboratory methods outlined by the NOAA Marine Debris Program (Masura et al., 2015).

Once the samples were processed, their weights recorded in a dataset before the data was normalized to reflect grams of plastic per cubic meter. The normalized data was then analyzed and visualized in Microsoft Excel.

Results

Not all locations sampled had large enough sample weights to produce non zero concentrations. Although concentrations by weight were not always non zero, microplastics were observed al all 15 sample locations (Table 1). The average concentration of microplastics in Puget Sound is 3.05×10^{-5} g/m^3. It was noted that fibers were found across the water column. If larger particles were present, they were mostly observed in the samples collected above the mixed layer.

Finally, it is important to note that in the sample collected at the Hood Canal Bridge, a large piece of styrofoam was collected. This is a classic example of marine debris but is classified as a macroplastic and therefore not included in this study.

Vertical distribution of microplastics

Station Name	Sample Depth (m)	Volume Sampled (m^3)	Concentration (g/m^3)	Visible Microplastics?
Shilshole	0	123.9048087	0.00E+00	yes
Shilshole	5	150	1.49E-05	yes
Shilshole	15	151	0.00E+00	yes
Shilshole	65	150	5.27E-05	yes
Everette	0	224.8474	8.81E-06	yes
Everette	25	154	1.88E-04	yes
Everette	50	144	0.00E+00	yes
Everette	134	183	0.00E+00	yes
Hood Canal - Seabeck	0	232.231019	1.64E-05	yes
Hood Canal - Seabeck	20	152	0.00E+00	yes
Hood Canal - Seabeck	50	155	1.61E-05	yes
Hood Canal - Seabeck	90	159	9.13E-05	yes
Hood Canal - Port Ludlow (1)	0	240.3499001	9.24E-06	yes
Hood Canal - Port Ludlow (2)	0	233.9235764	3.85E-06	yes
Hood Canal - Bridge	0	306.1168831	4.36E-05	yes
Hood Canal - Port Ludlow (Average)	0	237.1367383	6.54E-06	yes

Table 1. Detailed look at the data collected in this study, categorized by location and depth.

At Shilshole Marina, microplastic concentrations were observed above and below the mixed layer (Figure 6). The average concentration for this location is 1.69×10^{-5} g/m^3. This location has the shallowest water column and mixed layer interface sampled in this study.

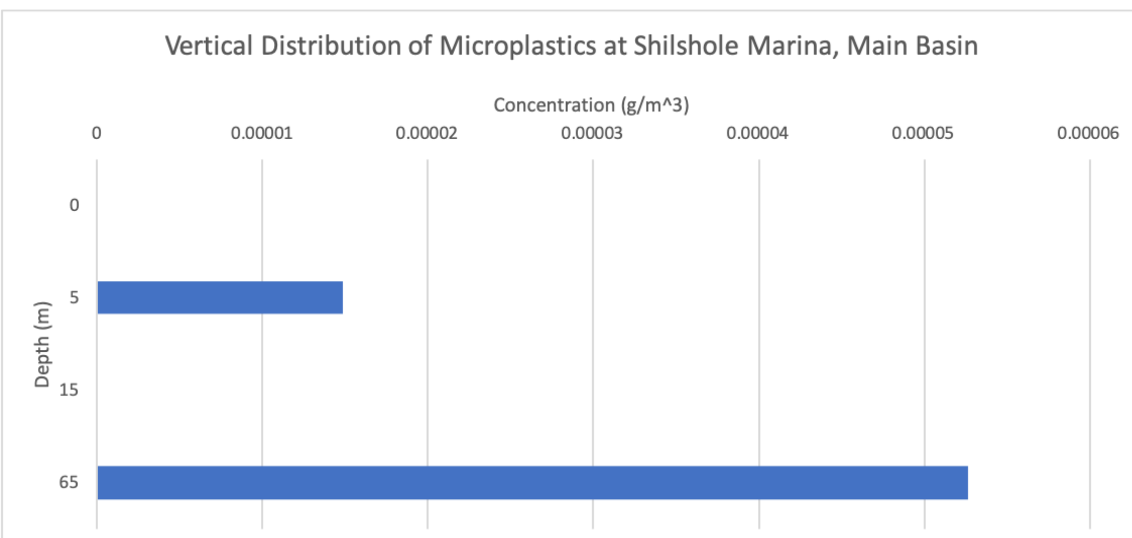

Figure 6. Concentrations of microplastics descending in the water column off of Shilshole Marina in the Main Basin of Puget Sound.

Vertical distribution of microplastics

In Possession Sound, near the City of Everett, microplastic concentrations were observed above the mixed layer (Figure 7). The average concentration for this location is 4.91×10^{-5} g/m^3. The highest concentration in this study is found to be 1.88×10^{-4} g/m^3 at 25 meters in Possession Sound. This location is the deepest water column and deepest mixed layer interface sampled in this study.

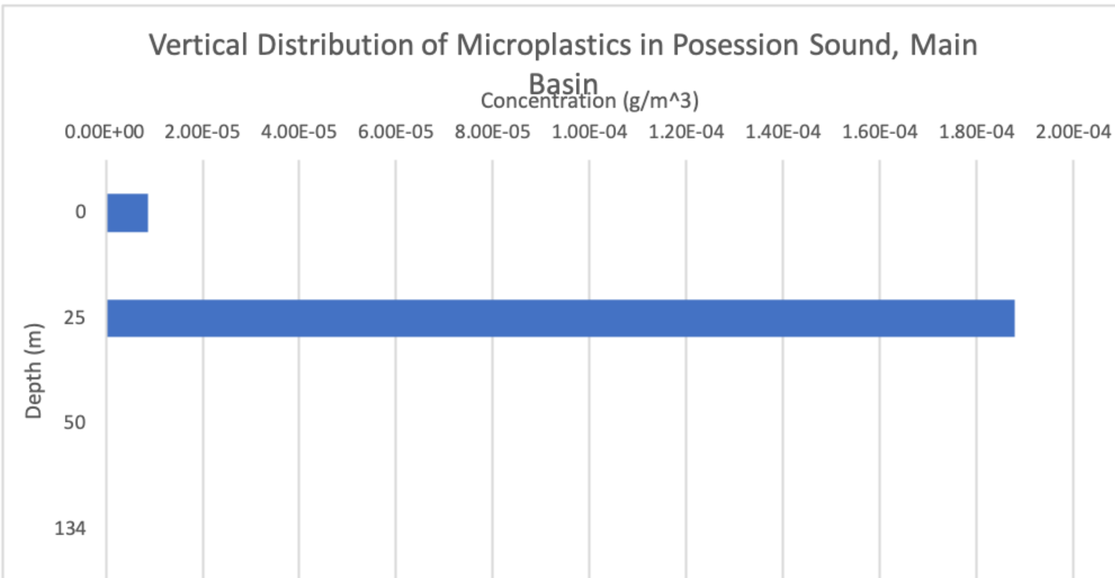

Figure 7. Concentrations of microplastics descending in the water column off of the City of Everett in Possession Sound, in the Main Basin of Puget Sound.

At Seabeck in Hood Canal, microplastic concentrations were observed above and below the mixed layer (Figure 8). The average concentration for this location is 3.09×10^{-5} g/m^3. This sample location does not hold any outlier data points.

Vertical distribution of microplastics

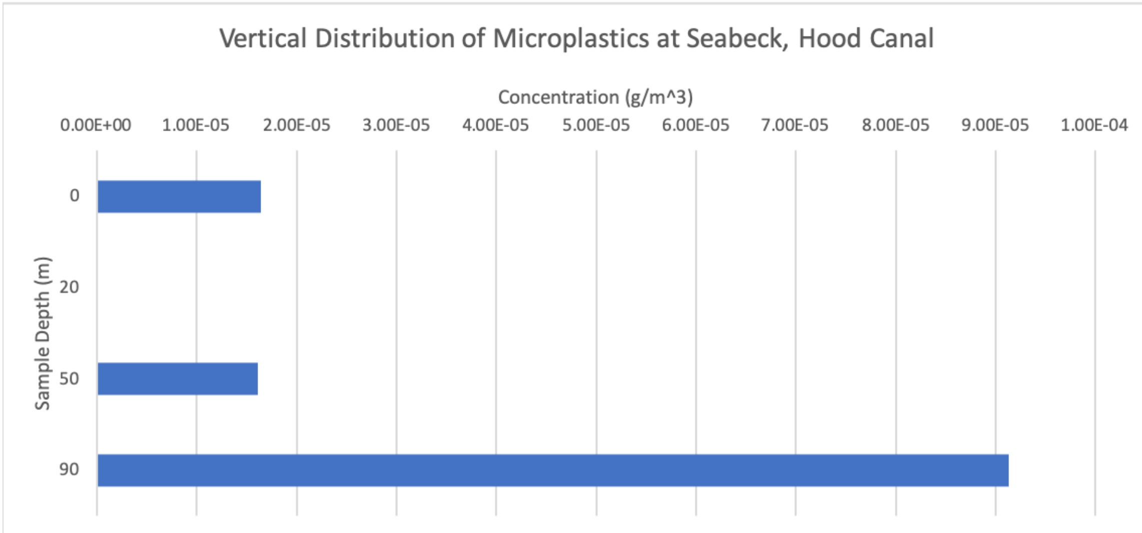

Figure 8. Concentrations of microplastics descending in the water column off of Seabeck in Hood Canal, Puget Sound.

When comparing surface concentrations across all stations and including additional surface samples, the two highest concentrations are found in Hood Canal at Seabeck and at the Hood Canal Bridge (Figure 9). The average surface concentration is 1.51×10^{-5} g/m^3. The highest concentration is 4.36×10^{-5} g/m^3 and was found at the Hood Canal Bridge. The smallest concentration is 6.54×10^{-6} g/m^3 and was found at Port Ludlow in Hood Canal; it is the location of the smallest, non zero concentration measured in this study. The concentration at Shilshole was found to be zero and the was the smallest volume of water sampled in this study.

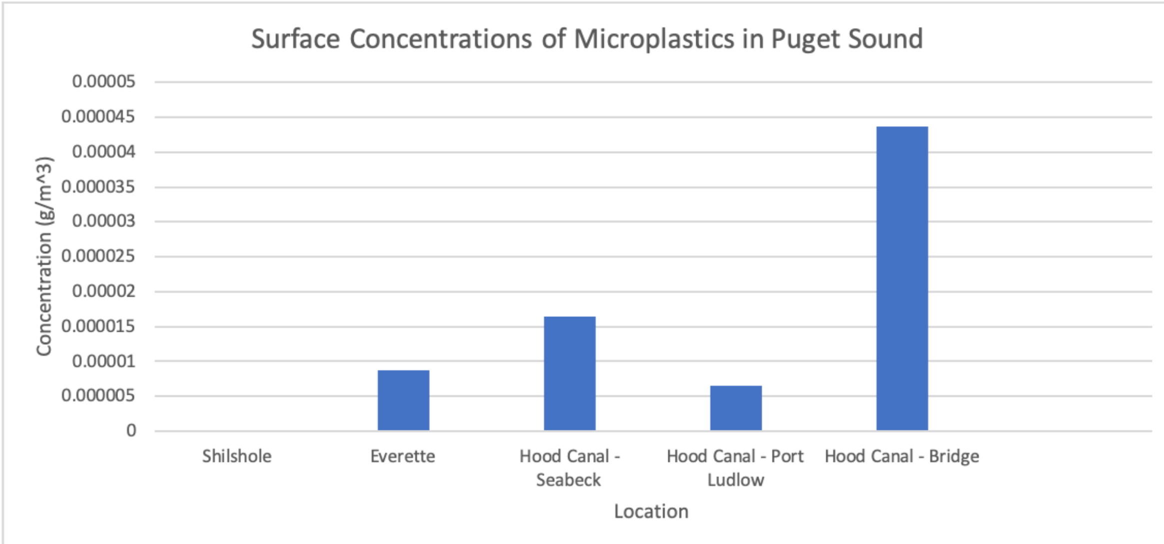

Figure 9. A comparison of surface concentrations across Puget Sound including the three sample stations and two additional surface samples.

Discussion

The presence of microplastics at all depths sampled speaks to the ubiquity of microplastics in the marine environment. This evidence would suggest that the current estimate of the total abundance of microplastics in the ocean - 2689.4×10^2 tons (Eriksen et al., 2014) - is underestimated as current models do not account for the presence of microplastics through the vertical water column. Due to this underestimation, the negative environmental effects of microplastics are likely amplified. Although unsurprising due to the large amount of uncertainty that remains in modeling microplastic abundance, the presence of microplastics in all samples collected serves as a reminder that more research on microplastics is needed before we are able to create accurate estimates of the abundance of microplastics and their spatial and vertical distribution.

In this study, microplastics were collected from three locations in order to look at different possible driving factors. Shilshole Bay was selected as a sampling location for its proximity to a marina and popular public beach. At this location, microplastic concentrations were found in and below the mixed layer. Although concentrations were calculated, the vertical distribution at this location makes it difficult to reach a conclusion about the impacts the marina may have had on the concentrations and distribution of microplastics. I believe it is more likely that a the proximity of this station to the Hiram M. Chittenden Locks, the connection between Lake Union and Puget Sound, has a greater impact on the concentrations and distributions of microplastics in Shilshole Bay than the presence of the marina and public beach.

The Possession Sound location was selected for its proximity to the city of Everett, which has a population of approximately 110,000 people (U.S. Census Bureau, 2017). Although the highest concentration of this study was found in Possession Sound, microplastic concentrations were only calculated for the mixed layer at this location. This suggests that although population centers are a source of microplastics to the marine environment, they are not a driving factor of their vertical distribution.

The Hood Canal location was selected for its long residence times - between 8 and 16 days - and low population density. As expected, larger pieces of marine debris were found in the surface layer and at areas of convergence, such as the Hood Canal Bridge where we collected an intact piece of styrofoam, or in regions of long residence times, such as at Seabeck in Hood Canal.

Previously, these factors seemed to impact the distribution of microplastics more than proximity to dense population centers (Mahoney, 2017). The consistency of microplastics vertically at Seabeck and the surface concentrations found at Port Ludlow and the Hood Canal Bridge in addition to the conclusions made about distribution in Possession Sound support this hypothesis.

This study was time limited and therefore lacks sample replication, large sample volumes and limited scope. The lack of sample replication does not allow for variations, such as seasonality or tidal variation, to be observed in the data. Therefore concentrations with weights that are non zero may be due to natural variability. Furthermore, the lack of sample replication allows for higher variation due to sampling error. It is likely the target sample volume, 150 m^3, and the average sample volume, 181.04 m^3 (Table 1), are not large enough to accurately reflect the microplastic concentration at the location. These volumes were constrained by time, suggesting that future studies of microplastics using subsurface net tows will require more time.

This study uses new sampling methods to address a previously unanswered question. Therefore, it is expected that not all sampling parameters will remain constant as the sampling method develops and the questions it is used to answer change. Such is the case with the target sample volume in this study. In future studies wishing to use this or a similar sampling method, the author recommends using a significantly larger target sample volume.

Conclusion

This study observed the vertical distribution of microplastic concentrations at three discrete locations in Puget Sound. Having selected the sampling locations for different factors that may affect the distribution and concentration of microplastics, we were able to support the hypothesis that residence time is a stronger factor than proximity to population density when considering concentrations and vertical microplastic distribution. Although we were unable to see an impact on concentration and distribution from proximity to marina's, we were able to identify that areas of water input, such as the Chittenden Locks, are more likely to be a strong factor when considering the concentration and distribution of microplastics.

With the ubiquity of microplastics in the marine environment, further research is needed to better understand the scope of the global microplastic reservoir, their distribution over the water column, their sink and how they interact in diverse systems such as the open ocean and estuaries. This study could be built upon through replication or expansion of the sampling technique and further exploration of the vertical distribution of marine debris in an estuary and could include sediment samples to provide a more complete picture of microplastics in Puget Sound. Further modeling of microplastic settling velocity and wind-driven mixing are needed to further the field and our understanding of how microplastics behave in the marine environment.

Microplastics are an increasingly important anthropogenic threat facing our oceans and other marine environments. Although the United States Government has taken limited steps to address the issue, further national and international attention is needed as these efforts are often focused on the larger issue of marine debris. From an increased risk of bioaccumulation to an increased risk of human consumption, microplastics, and more largely marine debris, will continue to be a challenge for researchers, policymakers, and the growing public.

Acknowledgments

I would like to thank those that made this study possible. My advisors, Kathy Newell and Arthur Nowell who have been both understanding and invaluable in this process. The Captain and Crew of the R/V Rachel Carson and the students on the MLK Day Senior Cruise for making the often confusing sampling method happen. Julie Kiester for allowing me to put her Multinet close to the seafloor. My Ocean Squad for their unwavering support, understanding, and friendship. Finally, my family for supporting my dream of studying marine science for the past twelve years.

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