

**The concentration of microplastics compared to  
relative population proximity and basin residence  
times in Hood Canal and Whidbey Basin in Puget  
Sound, WA**

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## **Abstract**

Microplastics enter waterways due to humans, however water circulation and winds can have an effect on where they concentrate. Microplastic concentrations are determined in Hood Canal and Whidbey Basin in Puget Sound, WA during December 2016. Eight stations were sampled using a 335  $\mu\text{m}$  Manta Net towed from the R/V Barnes, then sieving water samples through a 0.33mm mesh sieve. Remaining products were then rid of organics, placed in a density separator, dried, and extracted for microplastics. By comparing microplastic concentration to basin residence times and population density, the main contributor to microplastic accumulation can be determined. Residence time (determined by wind and circulation) is a more important indicator to where plastics will distribute in Puget Sound. Microplastic concentration ranges from 0.069 pieces/ $\text{m}^3$  in Whidbey Basin to 0.36 pieces/ $\text{m}^3$  in southern Hood Canal. The mass of microplastics at each station was strongly attributed to the amount of Styrofoam present. This study acts as a baseline study for Puget Sound estuary and could help serve to understand where pollutant cleanups could be effective.

## **Introduction**

Marine pollutants are becoming a problem worldwide due to human waste and activities. Plastics are synthetic polymers that are created by humans to be strong, lightweight, and to have multiple purposes. Plastics can enter marine areas through the runoff from land due to human usage (Andrady, 2011).

Microplastics (<5mm diameter) have been found in most large bodies of water around the world (National Oceanic and Atmospheric Administration, 2015). Plastics are becoming an increasing marine pollutant, and therefore need to be studied, because they accumulate and break down into smaller pieces without ever fully degrading (Moore, 2008). As plastic usage becomes more common, the load on the environment increases the potential for marine animals to ingest these plastics and cause harmful side effects. Microplastics are ingestible for a wide variety of animals, which can negatively affect an animal's health.

Plastics can absorb chemicals in the water column (Teuten et al., 2007) and when consumed by an organism, microplastics can release and transfer their contaminants more readily (Law and Thompson, 2014; Browne et al., 2007). Not only can plastics release toxins, but they can also promote colonization of bacteria and biofilm on their exterior. With this colonization and slow degradation, they serve as a unique ecological habitat in the open ocean (Zettler et al., 2013). Microplastics have immediate effects on marine pollution, but potentially varying effects on organisms that ingest them, like sudden death or entanglement.

The concentration of plastic in the ocean is increasing due to newly added plastics entering the ocean and previously deposited plastics not being able to

break down (Moore et al., 2008; Barboza and Gimenez, 2015). Starting in July 2017, there will be a federal ban against the use of microbeads (*Chemistry World*, 2016), which could potentially mean that fewer total plastics are entering bodies of water. However, with no regulation on any other plastics, pieces of large plastic could continuously end up in the ocean while getting smaller, but never disappearing. Microplastics can be used as a reference to understand how many total plastics have broken down thus far in the ocean. Unfortunately due to inconsistencies of procedures with collection and analysis, little is known about the concentration of microplastics in marine environments (Hidalgo-Ruz et al., 2012), especially with changing factors like population, circulation, residence times, and winds.

Debris in the ocean, such as plastics, are distributed based on water circulation, winds and tides. Plastics can help trace and track particle distribution in the water column, show debris sources, and demonstrate the ecological implications of pelagic plastic debris (Morét-Ferguson et al., 2010). The amount of plastics that are present on the surface of the water column are influenced by the wind speed and distribution in the mixed layer (Kukulka et al., 2012). Organisms in the water column can attach to pieces of plastic and move around the ocean based on water circulation (Zettler et al., 2013). This means that plastics can help foster invasive species, potentially having negative implications on predator-prey interactions, the economy, and human health.

It is critical to understand where plastics will accumulate in the world's oceans, but before attempting to understand plastic distribution on a global level it is important to study plastic circulation in smaller systems, like estuaries. Puget

Sound is an estuary system that consists of four main basins where circulation is driven by density, because of the input of fresh water and saline waters from the Pacific Ocean (Babson et al., 2006), and also tides. Each basin (Whidbey, Hood Canal, South Sound, and Main basin) has different residence times, currents, and circulation patterns (Khangaonkar et al., 2012). Differences in residence times can be a result of sills and basin depths, as well as a change in circulation speed (Khangaonkar et al., 2012). Because Hood Canal is sheltered behind its own individual sill, it has a very long residence time compared to the rest of Puget Sound. Circulation patterns from one basin to another can be used to show the transportation of pollutants around Puget Sound, even though circulation is highly variable (Babson et al., 2006). In Whidbey basin, surface volume transport of water is flowing to Admiralty Inlet at about  $0.8 \text{ m}^3/\text{s}$ , where it then flows out of the Strait of Juan de Fuca at about  $1.5 \text{ m}^3/\text{s}$ . Whereas water in southern Hood Canal to Strait of Juan de Fuca occurs over longer timescales because surface volume transport is about  $0.4 \text{ m}^3/\text{s}$  (Babson et al., 2006). In high population, urban areas along the coast of Puget Sound, there is a potential that more plastics are being used and contributing to marine pollution. In addition, popular human activities like fishing can contribute to an increase in plastics in the water because of their use of plastic fishing line and nets. Thus, there would be an expected increase in microplastic concentrations found in populated areas compared to in rural areas.

In order to better understand where microplastics accumulate in Puget Sound, it is crucial to see if there is a relationship between residence times of Puget Sound basins and microplastic concentration. Once it is found where

microplastics accumulate, they could be collected and rid the marine environment of these pollutants. This research will be looking at more densely populated locations and more rural locations in both Hood Canal and Whidbey Basin to see if population affects plastic concentrations. It is expected that there will be a higher concentration of microplastics in Hood Canal due to its slow residence time and a higher abundance of microplastics in more densely populated areas. The results of this study could be used as a baseline and comparison for microplastic concentrations in Puget Sound for years to come. This research will also shed light on the dictating factors of microplastic concentrations in small, highly variable areas like Puget Sound.

## **Methods**

### *Overview*

This research looked at two of the four main basins in Puget Sound: Hood Canal and Whidbey Basin. Residence times from previous research studies was used to compare microplastic concentrations observed in this study. Since plastics do not get evenly distributed throughout the water column and are concentrated at the surface, surface residence times will be used for each basin. Northern Hood Canal has a residence time of 8.4 days and southern Hood Canal has a residence time of 15.8 days, while Whidbey Basin has a residence time 4.9 days (Babson et al, 2006). Eight total stations were analyzed, with four stations in each basin. Two stations in each basin were chosen due to their closer proximity to highly populated areas, while two stations in each basin were chosen because of the lack of densely populated areas surrounding them to investigate if

microplastic concentrations are denser near areas with more people (United States Census Bureau, 2010).

Locations in Whidbey Basin are: Station 1 between Shoreline and Everett, Station 2 near Everett and Marysville, Station 3 which is not near any large city, and Station 4 which is also not located near any large city (Table 1, Figure 1). These stations will be compared to the residence time of Whidbey basin, which is 4.9 days (Babson et al., 2006).

Locations in Hood Canal are: Station 5 located by Port Ludlow and Port Gamble, Station 6 by Brinnon and the Bangor Trident Base, Station 7 which is not near any large city, and Station 8 which is not near any large city (Table 1, Figure 1). Station 5 and Station 6 are both in the northern part of Hood Canal and will be compared to the residence time of 8.4 days; while Station 7 and Station 8 are in the southern part of Hood Canal and will be compared to the residence time of 15.8 days (Babson et al., 2006).

Data was collected on December 15-17, 2016 on the University of Washington's R/V Clifford A. Barnes. A manta net with an area of 0.075m<sup>2</sup> and a mesh size of 333 μm was towed at 2 knots through the surface water at each station, suspended microplastics were collected and kept. Samples were then stored until January 2017 when lab analysis was conducted. Volume of water sampled at each station was determined by using the flowmeter on the Manta to estimate the amount of water that flowed through the manta net and the duration of each Manta deployment.

#### *Laboratory Sample Analysis*

Each sample was analyzed using the National Oceanic and Atmospheric Administration's "Laboratory Methods for the Analysis of Microplastics in the Marine Environment". Samples were wet sieved using distilled water and 5.6-mm and 0.3-mm mesh sieves. The microplastics were transferred into a pre-weighed beaker where they were placed into an oven for 24 hours at 90°C to be dried. After 24 hours, the weight of the sample was determined from the difference between the initial and final weight of the beaker. To remove the biological material from the microplastics, 20mL of 30% hydrogen peroxide solution was used to oxidize organic material and 20mL of aqueous 0.05 M Fe(II) solution to catalyze reaction and placed under the fume hood. After five minutes, the beaker was placed on a hotplate at 75°C with a stir bar until gas bubbles were seen at the surface. Then the sample was placed on a hotplate at 75°C for 30 minutes. In some cases an additional 20mL of 30% hydrogen peroxide was used to rid the sample of observable organic material. When no organic material was present, then ~6g of NaCl per 20 mL of 30% hydrogen peroxide was used to increase the density of the solution for plastics to float. The sample remained on the hot plate until all salt dissolved.

The sample was transferred to a density separator where it remained overnight and in some cases two nights. Upon inspection, if microplastics were visible they were removed by forceps and were collected in a clean 0.3-mm sieve and air-dried for at least 24 hours. Then the solids in each sample were inspected using a microscope and were categorized as either microplastic Styrofoams, clumps, or fibers. By using the number of microplastics in each sample per

volume of water the manta net sampled, it was possible to get the microplastic concentration at each of the eight stations in this study.

## **Results**

### *Counts*

Microplastics were found at the surface of all eight stations in both Hood Canal and Whidbey Basin. The number of microplastics in a sample varied from 15 pieces in Northern Hood Canal to 47 pieces in Southern Hood Canal (Figure 2). The average number of plastics per sample in Whidbey Basin was 19.75 (SD  $\pm$ 1.7), while in Hood Canal it was 25.5 (SD  $\pm$ 14.6)

### *Composition*

The composition of microplastics at each station varied, most frequently clumps more associated with Whidbey Basin, styrofoam with Hood Canal, and fibers distributed throughout both basins (Figure 3). The most poorly sorted area was at Station 8, with 91.5% of the total microplastics that were found was styrofoam. The most mixed microplastic composition was at Station 4 in Whidbey Basin, with the sample consisting of 38.9% styrofoam, 55.6% fibers, and 5.56% clumps. The mass of microplastics at each station can mostly be attributed to the amount of styrofoam found (Figure 4). Mass of total microplastics ranged from 0.0002g (SD  $\pm$ 0.00421) at Station 7 in Southern Hood Canal to 0.0179g (SD  $\pm$ 0.00821) at Station 8 in Southern Hood Canal.

### *Concentration*

The concentration of microplastics ranged from 0.080 pieces/m<sup>3</sup> in Northern Hood Canal to 0.36 pieces/m<sup>3</sup> in Southern Hood Canal (Figure 5). The average

concentration for Whidbey Basin was 0.092 pieces/m<sup>3</sup> (SD ±0.024) while for Hood Canal it was 0.36 pieces/m<sup>3</sup> (SD ±0.13). The concentration at each station was highest where there was a longer residence time, which is from samples in Southern Hood Canal. However, there is no correlation between concentration and population at each station.

## **Discussion**

If microplastic concentrations were dictated by population density in Puget Sound, Whidbey Basin would have higher concentrations than Hood Canal because of its proximity to major cities like Everett, Marysville, Mukilteo, and Shoreline (Table 1). However, microplastic concentrations in Puget Sound are more strongly dictated and influenced by the residence times of each basin, rather than by population (Figure 6). Plastics are in the water because of human input, so it is assumed that more plastics enter from more densely populated areas; however, those plastics do not stay there permanently. Plastics will travel according to circulation patterns in the region from where they are discharged (Figure 2; Figure 6). Whidbey Basin has huge influxes of river water, which mixes with saline waters, and transports surface water to Admiralty Inlet at about 0.8 m<sup>3</sup> s<sup>-1</sup>. Whereas Northern Hood Canal to Admiralty transports surface to Admiralty Inlet at 0.4 m<sup>3</sup> s<sup>-1</sup>, and Southern Hood to Northern Hood Canal at about 0.25 m<sup>3</sup> s<sup>-1</sup> (Babson et al., 2006). These changes in surface transports could be due to considerably more year-round river discharge into Whidbey Basin than in Hood Canal (Babson et al., 2006).

However, plastic distribution can also be influenced by wind direction and seasonality. In winter months with increased wind, the mixed layer of the ocean

becomes deeper, causing homogenous mixing throughout this part of the water column. Microplastics can become distributed to deeper depths in the ocean than just the surface depending on the winds. With winds of 0.75 cm/s, 54% of plastics can be mixed below sampling tow depth, resulting in potentially inaccurate data of overall water column plastic concentration (Kukulka et al., 2012). Since this research took place in December, it could be that Puget Sound has higher microplastic concentrations than these results found due to only the surface being sampled. Thus, our local and global estimates of microplastic concentrations may be severely undervalued depending on the seasonality and day of measurement (Kukulka et al., 2012).

Stations 1 and 2 were conducted in the early morning where, according to models, wind speed should be at its minimum in Skagit Bay. Maximum wind speeds should occur in the late afternoon, which is when Station 3 and 4 were measured (Raubenheimer et al., 2013). Less microplastics could have been found in Stations 3 and 4 because of the wind strength mixing them down in the water column. Stations in Whidbey Basin had slower wind speeds than stations in Hood Canal (Table 2). Faster wind speeds can be associated with more microplastics being distributed deeper in the water column, and not having the opportunity to be collected for sampling (Kukulka et al., 2012). Although, no data is present from any of the mornings of sampling days, resulting in missing values for Stations 1, 2, and 8 (Table 2).

These results can be affirmed by a study looking at microplastic transportation and deposition along the Goa coast in India, which found that winds and surface currents dictate these patterns (Veerasingam et al. 2016).

Microplastic concentration varies by residence time, surface flow and winds, so values are variable depending on specific locations throughout the world. For example in the Ross Sea in Antarctica, concentrations ranged from 0.0032 to 1.18 pieces/m<sup>3</sup> (Cincinelli et al., 2017). While in urban surface waters in China, concentrations ranged from 1660 pieces/m<sup>3</sup> to 8925 pieces/m<sup>3</sup> (Wang et al., 2017).

This study acts as a baseline measurement for basins in Puget Sound, WA, since no other papers have been published on this topic. However, for a baseline study, this research focused on a small data set with relatively few stations. To improve on this, more research could be done in other basins in Puget Sound, as well as different times of the year to account for the seasonality. Improvements should be considered, especially in Puget Sound region, because marine organisms living in the ocean can ingest these microplastics and cause plastic to accumulate up the food web, but organisms can also colonize onto plastic particles. While there have been some studies that have attempted to determine which organisms colonize on plastic, the sheer number and species is still unknown (Debeljak et al., 2017). It also may be beneficial to determine how long plastics remain in Puget Sound, and if that relates to the residence time, before getting flushed out because of human recreation, food use, and bioaccumulation.

## **Conclusion**

Water samples were collected and sieved for microplastics in Whidbey Basin and Hood Canal in Puget Sound, WA to gather data on type and distribution of microplastics in the water. Through the survey of eight stations in Puget Sound, it was found that microplastic concentration was closely linked with

residence times, and not with population density. When plastics are input into the water by humans via rivers, recreational activities, and waste, their circulation patterns were determined to be dependent on surface water flows and winds. Thus, population may determine the amount of microplastic input but microplastic distribution is determined by residence time. Microplastics collect at Station 8 because Puget Sound is slow flushing, and water flows into Hood Canal from Admiralty Inlet. Overall, this study shows that residence times of Puget Sound basins affect where plastics are distributed through the entire system.

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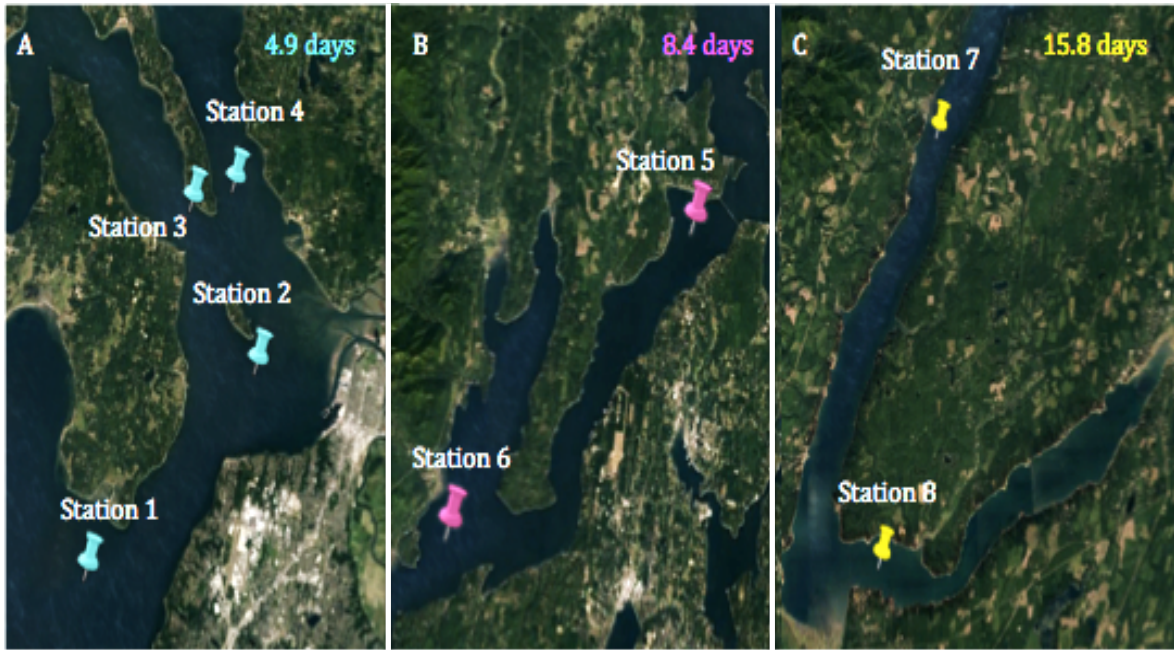
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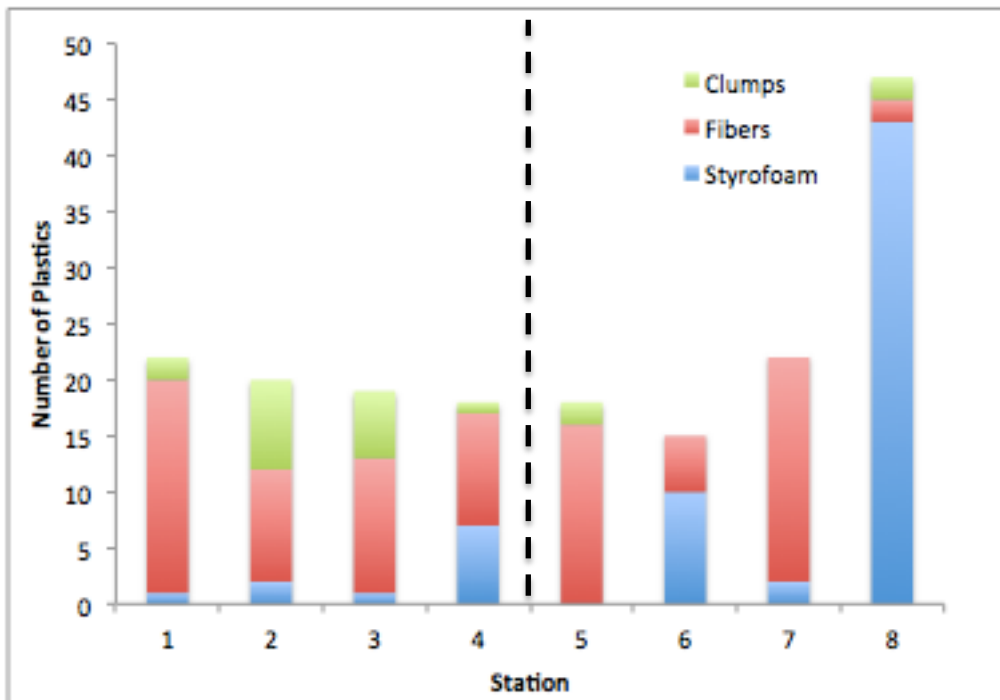
## Figures

**Table 1:** The relationship between surface residence times and population to the Station location.

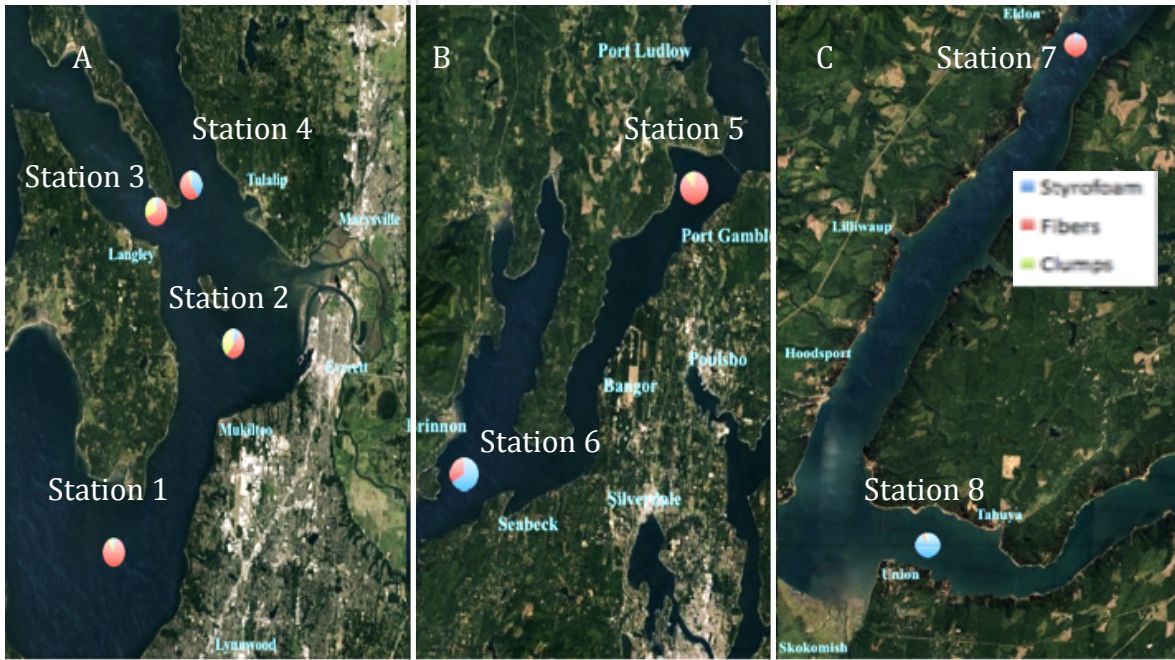
Station	Latitude (N)	Longitude (W)	Location	Estimated Population	Surface Residence Time (days)
Station 1	47° 52' 35"	122° 24' 12"	South Whidbey Basin	65,061	4.9
Station 2	47° 59' 17"	122° 17' 49"	East Whidbey Basin	194,310	4.9
Station 3	48° 03' 06"	122° 22' 47"	East Whidbey Basin	2,696	4.9
Station 4	48° 04' 00"	122° 20' 48"	East Whidbey Basin	1,561	4.9
Station 5	47° 50' 34"	122° 39' 46"	North Hood Canal	5,173	8.4
Station 6	47° 39' 40"	122° 52' 43"	North Hood Canal	7,872	8.4
Station 7	47° 31' 55"	123° 01' 54"	South Hood Canal	336	15.8
Station 8	47° 21' 46"	123° 05' 03"	South Hood Canal	3,998	15.8



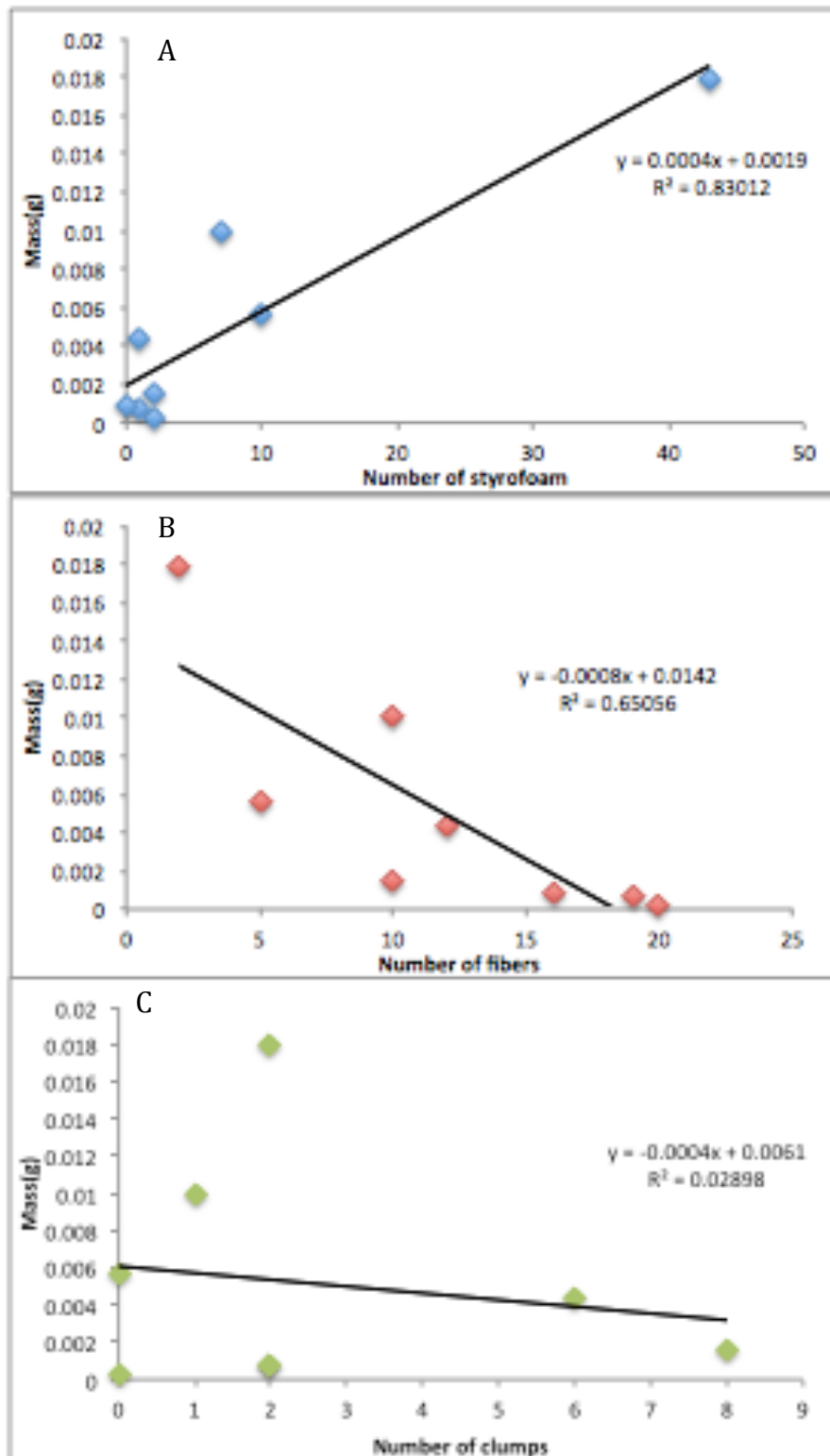
**Figure 1:** Surface locations and residence times in (A) Whidbey Basin (Station 1-4) with surface residence time of 4.9 days, (B) Northern Hood Canal (Station 5,6) with surface residence time of 8.4 days, and (C) Southern Hood Canal (Station 7,8) with surface residence time of 15.8 days



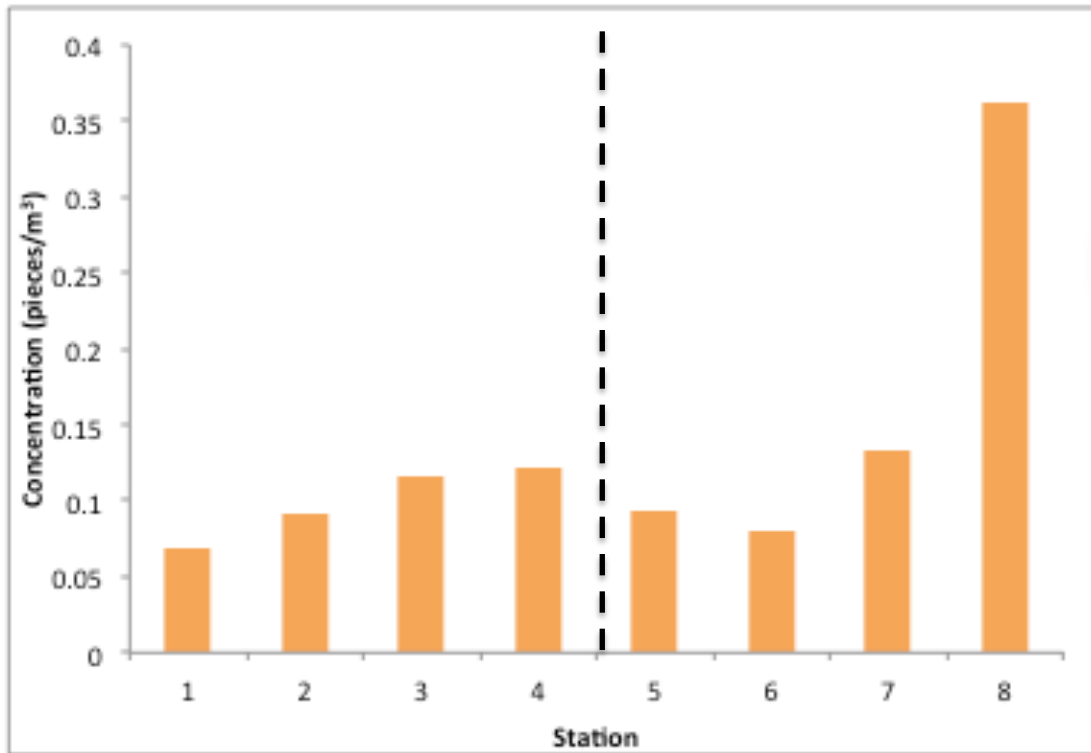
**Figure 2:** The number of plastics found in the various stations throughout Whidbey Basin (Stations 1-4) and Hood Canal (Station 5-8), with the dash line showing the distinction between the two basins.



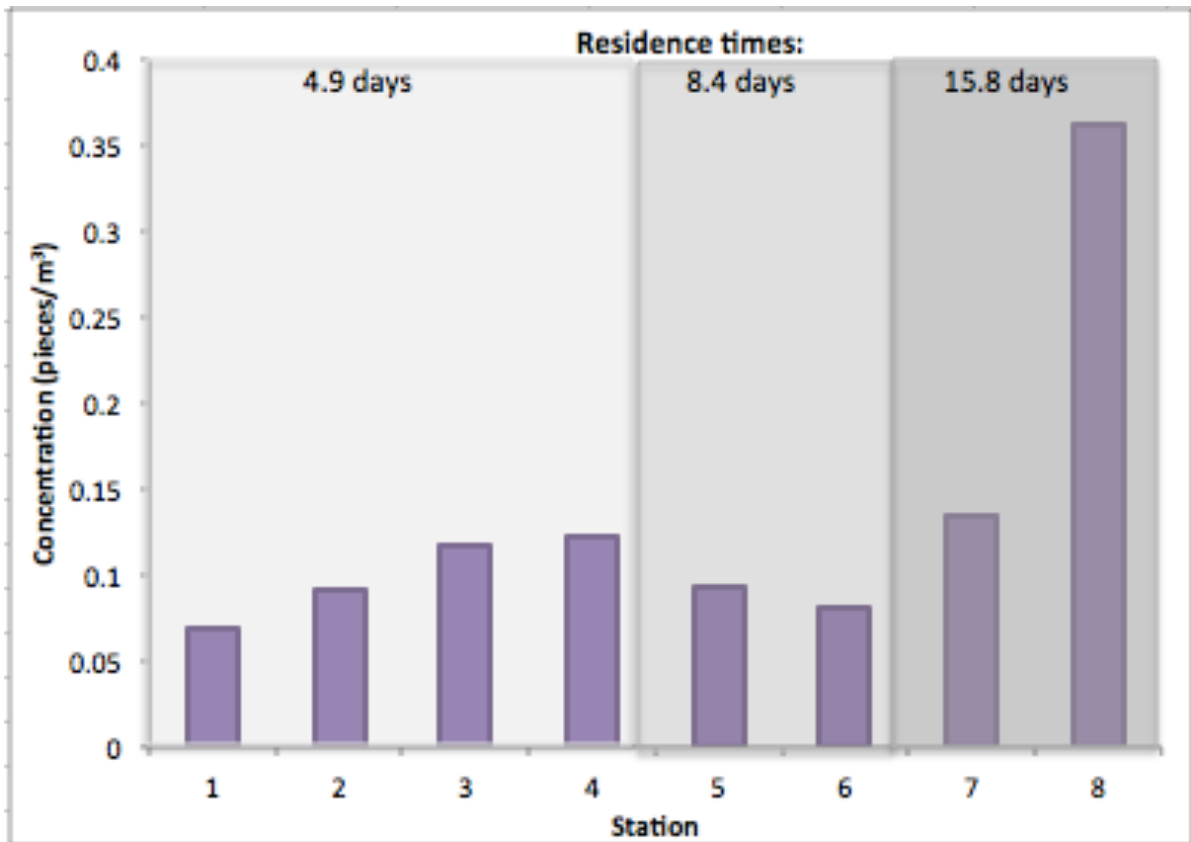
**Figure 3:** The composition of microplastic styrofoam (blue), fibers (red), and clumps (green) at each station in (A) Whidbey Basin, (B) Northern Hood Canal, and (C) Southern Hood Canal.



**Figure 4:** Contribution to total station composition by microplastic (A) Styrofoam, (B) fibers, and (C) clumps on the mass of each sample.



**Figure 5:** The concentration (pieces/m<sup>3</sup>) of all microplastics at stations in Whidbey Basin and Hood Canal, with the dashed line showing the differences between the two basins.



**Figure 6:** Concentration (pieces/m<sup>3</sup>) of microplastics found at each station with a determined surface residence time of 4.9 days (light grey), 8.4 days (medium grey), and 15.8 days (dark grey).

**Table 2:** The range of wind speed (kts) measured at each location in Puget Sound.

<b>Station</b>	<b>Basin</b>	<b>Wind Speed (kts)</b>
1	Whidbey Basin	No Data
2	Whidbey Basin	No Data
3	Whidbey Basin	1.06 - 4.52
4	Whidbey Basin	1.87 - 9.06
5	Northern Hood Canal	4.55 - 15.04
6	Northern Hood Canal	3.89- 21.23
7	Southern Hood Canal	11.16- 26.65
8	Southern Hood Canal	No Data