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# **The quantification of microplastics along a primary Puget Sound river**

**A study from headwaters to estuary**

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Gerrad Hofmans

University of Washington, Oceanography Department  
Seattle, Washington, 98195

hofmag@uw.edu

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## **Abstract**

The world's reliance on plastic is a contemporary dependence as its malleable function, low production cost, and increasing abundance has been universally favored over all other products. Created with the intention of short-term and one-time use, the global production of plastic reached 299 million tonnes in 2013, with 10-20 million tonnes ending up in the oceans annually. This study explores the contribution of microplastics to the marine environment from river systems, and quantifies the microplastic load within a stream as it passes from rural to urban environments. The sampled river is fed by a remote, glacially fed lake in the Cascadia Mountain Range, flowing into the upper Skykomish River, the Snohomish River, and eventually to the Puget Sound. Samples were collected by towing a 335  $\mu\text{m}$  mesh manta trawl during an ebb tide and analyzed, after a wet peroxide oxidation and density separation, to quantify the concentration of microplastics present in the stream. From the 16 samples analyzed, a trend has been found between the quantity of plastics in the stream and the streams proximity to the headwaters. This trend implies that the growing quantity of microplastics within the stream, as it flows from rural to urban environments, is supplied through anthropogenic influences. This study has found 0.12 tonnes of microplastics are transported every year by this river system, equating to  $1.2 \times 10^9$  pieces of microplastics. Following this study, microplastic pollution can no longer be thought of as a coastal and marine issue, but rather a problem that starts much further inland.

## **Introduction**

Plastics can be categorized by size, with microplastics (size range 0.33mm to <5mm) being the focus of this study (Masura et al., 2015). Microplastics are separated into two categories based on how they are formed; primary and secondary. Primary microplastics are manufactured at less than 5mm and are generally used as resin pellets, small plastic pellets which are melted down to form anything from shampoo bottles to water bottles (Mato et al., 2001). Secondary microplastics result from the breakdown of macroplastics after extended exposure to UV radiation and/or weathering. The rate of degradation in the ocean, slowed by the cold and dark environment, causes plastics to breakdown over time but never fully mineralize, which is why they pose such a threat to the marine ecosystem. Many papers have been published highlighting the harmful impacts of plastic on marine biota, birds, and even humans. Small, buoyant, and colorful, microplastics are often mistaken for food. Filling stomachs, yet never digested, species that fall prey to microplastics quickly die of starvation (Mato et al., 2001; Murray and Cowie, 2011). Microplastics are also toxic, adsorbing harmful bacteria and chemicals such as PCBs, DDEs, or NPs from surrounding waters and concentrating them onto very small ingestible material, which can cause extreme health problems for any organism that consumes the plastic (Mato et al., 2001). These health problems can impact an organism's development and reproduction, can cause endocrine disruption, and are carcinogenic (Murray and Cowie, 2011). As smaller organisms consume marine plastic filled with toxins, bio-magnification takes effect, increasing microplastic concentrations through trophic levels. This increase in concentration poses a great threat to predatory species, including humans, who in turn consume a considerable amount of both plastic and toxins (Van Cauwenberghe and Janssen, 2014).

As interest grows in this newly discovered global issue, the major source or input of microplastic to our oceans is still debated. One idea that has yet to be explored is river transport,

broadening the scope of microplastic contribution from coastal environments, to any environment containing a waterway that empties to the ocean. Plastics can be transported through waste water and drainage systems where a percentage bypasses wastewater treatment plants and are directly deposited to our oceans and rivers (Carr et al., 2016; Magnusson and Norén, 2014). One study reports the washing of a synthetic jacket releases an average 1.7 grams of microfibers, 40% of which bypass wastewater treatment plants and enter the aquatic environments (Hartline et al., 2016). Other studies suggest the microplastic pollution is caused by improper waste disposal on land. With 192 coastal countries, the global quality of waste management is put into question, as 20 fast developing nations cause 83% of the marine pollution (Jambeck, 2015). Rivers and the amount of material they transport to the ocean is one notion that has received little attention in the context of microplastic pollution. Rivers transport 35,000 km<sup>3</sup> of freshwater and 20-22x10<sup>9</sup> tonnes of solid and dissolved sediment to the global ocean every year (Milliman, 2001), making them a highway for buoyant plastics. The main focus of study and clean-up efforts would seem more logically focused not on coastal cities and open ocean, but rather on all major water transport systems to the global ocean.

This study was conducted on a major water transport system of the Pacific Northwest, to sample and quantify the amount of microplastics transported by the conjoined Snohomish and North Skykomish rivers. These rivers discharge an average 10,000 ft<sup>3</sup>/sec of freshwater and 490K tons of sediment annually (measured at the mouth of the Snohomish river) (Czuba et al., 2011; Dalrymple et al., 2012), making it the second largest freshwater input and fourth largest sediment input into the Puget Sound in Washington State. This fresh water system is ideal for tracking anthropogenic inputs because it starts at a remote, glacially fed lake located high in the Cascade Mountain Range, Blanca Lake. From this lake the water travels through small, remote towns (increasing in population) until it reaches the largely populated port town of Everett. Here the water is deposited into the second largest estuary in the United States, according to the Department of Ecology, the Puget Sound.

The location of this river and the attributes it provides makes it an ideal sampling site for microplastics. If microplastic waste is transported by rivers, then the highest concentration of plastics will be at the mouth of the river, before entering and dispersing into the larger marine body, which in this study is the Puget Sound. If this waste is attributed to an anthropogenic input, then an increase of microplastic concentrations will be seen as the river passes from a remote to a largely populated area. Thus, the final quantity of microplastics that passes into the marine environment will be an accumulation of this river's microplastic concentration, adding to the global concentration of marine pollution.

## **Methods**

Water samples were taken at multiple points along the North Skykomish and Snohomish rivers (see Table 1), with a focus on sampling downstream of towns and any wastewater treatment plants along the rivers. These samples were taken during the winter months, between December of 2016 to March of 2017, when the stream flow ranged between 48,000 – 2,800 ft<sup>3</sup>/sec, with an average of 15,000 ft<sup>3</sup>/sec (measured at station 12150800 near Monroe Washington; USGS, 2017). The mouth of the river as it empties into Possession Sound, a basin of the Puget Sound, was also tested at three separate locations, as the main Snohomish River splits into three sections as it flows through the town of Everett. These samples were taken

during an ebb tide to ensure they were coming from the river and not from Possession Sound. Samples were also taken within Possession Sound to evaluate the amount of plastics in the Sound, at both the north and south end as well as near the mouths of the river. A total of 16 samples were collected during this study (see Figure 1 below).



Figure 1. A map of the sampled area as the river flows from rural to urban environments (moving from east to west). The stars represent the sampled sites, with a corresponding number to indicate what site they are listed as throughout this study.

- Field Methods

Samples were collected using a 335  $\mu\text{m}$  mesh manta trawl. See Figure 2 for detailed dimensions. A cod end was attached to the base of the net to catch the sample. A flow meter was attached to the mouth in order to record the amount of water passing through the net.

Samples collected in the river were collected using one of two methods. The first method required the manta trawl to be deployed from the bank of the river. It was used if the flow of the river was too quick for a boat to navigate safely, the river was too shallow, or impedance prevented access for a boat. Locations for this method were selected based on

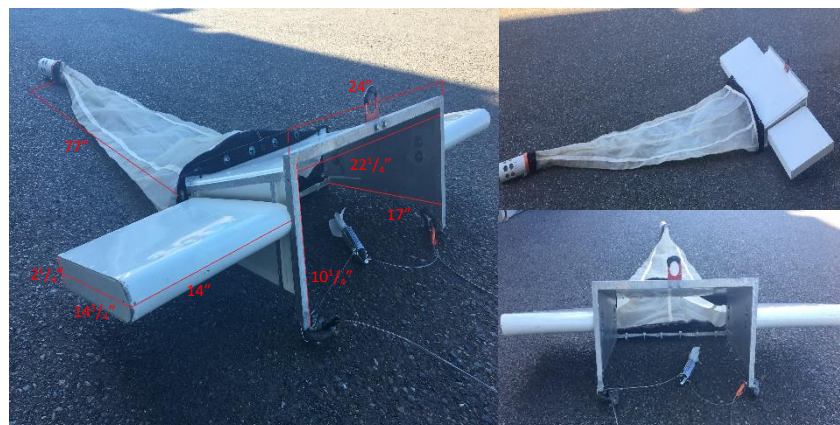


Figure 2. Schematic of manta trawl.

proximity to towns and wastewater treatment plants, bank side accessibility, where the flow was

fast enough to turn the flow meter, and a significant amount of the stream was flowing in the current near the shore.

The second method of testing the river was with the use of R/V Welander, a small flat bottom boat. By maintaining its position within the river, and with the net deployed over the side, water was allowed to flow through the manta trawl. Both methods used the 335 $\mu$ m mesh manta trawl for 30 minutes with a flow meter attached to the mouth of the manta trawl to track the volume of water flowing through the net. In both cases the samples were collected into separate jars and taken back to the lab for further testing.

Samples collected in Possession Sound were taken from the R/V Barnes using the same methods presented in the second method of river sampling. However, rather than staying in a fixed location, the boat towed the net at a steady 2 knots for 30 minutes.

- Sample Sites

Table 1. All sampled locations, with sampled date, latitude and longitude, which method used to sample, and the flow rate of the river based on the flow meter readings after 30 minutes of deployment.

Station Number	Date Sampled	Latitude & Longitude	Method of Sampling	Flow Meter (ft <sup>3</sup> /sec)
1	12/15/2016	4758.8217N, 12219.0659W	Boat Deployment	4.275
2	12/15/2016	4802.5055N, 12222.2914W	Boat Deployment	3.188
3	12/15/2016	4803.4809N, 12220.8750W	Boat Deployment	2.892
4	2/04/2017	48.02191N, -122.24043W	Boat Deployment	2.850
5	2/04/2017	48.0386385N, -122.2180117W	Boat Deployment	2.789
6	2/04/2017	48.03037N, -122.20920W	Boat Deployment	2.838
7	2/04/2017	48.01984N, -122.20046W	Boat Deployment	2.921
8	2/23/2017	47.921283N, -122.131675W	Boat Deployment	2.025
9	2/23/2017	47.882878N, -122.086680W	Boat Deployment	2.539
10	3/22/2017	47.851347N, -121.960961W	Bank Deployment	3.666
11	3/22/2017	47.839998N, -121.856882W	Bank Deployment	2.266
12	2/23/2017	47.857537N, -121.821626W	Boat Deployment	2.001
13	2/23/2017	47.837027N, -121.660007W	Bank Deployment	3.315
14	3/22/2017	47.814944N, -121.585389W	Bank Deployment	3.662
15	3/22/2017	47.822806N, -121.544833W	Bank Deployment	0.745
16	3/22/2017	47.863750N, -121.489861W	Bank Deployment	0.919

- Lab Methods

The following lab methods are a summary of the standardized methods provided by NOAA Marine Debris Program (2015) and have been taken directly from the NOAA Technical Memorandum NOS-OR&R-48. To see a detailed description of the materials and lab methods used, refer to the Technical Memorandum.

- Water Sample Analysis

Once a sample was collected using the 335µm mesh manta trawl, it was poured through two stacked stainless steel mesh sieves, 5.6mm (No. 3.5) and 0.3mm (NO. 50) in size. The plastics retained by the 5.6mm sieve, if any, were annotated. The material retained by the 0.3mm sieve was transferred to a 500mL beaker, where it was placed in a 90° C drying oven for 24 hours or until the sample was dry.

Once dried, the sample underwent a wet peroxide oxidation. An aqueous solution of 0.05 M Fe (II) and 30% hydrogen peroxide was added to the dried sample and heated to 75° C for 30 minutes. Due to the high levels of natural organic material in the samples, another 20 mL of 30% hydrogen peroxide was added every 30 minutes, or until it was no longer visible.

Once all organic material was removed, the sample was placed in a density separator and allowed to settle overnight. The settled solids were removed and discarded, while the floating solids were collected on a custom 0.3mm sieve. The samples were then air dried before looking at the sieve under a dissecting microscope. When microplastics were identified, the samples were collected in clean vials, each sample site with an individual vial. The weight, quantity, and characteristics of the microplastic was recorded.

## Results

The first sites were taken within Possession Sound (1-4), followed by the mouth of the river (5-7), and the main river (8-16). The majority of plastics found within the 16 sampled sites are at the mouth of the Snohomish River, indicated by sites 5, 6, and 7 (Fig. 3). This figure also shows the quantity of plastics found at each sampled site (sample sites correlating with the sites on figure 1), moving from downstream to upstream (1-16). The quantity of microplastics found at each site has been broken into categories based on visual characteristics; line/fiber, fragment, film, foam, and bead. Line/fiber was the most abundantly found, with 53% of the total microplastics (Fig.4.A). There was no correlation between the characteristic of plastic found and its sampled location.

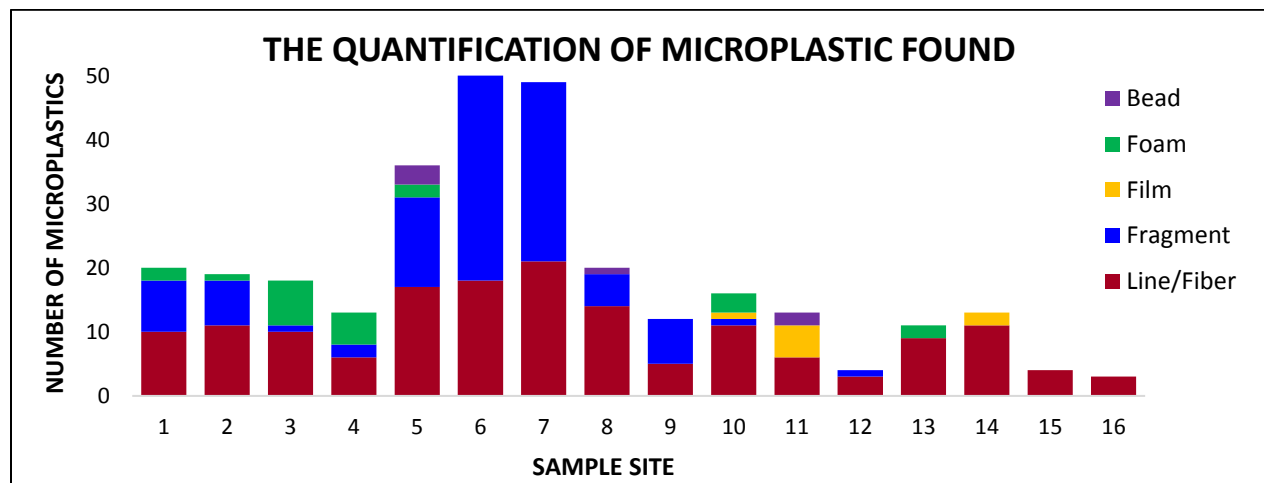
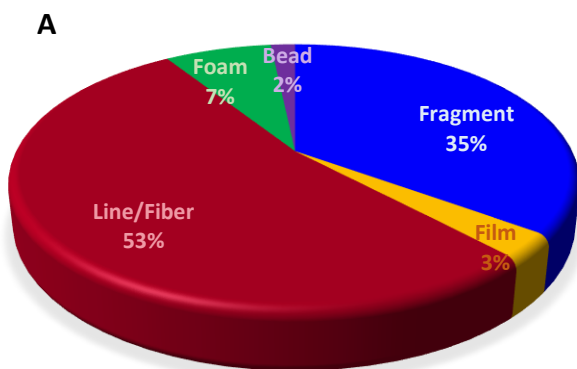


Figure 3. The quantification of plastics at each sample site, broken into visual classifications. The greatest quantities are seen at the mouth of the river (sites 5, 6, 7).

## TYPES OF PLASTIC



## COLOUR OF PLASTICS

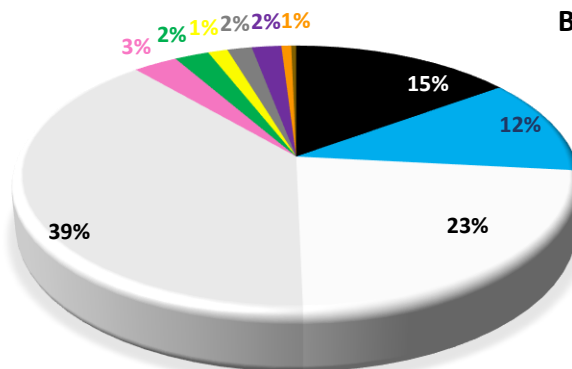


Figure 4. **A)** The types of microplastic found at the 16 sample sites broken into five different classifications. The most common was line/fiber with 53% abundance. **B)** The colour of the microplastics found at the 16 sample sites with the most abundant being clear and white. The colours of the graph indicate the colours of plastic found (with off-white representing clear).

Table 2. All microplastics found, broken into colour and category. The most abundant colour was clear, with 117 pieces, and the most abundant category was line/fiber with 159 pieces. There was a total of 300 microplastic pieces found.

Colour	Fragment	Film	Line/Fiber	Foam	Bead	Total
Black	8		36		1	45
Blue	4		30		1	35
White	29	5	12	22	1	69
Clear	47	3	67			117
Pink	4		5			9
Green	2	1	4			7
Yellow	3				1	4
Grey	5					5
Purple			5		1	6
Orange	2					2
Brown	1					1
<b>Total</b>	<b>105</b>	<b>9</b>	<b>159</b>	<b>22</b>	<b>5</b>	<b>300</b>

As the sample sites move farther up river there is an increasing linear trend with the amount of plastics found at each sample site moving from site 16 to site 5 (Fig. 5). Slight variations were seen between each sample location, however the overall trend of the data shows an increase in the quantity of plastics as the river flows from rural to urban environments. Due to the varying flows within the sampled river system, the quantities of plastic were measured based off of 1 cubic meter of water. This allows a better representation of the rivers plastic load, giving a uniform volume for each site sampled. The largest quantity of microplastics found was at the mouth of the river at site 6 with 0.346 pieces of plastic per cubic meter of river water.

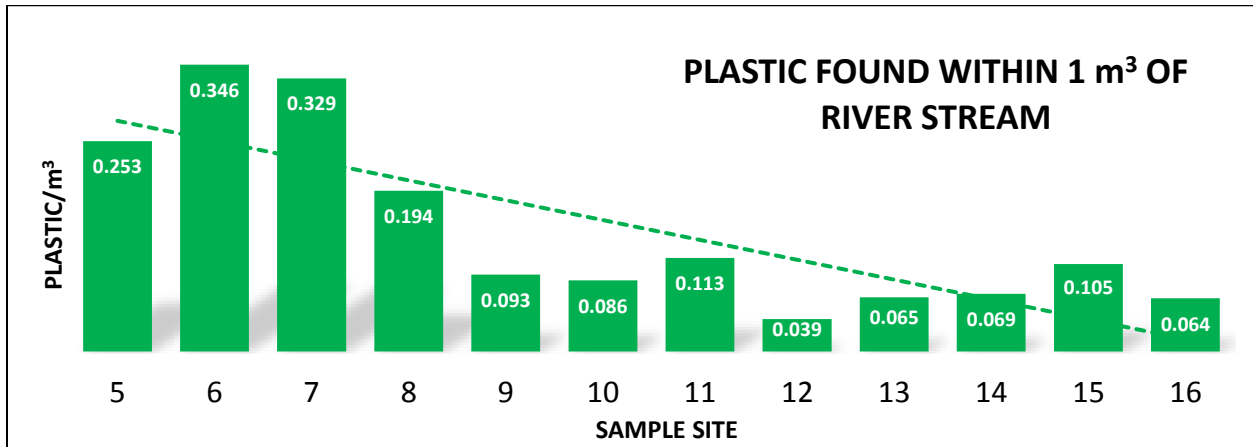


Figure 5. The quantity of plastic found within every cubic meter of the sampled river, indicated for each sample site by the number at the top of each bar. Also shown is the increasing linear trend of plastics found within the river as the stream moves from a rural environment to an urban environment.

Sites 1-4 were sampled within Possession Sound, with lower quantities found than those coming out of the mouth of the Snohomish River (Fig. 3). However, small they may seem compared to sites 5-7, sites 1-4 are actually on par with other findings of the Puget Sound (Fig. 6). The sampled sites within Figure 6 show quantities of microplastics found within the surface waters of the Puget Sound. Sites 1-4 are taken from this study, while sites 5-8 were taken from a study conducted during the same time frame, and using the same field and lab procedures used in this study (Mahoney, 2017).

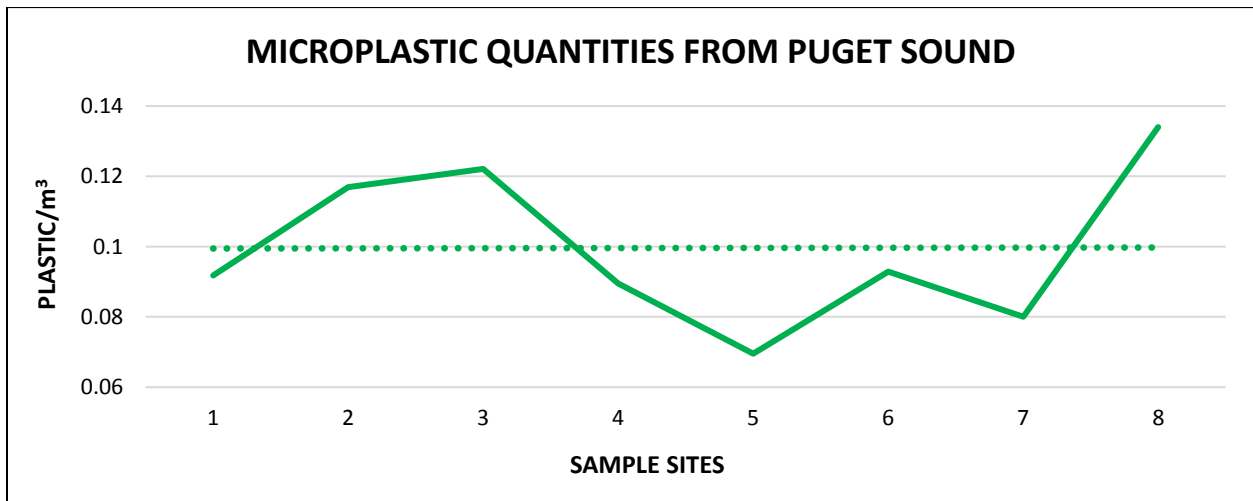


Figure 6. The quantity of microplastics per cubic meter of surface water found within Puget Sound. Sites 1-4 are from this study, while sites 5-8 are from another study conducted around the same time frame, with the same field and lab procedures.

Station Number	Latitude & Longitude	Microplastic/m <sup>3</sup>
1	4758.8217N, 12219.0659W	0.091786
2	4802.5055N, 12222.2914W	0.116941
3	4803.4809N, 12220.8750W	0.122118
4	48.02191N, -122.24043W	0.089485
*5	4752.3092N, 12224.0533W	0.069541
*6	4749.6420N, 12239.8823W	0.092922
*7	4738.8003N, 12253.3648W	0.080041
*8	4731.2280N, 12302.0327W	0.133989

Table 3. The samples taken from Puget Sound with latitude and longitude, and pieces of microplastic per cubic meter. \* indicates sites taken from another study.

## Discussion

With the second largest flow rate into the Puget Sound at 10,000 ft<sup>3</sup>/sec (Czuba et al., 2011), this study indicates the transport of 0.12 tonnes of microplastics every year by this river system. This equates to  $1.2 \times 10^9$  pieces of microplastic every year. The value of pieces of plastic is much larger than the weight of plastic transported because of the abundance of line/fiber found within the samples (over half of the total plastic found). This type of microplastic has a small mass, and therefore, the weight of plastic being transported every year is misleading and not a proper indication of plastic abundance within the river. Filter feeders are more likely to consume the smaller pieces of microplastics, even those with a smaller mass, which will be passed up the food chain through bio-accumulation. In the context of being a threat to species, including humans, the quantity of plastics within the marine ecosystem is more important than the total mass of the plastic found.

Figure 7 represents the portion of the sampled river with the highest quantities of plastic found within the stream. The main river splits into three separate mouths as it transverses through the port town of Everett Washington; the southern mouth bordering the city (site 7), the central mouth passing through the Snohomish River Estuary and Everett's industrial district (site 6), and the northern mouth passing by the neighboring town of Marysville's garbage sewer water treatment facility and the Tulalip Reservation (site 5). Such high quantities at each of these locations could have detrimental and long term effects on the ecosystem, including that which impacts humans.

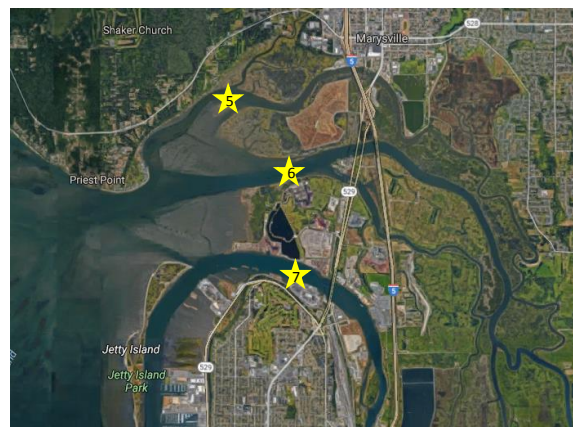


Figure 7. Snohomish River as it splits into three mouths, sites 5, 6, and 7.

The mouth of the Snohomish River provides essential and diverse conditions for an abundance of species (Brennick, 1999). The estuary of the Snohomish River contains acres of both mudflats and wetlands which, ideally, provide safe habitats and nurseries for fish, bivalves, birds, reptiles, mammals, and plants (Brennick, 1999). However, these habitats have become

compromised. They are surrounded by industry and an inflowing river system, causing a great impact from anthropogenic waste. As indicated from this study, these crucial and delicate habitats are subjected to microplastics. Sites 6 and 7 are located in the mouths of the river, surrounding Spencer Island and neighboring wetlands, a number of which are under current restoration (Snohomish County, 2017). However, these efforts of restoring the area to its natural wetlands and estuaries will all be for not if the impact of microplastics is not addressed.

In addition to the estuary environment, as the northern fork of the Snohomish River (site 5) empties into Possession Basin, the surrounding lands belong to the Tulalip Native Americans. This tribe, as with many in the Pacific Northwest, are culturally reliant on fishing, namely salmon. The Snohomish and Skykomish Rivers are known to contain Chinook, coho, pink, and chum salmon for the greater part of the year, with an average of over 1 million returning adults every year (WDFW). These rivers also contain two Washington State Fish and Wildlife salmon hatcheries, aiding in the restoration of the Pacific salmon population. Due to the consumption of microplastics by marine organisms, it is estimated based on plankton consumption, that adult salmon consume an average of 62.2 microplastics per day (Desforges et al., 2015). Microplastics can carry harmful toxins making their consumption by salmon a Federal concern since wild Puget Sound Chinook and coho are currently listed on the Federal Endangered Species Act as endangered and threatened, respectively. It also harms all who consume salmon, including seals and orca whales, which are also listed on the Endangered Species Act, as well as the Native Americans and local residents.

The low quantities found at sites 1-4, just beyond the mouths of the Snohomish River, could be attributed to the outgoing tide at the time samples were collected, as well as a larger volume of water for the plastics to disperse into. Characteristic of the tides in Puget Sound, plastics move out of the Everett basin into the Straits of Juan de Fuca, the main current flowing in and out of Puget Sound. This could be why higher quantities of plastic are seen at sites 2 and 3 (Fig.6), which are farther in the Everett basin, compared to site 1 which is at the mouth of the basin. The close proximity to the Straits of Juan de Fuca allow the plastics at site 1 to disperse more rapidly as the tide has more influence over this area. Site 5, sampled by Mahoney (2017), indicates the influence that the Strait has over microplastic quantities in surface waters, as this site has the lowest quantities of the Puget Sound (Fig. 6). Alternatively, it is common for plastics to experience long residence times within the Puget Sound, especially in areas of low tidal influence. These long residence times could lead to a build-up of plastics along Puget Sound's 1,332 mile long shoreline (Lincoln, 2017).

The data collected from the upper Snohomish River and the Upper Fork of the Skykomish River shows small fluctuations in the amount of microplastics found within the stream. These fluctuations cannot be correlated to population density or proximity to wastewater treatment plants. However, despite not being able to justify individual sample sites, there is an overall increasing trend in the quantity of plastics found within the stream as it travels from rural to urban environments. This indicates that plastics are accumulating in the stream and are being carried downstream, eventually emptying into the marine environment.

## **Conclusion**

Quantifying microplastics along this river was of great importance, both in understanding the influence that river transport has on marine microplastic concentrations, and in pinpointing

large input locations along this river. It has been found that microplastics are transported along river systems, and this study has provided a very detailed description of a microplastics path along this river, where the largest inputs are found, how they behave physically within the stream, and how much end up in the marine ecosystem. This information is able to provide point-sources of microplastic pollution along the river, which could be valuable information for clean-up efforts and prevention solutions. From this research the remaining 10 major rivers flowing into Puget Sound can be tested to gain a full estimate of river contribution of microplastics to the marine environment.

## References

- Brennick, C. (1999). Snohomish River Estuary recreation guide: To better understand, enjoy, and preserve the Snohomish River Estuary. *Snohomish County Parks and Recreation*.
- Carr, S. A., Liu, J., & Tesoro, A. G. (2016). Transport and fate of microplastic particles in wastewater treatment plants. *Water research*, 91, 174-182.
- Cole, M., Lindeque, P., Fileman, E., Halsband, C., Goodhead, R., Moger, J., & Galloway, T. S. (2013). Microplastic ingestion by zooplankton. *Environmental science & technology*, 47(12), 6646-6655.
- Czuba, J.A., Magirl, C.S., Czuba, C.R., Grossman, E.E., Curran, C.A., Gendaszek, A.S., and Dinicola, R.S., 2011, Sediment load from major rivers into Puget Sound and its adjacent waters: U.S. Geological Survey Fact Sheet 2011-3083, 4 p.
- Dalrymple, R. A., Breaker, L. C., Brooks, B. A., Cayan, D. R., Griggs, G. B., Han, W., ... & Pfeffer, T. (2012). Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. *National Research, Council. The National Academies Press Washington DC*, 134.
- Desforges, J. P. W., Galbraith, M., & Ross, P. S. (2015). Ingestion of microplastics by zooplankton in the Northeast Pacific Ocean. *Archives of environmental contamination and toxicology*, 69(3), 320-330.
- Gorman, B. (2007). Puget Sound Steelhead get protection under endangered species act. NOAA Magazine.
- Gourmelon, G. (2015). Global plastic production rises, recycling lags. New Worldwatch Institute analysis explores trends in global plastic consumption and recycling. *Worldwatch Institute*.
- Hartline, N. L., Bruce, N. J., Karba, S. N., Ruff, E. O., Sonar, S. U., & Holden, P. A. (2016). Microfiber Masses Recovered from Conventional Machine Washing of New or Aged Garments. *Environmental Science & Technology*, 50(21), 11532-11538.
- Hayley, A., Hofmans, G., Grimmet, S., Solt, I., Thomas, A., Sythoff, A., & Weaver, S. (2015). Analyzing microplastic concentrations in the Skykomish River. *North Seattle College UGR*.
- Lincoln, J.H. (2017). The Puget Sound Model Summary. Pacific Science Center. Visited 5/28/17. [http://exhibits.pacsci.org/puget\\_sound/PSSummary.html](http://exhibits.pacsci.org/puget_sound/PSSummary.html)
- Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., ... & Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science*, 347(6223), 768-771.

- Magnusson, K., & Norén, F. (2014). Screening of microplastic particles in and down-stream a wastewater treatment plant.
- Mahoney, T. (2017). The concentration of microplastics compared to relative population proximity and basin residence times in Hood Canal and Whidbey Basin in Puget Sound, WA. *University of Washington, School of Oceanography*.
- Mato, Y., Isobe, T., Takada, H., Kanehiro, H., Ohtake, C., & Kaminuma, T. (2001). Plastic resin pellets as a transport medium for toxic chemicals in the marine environment. *Environmental science & technology*, 35(2), 318-324.
- Masura, J., et al. 2015. Laboratory methods for the analysis of microplastics in the marine environment: recommendations for quantifying synthetic particles in waters and sediments. NOAA Technical Memorandum NOS-OR&R-48.
- Milliman, J. D. (2001). River Inputs. *Academic Press*, 2419-2427. DOI: 10.1006/rwos.2001.0074
- Murray, F., & Cowie, P. R. (2011). Plastic contamination in the decapod crustacean *Nephrops norvegicus* (Linnaeus, 1758). *Marine pollution bulletin*, 62(6), 1207-1217.
- Pantsios, A. (2015). 8 Million metric tons of plastic dumped into world's oceans each year. EcoWatch.
- Snohomish County, WA. (2017). Smith Island Restoration Project. Visited 5/28/2017. <https://snohomishcountywa.gov/1150/Smith-Island-Restoration-Project>
- Van Cauwenberghe, L., & Janssen, C. R. (2014). Microplastics in bivalves cultured for human consumption. *Environmental Pollution*, 193, 65-70.