

**Spatial distribution of plastic pollutants in a transit from Puget Sound to outside Nootka**

**Sound, Canada**

Bryan Swaffield

Swaff257@uw.edu

University of Washington

Seattle, WA 98105

School of Oceanography

5/17/2015

## **Acknowledgements**

The entirety of this research was a learning process, from writing the proposal, to sampling aboard the R/V Thomas G. Thompson, to analyzing the data, and finally, typing up this manuscript. Along the way I had the pleasure of working closely with many knowledgeable scientists, as well as the University of Washington oceanography graduating class of 2015. I could not have succeeded without their aid. My thanks to Kathy Newell, who acted as my principal science advisor over the three quarters. Acknowledgements also to the following: Julie Keister, who helped with much of the sampling aboard the cruise; Julie Masura, who lent me her manta net for the surface tows; Giora Proskurowski, a microplastics researcher who advised me during my proposal; and finally, Arthur Nowell, Ashley Maloney, and the rest of the faculty who worked with the class of 2015 during our efforts.

## **Abstract**

The study of microplastic pollution is relatively new in the science of oceanography, with the first paper published in 1972. Since then, many papers have been written in attempts to gain a better understanding of how and where these plastics congregate in the world's oceans, and what issues arise in turn. Succinctly, this problem is ubiquitous and openly threatens all marine biota. This paper examines the link between higher concentrations of plastics with anthropogenically active and highly populated regions. Six stations were sampled for surface plastics in Puget Sound, starting near Seattle, WA and ending in the open waters outside of Nootka Sound, Canada. A modified Manta net was deployed at each station. The samples were sieved, the plastic pieces picked out under a microscope, counted, and placed into labelled sample jars. Analysis showed higher concentrations were found within Puget Sound, and lower concentrations in the open ocean. A spike towards the high concentration end was also measured

near Victoria, B.C. This study furthers the continuous realization that our ocean waters are accumulating plastic pollution, and the largest concentrations are found in waters adjacent to large populations of people and industrial activity.

### ***Introduction***

Microplastic studies in the marine environment have only been carried out in the last 40 years since the first paper published in *Science*, in 1972, by E. J. Carpenter and K. L. Smith. Predicted was the idea that the increasing production of plastic combined with the current waste-disposal practices will lead to greater concentrations on the sea surface (Carpenter and Smith, 1972). Since then, many papers have been published in relation to this topic and its implication in environmental ethics. The annual global demand for plastics consistently increases every year, and stood at about 245 million tonnes in 2011 (Andrady 2011). It is estimated that 5-14 million of these tonnes end up in the world's oceans yearly (Jambeck et al., 2015).

There are 5 different types or categories of marine plastics, and the classifications are based first upon size, and then shape or source (Moret-Ferguson et al., 2010). Some papers include a sixth category, films or sheets, but none were found in this study. The large examples, such as soda bottles, plastic containers/bags, and piping, are referred to as macroplastics. Although larger examples are the most apparent, their sizes range from the largest marine plastics all the way down to a minimum of 5 mm (Andrady, 2011). These larger plastics tend to degrade and fragment down into the micro size range (less than 5 mm), creating “fragment” plastic particles. Polystyrene is another category of microplastics. It is typically found as spherical balls or clumps of Styrofoam. Additionally, there are spherical pellets used as the building blocks of other plastics such as grocery bags and Tupperware products. These pellets can also be found as microbeads in facial scrubs. They are referred to as nurdles, and their sizes range from 10

micrometers to 1 mm. Finally, there are microplastics referred to as fibers, which come from marine related ropes and line.

Of all the microplastics that have been studied, 99% were found to be less dense than seawater (Law et al., 2010) and tend to float. The other 1% generally sinks near their source. This creates a large segregation between benthic and surface plastics. Their presence within coastal sediments results in changes in the physical properties of beaches, causing an increase in permeability and a lowering of subsurface temperatures at the seafloor (Carson et al., 2011). Plastics, with their low density, are transported via surface currents across the global ocean. With many sources of plastics and currents connecting all ocean basins, their effects are far reaching. This type of pollution is ubiquitous, and openly threatens all marine biota.

Plastic pollution has many hazardous effects on the marine environment. The small size of microplastics allows a variety of specimens to concentrate on them. Diatoms and hydroids have been commonly found attached to their surfaces (Carpenter and Smith, 1972). With the inclusion of currents, organisms which are possibly alien and invasive get transported into other water systems, disrupting the delicate balance of the food web there. In addition, the plastic particles may adsorb potentially damaging toxic compounds from the seawater and be ingested by microorganisms. This would then result in bio-accumulation to other trophic levels. Ingestion of the particles and entanglement with macroplastics comes with its own set of problems. These include wounds, skin lesions, reduction in quality of life and reproductive capacity, drowning and limited predator avoidance, and the impairment of feeding capacity (Gregory, 2009). Finally, the breakdown of plastics in the ocean is slow, causing them to have a continuous impact over tens to hundreds of years (Barnes et al, 2009).

With the diverse and resilient impacts plastics have, it is important to understand and study the origins of these pollutants. There are a few factors to consider when developing a research plan to study plastic concentrations. Surface currents play a large role in the spatial distribution of plastics. Puget Sound is where 4 of the 6 stations were located. It is a fjord-like estuary, with its surface flow patterns affected by tidal currents, river input, and internal mixing. Twice a day, tidal forces cause water from the ocean to enter via Admiralty Inlet, causing some surface waters to pool up near the coast lines of the Sound (fig. 1a). As the tide ebbs out, surface water is funneled nearer to the center of the inlet as the water flows towards the open ocean (fig. 1b). These surface flow patterns could vary the locations of plastic concentrations.

Another factor is wind speed. In 2012, Kukulka et al. demonstrated that buoyant plastic debris can be vertically distributed in the water column if wind is present. The depth at which the plastics are mixed depends on their density and the surface wind speeds. For example, their data concluded that surface net tows cannot account for the total amount of plastics except when wind speed does not exceed 5 m/s, or about 10 knots.

Studies of the concentration of surface plastics within populated fjord-like estuaries are nearly nonexistent. As such, the goal of this research is to determine where plastics are most concentrated within Puget Sound, and whether or not there is any correlation between concentration and proximity to population centers. It has been suggested that recreational areas as well as harbors and large cities near the water tend to release plastics into the marine environment (Barnes et al., 2009; Desforrest et al., 2014). If this is true, a decreasing gradient should be found in the spatial distribution of plastics from Seattle, where there is a high concentration of anthropogenic activities, out to the open ocean, where anthropogenic effects should be minimalized. Because of Puget Sound's connection to the open ocean, there are many

ports, shipping centers, and marinas. Furthermore, much of the land bordering the Sound is heavily populated, with about 3.6 million people living in the Seattle metropolitan area alone.

A prior study measured microplastic concentrations in the northeast Pacific Ocean, including the waters surrounding Vancouver Island (Desforges et al., 2014). Although their highest concentrations were found in an area that is sparsely populated, their results show an agreement agree with my proposed hypothesis, that higher concentrations are found near populated areas as compared to open ocean waters (fig. 2). They suggest the highest concentrations were found northeast of Vancouver Island because of eddies that form there, holding plastics for up to weeks at a time, as well as finfish aquaculture, harbors, and fishing related activities in the area. If continuous parallels are discovered between highly populated areas and large concentrations of plastics through further research, stricter and more environmentally conscious policies on waste pollution management and the overall production or use of plastics should be implemented.

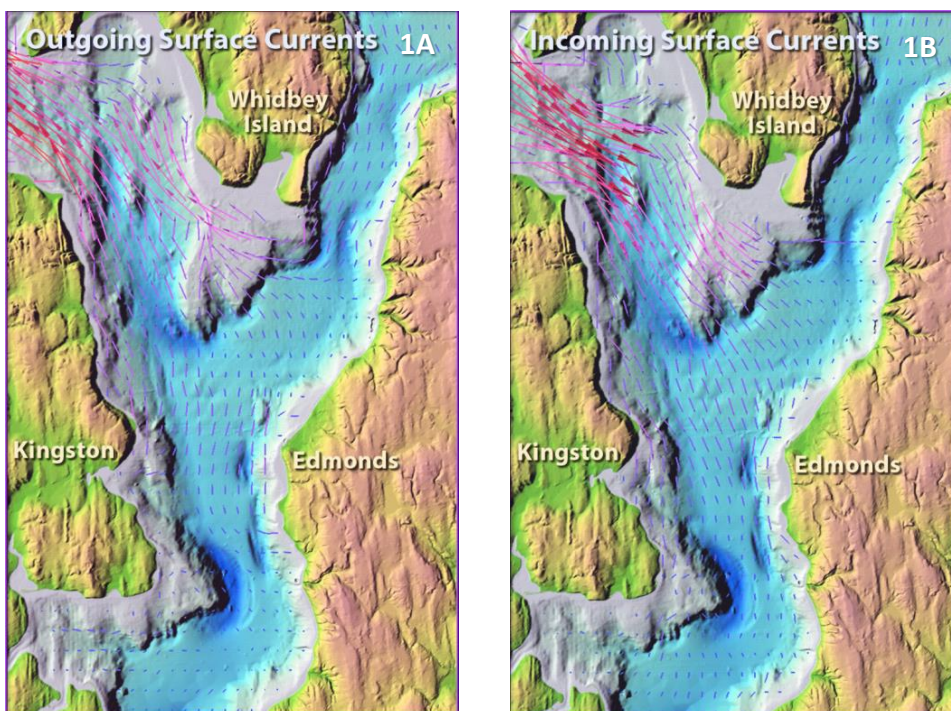


Figure 1. Surface currents of the Puget Sound. Specifically, the area in which the Admiralty Inlet connects with the Central Basin is pictured. A) Surface current during tidal outflow. Surface waters are pulled from the coastlines and funneled through the inlet. B) Surface current during tidal inflow. As the tide comes in, water is pushed out to the edges. (Mitsuhiro, Hagerud. 2009)

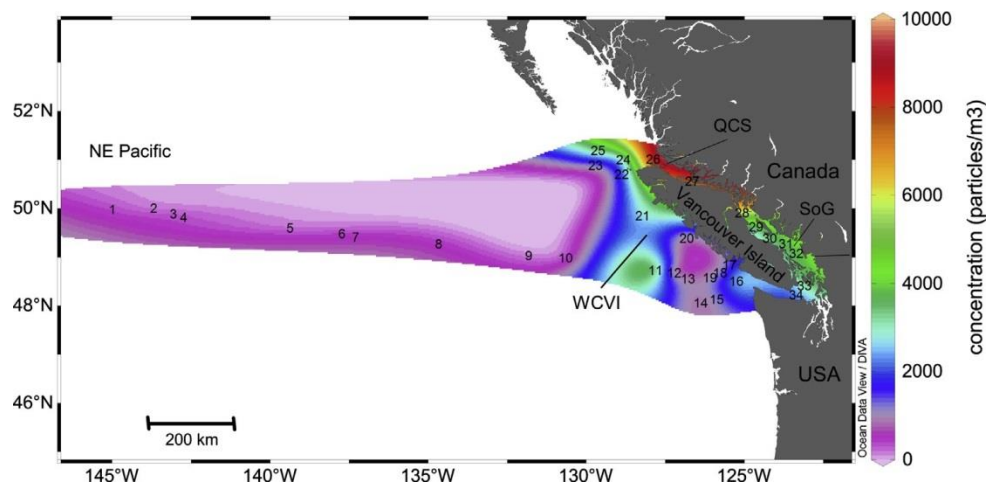


Figure 1 - Total microplastic concentrations (particles/m<sup>3</sup>; detected particles >62  $\mu$ m) in subsurface waters (4.5 m) of the NE Pacific Ocean in and around coastal British Columbia, Canada. (a) Sample locations are numbered (1–34), and the concentration gradient was estimated using DIVA gridding function of Ocean Data View 4 (Desforges et al., 2014).

## Methods

### Sample Collection

Sampling was conducted onboard the R/V Thomas G. Thompson during a research cruise from December 11<sup>th</sup> to December 22<sup>nd</sup> of 2014. The transit started near Seattle, Washington and ended at the estuary of Nootka Sound, Canada. The cruise was led by a team of faculty members of the School of Oceanography at the University of Washington. Generic sampling methods were taken from *Distribution of surface plastic debris in the eastern pacific ocean from an 11-year data set* (Law et al., 2014). A few modifications were made to better fit the debris-congested waters of the Puget Sound; mainly, decreased tow times and keeping the net closer to the boat. A modified manta net, provided by Julie Masura of the University of Washington Tacoma, was used for the surface tows. The mesh size of the net as well as the codend filter size was 335 microns. A flowmeter was connected to the opening of the net to calculate the distance, and then volume, detailed below. Six tows, spaced out relatively evenly, were taken on a track line in the

Puget Sound, starting near Seattle and north to the open ocean (fig. 3). The net was towed a hundred feet or so behind the ship before bringing the speed up to two to three knots, allowing it to remain just under the surface. Tow times depended mainly upon the amount of debris in the water. For example, large amounts of debris, typically logs or sticks, forced us to stop the tow early. Data recorded for each tow includes: station name, date, beginning and ending latitude and longitude, start and end time, flowmeter start and end values, and average ship and wind speed.

### *Sample Analysis*

Sample analysis methods were based off guidelines from *Laboratory Methods for the Analysis of Microplastics in the Marine Environment* (Baker et al., 2010). Once the net was pulled back in, it was sprayed down with a deck hose, rinsing any plastics down into the codend. The contents of the codend were then taken to the onboard science lab and poured over 5.6mm and 0.3mm sieves. Once sieved and rinsed, the plastics and excess debris were transferred into labelled glass sample jars. Plastic pieces that were larger than 5.6mm were counted and placed into a separate sampling jar, again labelled by station. A 30% hydrogen peroxide solution was poured into the microplastic sample jars to aid in the dissolution of any organic materials. The samples were poured back onto the 0.3mm sieve and rinsed. Finally, they were transferred back into the sample jars and left overnight in a drying oven at 60°C.

Once dried, the contents of a jar were poured onto a petri dish and placed under a Nikon-SMZ dissecting scope with power range of 15x-60x. The microplastics were sorted and placed into a separate petri dish. Counts were documented for each plastic and separated into the 4 categories: fragment, nurdle, fiber, and polystyrene. Once all samples had been counted, each one was weighed on a Mettler B204-S series scale, organized by station. Concentrations by weight were calculated by dividing the measured mass by the volume.

### *Concentration Calculations*

Final plastic concentrations were calculated by dividing the number of plastics at each station by the total volume filtered for the final units of pieces/m<sup>3</sup>. Volume was calculated by multiplying the distance towed and the area of the net opening. Distance was calculated three different ways to check and maintain consistency. The first method was by use of the flowmeter start and end counts for each tow, and the use of the flowmeters online instruction manual, where equation one was taken from. The standard speed rotor constant is given as 26873.

$$\text{Equation 1: Distance} = \frac{\text{Difference in Counts} \times \text{Standard Speed Rotor Constant}}{999999}$$

The second method was by using an online calculator to determine the distance between the recorded start and end latitude and longitude values. Finally, for comparison, a third distance for each sample was calculated by multiplying the recorded average ship speed and tow time together. The distance used in the final values depended on a number of factors. The basis of determination was typically whether or not a calculated distance matched up with the other two values. For example, a flowmeter malfunctioned at one station and gave us extremely low counts. At another station, the calculated distance using start and end latitude and longitude was 14.7km. This was too great of a distance compared to the other two calculated values for that station.

### ***Results***

Plastics were found at all 6 tow stations. More plastics were found within the contours of the land, while minimal plastics were found nearer to the open ocean. Total concentrations ranged between 0.0365 and 6.91 pieces/m<sup>3</sup>. The highest concentration occurred off the shores of Victoria, B.C., with the lowest at the northern extent of the Puget Sound in the Straits of Juan de Fuca (fig. 3).

The total concentration values are made up of the 5 sub-categories of plastic types: macroplastics, polystyrene, fibers, nurdles, and fragments (fig. 4). Polystyrene was the most abundant overall, followed by fragments, fibers, nurdles, and macroplastics, respectively (table 1). Victoria’s station was dominated by polystyrene, with 97% of its total pieces consisting of that category. The second largest count came from Admiralty Inlet, with 54% of its plastics as fragments.

Weight concentrations were highest for Admiralty Inlet, with a value of 76.56 mg/m<sup>3</sup> water (fig. 5). This station contained the most fragments, as well as the most macroplastics. The lowest was the Straits of Juan de Fuca at 0, with the 3 fibers and single polystyrene not registering a weight on the scale. All of the plastics in Shilshole Bay were relatively small in size, and thus weight, compared to every other station.

Notable wind speeds include the Admiralty Inlet, Fort Casey, and Juan de Fuca Straits stations, with gusts up to 14, 13, and 27 knots, respectively. Other station wind speeds stayed below the threshold of 10 knots. Additionally, tidal currents at each station were all in some phase of ebb, or flow out of the Puget Sound. Current speeds ranged from 0.2 to 2.0 knots outwards, with Admiralty Inlet and Shilshole Bay at around 2 (table 2).

Plastic Type	Fragments	Nurdles	Fibers	Polystyrene	Macroplastics	Total
<b>Abundance</b>	201	42	48	509	22	822
<b>% of Total</b>	24.45%	5.12%	21.62%	61.92%	2.68%	100%

Table 1 – Abundance, in number of pieces, for each category of plastics. The percentage of each category compared to the total number of pieces is also given.

**Discussion**

Station	Shilshole Bay	Admiralty Inlet	Fort Casey	Victoria	Straits	Open Ocean
<b>Current Speed (kts)</b>	2	1.8	0.7	0.2	1.4	no data
<b>Wind Speed (kts)</b>	no data	5 - 14.25	7.9 - 13	no data	27	4.5 - 7

Table 2 Surface current speed and wind speed for each station. Current speed was taken from <http://www.dairiki.org/tides/> and wind speed recorded manually from the Thompson G. Thompson’s onboard sensors.

The overall data show higher concentrations within the Puget Sound and lower concentrations in the open ocean, yet there are many factors to be considered in determining whether or not each samples concentrations can be considered absolute. Because each sample was collected at an ebb tide, there is a chance that the higher concentrations of plastics within Puget Sound could partly be due to their accumulation away from the shorelines and embayments, and thus nearer to the sampling sites. Admiralty Inlet in particular was at the end of an ebb tide and reaching maximum current velocity. This may be why a spike in concentrations was noticed there, as all the plastics and additional debris were funneled through it. Because of its unique shape, water column stratification, and many sills, the Puget Sound also has a residence time of about 1-3 months. Waters passing through the Straits of Juan de Fuca do not have a residence time and are just flushed out. These waters then mix with waters relatively low in plastic concentrations. Thus, plastics within the Puget Sound may have been accumulating there for up to 3 months while plastics that wash out to the ocean disperse and do not accumulate in such a fashion.

The station near Fort Casey had wind speeds up to 13 knots, which could have lowered its apparent concentration. The Straits of Juan de Fuca station had wind speeds up to 27 knots, well above the 10 knot threshold. This would have mixed surface microplastics well below the surface, lowering the sampled concentration. With all stations only having one data point, it is hard to say how close the calculated value is to the absolute average concentration for the stations' local waters, especially when factoring in a temporal scale.

### *Limitations*

The first and major limitation is only having six sample stations, and thus six data points to work with; especially with only 2 close to the open ocean. No major, over-arching conclusions can be pulled from such a limited sample size, only relative trends. Adding on to this is the fact that each station was sampled only once, not taking into account the highly variable and temporally changing surface current and wind conditions which affect concentrations dramatically.

A second limitation was the fact that surface tows were done in the top half meter of the water column, which doesn't collect plastics that may be up to 15 meters deep, depending on wind conditions. In Kukulka et al. 2012, their data and model calculations conclude that surface concentration values are predicted to be an average of 2.5 times higher under minor wind conditions, with a maximum of 27 times in high-wind conditions.

Further studies are needed to gain an understanding of the concentration of plastics within the Puget Sound as well as possible sources. Specifically, more sample tows over a wider range of time would give a much better average at certain locations. Also, sampling from more areas within and outside of the Sound would give a better understanding of the overall spatial distribution. In addition, vertical tows, depth specific tows, or samples from the flow-through system would include plastics below the surface and greatly increase the chances of getting an absolute value for a sampling location.

Although each of these additional studies would better aid our understanding of spatial distribution of plastic concentrations in the Puget Sound, an issue arises when attempting to determine specific sources. Even if higher concentrations were found near a recreational boating dock, it does not necessarily mean the dock is the source. The major problem is the constant variation of currents, which quickly move surface debris around the fjord. The other problem is that most plastic pollution enters the waters as macroplastics. This is assumed as the breakdown

and fragmentation process of the plastics typically starts once in the water. Thus, chances are that any microplastics found near a possible source were most likely transferred into the water elsewhere, slowly broken down, and transported via surface currents to the aforementioned area. A counter-proposal to this can be drawn from the microplastics found within Shilshole Bay. Although no actual data was taken about individual size of each microplastic, it was overwhelmingly evident that the plastics found at Shilshole Bay were considerably smaller than at any other stations. In addition, they seemed to be torn-up; fragments were broken down to smaller pieces or disfigured, and polystyrene seemed to be shredded rather than in the spherical shapes typically found among other samples. The water was also the murkiest here. Shilshole Bay is known by the local residents to be affected by large amounts of stormwater runoff from parking lots and city streets. It is also home to treated sewage waste from the West Point Treatment Plant. The accrual of this evidence points to the possibility that microplastics found within Shilshole Bay are either making it through the treatment process or sourced from stormwater runoff, but this is only speculation. If so, it gives record to the possibility that microplastics may be found near their source, and thus, a source of plastic pollution could be determined.

### ***Conclusions***

The original hypothesis was that a gradient in plastic concentrations would be found, with the highest near Seattle and the lowest in the open ocean. This exact gradient was not found, but the general theme was higher concentrations within the Puget Sound, and lower in the two stations of the open ocean. The high concentration at Victoria also supports the hypothesis that large cities produce more plastic pollution. This data allows a conclusion that, at minimum, the Puget Sound region as a whole, with its high population and industrial activity, contributes to the overall plastic pollution found within the world's oceans today. With all of the negative environmental effects

plastic pollutants have, it is imperative that more attention be placed first upon our overproduction and consumption of resources, and then how we manage our waste and recycle our plastics.

## ***References***

- Andrady, A.L., 2011. Microplastics in the marine environment. *Mar. Pollut. Bull.* **62**: 1596-1605, doi:10.1016/j.marpolbul.2011.05.030
- Baker, J., Foster, G., Masura, J., and Arthur, C. 2014. Laboratory methods for the analysis of microplastics in the marine environment. NOAA Technical Memorandum NOS-OR&R-48
- Barnes, D. K. a, F. Galgani, R. C. Thompson, and M. Barlaz. 2009. Accumulation and fragmentation of plastic debris in global environments. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.* **364**: 1985–1998.
- Carpenter, E. J., K. L. Smith, 1972. *Science*, New Series. Plastics on the Sargasso Sea Surface. **175**: 1240–1241.
- Carson, H. S., S. L. Colbert, M. J. Kaylor, and K. J. McDermid. 2011. Small plastic debris changes water movement and heat transfer through beach sediments. *Mar. Pollut. Bull.* **62**: 1708–13.
- Desforges, J. P. W., M. Galbraith, N. Dangerfield, and P. S. Ross. 2014. Widespread distribution of microplastics in subsurface seawater in the NE Pacific Ocean. *Mar. Pollut. Bull.* **79**: 94–99.
- Gregory, M. R., 2009. Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. *Phil. Trans. R. Soc.* **364**: doi: 10.1098/rstb.2008.0265
- Jambeck, J. R., R. Geyer, C. Wilcox, T. R. Siegler, M. Perryman, A. Andrady, R. Narayan, and K. L. Law. 2015. Plastic waste inputs from land into ocean. **347**: 768–771.
- Kukulka, T., G. Proskurowski, S. Morét-Ferguson, D. W. Meyer, and K. L. Law. 2012. The effect of wind mixing on the vertical distribution of buoyant plastic debris. *Geophys. Res. Lett.* **39**: L07601
- Law, K. L., S. Morét-Ferguson, N. a Maximenko, G. Proskurowski, E. E. Peacock, J. Hafner, and C. M. Reddy. 2010. Plastic accumulation in the North Atlantic subtropical gyre. *Science* **329**: 1185–1188.

Law, K. L., S. E. Morét-Ferguson, D. S. Goodwin, E. R. Zettler, E. Deforce, T. Kukulka, and G. Proskurowski. 2014. Distribution of surface plastic debris in the eastern pacific ocean from an 11-year data set. *Environ. Sci. Technol.* **48**: 4732–4738.

Morét-Ferguson, S., K. L. Law, G. Proskurowski, E. K. Murphy, E. E. Peacock, and C. M. Reddy. 2010. The size, mass, and composition of plastic debris in the western North Atlantic Ocean. *Mar. Pollut. Bull.* **60**: 1873–1878.

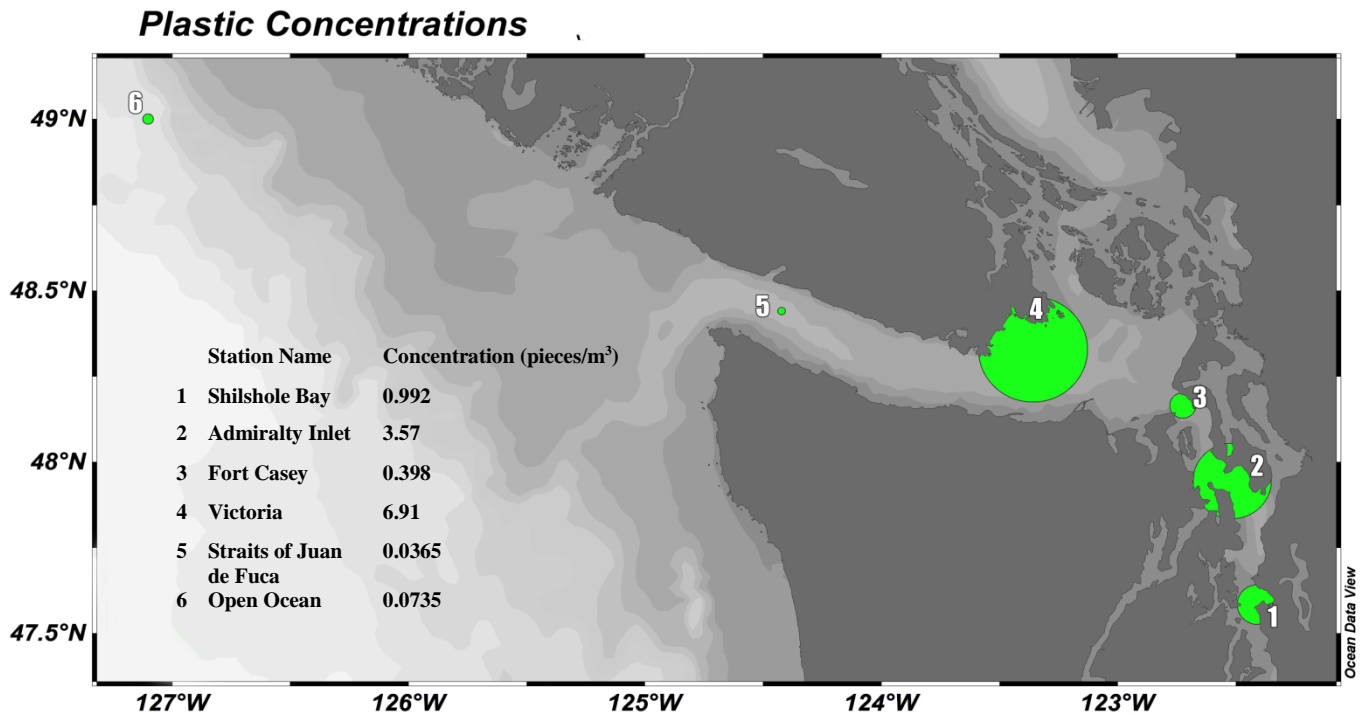
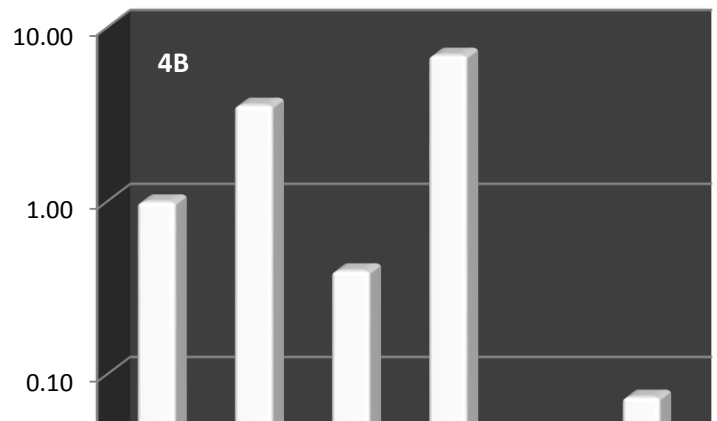


Figure 3 - A topographic map of the study area, consisting of the Puget Sound and the waters off the west coast of Vancouver Island. The size/diameter of the green circle represents the relative concentration of microplastics. The figure legend gives the station name and the actual concentration values, in pieces/m<sup>3</sup>.

### Plastic Concentrations by Type

### Total Plastic Concentration



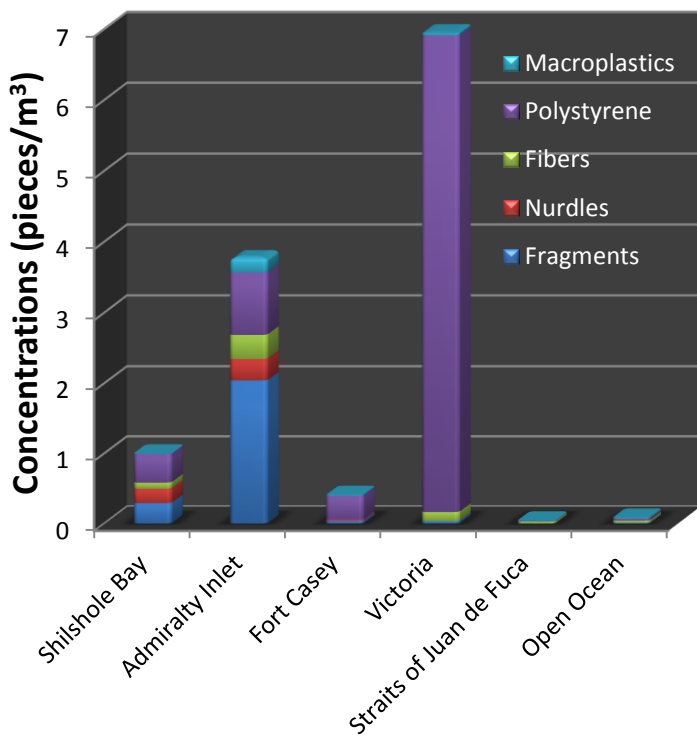


Figure 4A - The plastic concentration for each station separated into the five respective sub-categories: macroplastics, polystyrene, fibers, nurdles, and fragments. Figure 4B – A log scale has been implemented to remove the skew of the large spike at Victoria and allow a better comparison of the concentrations.

### Spatial Mass Density

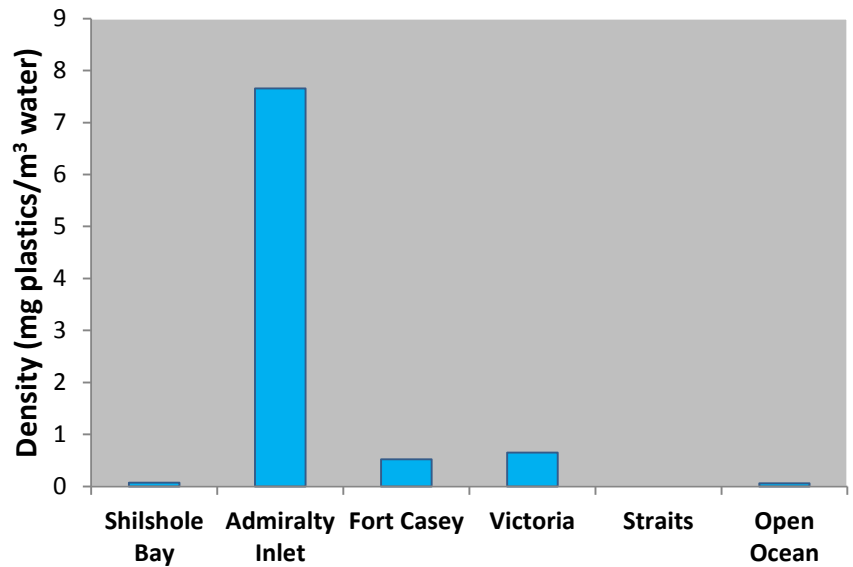


Figure 5 – Concentration of plastics at each station by mass rather than by number of pieces, giving a more quantitative value. All plastic types are included in the value, including macroplastics. Removing macroplastics' mass from the density calculations does not change the graph in a major fashion.