Stamatopoulos, J Marine Sci Res Dev 2020, 10:1

Journal of
Marine Science: Research & Development

Research Article Open Access

Distribution of Microplastics in the Marine Environment: Plastic Density Relative to Location and Current Magnitude off the New England Coast

Miya Mei-ling Khoo*
Independent Honors Research Scholar Program
University of Southern Molecular and Computational Biology Lab
The Marlborough School
1245 Wilshire Boulevard, #717
Los Angeles, California 90017
310-405-4247
miyakhoo@gmail.com

Abstract
In this study, we aimed to quantify the densities of microplastics in the coastal and outer mid-Atlantic regions and to better understand the mechanisms by which they are distributed. Originally, we hypothesized that microplastic fragments would linearly decrease with distance from shore as we move away from human sources of pollution. We measured the microplastic densities through a combination of surface and subsurface water measurements from a marine research vessel. We observed that while surface sample plastic densities did decrease with proximity from shore subsurface samples from the same locations surprisingly did not. In actuality,we found that subsurface microplastics reached maximum density at the farthest points from shore. We thus concluded that subsurface plastic debris vary more due to the complex interplay between wind and current influences rather than to just simple shore proximity. This implies that regional pollution sources feed plastic debris into local outbound subsurface oceanic streams that are then carried far offshore by current gyres to the larger oceanic plastic patches and gyres.

Keywords: human sources; microplastic fragments; plastic debris; mid-Atlantic regions.

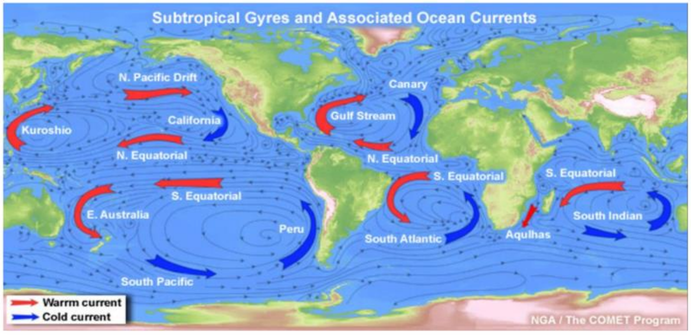
Introduction

As society become increasingly reliant on plastic products as an everyday convenience, the implications of plastics production and their subsequent dispersal to global environments have become a growing issue. Plastics enter the marine environment through various random methods of disposal. It is estimated that at least 10% of all plastic produced worldwide will eventually enter the ocean [9]. Interactions between plastic debris and the marine ecosystem are complex. The impacts of larger debris were detailed by Kühn et al. [5] with a myriad of political, social, and economic consequences [8] beyond that of the numerous direct environmental impacts on marine biota [1,2].

The unfortunate reality is that, in recent years, microplastics are emerging as the now most dominant form of marine pollutant. Microplastics are essentially pieces of debris formed by larger artificial plastic products broken down by the ocean overtime, thereby forming plastic fragments smaller than 5 micrometers. While microplastics are barely visible to the naked eye, the detrimental implications of their distribution are felt throughout the marine environment. Through food webs, the marine biota directly ingest and thereby interact with terrestrial organisms such as birds, mammals, and even humans. This distributed impact of the debris underscores the concept that increasing contamination by plastics poses a serious threat to the stability of the world's ecosystems. Previous literature [7] have confirmed microplastics are able to be ingested by most species of plankton which form the very foundation of the aquatic food chain. As larger predators then consume the plastic-containing planktons, the microplastics are subsequently transferred to and accumulate within predators as they ascend the trophic levels. This ingestion process ultimately results in apex predators such as Tuna, valuable market fish, containing dangerously high densities of plastics which directly results in harmful effects on the health of millions of human consumers.

Although the impact of microplastics has been widely publicized, the exact extent and mechanisms by which they have infiltrated the world's oceans is poorly quantified. It is a common misconception that only marine habitats directly exposed to garbage sources such as cities and industrial sites suffer from the effects of plastic pollutants. However, the recent media attention provided to the Great Central Pacific Garbage Patch has now publically brought to light that the effects of human pollution are felt even in the most remote regions of the ocean [6]. Even hundreds of miles away from any landfall, human trash pollutes the marine environments as the plastics are carried by wind and current gyres to these often remote stagnant "patches". There are five well known ocean gyres which correspond perfectly with the five largest observed "garbage patches" as well (Figure 1).

Figure 1- Global Distribution of Larger Ocean Gyres and associated Garbage patches [1]



Our study aimed to quantify the extent to which plastics have polluted the world's deeper waters through measurements of microplastic densities at varying distances from the New England continental shelf. It would be reasonable to assume that the plastic densities will be highest in samples nearest the shore, as these regions most directly interact with humans through harbors, waste plants, and fisheries. This study thereby focused primarily on the comparison of plastic densities between samples on the continental shelf versus samples taken at increasingly distant intervals along the continental slope. Furthermore, by studying these concentrations, we hoped to demonstrate the relationship between the magnitude of ocean currents and the resultant relative microplastic densities at each location. Gaining a better understanding of the interactions between plastic debris and the movements of prevailing oceanic currents will provide valuable bases for interventions and future studies.

Materials and Methods

Our primary goal of this experiment was to determine how the distribution of microplastics in the marine environment are influenced by distance from shore, direct human contact alone, and to what extent these densities evolve in relation to the magnitude of ocean and wind currents and other distribution forces. Sailing out on the Corwith Cramer, a 120 foot research corvette based out of the Woods Hole Oceanographic Institution, we developed a project comparing microplastic concentration based on major ocean currents/gyres and distance from the New England continental slope and shore at the time of sampling. Samples were obtained aboard the Corwith Cramer which launched from Falmouth, Massachusetts, USA during a 10 day course through the near Atlantic Ocean returning to Boston, Massachusetts in the summer of July 2018. At each sample location, the direction, magnitude of prevailing currents and surface conditions were recorded via shipboard instrumentation.

2a. Surface Samples and Neuston Tows

To accomplish these goals, we employed several different methods of debris sampling. At each location, we sampled the waters by both direct surface sampling and by performing a subsurface neuston tow. Direct surface samples were obtained by intermittently lowering collection buckets into the water and extracting a fixed volume of sample water. This water was then filtered and its contained plastics content then concentrated into a glass petri dish for subsequent quantification. With regards to very small plastic particles, this bulk sampling method was more effective than the neuston tow as it captured particles too small to be otherwise captured by the mesh of the neuston net, providing us a wider range of microplastic samples.

The subsurface samples were obtained by the neuston tows which removed microplastics samples from the sea surface through filtration. Our neuston had a single net with a mesh size of 333 μm extending from a rectangular stainless steel tow frame (Figure 2a).

During each tow, the net was deployed for 20 minutes off the side of the vessel at a consistent speed of 2 knots per hour, with only half the rectangular intake frame mouth submerged (Figure 2b). Before removing the cod-end of the neuston net, where all planktons and microplastics were entrapped, the mesh was thoroughly rinsed for five minutes to ensure that all plastics and micro-organisms were removed prior to the next use. Particle measurements may be contaminated by particles left within the mesh therefore mandating thorough cleansing of the tows between each use. This would prevent residual carryover of microplastics into subsequent samples from the same neuston apparatus [10,11]. The captured microplastics and biota were then filtered from the cod-end and stored in glass petri dishes, separate from the surface sample plastics.

2b. Plastics Filtration

From each surface sample, we filled a one liter rubber bottle with water from the collector as a representative measurement for that sample location. Similarly, we drained the neuston net's cod-end jar into a separate one liter bottle. We then carefully drained the water from each bottle, straining the water through a circular, gridded filter mesh which would catch only the plastic fragments and fibers. These filters would be dried in a contained environment for 24 hours and later transferred into glass petri dishes for microscopic analysis.

We then inspected the filters under a dissecting microscope at 4.5x magnification. Each filter slide was analyzed row by row as we counted and recorded the microplastics manually using bifringent visual techniques for every sample.

2c. Plastics Identification and Quantification

For this study, we employed the methodology described by Hidalgo-Ruz et al. [4] for identifing microplastics from collected marine biota. Firstly, in true microplastic particles there should be no cellular or organic structures observed. Under a confocal microscope, cellular structures such as cell walls and cytoplasm become visible thereby establishing the material as organic and not artificial. Although this is generally true of all inorganic material, "biofouling" or organic growth on the surface of artificial materials may alter the microscopic appearance of plastic particles. In cases of biofouling, we would determine whether the organic structures appeared wrapped around the plastic piece or only exhibited growth on a portion of the plastic's surface. If growth only appeared in a particular region of the plastic, this would violate the second rule of Hidalgo-Ruz et al [4] in that fibers should be equally thick throughout their entire length. Aside from the fraying of fibers or chipping of solid plastics (which are easily identifiable under a microscope) inconsistent regions of growth always indicate either biofouling or that the subject is composed of organic material. This final rule requires that particles exhibit clear and homogeneous color throughout their surface topography as well. In some cases, plastic fragments will exhibit patterns such as stripes but such color variations are often irrelevant by the third step, as we were usually able to determine whether the material was organic or not after the first two rules.

In the rare event where we remained unsure of the nature of the material after the method of Hidalgo-Ruz et al. [4], we use the hot needle test technique as described by De Witte et al [3]. For this test, we would heat a needle for sixty seconds and then touch it to the material under the microscope (Figure 3a,b). If the material was plastic in nature, it would either melt or start to fray, whereas organic or non-plastic materials would not (Figure 3c,d). This test was thus used in addition to knowledge of other characteristics of microplastic fragments.

Results

During the circumferential course of the research vessel's journey, the direction and magnitude of the currents were measured and recorded at each water sampling. The longitude and latitude of the sample location was established and confirmed via the ship's marine Global Positioning Systems. The range of the research vessel was from 41.8 to 40.3 degrees north latitude and 71.3 to 68.6 west longitude. The individual current and location data was then co-registered. The currents observed during the experiment varied by several factors including the seasonal currents of this portion of the Atlantic, prevailing winds, local thermal currents, and daily weather patterns. When cross-referenced to typical oceanographic current data from public domain sources, our observed currents matched the reported patterns well (Figure 4). It is important to note that even within the region of our ship's sampling range, several current gyres were observed as shown in the vector arrows of Figure 4.

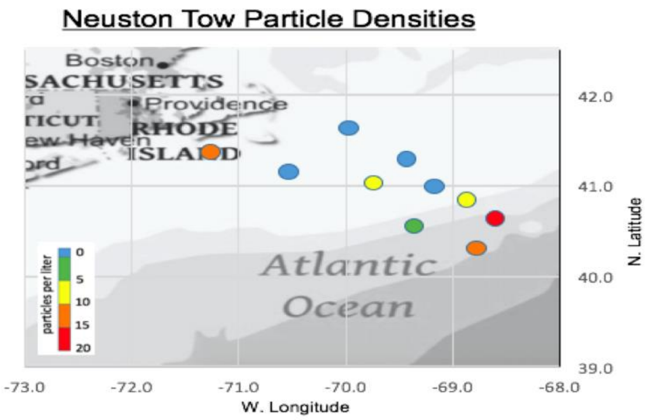
There were concentration gyres seen both proximal to distal from the New England coastline. These gyres were also correlated with areas of microplastics accumulation and concentration far out to sea in the mid-Atlantic waters.

Surface sample measurements of microplastics varied from 35 to 90 counted particles per sampled liter with a mean of 52 particles / sample. Surface sample particle concentrations seemed to vary directly with the distance from the coast which fit with our initial hypothesis that microplastics concentrations would vary in this way (Figure 5a). Near the coastline, concentrations of greater than 70-80 were demonstrated. With increasing distance from shore, samples revealed progressively decreasing density of the microplastic particles. In no samples did we observe less than 25 particles/sample.

As shown from the mid-Atlantic samples, concentrations of 45-68 particles per / liter were seen confirming that microplastic contamination of the near marine environment is both significant, consistent and ubiquitious in nature. It is important to note that surface samples typically contained significantly larger plastic fragments than those obtained from the subsurface neuston tow. As such, the smaller particles from subsurface collections represent plastic waste that has been broken down much further by mechanical, chemical, solar and wave action than the larger pieces of plastic seen on the surface.

The microplastics concentration of the subsurface filtration samples obtained from the neuston tow apparatus did not, however, diminish with increasing nautical distance from the coastline pollution source as we had hypothesized (Figure 5b).

Figure 5b – Subsurface Neuston tow microplastic average particle densities



Overall, a lower concentration range of particles per sample were seen in the neuston tow collections (2-30 particles/liter) than in the unfiltered bulk collections of the surface samples (35-90 parts/iter). However, we again observed microplastic debris in all samples from all locations again underscoring the widespread contamination of the waters in the region by these small plastic waste debris. Immediately offshore from New England, a high concentration of 10-15 microparticles / sample was observed. The concentrations of samples more distant from shore then decreased as expected (0-5 particles / sample) until we were 2 degrees east and 1 degree south. Surprisingly, measurements obtained between -68.5 and -70 degrees west longitude and 41 to 40 degrees north latitude revealed some of the highest subsurface concentrations of particulate matter (20-30 particles / liter) (Figure 5b).

Discussion

At the surface sample site closest to shore, the density of microplastics from the surface sample exceeded 72 plastic fragments (as displayed by the red circle in Figure 5a making it the most heavily polluted region throughout the study. Per our pre-experimental hypothesis, this was a logical result, as the loci of these samples were closest to plastic contamination sources emanating from nearby urban centers, rivers, coastal runoff and drainage outlets. Additionally, when we sampled these proximal coastal sites, we also observed several commercial fishing liners and traps floating throughout the area, where microplastics may have degraded direcly from fragments of fishing line, nets, buoys, and other maritime equipment. Similarly, subsurface neuston tow samples from these areas also demonstrated similarly high concentrations of 10-15 fragments per liter as well (Figure 5b),

The density of microplastics in the surface samples did decrease linearly with distance from shore. This again is an expected result as the samples are taken further from direct human sources of pollution. However, the highest number of microplastic particles seen in the neuston filtration mesh were actually observed at our most distal sampling location at 40.8 north latitude and 68.6 west longitude (red dot, Figure 5b). This region between -68.5 and -70 degrees west longitude and 41 to 40 degrees north latitude contained some of the most elevated concentrations of larger subsurface particles (10-30 / liter) with fairly homogenous size. When compared to the intervening near coastal waters (5-10 parts / liter), this mid-Atlantic ocean region appears to be an area of concentration of these subsurface layer microplastic particles that cannot be explained directly by our theory of proximity to the pollution sources.

When analyzing the regional surface ocean recordings from the experiment, there was an arrangement of surface currents observed that represents a local eddy or gyre in this region of the mid-Atlantic. Local gyres are well described in maritime charts and often contain areas of entrapped ocean regions . Such relatively stagnant waters or doldrums typically have weak or minimal current and wind action thereby predisposing the area to act as collection points for marine fauna and human pollution and waste debris as well [6]. When the ocean current vectors (Figures 4) and the neuston tow microplastics measurements (Figure 5b) are analyzed together, it is evident that the local ocean current gyre here and its contained stiller waters may partly explain the high subsurface particle concentrations obtained from this region. Furthermore, the concentrations of surface particles remained consistent within the area of this doldrum whereas there was an increasing concentration of subsurface plastic particles toward the edges of the local gyre loop. Based on our working hypothesis, this was a result we did not anticipate as the densities of subsurface microplastics farthest from shore did not echo the results of the surface samples which decreased steadily with their coastal distance . Both the surface and neuston tow plastics densities were seen to inflate at the farthest end of the loop (20-30 particles / liter; 40.8 N. longitude, 60.8 W. latitude) and decreased once again in the middle. The circulating warmer and cooler waters of mid-Atlantic currents also form a large central gyre that contains one of the five well described stagnant plastic “garbage patches” [6] (Figure 1). Based on the GPS coordinates of the Corwith Cramer, it is likely that we first encountered a local gyre with its contained moderate microplastics concentration before sailing onward to just touch the edge of the true mid-Atlantic gyre with its much higher microplastics subsurface debris (Figure 5b).

Conclusion

Based on the results of our limited investigation, we revised our initial hypothesis to conclude that whereas surface microplastics concentrations do indeed diminish with distance from coastal pollution sources, subsurface plastic debris vary more as the result of complex interplay between wind and current influences rather than with just simple shore proximity. As such, subsurface currents with their contained particles measured in the neuston tow data seem to act as feeder streams to concentration gyres seen far offshore. We demonstrated a local gyre with its surrounding feeding currents and its higher concentration of microplastic surface particles. This gyre then, in turn, seemed to feed into the better known large mid-Atlantic gyre and “garbage patch” which lay just at the edge of our sampling region. These observations support the growing belief that solving the problems of pelagic ocean plastic "garbage patches" will require a combined multinational cooperative effort as the sources of these macro- and microplastic debris "patched" come from far flung pollution sources over a great span of coastal geography.

Data Availability

All datasets are ready to be sent, upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

I would like to acknowledge the efforts and assistance of the crew of the Corwith Cramer and the SEA Semester Program of the Woods Hole Oceanographic Institute. I would like to thank Director Peg Brandon of the SEA education program and my co-investigator Annie Stewart for their contributions and support.

References

1. [1] .Barnes, D. K. A., Galgani, F., Thompson, R. C., & Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society of London B, 364(1526), 1985–1998.
2. [2] Derraik, J. G. B. (2002). The pollution of the marine environment by plastic debris: A review. Marine Pollution Bulletin, 44(9), 842–852.
3. [3]. De Witte, B.; Devriese, L.; Bekaert, K.; Hoffman, S.; Vandermeersch, G.; Cooreman, K.; Robbens, K. (2014) – Quality assessment of the blue mussel (Mytilus edulis): Comparison between commercial and wild types. Marine Pollution Bulletin, 85(1):146-155. DOI: 10.1016/j.marpolbul.2014.06.006
4. [4]. Hidalgo-Ruz, V.; Gutow, L.; Thompson, R.C.; Thiel, M. (2012) – Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification. Environmental Science & Technology, 46:3060-3075. DOI:dx.doi.org/10.1021/es2031505
5. [5]. Kühn, S., Bravo Rebolledo, E. L., & van Franeker, J. A. (2015). Deleterious effects of litter on marine life. In M. Bergmann, L. Gutow, & M. Klages (Eds.), Marine anthropogenic litter (pp. 75–116). Springer, Berlin.
6. [6]. Lovett, Richard A. "Huge Garbage Patch Found in Atlantic Too." National Geographic, 2 Mar. 2010, news.nationalgeographic.com/news/2010/03/100302-new-ocean-trash-garbage- patch/
7. [7]. Lusher, A.L. (2015). Microplastics in the Marine Environment: Distribution, Interactions and Effects.
8. [8]. Newman, S., Watkins, E., Farmer, A., Ten Brink, P., & Schweitzer, J.-P. (2015). The economics of marine litter. In M. Bergmann, L. Gutow, & M. Klages (Eds.), Marine anthropogenic litter (pp. 371–398). Springer, Berlin.
9. [9]. Thompson, R. C. (2006). Plastic debris in the marine environment: Consequences and solutions. In J. C. Krause, H. von Nordheim, & S. Bräger (Eds.), Marine Nature Conservation in Europe (pp. 107–115). Stralsund, Germany: Federal Agency for Nature Conservation.
10. [10]. Barrow, A.P.W. Cathey SE, Peterson CW, (2018): Marine environment microfiber contamination: Global patterns and the diversity of microparticle origins. Environs. Pollut., 237,275-284.
11. [11]. Peeken, I., S. Primpke, B. Beyer, J. Gütermann, C. Katlein, T. Krumpen, M. Bergmann, L. Hehemann, and G. Gerdts, 2018: Arctic sea ice is an important temporal sink and means of transport for microplastic. Nat. Commun., 9, 1505, doi: 10.1038/s41467-018-03825-5.