samples mostly consisted of microfibers which could be due to marine based activities (i.e. fishing and boating activity) and/ or waste water effluent discharge. These results provide a foundation for future research on microplastic sources and sinks within the USVI territory as well as their impacts on the environment and humans.

Microplastic Abundances Influenced by Anthropogenic Activity

By

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CONTRIBUTION OF AUTHORS

Danielle N. Lasseigne planned, collected, and processed samples, performed data analyses, and wrote the submitted thesis document

Dr. Marilyn E. Brandt provided guidance and assistance in planning of sample collection, data analysis, applying for funding, and writing.

Dr. Kristin Wilson-Grimes provided advice and guidance in project planning, data interpretation, equipment to process sediment for grainsize analysis, and writing.

Julie Masura M.S. provided guidance in sample processing, a lab space to work in after the 2017 hurricanes, and assistance with writing.

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Chapter 1: Introduction

Annually, over 300 million tonnes of plastic is produced each year (Thompson, 2017). They are made by polymerizing single monomers with various chemicals such as Bisphenol A (BPA), phthalates, and other solvents and additives (Rochman, 2015). Initially, plastics are made into the form of pellets that range from 1-5 mm in diameter (Mato et al., 2001; Kershaw & Leslie, 2015). They are then shipped to a factory, melted and remolded into the items that we are familiar with, as well as microbeads that are in face washes and hand soaps (Mato et al., 2001; Fendall & Sewell, 2009). Additionally, synthetic textile fibers are produced in a similar process, using additives and dyes to create single, continuous filaments to make woven fabrics, which are then used to make clothing, such as sportswear, furniture, and equipment for aquaculture and fishing, such as ropes, nets, and fishing line (Cole et al., 2011; Cesa et al., 2017; Dris et al., 2017). Although plastic and synthetic fibrous material are made to last, they can break down overtime through mechanical weathering. For example, when exposed to ultra-violet radiation and heat, the polymers of the plastic materials begin to photodegrade, become brittle, and breakdown into smaller pieces due to mechanical weathering (Andrady, 2011; Kershaw & Leslie, 2015). Items made with synthetic fibers tend to shed small fibers when they become worn or, in the case of clothing, washed using washing machines (Brown et al., 2011; Napper and Thompson, 2016; Almroth et al., 2018). Over time, these materials will breakdown to sizes smaller than 5 mm. Microplastics and microfibers are defined as any synthetic polymer that is less than 5mm in size (Arthur et al., 2009, Barrows et al., 2018). This includes the pre-production pellets (primary microplastics) and the degraded plastics pieces (secondary microplastics) (Kershaw & Leslie, 2015). Another property plastics, including synthetic fibers, have is the ability to adsorb other types of pollutants that have leached into the environment such as polychlorinated biphenyls (PCBs; found in electrical equipment), dichlorodiphenyltrichloroethane (DDT; found in pesticides), and polybrominatediphenyl (PBDE; found in flame retardants in baby clothes (Rochman, 2015; Bruce et al., 2016). Both photodegradation and the adsorption of pollutants can occur when plastics enter the marine environment, becoming marine debris – any solid, manmade item that's been discarded or accidentally spilled into the marine environment (NOAA, 2016).

Marine debris (including microplastics and microfibers) are known to originate from land-based sources: entering the marine environment through sewage disposal and wastewater effluent discharge, storm water run-off, run-off from landfills, and spillage of industrial products during transport (Browne et al., 2011; Carr et al., 2016; Mason et al., 2016; Pawar et al., 2016). They can also be from marine-based sources: litter from recreational boaters, fishing activities, buoys of moorings and fish traps, and oil platforms (Sheavly, 2005; Kershaw & Leslie, 2015; Pawar et al., 2016; Cesa et al., 2017). Ocean currents can transport marine debris from other areas around the globe, where no humans live, such as centers of large subtropical gyres, polar waters, and uninhabited islands (McDermid & McMullen, 2004; Eriksen et al., 2013; Law et al., 2014; Lusher et al., 2015). Microplastics including microfibers are also transported through the atmosphere as well (Dris et al., 2016). However, no matter the source, the presence of plastic pollution in the marine environment poses a threat to marine life (Pawar et al., 2016; Wilcox et al., 2016).

Larger marine plastic debris such as abandoned fishing gear, plastic bags, and bottles have been found to change benthic community structure and entangle organisms such as marine mammals and sea turtles (Nelms et al., 2015; Wilcox et al., 2016). When plastics breakdown, organisms are at risk of ingesting the pieces. Mero-plankton (larval mollusks, crustaceans, etc.) and holo-plankton (copepods) have been found to ingest microplastic pieces, or graze on surfaces of plastics (Cole et al., 2013; Cole et al., 2014; Reisser et al., 2014). *In situ* experiments observed fish collected near the ocean surfaces, mesopelagic zones, and demersal zones had consumed numerous pieces of small plastics, mistaking them for plankton or other sources of food (Boerger et al., 2010; Davison & Asch, 2011; Lusher et al., 2013). Additionally, fresh water muscles ingesting microfibers increased their rate of mortality (Jemec et al., 2016). Ingestion of microplastics and microfibers in these organisms not only have a potential to cause physical damage to their digestive systems, but their body tissues could absorb the chemical contaminants from plastics into their body tissue (Rochman, 2015).

High concentrations of chemical additives used to make plastics (i.e., BPA and phthalates) and pollutants adsorbed from the environment (PCBs, DDT, PBDE, etc.) may result in endocrine disruptions, neural behavioral disorders, and reduced spawning in marine organisms (Mato et al., 2001; Rios et al., 2010; Rochman, 2015). Chemical contaminants from ingested microplastics have the potential to become part of the food web, and can biomagnify in organisms in higher trophic levels of the web, potentially including humans (Rochman, 2015; Rochman et al., 2015). Rochman et al. (2015) found marine debris in 67% of 76 fish sold for human consumption in Indonesia and 25% of 64 fish sold in the USA, showing that humans are at risk of being exposed to microplastics and their associated chemical contaminants, therefore, potentially impacting human health.

To gain a better understanding of potential impacts microplastics have on the marine environment, organisms, and potentially humans, researchers quantified microplastics present in the environment. Microplastics and microfibers have been quantified on shorelines around the world (Table 1). These studies collected sediments from beaches, estuaries, and exposed sediments around mangrove habitats. Browne et al., (2011) also found that with an increasing number of people living near the beaches, there were greater numbers of microplastics on associated beaches. Definitions of microplastics and size ranges quantified in each study, differ, and can make comparisons difficult.

Table 1: Global studies quantifying microplastic in sediments

Reference	Collected	Location (s)	MP Definition	Size Range Found
Brown et al., 2011	Beach sediment	Australia, Japan, United Arab Emirates, Chile, Philippines, Portugal, Azores, USA, South Africa, Mozambique, United Kingdom	Less than 1 mm	Less than 1 mm
Mohamed Nor & Obbard, 2014	Exposed sediments associated with mangroves	Singapore	Less than 5 mm	.023 mm - 5 mm
Lee et al., 2015	Beach sediment	Beaches along the coast of South Korea	Less than 5 mm	Large microplastic (1-5 mm)
Wessel et al., 2016	Estuarine beach sediment	Mobil Bay, Alabama, US (northern Gulf of Mexico)	Less than 5 mm	.05 mm - 5 mm
Herrera et al., 2017	Beach sediment	Lambra, Famara, Las Canteras islands (Canary Islands)	Less than 5 mm	1 mm - 5 mm
Abidili et al., 2018	Beach sediment in the litterol zone	North Tunisian Coast (Mediterranean Sea)	Less than 5mm	0.1 mm - 5 mm
Digka et al., 2018	Beach sediment	Corfu Island, Northern Ionian Sea	Less than 5 mm	Small microplastics (<1 mm); Large microplastics (1-5 mm)

Studies quantifying microplastics in sediment have also looked at the relationship between sediment grainsize and microplastic abundances. Alomar et al (2016), quantified microplastics in sediment cores collected from coastal shallow waters in the Mediterranean Sea, and observed that most microplastic concentrations (particles <1mm) were found in more coarse sediment (2mm -.5mm) than finer sediments (0.25mm-0.065mm). However, Strand et al (2013) found that samples with a higher percentage 0.063mm grain size contained a higher concentration of microplastics.

Microplastic debris have also been collected from large scale, open ocean surfaces (i.e, south subtropical gyres) as well coastal surface waters and sub surface waters where land based human activity is high (Table 2).These pieces can be introduced from shore and carried out by sea surface currents. For example, Hidalgo-Ruiz & Thiel (2013) compared abundance of plastic found on the beaches of Chile and Easter Island, and found that Easter Island had more plastic possibly due to the currents transporting the debris from the coast of Chile.

Table 2: Global Studies quantifying microplastics in surface and sub-surface waters.

Reference	Collected	Location	MP Definition	Size Range Found
Desforges et al., 2012	Coastal to open ocean sub-surface waters	Coastal British Colombia	Less than 5 mm	0.062 mm - 5 mm
Eriksen et al., 2013	Open ocean surface water	South Pacific Subtropical Gyre	Less than 1 mm	0.499 mm-4.47 mm
Law et al., 2014	Open oncean surface water	Eastern Pacific Ocean	Less than 5 mm	1 mm - 5 mm
Collignon et al., 2012	Surface water	Northwestern Mediterranean Basin	Less than 5 mm	0.333 mm - 5 mm
Faure et al., 2015	Surface water	Western Mediterranean Sea	Less than 0.3 mm	< 0.3 mm
Lusher et al., 2015	Open ocean surface water	Barrent Sea (Arctic)	Less than 5 mm	0.25 mm -7.71 mm
Digka et al., 2018	Coastal surface water	Corfu Island, Northern Ionian Sea	Less than 5 mm	<1 mm (small) to 1-5 mm (large)

Currently, little is known of the presence and abundance of microplastic pollution and its source of input in the Caribbean. However, there are more recent studies quantifying microplastics on beaches on islands within the Caribbean region (Table 3). Each study quantified microplastics within different size ranges, and Yu et al. (2018) found microfibers in their samples, but quantified them as microplastics. Schmuck et al., (2017) also reported that beaches with the most microplastic (or microdebris since they found other small pieces of anthropogenic litter) were beaches with large number of visitors.

Table 3: Microplastic Quantification studies conducted within the Caribbean.

Reference	Sample type	Location	MP Definition	Size Ranges
Schmuck et al., 2017	Beach Sediment	Wider Caribbean Region	Less than 5 mm	1 mm - 5 mm
Yu et al., 2018	Beach Sediment	Virgin Islands National Parks, St. John and Buck Island Reef National Monument, St. Croix	Less than 5 mm	0.01 mm - 5 mm

Schmuck et al. (2017) quantified micro debris in beach sediments from Caribbean islands (the islands of the Bahamas, British Virgin Islands, Dominican Republic, Grenada, St. Vincent, Turks and Caicos, the Caymans, Martinique, and St. Eustatius) and found on average 1.23 pieces/ m^2, but only quantified micro debris in 1- 5mm size ranges. Within the USVI the National Park Service quantified microplastics on two beaches within the Virgin Islands national park on St. John and Buck Island Reef National Monument (Yu et al., 2018).

There are potential factors on the island of St. Thomas, US Virgin Islands that could contribute to microplastic abundances in coastal environments. On the island, there is a large human population density, and during the tourist seasons in St. Thomas, the population on the island increases through cruise ship passenger and air passenger arrivals. For example, from January 2015- August 2016, about 795,000 people visited the island (VI Bureau of Economic Research). The large populations on island potentially increases the amount of plastic waste being discarded on island. There are several dumpsters placed along the main roads, usually located on or near a gut. Guts are ephemeral waterways that channel rainwater from the upland to the marine environment, connecting terrestrial and marine ecosystems (Daley et al., 2009). Even though the dumpsters are there to allow residents and tourists to dispose of their trash, the dumpsters tend to over flow, causing trash (including plastic waste) to fall to the ground, and potentially enter the coastal environments through the guts or overland flow. With large amounts of solid waste and plastic entering the environment, it is unknown if microplastics are present and abundant in the marine environment surrounding St. Thomas, USVI.

This study tested several hypotheses to address whether microplastics are present and where they are most abundant in coastal marine environments surrounding St. Thomas. Since microplastics have been found to be positively associated with anthropogenic activity and population density in associated coastal areas (Browne et al., 2011), I hypothesize that:

(H1) Microplastics are abundant on beaches and (H2) in near shore surface waters in embayments that experience high anthropogenic activity in associated watersheds. To test this hypothesis, two types of samples will be collected from 8 beaches around St. Thomas, USVI that experience high and low anthropogenic activity in associated watersheds. These samples will consist of 1) beach sediment from the sandy beach of each watershed, and 2) surface water tows in the nearshore waters of the embayment associated with each watershed. I expect that both sediment and surface water samples from sites experiencing high anthropogenic activity will contain more microplastics.

Since smaller sediment grainsizes contain a greater number of microplastics (Strand et al., 2013), I hypothesize that:

($H1_a$) Finer sediment grains on beaches will contain a higher abundance of microplastics while coarser sediment grains will contain less and ($H1_b$) sediment grain size will not differ among the sites. To test this, sub-samples of collected beach sediments were poured through stacked sieves, and placed on a shaker to obtain grain size fractions of the sediment. Each size class was weighed, and the mass median diameter (MMD) will be calculated. I expect to see finer sediments will consistently contain more microplastics.

Since other aspects of each embayment's watershed may or may not have an influence on microplastic abundances, I hypothesize that:

($H1_c$) Water shed characteristics are different among the sites, and that the characteristic that will influence microplastic concentrations will be the population density in each site. To test this, data for watershed characteristics such as watershed area, population density, and cardinal direction of bay will be used to determine which sites are different, and which could most influence the abundance of microplastics.

Chapter 2: Methods

2.1 Study Area and Site Selection

To determine which sites experience high and low anthropogenic activity, a site selection analysis was conducted. Data on the average population density from the 2010 US Census (United States Census Bureau) was overlaid with watershed boundary maps from the University of the Virgin Islands' GeoCAS data base in ArcGIS to determine how many people live in each watershed. In ArcGIS, the break point analysis function was used to find the natural break in average human population density to classify which watershed had high average population density (>386 people/km^2) and low average population density (<386 people/km^2). Coordinate locations of all dumpster sites were collected using a handheld Garmin GPS while driving around St. Thomas, USVI, to see which watersheds may have the potential for plastic waste input through rain water runoff. Other data, such as land cover from 2012 NOAA Coastal Change Analysis Program (CCAP), Trash data from the 2015 International Coastal cleanup (ICC) weeks, number of available slips and moorings in associated embayments, number of beach bars and food trucks, and r of the beach of each embayment, was also used to determine which beaches experience higher human activity. Once all information was gathered, a non-metric multidimensional scaling analysis (nMDS) based on a Bray-Curtis similarity matrix was performed to examine similarities among the watersheds, and to determine which watersheds were associated with high or low anthropogenic activity. Results from the nMDS showed that average population density and the presence of dumpsters contributed most to the dissimilarity between the watersheds.

Eight embayments around St. Thomas, USVI were selected based on the site selection analysis mentioned above (Figure 1 & Table 1). Four embayments showed low anthropogenic activity in the associated watersheds, and four embayments showed high anthropogenic activity in associated watersheds. High anthropogenic activity was defined as having > ~386 people/km^2 (based on the 2010 US Census data) and dumpsters present in the associated watershed; low anthropogenic activity was defined as having < ~386 people/km^2 and no dumpsters present in the associated watershed

Table 4: List of study sites and their respective level of anthropogenic activity

Embayment	Population Density	# of Dumpsters	Level of Anthropogenic Activity
Bolongo Bay	~664 people/km^2	3	High
Brewers Bay	~2000 people/km^2	2	High
Lindbergh Bay	~2234 people/km^2	3	High
Magens Bay	~512 people/km^2	1	High
Perseverance Bay	~10 people/km^2	0	Low
Sprat Bay	~63 people/km^2	0	Low
Hendriks Bay	~59 people/km^2	0	Low
Sandy Bay	~62 people/km^2	0	Low

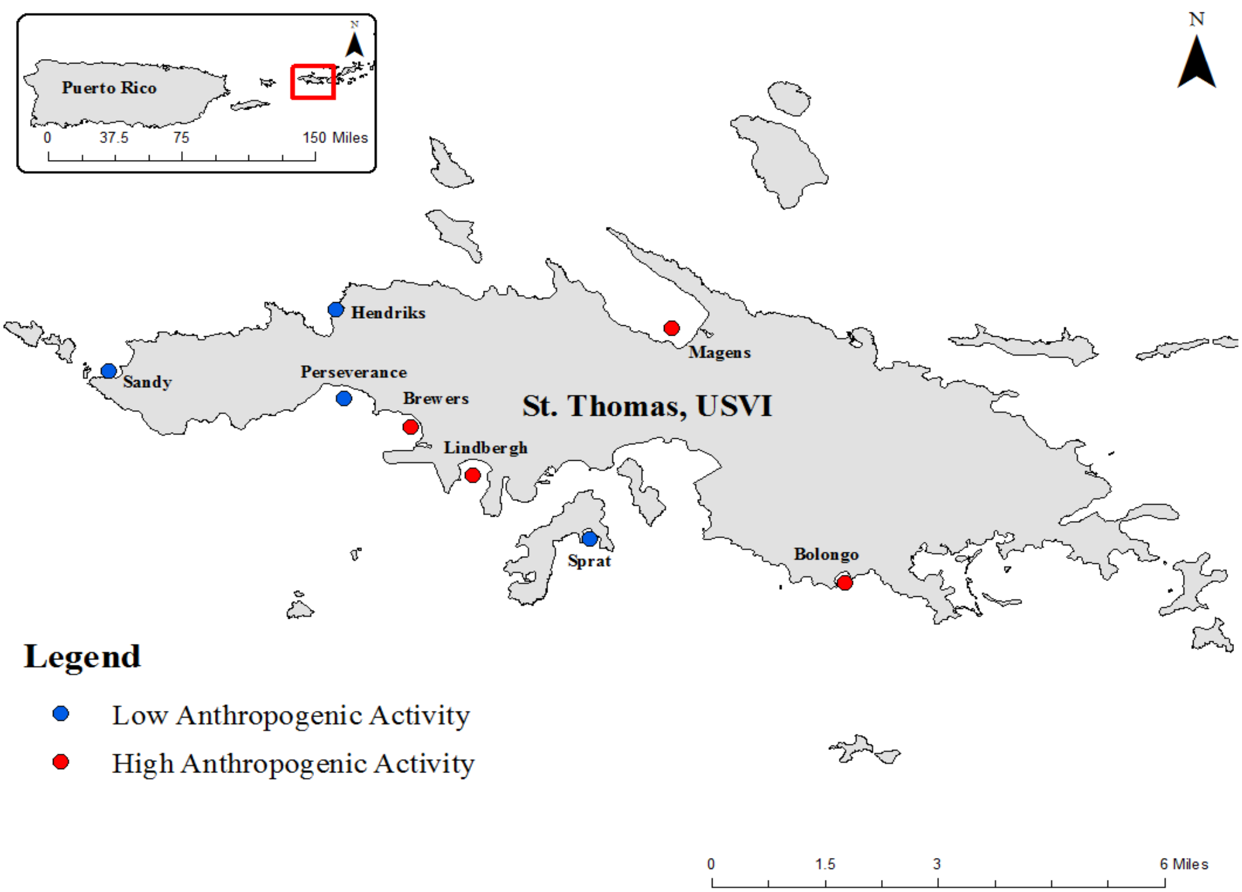

Figure 1: The eight embayments around St. Thomas where all sample types were collected. Sites in blue experience low anthropogenic activity (Sprat Bay, Perseverance Bay, Sandy Bay, Hendriks Bay) and sites in red experience high anthropogenic activity

2.2 Sample Collection

Two sample types were collected from each embayment between September 2016 and May 2017 (Table 2).

Table 5: Dates in which each sample type was collected from each site

	Beach Sediment	Surface Water
Site	Date	Date
Bolongo	10/24/2016	4/13/2017
Brewers	9/15/2016	2/13/2017
Lindbergh	11/8/2016	2/14/2017
Magens	10/31/2016	4/9/2017
Hendriks	10/23/2016	4/9/2017
Perseverance	10/22/2016	2/16/2017
Sandy	11/1/2016	4/9/2017
Sprat	9/9/2016	2/14/2017

2.2.1 Beach Sediment

Beach sand was collected during low tide from all 8 sites between September 2016 and November 2016 (Table 2). At the center of each beach, three transects were placed perpendicular to the shoreline, 5 m apart. The 0 m mark of each transect was placed 3 m below the high tide line or wrack line (HTL) and extended to where trees or bushes were established (i.e., the tree line; Figure 2). For each transect, the top 1-2 cm layer of sand was collected from seven 0.25 m^2 quadrats placed 3 m apart. Each beach's profile was different; therefore, quadrat samples were collected from standardized points along the transect, including 1) 3 m below the HTL, 2) at the HTL, 3) 3 m above the HTL, 4) 6 m above the HTL, 5) 6 m below the tree line, 6) 3 m below the tree line, and 7) at the tree line. The first 1-2 cm layer of sand was put into 2-gallon high density polyethylene buckets, sealed and taken to the Environmental Analysis Lab (EAL) at the University of the Virgin Islands (UVI). From each bucket, two 400g subsamples were taken (one to be processed for microplastics and the other for grain size analysis). All samples were stored in, 16 oz. glass jars at 20.5 °C prior to processing.

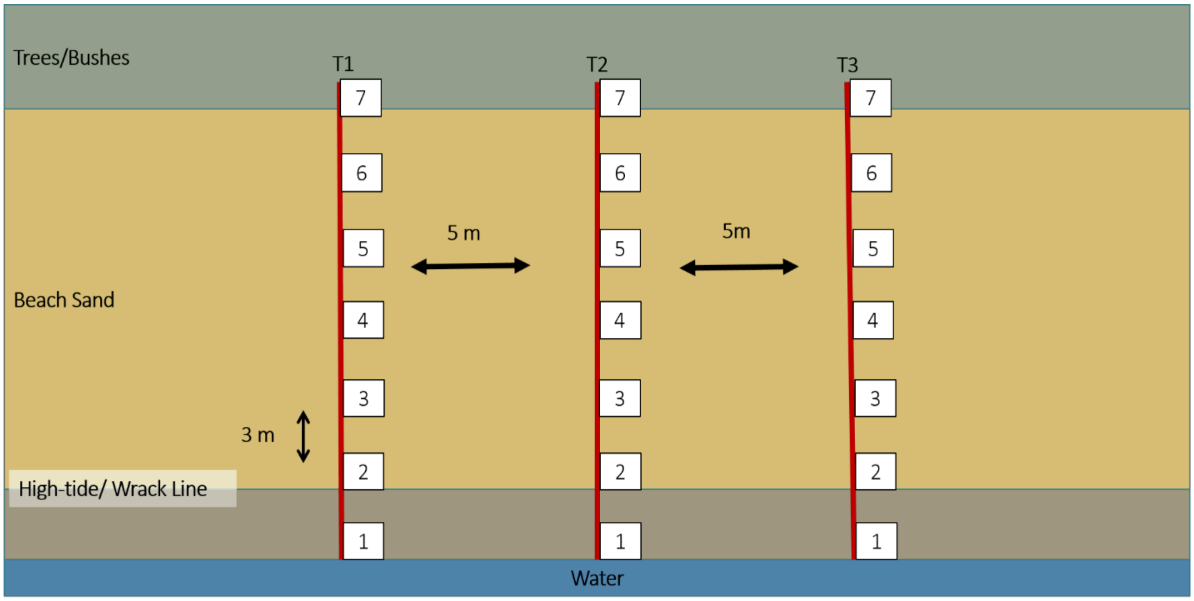

Figure 2: Sample design for collecting beach sediment. Due to the different beach profiles, distance between quadrats four and five may have been greater than 3 m.

A total of 21 samples were collected from each site, except for Perseverance Bay. At this bay, the profile of the beach was different from the other sites: there was a very short distance between the shore and the tree line, therefore the same sampling strategy could not be applied. Only 12 samples (four quadrats from each transect) could be collected, therefore these samples were removed from the analysis due to the inability to compare them to the other beach samples.

Each transect had a sample size of three except for quadrats two and three in Sprat Bay, due to loss of samples during transportation. Sub samples were pulled to process for microplastics, but there wasn't sufficient amount of sediment collected to pull a sub sample for grain size analysis. Due to boat availability and limited funds, re-sampling of the site could not be completed. Therefore, to compare the average MMD among the sites, and to determine the relationship between sediment grain size and microplastic abundance, quadrats two and three were removed from each site

2.2.2 Surface Water

Surface water samples were collected at three separate times in each bay between February 2017 and April 2017 using a manta tow (made by Ocean Instruments) with a 60cm square frame and .3 mm mesh net towed by UVI's 30ft Research Vessel, Garrupa, along a pre-determined transect. Each transect was planned to be as close to shore as possible, however due to the bathymetry and maneuverability of the boat under tow, transects for Sprat Bay, Bolongo Bay and Hendriks Bay were located at the mouth of the bay. Before each field day, the net was rinsed on the outside with fresh water to remove any solids that may have been stuck inside the net, and the cod-end rinsed with distilled water before being attached to the net. After each tow, the net was sprayed down with ambient sea water on the outside of the net to transfer any solids to the cod-end. Solids were then poured through an ASTM certified sieve stainless steel No. 50 0.3 mm mesh sieve, and transferred to a 16 oz mason jar using distilled water. Before re-attaching, the cod-end was also rinsed with distilled water. All samples were taken and stored in clean 16 oz. glass jars in a refrigerator at 2.7 °C at the EAL prior to processing.

2.3 Sample Processing

All sample types were processed using the laboratory protocols recommended by the NOAA Marine Debris Program (Masura et al., 2015).

To process collected beach sand, 400 g of each collected sample was dried at 90°C for 24 hours or until dry, and weighed again. Three hundred milliliters of diluted (1.6 g/mL) lithium metatungstate (LMT) was added to the dry sample and stirred vigorously for several minutes, then left to allow sediment to settle. Floating solids were poured through stacked sieves with 5 mm, 1 mm, and 0.3 mm mesh size, and rinsed with distilled water. Collected solids in the 1 mm sieve were transferred to 16 oz. mason jars using distilled water and archived. The 0.3 mm size fraction was transferred to 400 mL beakers using a metal spatula and distilled water, and dried for 24 hours at 90°C. After drying, beakers were weighed to get the total mass of solids collected. Then, 20 ml of an 0.05 M iron (Fe (II)) solution and 20 mL of 30% hydrogen peroxide was added to each sample to make the wet peroxide solution (WPO). After letting the solution react for five minutes, the sample was stirred and heated to 75°C. Additional wet peroxide was added, if needed, until most of organic material was oxidized. To increase the density of the solution ~ 6g of salt was added and dissolved for every 20 mL of the solution to float out any plastics present in the sample. Each sample was then poured into a density separator and left to settle overnight. Settled solids were drained first, then floating solids were drained and filtered using a 0.3 mm custom sieve. Each sieve was lightly covered with foil and left to air dry overnight. Once dry, each sieve was examined under a dissecting microscope to collect and store any microplastics or microfibers present from each sample. Microplastics found in sample were categorized as primary or secondary, microfibers were categorized as a single filament.

Surface water samples were poured through stacked sieves with mesh sizes 5 mm, 1 mm, and 0.3 mm, and rinsed with distilled water. Solids collected in the 1mm sieve were archived to be processed later. Solids collected in the 0.3mm sieve were then transferred to a tared 400 mL beaker using a metal spatula and distilled water, and dried for 24 hours at 90°C. After drying, the samples went through the same WPO solution and density separation as the beach sediment samples described above. Each batch of samples had an associated blank containing the same volume of distilled water as its associated sample and was processed along with the samples.

For beach sediment, average concentrations of microplastic and microfibers were calculated for each quadrat across the three transects at each site, and for each site by dividing the number of microplastics and microfibers by the amount of dry sand from each sample. For surface water, average concentrations were calculated for each site across the three tows by dividing the number of microplastics by the volume of water that has passed through the manta net. Volume was calculated using the following equations:

$$\text{Distance (m)} = \frac{(\text{Flow out} - \text{Flow in}) * \text{Standard Rotor Constant}}{999999}$$

$$\text{Volume (m}^3) = \frac{3.14 * (Net\ Diameter)^2 * \text{Distance}}{4}$$

Where *Flow out* and *Flow in* are values read from the flow meter attached to the manta before and after each tow.

2.4 Grain Size Analysis

To perform the grain size analysis, 400 g of wet sediment from beach sediment samples were dried at 90°C for 24 hours or until dry. Forty grams of sediment from each dried sample was then poured through stacked ASTM certified stainless-steel sieves with mesh sizes 5 mm, 2 mm, 1 mm, 0.3 mm, 0.180 mm, 0.150 mm, 0.063 mm, and < 0.063 mm. The stacked sieves were placed onto a shaker for 15 min, and sediment left in each fraction was weighed and then discarded. Measurements for each size fraction was then inputted to GRADISTAT, a grain size analysis program, to calculate the mass median diameter or MMD (D_{50}) for each sample. The mass median diameter is the diameter of sediment particles that makes up 50% of the sample. After, phi size was calculated using the following equation to run the regression:

$$\Phi = \text{Log}_2\left(\frac{1}{D_{50}}\right)$$

2.5 Statistical Analysis

All statistical analyses were performed using R. Although microplastics were classified as either secondary microplastics or monofilament microfibers, in the analyses, microfibers were included as microplastics. To determine the difference in microplastic concentrations in beach sediment among the sites (**H1**), a Kruskal-Wallis test was used since data did not meet the assumptions of a parametric test. When the Kruskal-Wallis test was significant, , a pairwise Mann-Whitney U –test was used for pair-wise comparisons. A linear regression was used to determine if there was a relationship between sediment grain size (Φ), and microplastic concentrations at each of the sites ($\mathbf{H1_a}$). A Kruskal-Wallis was also used to determine differences in median mass diameter among the sites and when significant, Mann-Whitney U-tests were applied for pair-wise comparisons was used ($\mathbf{H1_b}$). Additionally, an nMDS was performed using watershed characteristics and microplastic concentrations in order to look for similarities among sites with highest and lowest microplastic concentrations. The watershed characteristics included in the nMDS were: watershed area (km^2), population density within the watershed ($3/km^2$), cardinal direction of the bay, the median mass diameter of sediment grain size, and microplastic concentrations ($\mathbf{H1_c}$). Surface water samples satisfied parametric test assumptions after a cubed root transformation. The transformed data were tested for differences among embayments using a one-way ANOVA (**H2**), and a Tukey's post hoc test was used for pair-wise comparisons.

Chapter 3: Results

3.1 Microplastics Concentrations

Two types of microplastics were found within the 0.3 – 1 mm size fraction in collected beach sediment samples: secondary microplastic fragments and single filament microfibers (Figure 3). Microplastic concentrations were higher than microfibers in beach sediment at three of the seven beaches. However statistical differences between microplastic and microfiber concentrations could not be determined due to variability in the data. Figure 4 shows how the spatial distribution of average concentrations of microplastics and microfibers were distributed along the beach. Both appear to be most abundant farthest away from the shoreline (Quadrats 4 – 7). However, the data were zero-inflated and highly variable, therefore a statistical difference could not be determined.

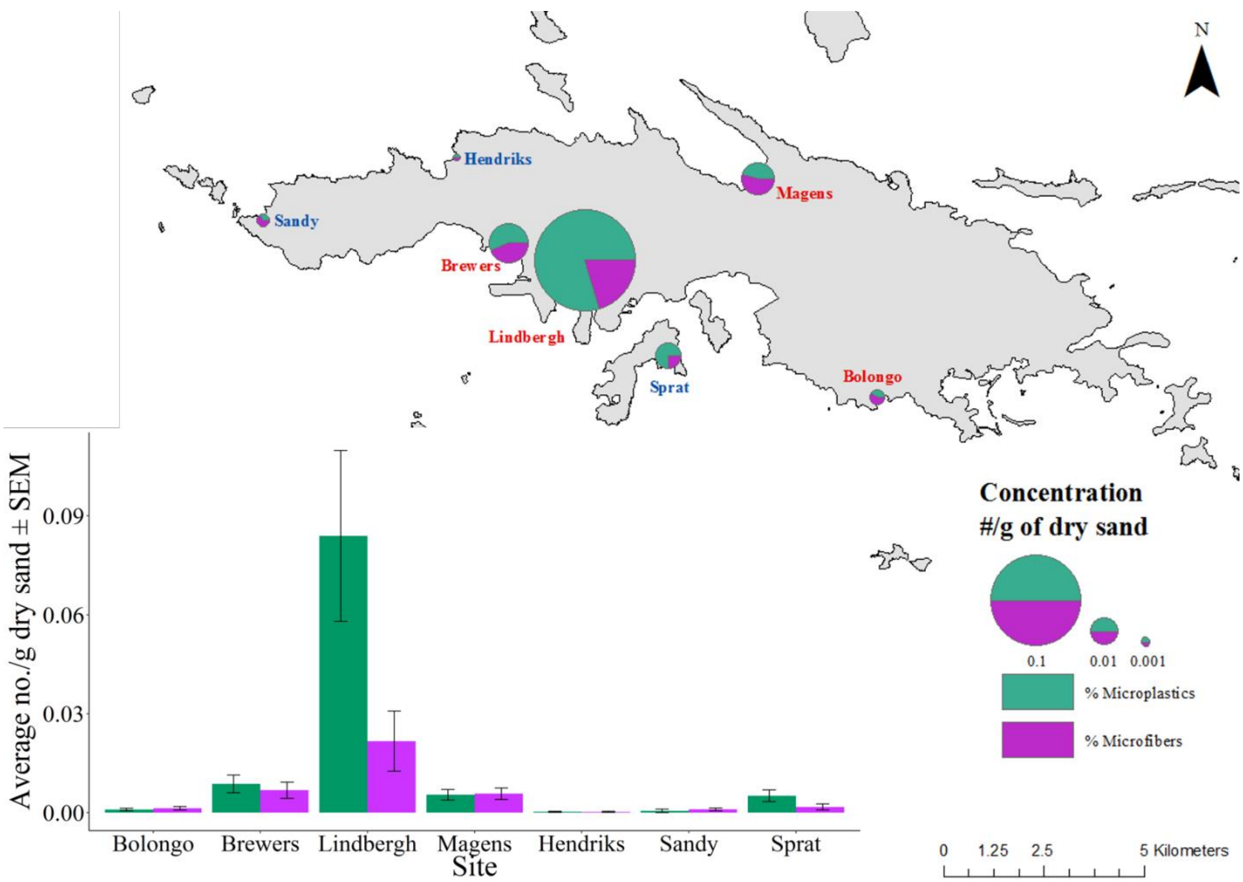

Figure 3: Average concentrations of microplastics and microfibers found in beach sediment by site. Error bars represent ± standard error of the mean (SEM).

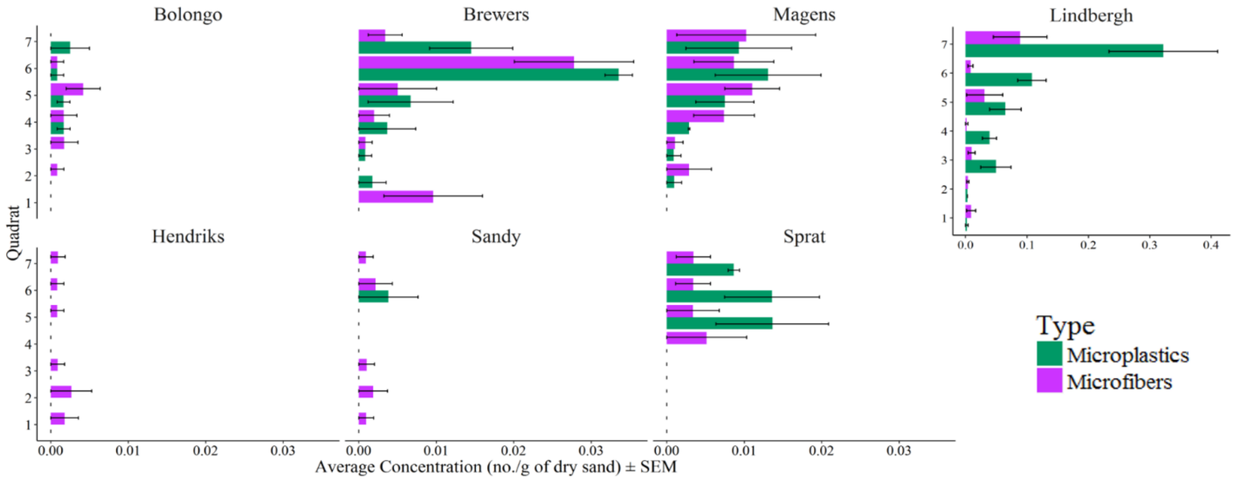

Figure 4: Average microplastic and microfiber concentrations in beach sediment by location along the transect at each site. To maintain standardized axes, concentrations found in Lindbergh beach are illustrated in a separate graph due to having an order of magnitude high

Total microplastic concentrations (including combined microplastics and microfibers) were significantly different among the sites (Figure 5; Kruskal-Wallis, $X^2 = 56.871$, df = 6, $p < 0.001$). Microplastic concentrations were significantly higher in beach sediment samples collected from Lindbergh Bay beach (0.11 pieces/ g of dry sand ± 0.034 SEM; $p < 0.05$), a high anthropogenic activity site, than in any other site (Figure 9). Concentrations of microplastics in samples from Brewers Bay (0.015 pieces/g of dry sand ± 0.0047 SEM) and Magens Bay (0.011 pieces/g of dry sand ± 0.0027 SEM), also high anthropogenic activity sites, were not significantly different from each other ($p = 0.858$), but were significantly higher than concentrations found in Bolongo beach sediment (0.002 pieces/ g of dry sand ± 0.0006 SEM; p = 0.023 and 0.026, respectively), a high anthropogenic activity site. They were also significantly higher than concentrations found in beach sediment from low- anthropogenic sites Hendriks (0.0005 pieces/ g of dry sand ± 0.0002 SEM; $p < 0.001$) and Sandy (0.0015 pieces/ g of dry sand ± 0.0006 SEM; $p < 0.01$). However, concentrations found in Sprat beach sediment (0.007 pieces/ g of dry sand ± 0.002 SEM), were not significantly different from concentrations from Brewers, and Magen beaches (p = 0.250, 0.243, respectively).

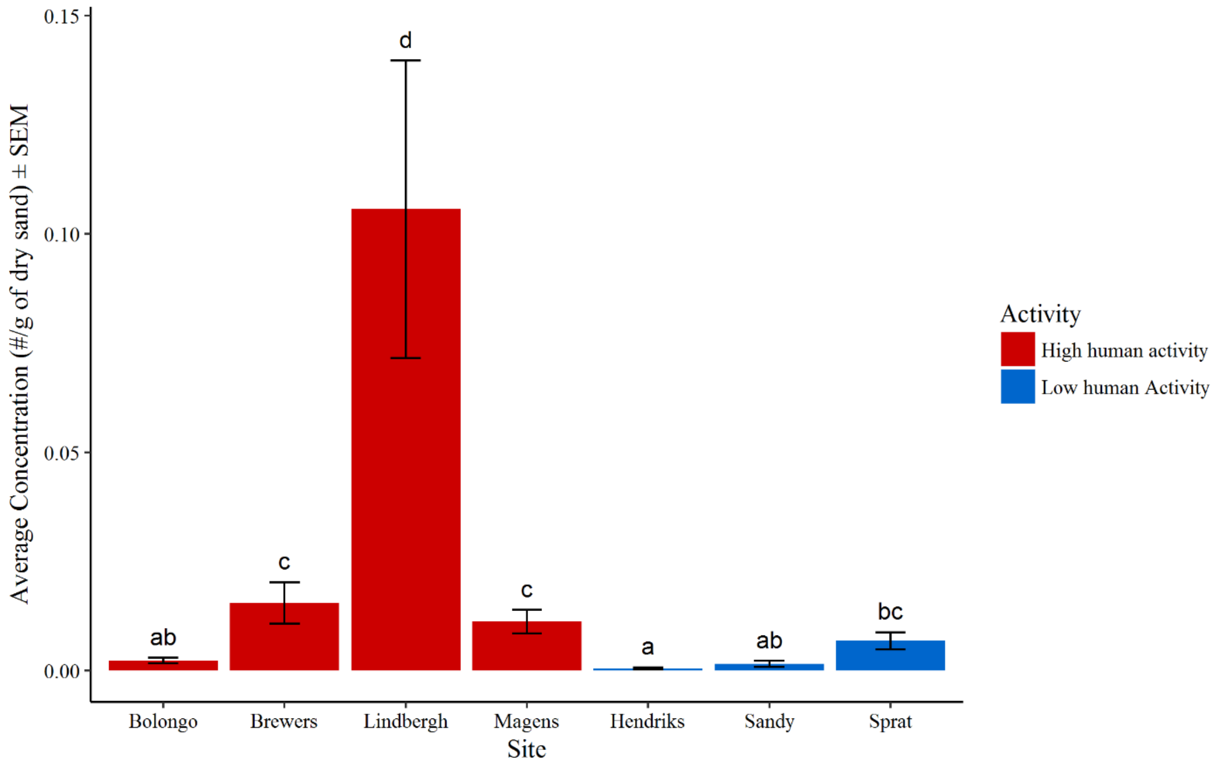

Figure 5:Average total microplastic concentrations (number of pieces per gram of dry sand) in beach sediment at each site. Different letters represent a significant difference among groups as determined by a pair-wise comparison.

3.2 Grain Size Analysis of Beach Sediment

Within each site, the average mass median diameter of sediment was similar in each quadrat along the transects except for at sites Bolongo, Sprat, and Hendriks (Figure 6). There were no significant relationships between sediment grain size and microplastic abundance within each site, except at Magen's Bay where a significant but weak negative relationship was detected (Figure 7; R^2=0.3162, $p < 0.05$).

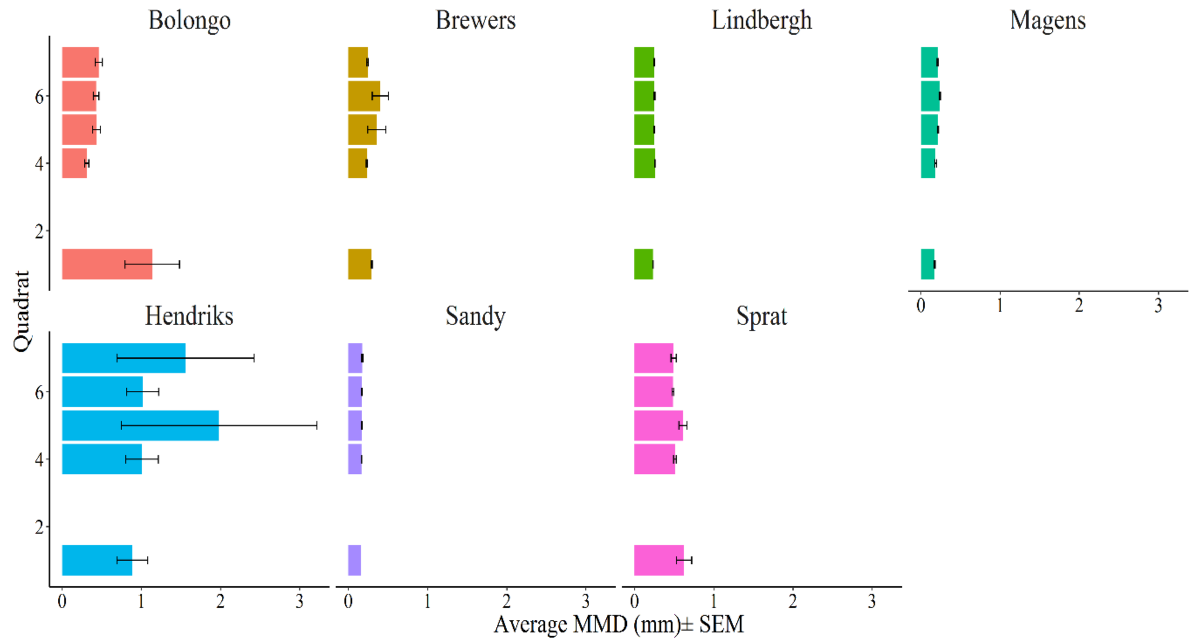

Figure 6: Average MMD of beach sediment in each Quadrat averaged across three transects at each site. Each quadrat had a sample size of 3 except for quadrats 2 and 3 in Sprat Bay (n=2).

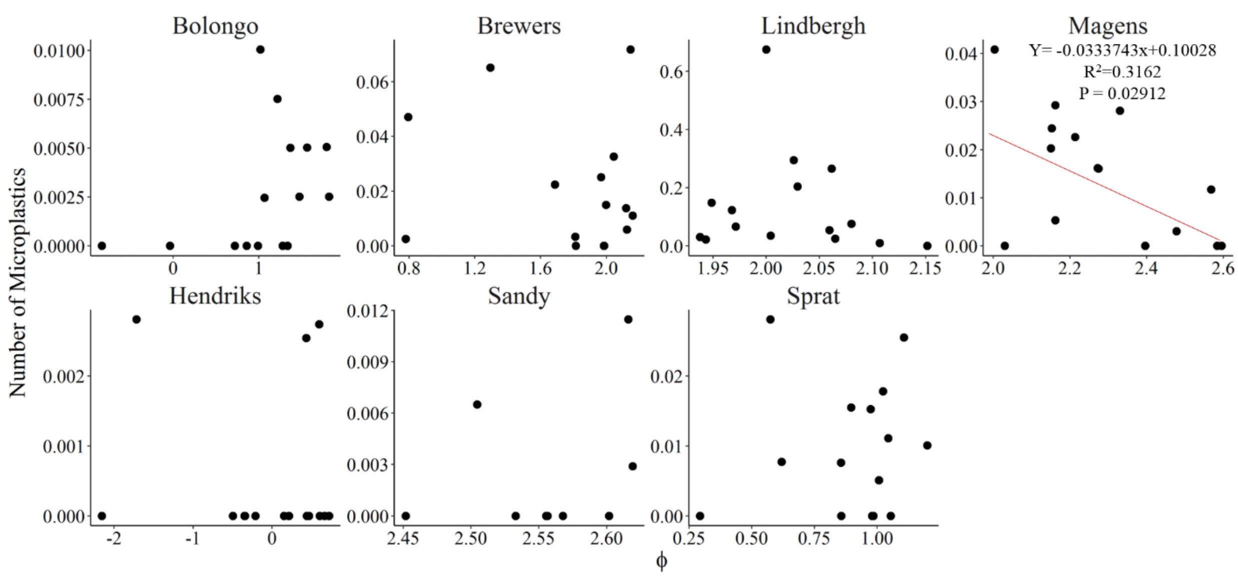

Figure 7: Scatter plot showing relationship between microplastic abundance and grainsize

The average mass median diameter (MMD) of sediment grain size was significantly different among sites ($X^2 = 84.607$, df = 6, $p < 0.001$). The beach in Hendriks bay had the largest average MMD (~1.29 mm ± 0.28 SEM; $p < 0.001$) versus the rest of the sites and its size indicates a classification of coarse sand. Beaches in Bolongo and Sprat bays had the second and third largest average MMD, which were not significantly different from each other (0.56 mm ±

0.099 SEM and 0.54 mm ± 0.025 SEM, respectively; $p = 0.052$) and also fell into the classification of coarse sand. Brewers and Lindbergh beaches had similar MMD (0.307 mm ± 0.031 SEM and 0.246 mm ± 0.003 SEM, respectively; $p = 0.267$). However, according to Wentworth (1922) Brewers sediment should be classified as medium sand while Lindbergh should be classified as fine sediment. Magens and Sandy bay beaches had the smallest average MMD and were significantly different from each other (0.206 mm ± 0.007 SEM and 0.17 mm ± 0.002 SEM; $p < 0.01$) but were both within the classification of fine sand (Figure 8 and Table 3).

Although the average MMD differed among the sites, there was not a significant overall relationship between sediment grains size (Φ) and microplastic concentrations (Figure 9; $F_{1,97} = 2.984$, $R^2 = 0.02985$, $p = 0.08726$).

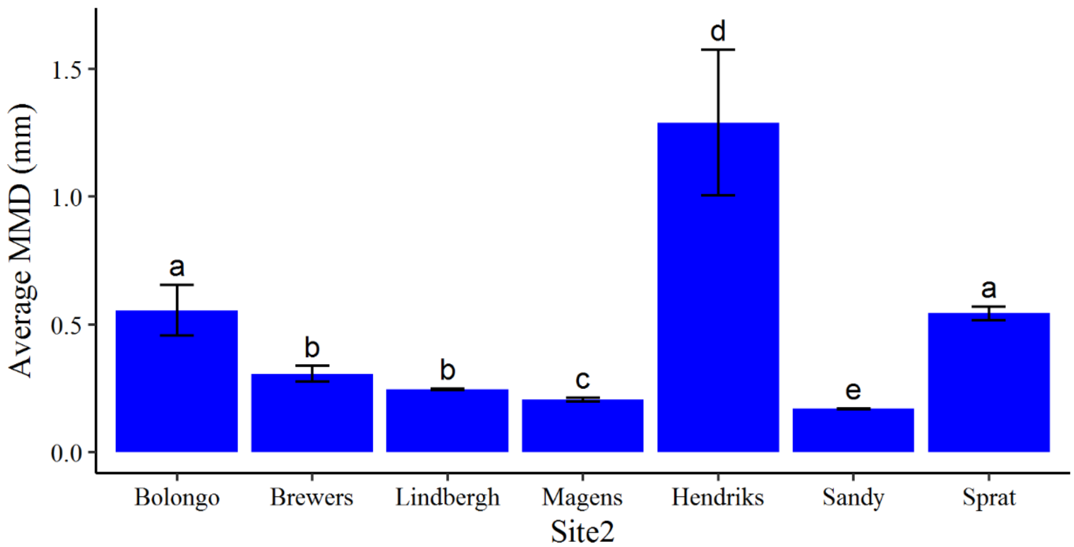

Figure 8: Average mass median diameter (MMD) of beach sediment at each site (± SEM). Letters represent significant difference

Table 6: Wentworth (1922) grain size classification at each site

Site	Average MMD (mm)	Phi Scale (Φ)	Wentworth class
Bolongo	0.555562742	0.84797824	Coarse Sand
Brewers	0.307076228	1.70333126	Medium Sand
Lindbergh	0.246158219	2.02234218	Fine Sand
Magens	0.20600587	2.27924265	Fine Sand
Hendriks	1.290562773	-0.3680003	Very Coarse Sand
Sandy	0.167847243	2.57477926	Fine Sand
Sprat	0.543626662	0.87931188	Coarse Sand

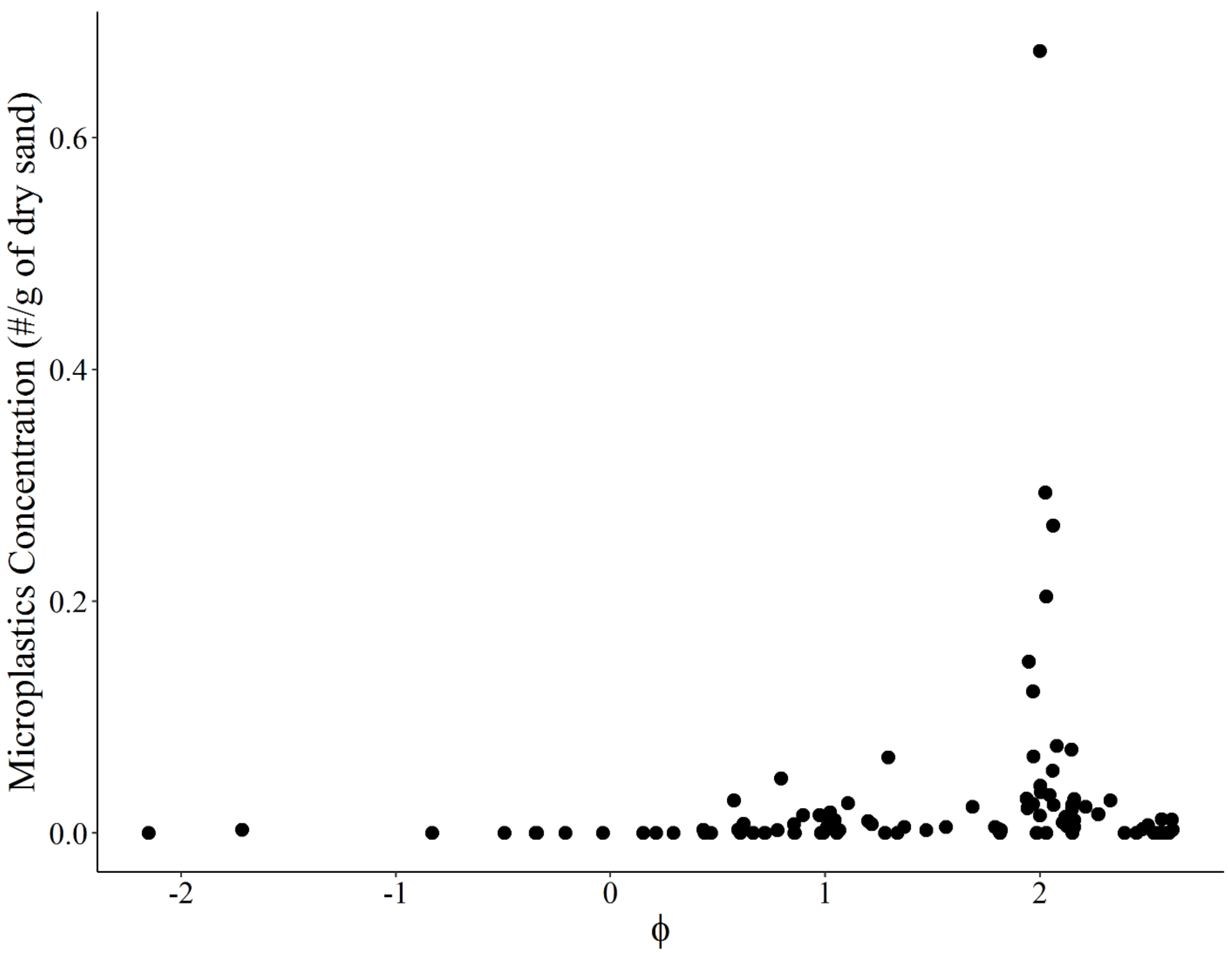

Figure 9:Scatter plot showing overall relationship between sediment grainsize and microplastic abundance.

3.3 Non-metric Multidimensional Scaling Analysis on Watershed Characteristics

The stress of the nMDS analysis was 0.097, showing that the dissimilarities among the sites were well represented in the ordination plot (Figure 10). Microplastic concentrations in the beach sediments were most closely associated with population density, but not with sediment grain size (MMD) and the aspect of the beaches (the cardinal direction of the bay). This illustrates that a large population density could contribute to high microplastic concentrations on beaches while larger grain sizes and the direction of the bay could contribute to lower microplastic concentrations. Lindbergh and Brewers bay sites overlapped because of their larger population densities, while Magens Bay sites showed greatest separation from the other sites based on its larger watershed area. These three sites also had medium to fine sediment grain size. Therefore, microplastic concentrations could be influenced by population density, water shed area, as well as sediment grain sizes.

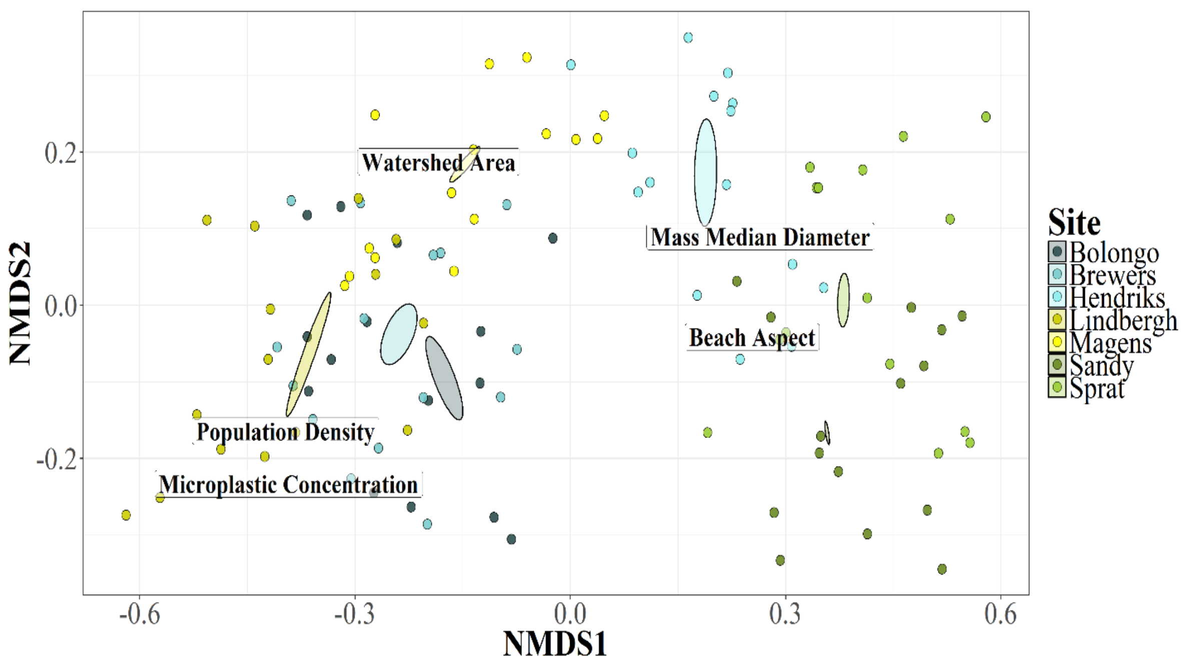

Figure 10: An nMDS ordination plot illustrating the separation of sites due to microplastics concentrations (MP Concentration) and watershed characteristics: Population Density, Watershed Area, Beach Aspect, and Median Mass Diameter (MMD).

3.4 Surface water

Microplastics and microfibers within the 0.3 – 1 mm size fraction were found in surface water samples collected from Bolongo, Brewers, Lindbergh, Perseverance, and Sandy embayments. Only microfibers were found in surface water samples from Magens, Hendriks, and Sprat embayments (Figure 11). Collected surface water samples had higher concentrations of microfibers than microplastics, however, due to variability in the data significant statistical patterns could not be determined between the two categories, and only total microplastics (combined microplastics and microfibers) were tested.

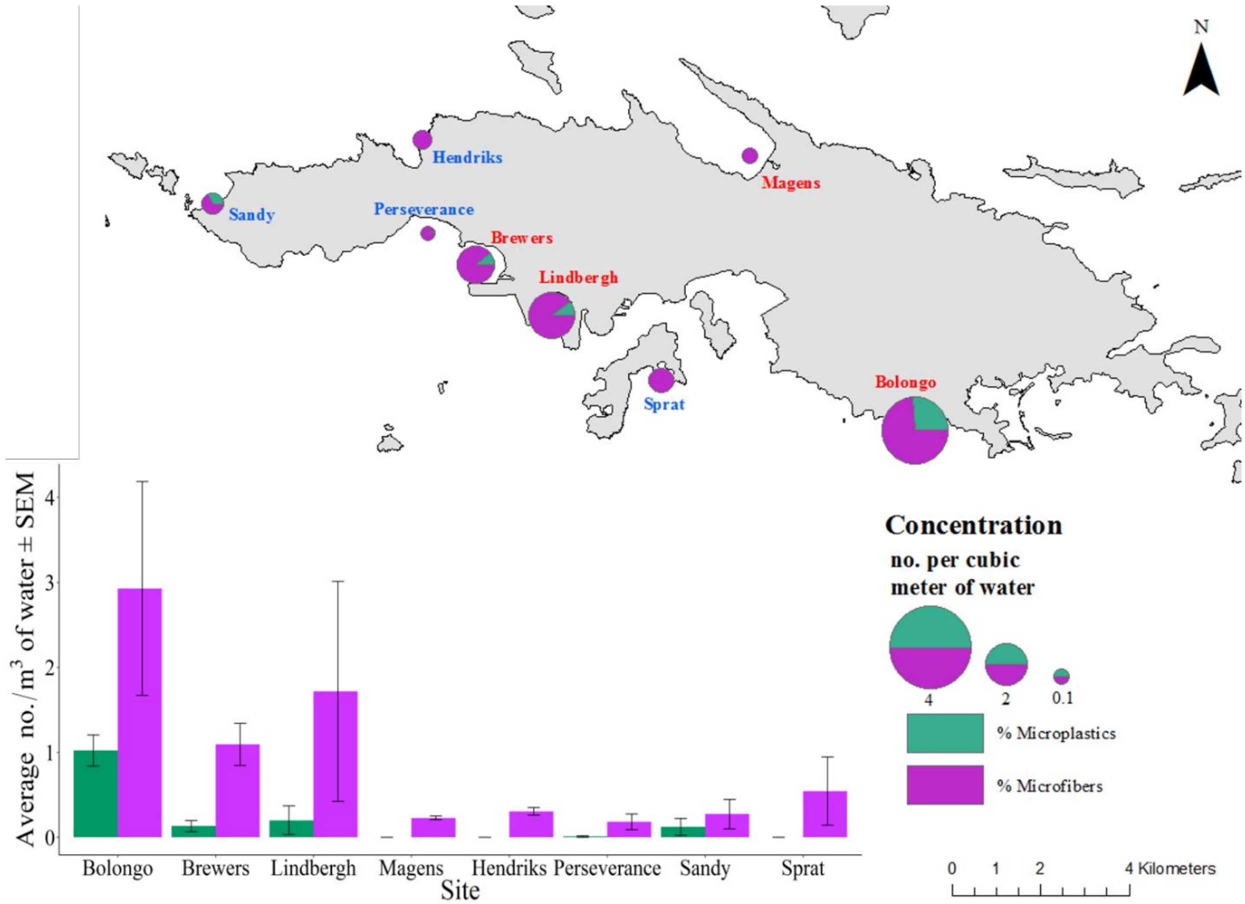

Figure 11: Average concentrations of microplastics and microfiber found in surface waters of each embayment.

Concentrations of total microplastics differed significantly among sites (Figure 12; ANOVA, $F_{7,16}$=4.513, $p < 0.01$). Among the high anthropogenic activity sites, concentrations found in surface waters of Bolongo Bay were higher than those found in Magens Bay ($p < 0.05$; 3.9 pieces/m^3 of water ± 1.11 SEM and 0.23 pieces/ m^3 of water ± 0.021 SEM, respectively), but they were not significantly different from concentrations found in surface waters in Brewers ($p = 0.471$; 1.22 pieces/ m^3 ± 0.21 SEM) and Lindbergh bays ($p = 0.495$; 1.92 pieces/ m^3 ± 1.46 SEM). Although concentrations found in surface waters of embayments experiencing high anthropogenic activity (Bolongo, Brewers, Lindbergh, and Magens bays) were higher than those found in embayments experiencing low anthropogenic activity (Hendriks, Perseverance, Sandy, Sprat), only Bolongo Bay showed a significant difference among Hendriks, Perseverance, Sandy, and Sprat Bays (P-value = 0.03, 0.004, 0.03, and 0.04 respectively).

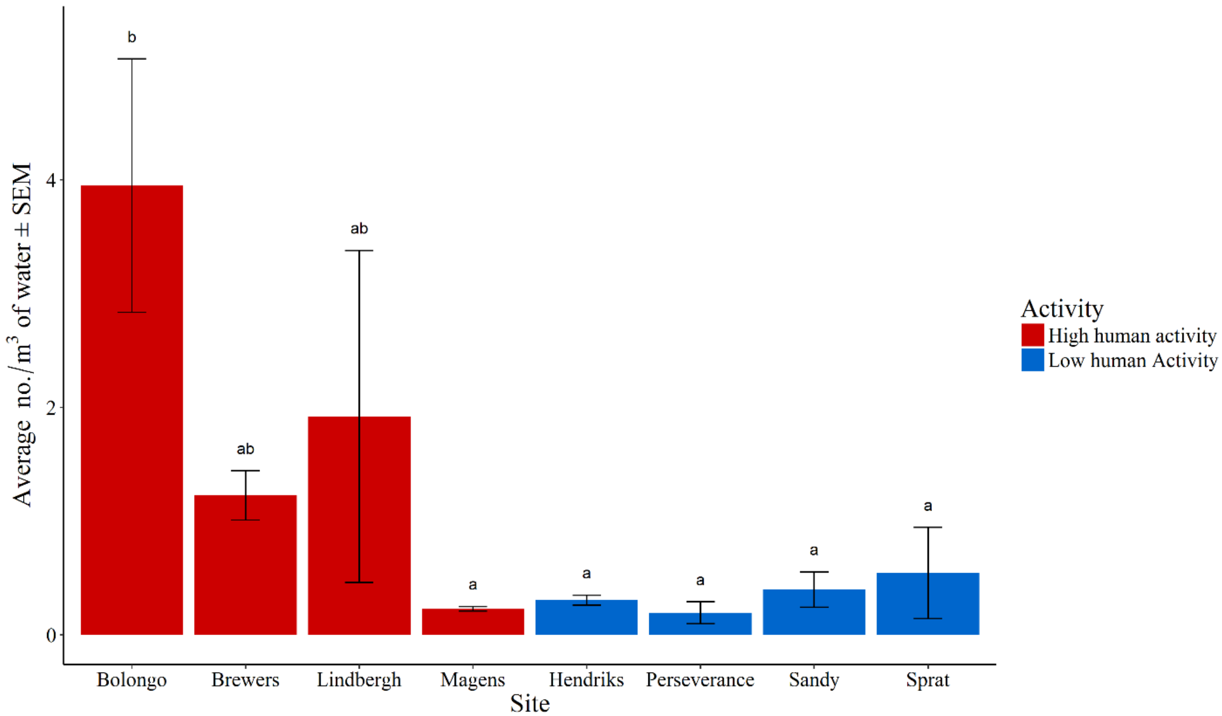

Figure 12: Average total microplastics concentrations found in surface waters at each site

Chapter 4: Discussion

4.1 Microplastic Concentrations on Beaches

Microplastic and microfibers were both found in beach sediment at all sites. Concentrations of microplastics were higher on Lindbergh, Brewers, and Magens beaches which are high human activity sites which supports the hypothesis that microplastic concentrations would be higher in high anthropogenic activity sites than in low anthropogenic activity sites (**H1**). However, this did not hold true for Bolongo Bay, a high anthropogenic site. Microplastic concentrations found on Bolongo beach were not significantly different from those found on beaches in low anthropogenic sites: Hendriks, Sandy, and Sprat bays. Also, concentrations found on Sprat beach were not significantly different from those found on Bolongo, Brewers, and Magens beaches. During collection of beach sediment from Sprat Bay, evidence of human activity, such as beach chairs, portable grills, trash, etc. was seen (Personal observations, September 9, 2016). Therefore, even though Sprat bay has a low population density and no dumpsters within the watershed, the level of usage of the beach by people could contribute to the amount of microplastics.

Finding more microplastics on beaches associated with large population densities in the water shed have been found in past studies elsewhere (Brown et al., 2011; Schmuck et al., 2017). Brown et al. (2011) found a significant positive relationship between the amount of microplastics and the population density living on the coast. Schmuck et al. (2017) also found that beaches that are easily accessible had the highest number of microdebris in the sediments due to high rates of visitation by people. Lindbergh and Brewers beaches are both very accessible from the main roads to residents and tourists, which could also be the source of their high microplastic abundances.

Browne et al. (2011) also found that microplastics were most abundant along shorelines that had a waste water treatment effluent discharge site. Many buildings on island are connected to waste water treatment plants (based on the 2010 US census) and Lindbergh Bay has waste water effluent discharge point near the entrance to the embayment, which could explain the significantly higher abundance of microplastics found on its beaches compared with all other sites. Currents within and around the embayment could carry the discharge onto the beach. However, small-scale currents around the island of St. Thomas have not been quantified, and further research should be conducted on this matter. Many homes on St. Thomas are reliant on septic systems (2010 US census), which could also contribute to the high concentrations. Primary microplastics beads from beauty products and microfibers that have shed from synthetic material while in the washing machine don't settle out in a septic tank, and so they enter the environment directly when water leaves the tank (Whitmire et al., 2017). Therefore, microplastics and microfibers could be entering the marine environment through rain water runoff from land where septic systems are present. However, the significance of input from septic tanks are not well known and requires further research (Whitemire et al., 2017).

Despite having high anthropogenic activity in their associated watersheds, Bolongo, Brewers and Magens Bay beaches had significantly fewer microplastics than Lindbergh beach, and were not much greater than abundances found on beaches that experience low human activity. Bolongo, Brewers, and Magens beaches are each owned by a private entity (Table 7), that routinely cleans the beach as well as provides waste receptacles, whereas Lindbergh Bay beach is not owned or regularly cleaned, and has only one small trash can.

Table 7: List of private entities that own or maintain the beach at each site

Site	Entity	Frequency of Maintenance
Bolongo	Bolongo Beach resort	Daily
Brewers	University of the Virgin Islands	Approximately Weekly
Magens	Magens Bay Authority	Daily

Human littering behavior could also provide insight into why Lindbergh beach had more microplastics than the other high anthropogenic activity sites. The amount of plastic macro litter can contribute to the amount of microplastics in the environment (Mohamed Nor & Obbard, 2014). Schultz et al., (2013) found that littering occurred in areas where large amounts of litter were already present, and where there were no waste receptacles. However, littering was reduced when waste receptacles were provided since it was convenient to do so. Gellar et al., (1980) showed that the strategic placement of waste receptacles in a public space reduced the amount of litter in an area as long as receptacles were maintained and emptied on a regular basis. However, Lehman & Gellar, (2004) mention that providing waste receptacles for proper disposal is an oversimplified solution, and intervenes at the end of the waste stream. They suggest that intervention should occur at the beginning of the waste stream (at the production or consumption of single use items). However, this does provide implications of an immediate solution, conducting regular maintenance and providing waste receptacles on beaches, to reducing large marine debris and thereby microplastics in the marine environment.

Although no standardized method of collecting and quantifying microplastics has been determined, results of this study can still be compared to concentrations found elsewhere. Microplastic and microfiber concentrations are reported in different studies, and is difficult to make comparisons. For example, in table 8, concentrations are reported as number of pieces per square meter (pieces/ m^2) or number of pieces per gram of dry sediment (pieces/ g of dry sediment). Although conversions on reported values from past studies cannot be done, concentrations from this study can be converted to make comparisons. These are highlighted in grey in table 8. Compared to other studies, the average total microplastic concentrations found in St. Thomas, USVI were comparably lower than those found in past studies globally and locally; especially with concentrations found in Virgin Islands National Park in St. John, USVI and Buck Island Reef National Monument, in St. Croix, USVI (Yu et al., 2018). Yu et al., (2018) found concentrations that were significantly larger than this study, despite having low development and low population density on land. This could be due to this study's quantification of microplastic within a limited size range (0.3 – 1 mm) whereas Yu et al., (2018) were able to identify microplastics between 0.01 – 5mm in size. Therefore, quantification within a larger size range in a future study could provide more information on microplastic abundances with in the USVI. An additional explanation for the low concentrations found in this study could be that there are other sinks on island, or after entering the water within the embayment through rain water run-off, microplastic particles may not be pushed back on to the beach. Due to lack of information on small scale ocean currents with in the embayments, it is unknown if microplastics would be pushed back onto shore, settle out in shallow sediments, or carried out to open ocean.

Table 8: Microplastic concentrations found globally and in the Caribbean

Reference	Collected	Location (s)	MP Definition	Size Range Found	Concentrations
Global Concentrations					
Lee et al., 2015	Beach sediment	Beaches along the coast of South Korea	Less than 5 mm	Large microplastic (1-5 mm)	880.4 pieces/ m^2
Wessel et al., 2016	Estuarine beach sediment	Mobil Bay, Alabama, US (northern Gulf of Mexico)	Less than 5 mm	.05 mm - 5 mm	50.6 pieces/ m^2
Abidili et al., 2018	Beach sediment in the litterol zone	North Tunisian Coast (Mediterranean Sea)	Less than 5mm	0.1 mm - 5 mm	316,030 pieces/ g of dry sediment
Digka et al., 2018	Beach sediment	Corfu Island, Northern Ionian Sea	Less than 5 mm	<1 mm (small); 1-5 mm (large)	1760 pieces/ m^2 (Small microplastics); 56.7 pieces/ m^2
Caribbean Concentrations					
Schmuck et al., 2017	Beach Sediment	Wider Caribbean Region	Less than 5 mm	1 mm - 5 mm	1.23 pieces/ m^2
Yu et al., 2018	Beach Sediment	Virgin Islands National Park, St. John, USVI	Less than 5 mm	0.01 mm - 5 mm	306,000-443,000 pieces/ g of sand
Yu et al., 2018	Beach Sediment	Buck Island Reef National Monument, St. Croix	Less than 5 mm	0.01 mm - 5 mm	56,000-123,000 pieces/ g of sand
This Study	Beach Sediment	St. Thomas, USVI	Less than 5 mm	0.3 mm - 1 mm	$9.84*10^{-06}$ / m^2; 0.019572/ g of dry sand

4.2 Grain Size Analysis

Overall, there was no significant relationship between microplastic abundance and sediment grainsize among the sites as well as within each site, except for Magens Bay where there was a weak but significant negative relationship. These results do not support the hypothesis that finer grain size sediment will have higher microplastic concentrations (**$H1_a$**). Seeing a lack relationship is in fact supported by past studies (Browne et al., 2010; Kaberi et al., 2013; Mathalon & Hill, 2014; Alomar et al., 2016). Alomar et al. (2016) quantified microplastics within each sediment size fraction after being separated and weighed, and Brown et al. (2010) quantified microplastics in clay sediments found in estuaries. Both studies found that smaller sediment grainsizes do not contain higher concentrations of microplastics. Grainsize analysis methods used in this study were similar to that of Mathalon & Hill (2014), where they used separate sub samples for grainsize analysis and quantifying microplastics, and found no relationship between sediment grainsize and microplastic abundance. However, in this study, only microplastics found within the 0.3 – 1mm size range were quantified. Materials within 1 – 5mm were not processed; therefore, the lack of a relationship may have been due to the restricted range in sizes of the microplastics quantified.

Sediment grain size among the sites were significantly different, which did not support the hypothesis that they would be similar (**$H1_b$**). Results showed that Hendriks, Bolongo, and Sprat bay beaches had larger sediment grain size, and that they should be classified as having very coarse to coarse sediment based on the Wentworth 1992 classification. The presence of larger grain sizes in these beaches could be due to their exposure to higher wave activity. Due to the aspect of the bays, these beaches are not sheltered when large swells come in. Beaches exposed to large wave activity are mostly comprised of larger grains of sand whereas sheltered beaches are composed of smaller grains of sand (Flemming, 2011). This can explain why microplastic from 0.3-1mm in size are not as abundant, and the processing of the archived samples could provide more information on the relationship between microplastic concentrations and sediment grain size. Sandy bay beach was another site that is exposed to large wave action, but the sediment grain size was significantly smaller, and this site had the lowest abundance of microplastics. Other watershed characteristics differed among sites (**$H1_c$**), and those differences could influence microplastic abundances; however, population density was more closely associated with high microplastic concentrations. Therefore, this provides evidence that population density contributes most to the number of microplastics in coastal marine environments.

4.3 Microplastic in Near Shore Waters

Microplastics and microfibers were both found in near shore surface waters, however, microfibers were more abundant than microplastics. Concentrations of microplastics were higher in Bolongo, Lindbergh, and Brewers surface waters which are all high anthropogenic activity sites. This supports the hypothesis that microplastic concentrations would be higher in high anthropogenic activity sites (**H2**). However, this was not true for Magens Bay, a high anthropogenic activity site. Concentrations in Magens bay surface waters were not significantly different from those found in surface waters of low anthropogenic activity sites (Perseverance, Hendriks, Sandy, and Sprat bay). The high concentrations of microplastics and microfibers found in Lindbergh, Bolongo, and Brewers could be due to the high population density in the associated watershed. Residential homes in the watershed are not connected to waste water treatment plants, and so effluent from washing machines either goes to septic systems or directly into the environment. Bolongo and Lindbergh Bays, however, had the highest concentrations of microfibers of all the sites. Both sites could be experiencing inputs of microplastics from both waste water treatment discharge points near each of these bays and inputs from septic tank systems. Browne et al. (2011) found that microfiber input to the marine environment was from waste water, and the types of fibers found were similar to those that are in clothing. Therefore, the source of microfibers could be waste water effluent from washing machines either directly from residences or from waste-water treatment plants or the combination of both.

Another reason more microfibers were found in Bolongo surface waters could be due to the presence of floating macro algae or seagrass that were caught in the manta net. Microfibers and microplastics have been found to adhere to surfaces of seaweed and algae because of their mucus layer (Nassar et al., 2003; Turner et al., 2012; Gutow et al., 2015). However, pelagic sargassum usually forms in the Atlantic Ocean (Doyle & Frank, 2015), therefore the sargassum found in collected samples from Bolongo could have microfibers and microplastics from the Atlantic Ocean rather from a land based activity within Bolongo Bay's associated watershed. Gutow et al. (2015) also found that microplastics were more likely to adhere to seaweed then microfibers when particle concentrations were high. Knowing this, microplastics within the 0.3 -1 mm size range from samples could have adhered to seaweed that were caught in the 1mm sieve, which could explain why more microfibers were seen than microplastic. Therefore, the processing of archived samples should be completed to fill potential gaps in microplastic concentrations within 0.3-1mm size range.

Higher concentrations of microfibers than microplastic pieces in samples are seen in past studies (Cesa et al., 2017). Cesa et al. (2017) mentions higher microfiber concentrations in various sample types including surface water and beach sediment samples. This study, however, only surface water samples had higher concentrations of microfibers. This is potentially due to the time of year when each sample type was collected. Beach sediment samples were collected during the fall when the island experiences large rain events throughout the season. These large rain events could be bringing secondary microplastic pieces into coastal environments. Surface water samples were collected during the spring when large rain events don't occur as often, therefore microfibers could be from waste water inputs.

Although the high abundance of microfibers in surface waters could be from land, it is possible that they are from a marine source. Jeng et al. (2014) found that fibers found in samples were from the same material in ropes used for moorings, fishing, and fish traps. On the days water samples were collected in Brewers, Lindbergh, and Bolongo, there were several yachts moored or anchored in the bays, as well as marked fish traps scattered through the bays. Therefore, the large number of microfibers in the embayments could be from marine-based human activities.

Microfibers are known to be transported not only by water, but by air as well (Dris et al., 2016; Barrows et al., 2018). Therefore, the presence of microfibers in both surface water and beach sediment could also be due to atmospheric transport. In the late spring and early summer months, the Caribbean is affected by dust from the Sahara Desert transported from Africa (Garrison et al., 2003; Griffin & Kellog, 2004). The extremely high temperatures in the desert causes the sand particles to rise and be transported via trade winds across the Atlantic (Moulin et al., 1997). These dust particles have been found to carry living bacteria and fungi, chemicals, metals, and manmade compounds (Garrison et al., 2003; Griffin & Kellog, 2004). Since the dust travels over Africa's west coast countries where many textile and clothing manufacturers have their factories, it is possible that synthetic fibers are being picked up and transported across the Atlantic and to the Caribbean. Surface water samples from Bolongo, Sandy, Hendriks, and Magens were collected in May of 2017 which corresponds with the greatest deposition of

Saharan dust in St. Thomas, hence any fibers found in these samples could originate from African dust.

Similar to collecting and quantifying microplastics in sediment, there is no standard method for quantification in surface water. In table 9, each study quantified microplastics within different size ranges. Unlike concentrations found in beach sediment, this study's surface water concentrations are similar to other studies from the Mediterranean and Ionian Sea (Collignon et al., 2012; Digka et al, 2018), whereas other studies found higher concentrations in open water (Eriksen et al., 2013; Law et al., 2014). Higher concentrations found in open water could be due to greater sampling effort and sampling within accumulations zones, whereas this study collected coastal surface water samples where accumulation zones may not be present, and only sampled once at each site.

Table 9: Surface water microplastic concentrations found in past studies

Reference	Collected	Location	MP Definition	Size Range Found	Concentrations
Global Concentrations					
Eriksen et al., 2013	Open ocean surface water	South Pacific Subtropical Gyre	Less than 1 mm	0.499 mm- 4.47 mm	26,898,000 pieces/ m^2
Law et al., 2014	Open ocean surface water	Eastern Pacific Ocean	Less than 5 mm	1 mm - 5 mm	33,090,000 pieces/ m^2
Collignon et al., 2012	Surface water	Northwestern Mediterranean Basin	Less than 5 mm	0.333 mm - 5 mm	0.116 pieces/ m^2
Faure et al., 2015	Surface water	Western Mediterranean Sea	Less than 0.3 mm	< 0.3 mm	130,000,000 particles/ m^2
Lusher et al., 2015	Open ocean surface water	Barrent Sea (Arctic)	Less than 5 mm	0.25 mm - 7.71 mm	0.34 pieces/ m^2
Digka et al., 2018	Coastal surface water	Corfu Island, Northern Ionian Sea	Less than 5 mm	Small (<1 mm); Large (1-5 mm)	0.23 pieces/ m^2 (small); 0.18 pieces/ m^2 (large)
Caribbean Concentrations					
This Study	Coastal surface water	St. Thomas, USVI	Less than 5 mm	0.3 mm - 1 mm	0.1136/ m^2

4.4 Management Implications and Future Research

This study provides baseline data on microplastics for St. Thomas USVI, and provides a foundation for further research into microplastics and its impacts on the territory. This study only sampled from each site once, but conducting seasonal or episodic sampling after large rainfall events to monitor for changes in microplastic abundances could provide a better understanding of the dynamics of microplastic abundances around the island (Shmuck et al., 2017). Conducting seasonal or episodic sampling could also provide insight into what influences the abundance and distribution of microplastics on beaches and in surface waters. Also, research on how small-scale surface currents within the bays may transport land-based microplastic inputs could be informative; for instance, are they being carried onto to the beach, carried out to open water, or settling out in the bay?

Even though a spatial pattern of microplastics concentrations on the beach could not be determined, further research could investigate this in more detail. For instance, a future project could look at how microplastic and microfibers are affected by elevation, which was not examined in this study. Understanding how the slope of the beach may impact microplastic abundances may also help determine their potential sources (land versus marine).

Macro plastic debris present on beaches could also have an influence on microplastic abundance (Mathalon & Hill, 2014). Through the International Coastal Cleanup (ICC) events, there is baseline data on large marine debris and small plastic pieces found on Brewers and Lindbergh beaches collected around the same time beach sediment samples were collected. Therefore, data from ICC could be used to determine if there is a positive relationship between larger plastic debris and microplastic debris. Continued collection of beach sediment for microplastics at the same time as the ICC could monitor the relationship between the two variables to provide insight into annual trends and then be used to implement changes in waste management and use of single use items.

This study showed some evidence that the level of use of a beach by people could also have an influence on the amount of microplastics on that beach. For example, Sprat Bay was labeled as a low human activity site, however, the presence of recreational items and some trash on the beach gave evidence that it is being used by people. A future project could study the relationship between the level of beach use or the number of people visiting the beach and microplastic abundance. This also leads into another future project looking at the littering behavior on beaches and within the associated watersheds, as well as making comparisons between managed and unmanaged beaches.

During sample collection of beach sediment and surface waters, reef associated sediments were also collected. However, due to limited time and resources, they were not able to be processed. Therefore, processing of these samples should be done to determine if microplastics are settling and landing on local coral reefs. It has been found that microbial growth can occur on plastic waste and that when coming contact with corals, can cause disease (Zettler et al., 2013; Lamb et al., 2018). Corals have also been found to ingest microplastics due to chemoreception (Allen et al., 2017). If microplastics are present in reef associated sediments, there is a potential they are spreading disease through exposure externally or through ingestion, and this should be researched further.

Future research can also include studying microplastic abundances and distributions throughout the ghuts, mangroves, and sea grass beds to understand what other ecosystems are also impacted by microplastics. Once more knowledge is provided on where microplastics are most abundant around the island, impacts on marine organisms such as fish and coral can be examined.

Chapter 5: Conclusions

Although microplastics and microfibers were mostly abundant in embayments that experience high human activity in their associated watersheds, there are other factors that could be influencing the results of this study. For example, due to limited resources and bad weather, sample collection occurred over the span of nine months. Over that time, weather and seasonal changes occurring within the coastal environment throughout those months could have impacted the results. Additionally, consideration of the profiles and wave exposure of each beach was not taken and data on that was not collected, even though they may potentially influence microplastic abundances.

Usually when quantifying microplastics, a fourier transformed infrared (FTIR) spectroscope is used to provide confirmation that what was found was indeed a synthetic polymer and what type of plastic it was. However, due to limited resources, this additional step was not done, and therefore a false positive could have been made during the microscope examination. For future work, funding should be sought to provide a FTIR spectroscope for the University of the Virgin Islands or to coordinate with other laboratory partners to conduct the analysis. This would ensure accurate data collection and the reporting of accurate results in order to properly inform and influence management efforts

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