Spring 5-15-2016

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BY

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Marine Science

Submitted in Partial Fulfillment of the
Requirements for the Degree of Bachelor of Science
In the Honors Program at
Coastal Carolina University

Spring 2016

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December 16, 2016

Abstract:

Plastics are incredibly durable synthetic polymers used in a wide variety of consumer products. Microplastics are generally defined as plastic debris ranging from 0.33 to 5 millimeters in size. Microplastic pollution in the environment is a global concern because of their propensity to serve as a vector for bioaccumlation and the spread of harmful bacteria. This study characterized the concentrations of floating microplastics in Winyah Bay, South Carolina, the surrounding freshwater river systems, and 10 miles offshore of Winyah Bay. Samples were collected according to NOAA standard techniques for microplastic collection in water using a 335 μm and 153 μm plankton net. Additionally, whole water filtration was done to determine if the current standard sampling methods were overestimating the size of these microplastics. Microplastics were found to be in relatively high concentrations in Winyah Bay, S.C. and were found to be present throughout the environment. The average concentration of microplastics in Winyah Bay was 8.76 microplastics per liter of water. The majority of the microplastics were filamentous in nature, less than 1.5 mm in size, and blue in color. The distribution of the microplastics in Winyah Bay, S.C. and the surrounding river systems followed no distinct and observable trend. Additional research is necessary to gain a more developed understanding on how these microplastics are being transported through this environment. Additionally, larger masses of microplastics in samples obtained using a smaller plankton net size suggests that it is possible that some smaller plastics are able to escape the larger sized nets and that the current standard techniques for collecting microplastics in aquatic environments are being drastically underestimated.

Introduction:

Plastics are durable synthetic organic polymers that are inexpensive to produce and have a wide range of applications in everyday life (Derraik 2002). Because of their durability, plastics are used in common items such as toys, clothing, bags, toothbrushes, food containers, and many other things that are used on a daily basis (Fendall and Sewell 2009, Thompson et al. 2009). In the United States alone, it an estimated 30 millions tons of plastic are produced every year (Derraik 2002). Globally, plastic production reached 280 million tons in 2011 (Derraik 2002, Wright et al. 2013). Plastic litter can easily enter aquatic environments and it has been estimated that plastics make up 60-80% of all marine debris worldwide (Derraik 2002, Desforges et al. 2014). Plastics are found in very high concentrations in the ocean, with a recent estimate of a minimum of 5.25 trillion particles of plastic in the ocean at a weight of 268,940 tons (Eriksen et al. 2014).

Plastic debris can be differentiated into two main categories, macroplastics and microplastics. Macroplastics are commonly defined as plastic debris greater than 5 mm in size, while microplastics are defined as plastic debris that range from 0.33 mm to 5 mm in size (Masura et al. 2015, Wagner et al. 2014, Desforges et al. 2014). While many studies indicate a lower size limit on microplastics, recent evidence suggests that microplastics may be even smaller than 0.33 mm and the lower size limit could possibly be 0 mm (Table 1, Browne et al. 2011, Classens et al. 2011). Microplastics can also be categorized as primary or secondary microplastics. Primary microplastics consist of manufactured microplastics whereas secondary microplastics are produced from the degradation of larger plastics (Browne et al. 2011, Masura et al. 2015, Wagner et al. 2014, Desforges et al. 2014). These fragments of plastic can gradually break down further until they can no longer be seen by the naked eye and because of this small size they are readily available for ingestion by small organisms that are lower in the food chain (Masura et al. 2015, Wagner et al. 2014, Fendall and Sewell 2009). These microplastic particles are less dense than seawater and consequently float at the surface of the

sea, allowing for further global dispersal of these pollutants (Derraik 2002). Because of their vast quantities, capability for global dispersal, potential for carrying toxic substances, and ability for ingestion by organisms, microplastics are a significant threat to marine ecosystems (Derraik 2002, Eriksen et al. 2014).

It is estimated that approximately 70% of marine plastic debris originates from land (Devriese et al. 2015). The likely entry routes for plastic in marine ecosystems are wastewater treatment plants, beach litter, fishery, cargo shipping, harbors, atmospheric deposition, and runoff (Wagner et al. 2014, Desforges et al. 2014, Keller et al. 2010, Dris et al. 2016). Plastic debris can be deliberately dumped into the oceans as it has been dumped commercially in the past in amounts up to thousands of tons (Derraik 2002, Wagner et al. 2014). Plastic debris also intrudes marine environments from accidental and careless behavior, such as being left behind by beachgoers or at marinas and docks, well as the careless handling of solid waste (Derraik 2002, Wagner et al. 2014, Keller et al. 2010). Sewage effluent is proposed to be one of the largest contributors as an entry source for microplastics into aquatic ecosystems (Browne et al. 2011). Microplastics are commonly used in personal care products such as facewashes, and exfoliates, allowing them to easily make their way into wastewater treatment centers (Fendall and Sewell 2009). Polyester fibers are dislodged from articles of clothing during the washing process and retained in the wastewater from washing machines that is later released into environments (Browne et al. 2011). Recent studies have shown that for every wash cycle of common fleece materials, 0 to 2 grams of microfibers are dislodged in the washing process (Hartline et al. 2016). Microplastic analysis of sewage wastewater has shown that fibers found in wastewater effluent were mainly derived from washing clothes rather than the use of cleaning supplies and fragmentation of larger plastics (Browne et al. 2011). Clothing fiber has been identified as the largest constituent of fibrous plastics found in marine environments (Keller et al. 2010).

Various factors can affect the distribution of microplastic debris in marine environments such as debris color, size and shape; water circulation patterns and speed, wind speed, and proximity to anthropogenic sources (Browne et al. 2011, Wagner et al. 2014, Desforges et al. 2014, Devriese et al. 2015, Law et al. 2010, Moret-Ferguson et al. 2010). Microplastics are found in much higher concentrations in nearshore regions, which are closer to anthropogenic sources (Desforges et al. 2014). Microplastics have been found to contaminate coastal shorelines in magnitudes of 1-40 particles per 250 milliliters of sand (Browne et al. 2011). Sediments on a Belgian beach were found to contain 49-391 particles of plastic per kilogram of sediment (Classens et al. 2011). Plastic particles were found to be present in 96% (46/48) of water samples taken in the South Pacific gyre (Eriksen et al. 2013). The average abundance of plastics in these samples was found to be 26,898 particles per square kilometer of water with an average mass of plastic of 70.90 grams per square kilometer of water (Eriksen et al. 2013). In the subtropical North Atlantic gyre, 60% (3682/6136) of samples contained plastic, with amounts ranging from 0-200,000 particles of plastic per square kilometer of water (Law et al. 2010). The Yangtze Estuary that flows into the East China Sea has been found to have plastic particle concentrations ranging from 500-10,200 particles per cubic meter of water (Zhao et al. 2014).

Mircroplastic debris has proven to be an imminent threat to both freshwater and marine ecosystems worldwide (Masura et al. 2015, Wagner et al. 2014, Derraik 2002). Plastic can modify the environment by accumulating on the seafloor and inhibiting porewater gas exchange, resulting in anoxic and hypoxic bottom waters (Derraik 2002). Although the full impact of these microplastic particles is not fully understood, previous studies have indicated a wide range of issues associated with microplastic particles including their ability to act as a sink for chemical contaminants, as well as wildlife ingestion of these particles (Browne et al. 2011, Masura et al. 2015, Wagner et al. 2014, Derraik 2002).

Ingestion of plastics has been observed as a threat to 267 different species worldwide (Derraik 2002). The extent to which microplastics have disrupted the environment can be noted

in the discovery of microplastic ingestion in diverse phyla in deep sea species (Taylor et al. 2016). These findings show the persistence of human pollution, such as microplastics, to disrupt environmental health for extended periods of time, as well as the propensity for microplastics to be transported from one ecosystem to another. And while ingestion of macroplastics is well documented in causing diminished feeding, lowering hormone levels, reproductive failure, and the blockage of enzyme secretion, very little is known about the cellular effects of microplastic ingestion (Derraik 2002). Although the effects of microplastic are not fully known, the ingestion of microplastics has been well documented. 63% of brown shrimp assessed in the North Sea were found to have the presence of microplastic fibers of varying sizes in their gut content (Devriese et al. 2015). Both pelagic and demersal fish in the English Channel were found to have ingested plastic (Lusher et al. 2012). A large variety of other marine species have been found to ingest microplastics including Norwegian lobster in the Clyde Sea (Murray and Cowie 2011), suspension feeding sea cucumbers (Graham and Thompson 2009), marine mammals such as dolphins (Denuncio et al. 2011), and seabirds (Van Franeker et al. 2011). Studies have now revealed that a variety of species of zooplankton are capable of ingesting microplastic particles of various sizes and that the plastic particles were able to adhere to the appendages of the zooplankton as well as negatively impact the feeding rates of the specimens (Cole et al. 2013). The uptake of microplastic by zooplankton can be particularly problematic because this could later lead to the trophic transfer of microplastic and human consumption of microplastics (Cole et al. 2013). One study has revealed that when *Daphnia manga* was exposed to microplastic fibers, mortality rates were increased after 48 hours and *D. manga* was unable to recover from exposure to these fibers (Jemec et al. 2016).

Microplastics have been identified as a vector for various chemical contaminants, metals, and pathogens, increasing the risk of toxicity in organisms that ingest these plastics (Wagner et al. 2014, Browne et al. 2013, Ashton et al. 2010). Microplastics have been found to accumulate persistent, bioaccumulative, and toxic compounds such as PCBs and DDT (Engler

2013). Aside from chemical contamination, microorganisms are able to develop biofilms on the surface of these microplastics and offer a new habitat to microbial communities as well as some human pathogens, which suggests that microplastics could have a negative impact on water quality (Zettler et al. 2013). Research suggests that advanced microbial communities with phototrophy, symbiosis, heterotrophy, and active cell growth can be found on plastic particles (Zettler et al. 2013). Many of these bacteria have been identified as cyanobacteria and diatoms, although single plastic particles have been found to house over a thousand different species of bacteria (Zettler et al. 2013). These pollutants and pathogens can easily be transferred into filter feeders through the ingestion of microplastics and subsequently reach higher levels of the food chain through trophic transfer (Derraik 2002, Wagner et al. 2014). Additionally, the evidence of bacterial ecosystems thriving of the surfaces of these microplastics and the widespread dispersal of microplastics indicates that microplastics could act as a protagonist for the transport of invasive species of bacteria and algae into new ecosystems (Zettler et al. 2013, Maso et al. 2007). Studies have found the presence of harmful dionflagellate species on plastic surfaces in both the Mediterranean Sea and the Atlantic (Zettler et al. 2013, Maso et al. 2007).

The overwhelming evidence of the harmful impacts of microplastics has created a recent movement to ban the production of microbeads in cosmetics in favor of using various types of biodegradable plastics (Rochman et al. 2015). Others have suggested that clothing makers and designers of washing machines are also at fault and should take it upon themselves to design more environmentally conscious products to combat this issue (Browne et al. 2011). Litter from recreational activities runoff also constitute for a large portion of the plastic debris found near shore and consumers also need to be more conscious of the final destinations of the products they use in everyday life (Keller et al. 2010, Browne et al. 2011).

Winyah Bay, South Carolina is a partially mixed estuarine system with moderate stratification and semidiurnal tides (Goni et al. 2009). Winyah Bay is one of the largest estuarine systems on the east coast, with a drainage basin of 47,060 km^2 and an average depth of 4.2

meters (Goni et al. 2009). Winyah Bay has various freshwater inputs from rivers draining into the bay including the Waccamaw River, Black River, Sampit River, and Great PeeDee River (Patchineelam et al. 1999). High levels of industrialization and disposal of wastes into this system, particularly from the paper mill, steel mill, and sewage treatment center result in elevated amounts of pollution in the lower portion of Winyah Bay (Patchineelam et al. 1999). The Sampit River is an industrialized river and the Waccamaw River receives treated wastewater effluent, while the Great Pee Dee River and Black River are considered to be scenic, more pristine rivers. Winyah Bay flows into the South Atlantic Bight which borders the subtropical North Atlantic Gyre.

The objective of this study was to analyze the presence and abundance of microplastics in Winyah Bay, South Carolina and the surrounding river systems in order to hypothesize the sources of microplastics in the ocean. Water samples were collected from various locations in Winyah Bay and in the Pee-Dee River systems near the sewage effluent run off areas. It was hypothesized that microplastics would be found in Winyah Bay, and would likely increase with proximity to the location where sewage treatment effluent is released into Winyah Bay. A second objective for this study was to compare the common methodologies for collecting and analyzing microplastics in the water column. Three sampling methods were used in this study including whole water sample filtration and the standard NOAA procedures using two varying plankton net sizes. It was hypothesized that there is actually no lower limit to the size of microplastics in the water column and that the current standard practices for collecting microplastics are less efficient due to the large net sizes being unable to collect smaller plastic particles.

Methods:

Sampling Stations

Water samples were collected over an 8-month timespan at various locations in Winyah Bay, South Carolina and off the coast of South Carolina as well as rivers that lead into Winyah Bay including the Sandpit River, Waccamaw River, Black River, and Great Pee Dee River (Figure 1). Sampling route one included the Winyah Bay estuary and the Waccamaw River and was conducted on two dates; April 20, 2016 and August 15, 2016 (Figure 1B). Sampling route two included the Sampit River, the Black River, and the Great Pee Dee River and was conducted on two dates; May 6, 2016 and August 20, 2016 (Figure 1C). Sampling route three included four locations along a transect that spanned from the mouth of Winyah Bay to a site 10 miles offshore and was conducted on November 6, 2016 (Figure 1D). At each sample location, temperature, salinity, and dissolved oxygen were recorded using a YSI Pro 2030 *in situ*. Turbidity was also measured using a Hach 2100Q Portable Turbidity Meter and seechi depth was measured using a seechi disk. At each station, water samples were collected and analyzed according to NOAA laboratory methods for analysis of microplastics in water samples (Masura et al. 2015). Additionally, at each station whole water samples were collected.

NOAA Standardized Technique for Sampling Microplastics in Water

A 335 μm mesh plankton net and a 153 μm mesh plankton net were towed from a boat to collect surface water. A General Oceanics flow meter was attached to each of the plankton nets and used to calculate the volume of water towed for each sample. After each net tow was complete, the nets were rinsed with deionized water and the contents of the nets were transferred to glass bottles. The samples were then sieved through an arrangement of 5.6 mm to 0.15 mm sieves. Anything retained in the 5 mm sieve was archived and discarded. Only content retained in the 0.3 mm sieve was collected for the samples collected in the 335 μm net, as stated in the NOAA standard method. However, to identify the presence of smaller

microplastics, the content that was retained in the 0.15 mm sieve was collected from the samples obtained using the 153 μm net. The sieved solids were then transferred to beakers and dried at 90°C for 24 hours (Masura et al. 2015).

The dried solids were then exposed to a wet peroxide oxidation (WPO). Iron(II) was used as a catalyst to digest organic matter while the plastic debris remained. The remaining WPO solution underwent density separation in a NaCl aqueous solution. The floating solids were collected in a clean sieve. The collected solids were dried at 90°C for 24 hours. The remaining dry solids were then examined under a 40X-dissecting microscope. The mass of all microplastics was then be calculated using Formula (1) (Masura et al. 2015).

(1) mass of vial with plastics – mass of vial = mass of all microplastics

The final results were reported in mass of microplastics per cubic meter (mg/m^3). This was calculated using the mass of all microplastics found in Formula (1) and the calculated volume filtered through the plankton nets found using the flow meter.

Whole Water Samples

Whole water samples were collected from surface water at each station and stored in a glass jar. Four 200 mL samples were obtained at each sampling station. Each sample was filtered through a 5-micron filter and then analyzed under a dissecting microscope for the presence of microplastics. Plastic particles were categorized by type as beads, angular fragments, or as fibers. Additionally, the plastic particles were categorized by color and size. In order to approximate the sizes of the microplastic pieces, the sizes of the grid lines on the filter paper was used. Each grid line was 3 mm in length, so the microplastics were categorized as being less than half of one grid line (0-1.5 mm), between one half and one gridline in length (1.5 mm – 3 mm), or greater than one grid line in length (>3 mm).

The presence and concentrations of microplastics was analyzed spatially to determine the possible sources of microplastics into Winyah Bay and to analyze the ecological threat of microplastics in this particular environment. The concentrations of microplastics detected at each sampling site using the three sampling methods were compared in order to identify the most efficient form of methodology for the sampling of microplastics in the water column and to determine a lower size limit for the definition of microplastic.

Results:

The plastics identified in whole water samples were categorized based on shape, size, and color. In total, 152 whole water samples were collected. Of the 152 whole water samples analyzed, 120 samples were found to contain plastic particles. Concentrations of plastic particles found in whole water samples ranged from 0 plastic particles per liter of water to 27.5 plastic particles per liter of water. In the Winyah Bay environment, the average concentration of microplastics collected using whole water filtration was 8.76 plastic particles per liter of water. Across all of the samples, 284 plastic particles were identified. Of these 284 plastics, 60% were found to be between 0-1.5 mm in size, 29% were found to be between 1.5 and 3 mm in size, and 11% were found to be greater than 3 mm in size (Figure 2). The most frequently observed type of plastic was filamentous, making up 96.8% of the plastics observed (Figure 3). The second most frequent type of plastic was angular in shape, making up 2.8% of the plastics, and the remaining 0.4% of microplastics were beads (Figure 3). The most common color of plastic observed was blue (Figure 4). It was observed that 70.4% of plastics were blue, 8.8% were clear, 5.2% were grey, 4.2% were red, 4.2% were black, and the remaining 7.2% were pink, green, yellow, white, or orange (Figure 4).

From the sampling event on April 20, 2016 to the event on August 15, 2016, plastic concentrations decreased at the mouth of Winyah Bay (Figure 5, Figure 8, Figure 9). Contrasting this, plastic concentrations increased in the inner region of the estuary and in the Waccamaw River (Figure 5, Figure 8, Figure 9). From the sampling event on May 6, 2016 to the event on August 20, 2016, plastic concentrations decreased in Sampit River, Black River, and Great Pee Dee River (Figure 6). The highest concentrations of plastics found in whole water samples were found in the Black River and in the offshore region (Figure 6, Figure 7). Contrasting this, the highest concentrations found using the standard sampling techniques indicated that the highest concentrations of microplastics were found in the Sampit River (Figure 10, Figure 11).

In total, 38 samples were collected using the 335 μm plankton net and 38 samples were collected using the 153 μm plankton net. One sample was discarded after being dropped. Plastics were identified in all of the 75 net samples analyzed. The mass of plastics per volume for each of the stations collected in the 335 μm net ranged from 0.1 mg - 4 mg. The mass of plastics per volume for each of the stations collected in the 153 μm net ranged from 0.1 mg - 6 mg. For all sampling events, samples collected in the 153 μm net had larger masses of microplastics per volume than those collected in the 335 μm net (Figure 8, Figure 9, Figure 10, Figure 11, Figure 12).

Discussion:

Microplastics were detected in samples using whole water filtration and the NOAA standard methods for microplastic collection consistently at almost all stations sampled in this environment. The average concentration of microplastics found in Winyah Bay via whole water filtration was 8.76 plastic particles per liter of water. Given the large size of Winyah Bay, these findings suggest that microplastic contamination is a very serious threat to the Winyah Bay ecosystem. The concentrations of microplastics in Winyah Bay and the surrounding river systems followed no observable trend in distribution across Winyah Bay or the surrounding rivers. The varying concentrations found across Winyah Bay could be influenced by a wide variety of environmental factors such as rainfall, mixing patterns, salinity, wind, etc. Further research is needed in order to understand how these microplastic particles are circulating throughout the rivers and the bay.

It was observed that the majority of the plastics identified were filamentous in nature (Figure 3). A previous study conducted in Great Lake Tributaries also observed similar trends in that the majority of microplastics identified were fibers (Baldwin et al. 2016). Although this study is not able to directly pinpoint a source of microplastics in the environment, the higher frequencies of filamentous microplastics can suggest a possible source for plastics in this ecosystem. Clothing fibers have previously been identified as the largest constituent of fibrous plastics found in marine environments, suggesting that in this environment the release of clothing fibers into the environment from wastewater treatment centers could have a significant impact on the concentrations of plastics found (Keller et al. 2010). Polyester fibers from clothing can be dislodged during the washing process and retained in the wastewater from washing machines (Browne et al. 2011). Recent studies have shown that for every wash cycle of common fleece materials, 0 to 2 grams of microfibers are dislodged in the washing process (Hartline et al. 2016). This finding can be problematic and suggest environmental health threats for Winyah Bay because microplastic fibers have been found to have serious health implications

when ingested by aquatic organisms, particularly *D. manga*, and the organisms such as this readily uptake microplastic fibers when made available (Jemec et al. 2016).

The majority of the microplastics documented in this study were blue in color (Figure 4). Previous studies have not documented the color frequencies of microplastics found in aquatic environments, although the color frequencies could play a role in microplastic ingestion. Further research could be done in order to determine if there is preferential selection and ingestion of certain colors of microplastics and the impacts that can have on bioaccumulation.

It was observed that the majority of plastics identified were less than 1.5 mm in size (Figure 2). A previous study conducted in Great Lake Tributaries also observed similar trends in that the majority of microplastics were between the sizes of 0.35 mm and 0.99 mm in size (Baldwin et al. 2016). This finding can be problematic because smaller microplastic particles make plastic ingestion a larger risk to smaller aquatic organisms, which can lead to elevated bioaccumulation rates of microplastics. Smaller microplastics also have higher surface area to volume ratios and make them more adept to function as transport vectors for sorbed chemical pollutants.

Although it was hypothesized that concentrations of plastics would increase with proximity to the source of wastewater effluent in this environment, no such trend was observed. The results of previous studies in regard to wastewater as a source for microplastics has been varied. Some studies have been able to identify wastewater as a direct source for microplastics in the environment, while other studies have shown that most filamentous microplastics settle out in the sludge during the wastewater treatment process (Browne et al. 2011, Carr et al. 2016). At this point, the source of these microplastics can only be speculated. Based on the observation of predominantly filamentous microplastics, a possible source for these microplastics is clothing fiber and fishing line. Another possible source for the filamentous plastics is through atmospheric deposition. One study has found that fiber deposition from the atmosphere in Paris had rates up to 100 plastic fibers per m^2 per day in urban regions (Dris et

al. 2016). Possible sources for the fragmented microplastics could be degradation of other macroplastics while the sources for the pellets could be industrial release or wastewater effluent containing personal care products with microbeads.

The presence of microplastics in the smaller sized 153 μm plankton net suggests that the smaller mesh size is useful in obtaining a better idea of microplastic contamination in aquatic environments. Comparing the samples collected in the 153 μm net and the 335 μm plankton net at each individual site, it can be observed that larger masses of microplastics per volume were typically found in the 153 μm net (Figure 8, Figure 9, Figure 10, Figure 11, Figure 12). However, it is important to note that the 335 μm net samples were sieved in order to only capture microplastics between the sizes of 0.3 mm and 5 mm in size, whereas the 153 μm net was sieved in order to collect the sizes 0.1 mm and 0.3 mm. The concentrations of microplastics found in 153 μm net represent the concentrations of microplastics that are being ignored through the standard sampling techniques. The high masses of microplastics found in the 153 μm net suggest that using the standard sampling technique using a 335 μm net leads to drastically underestimated microplastic concentrations. Additionally, the concentrations found in the whole water samples were much higher than those found using plankton nets. Although the microplastics observed in the whole water samples were of the proper size to be collected in the plankton nets, it is possible that because of their predominantly filamentous shape, that they are able to pass through the nets or the sieves when oriented correctly, regardless of size. This discovery suggests that studies in the future should modify the standard sampling techniques to use smaller mesh sizes in order to more accurately report microplastic concentrations.

The results of this study add to the general knowledge of the presence microplastics in aquatic environments and the concentrations of microplastics that can be found in blackwater river systems such as Winyah Bay, S.C. Future studies in Winyah Bay, S.C. could should aim to observe the microplastic concentrations over a longer time span in order to develop an understanding of how microplastics flux in and out of this environment over time. Further

investigation is also needed in order to pinpoint the direct sources of microplastics in this environment as well as the fate of these microplastic particles. Further investigation could also analyze microplastic concentrations with relation to rainfall and runoff into the Winyah Bay environment.

Table 1. Table summarizing previous studies' collection techniques and standard size definitions for microplastics.

Study	Sampling Method	Microplastic Size Definition	Location
Eriksen et al. 2014	0.33 mm plankton net	0.33-4.75 mm	Worldwide
Browne et al. 2011	Whole water filtration	<1 mm	Worldwide
Desforges et al. 2014	Whole water collection, varying sieves as small as 62.5 µm	0.333-5 mm	NE Pacific Ocean
Eriksen et al. 2013	0.33 mm plankton net	0.355-4.75 mm	South Pacific subtropical gyre
Moret-Ferguson et al. 2010	0.335 mm plankton net	none	North Atlantic Ocean
Zhao et al. 2014	0.333 mm plankton net	0.5-5 mm	Yangtze Estuary, China

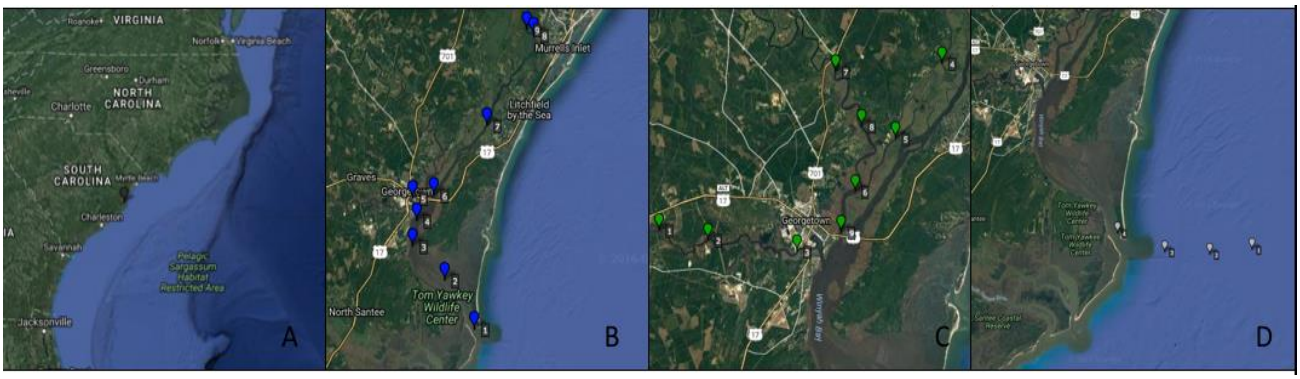

Figure 1. Map A indicates the location of Winyah Bay, S.C., in relation to the East Coast. Map B indicates Sampling Route One that included the Winyah Bay estuary and the Waccamaw River. Map C indicates Sampling Route Two that included the Great Pee Dee River, the Sampit River, and the Black River. Map D represents Sampling Route Three that included stations at the mouth of the Winyah Bay estuary and a transect that extended 10 miles off the coast of South Carolina.

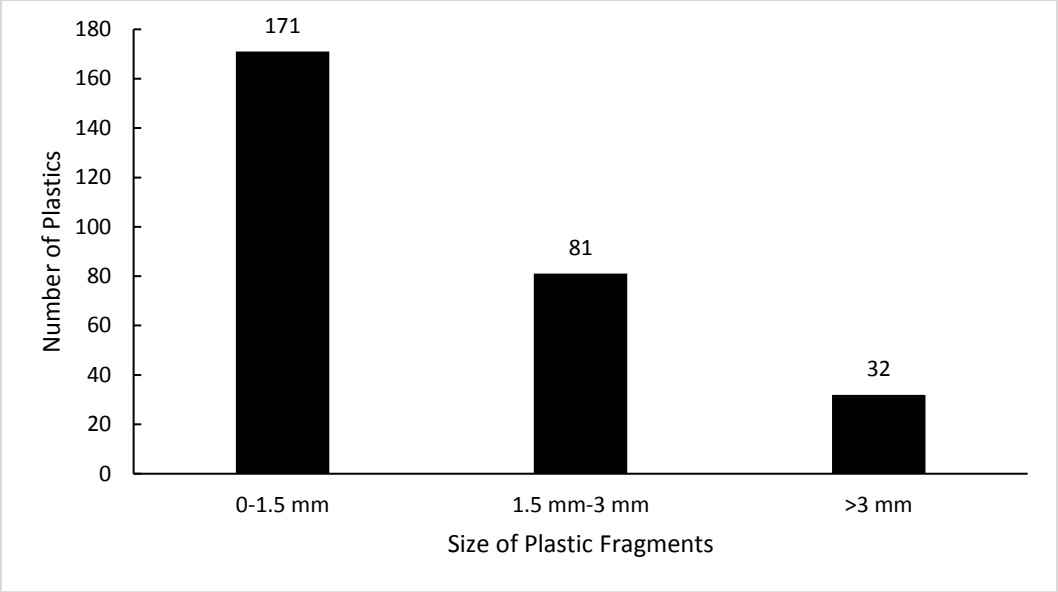

Figure 2. The number and sizes of plastic particles observed in all whole water samples. 60% of plastics were between 0 and 1.5 mm in size, 29% of plastics were between 1.5 and 3 mm in size, and 11% of plastics were greater than 3 mm in size.

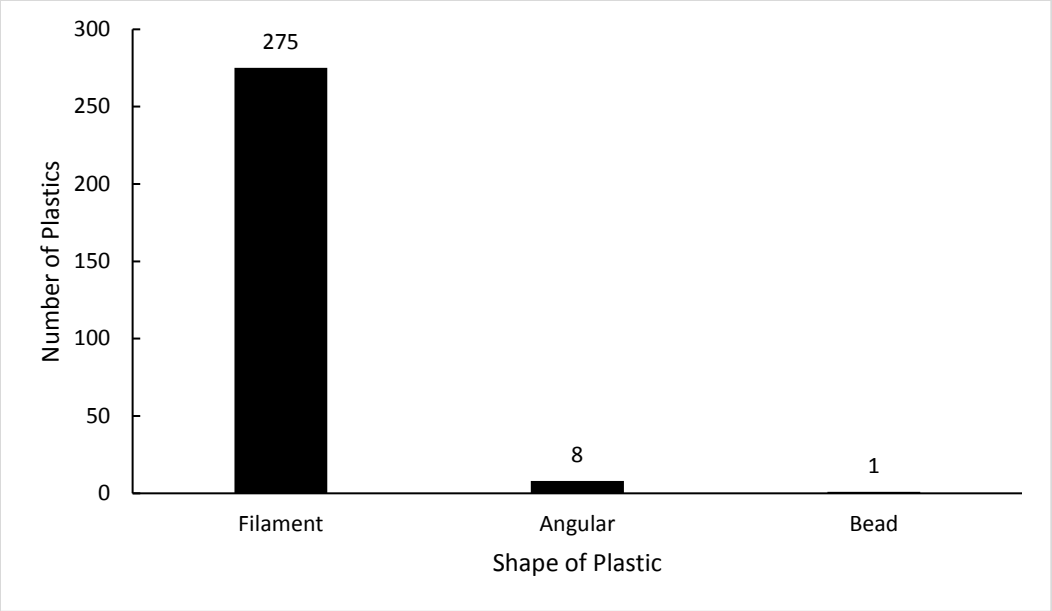

Figure 3. The number and types of plastic particles observed in all whole water samples. 96.8% of plastics observed were filamentous, 2.8% were angular, and 0.4% were beads.

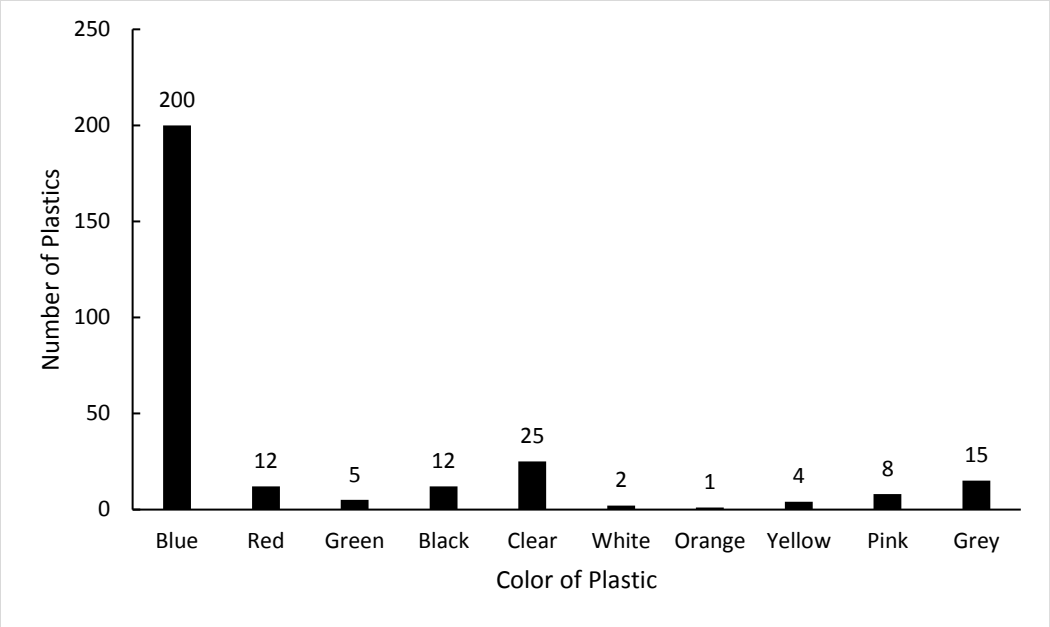

Figure 4. The number and colors of plastic particles observed in all whole water samples. 70.4% of plastics were blue, 8.8% were clear, 5.2% were grey, 4.2% were red, 4.2% were black, and the remaining 7.2% were pink, green, yellow, white, and orange.

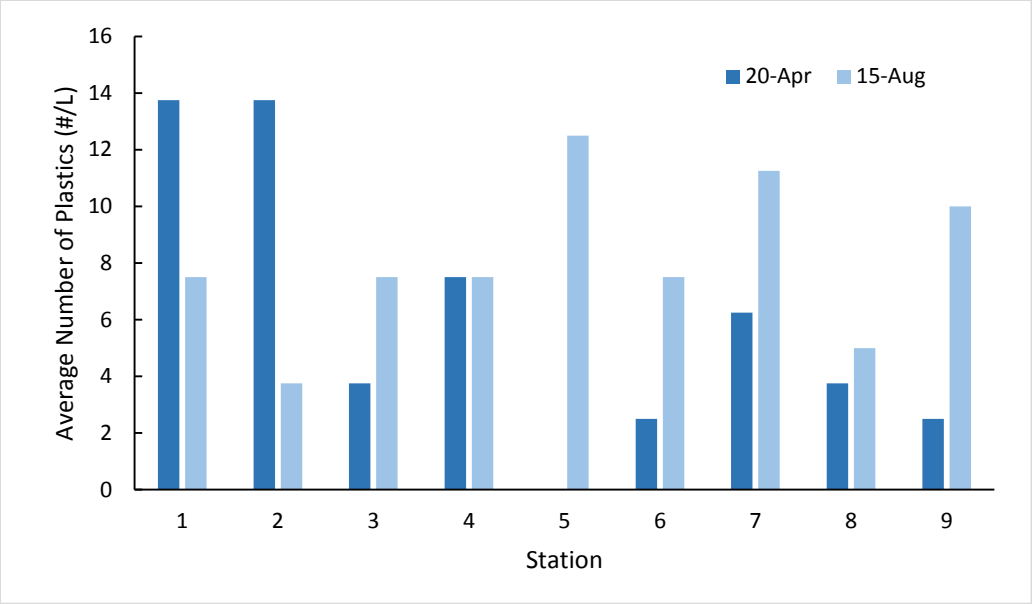

Figure 5. Average number of plastics per liter found in whole water samples of Sampling Route One on two sampling dates. Stations 1 through 5 represent stations in the Winyah Bay estuary and stations 6 through 9 represent stations in the Waccamaw River. Station 5 was not sampled on April 20, 2016.

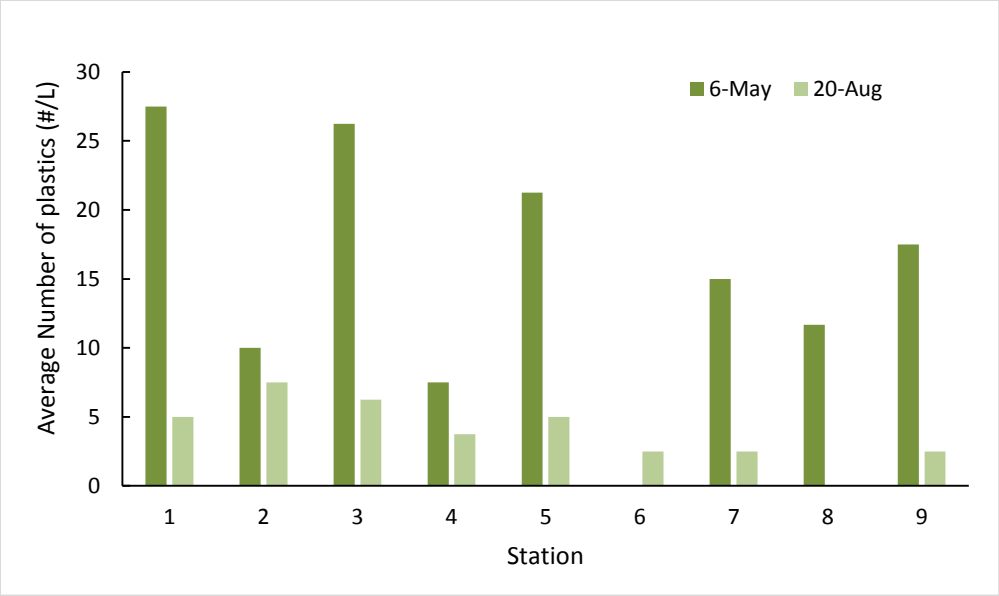

Figure 6. Average number of plastics per liter of water found in whole water samples of Sampling Route Two on two sampling dates. Stations 1 through 3 represent the Black River, while stations 4 and 5 represent the Great Pee Dee River. Stations 7 and 8 represent the Sampit River, and stations 6 and 9 represent the mixing zone of the Sampit and Great Pee Dee Rivers. Station 6 was not sampled on May 6, 2016.

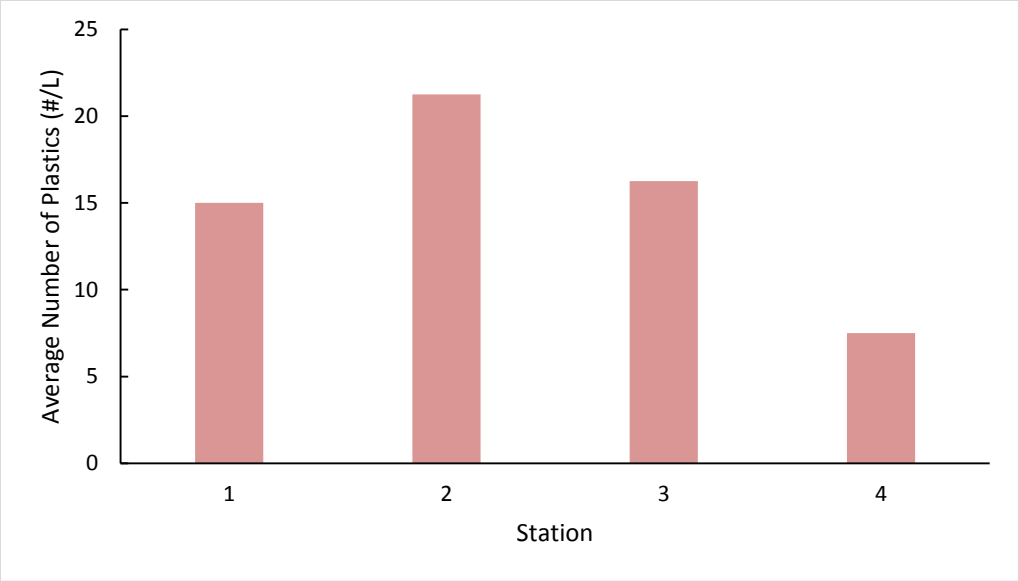

Figure 7. Average number of plastics per liter of water found in whole water samples in Sampling Route Three on November 6. 2016. The route includes a 10-mile long transect off the coast of Winyah Bay, S.C. Station 1 is located 10 miles off shore and station 4 is located at the mouth of the bay.

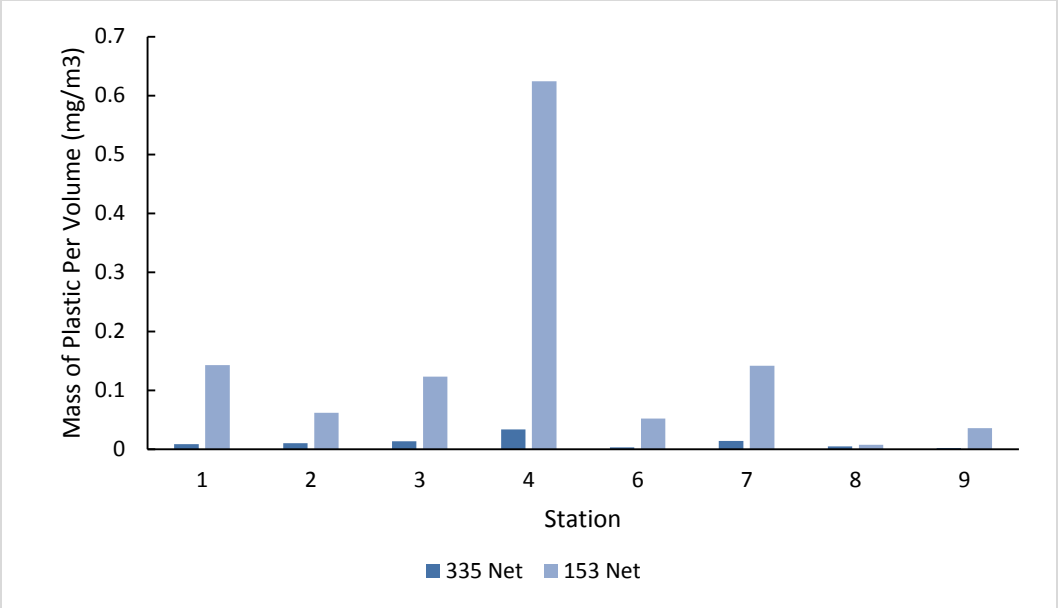

Figure 8. A comparison of the mass of plastics per volume collected using the 335 μm net and the 153 μm of Sampling Route One conducted on April 20, 2016. Stations 1 through 5 represent stations in the Winyah Bay estuary and stations 6 through 9 represent stations in the Waccamaw River.

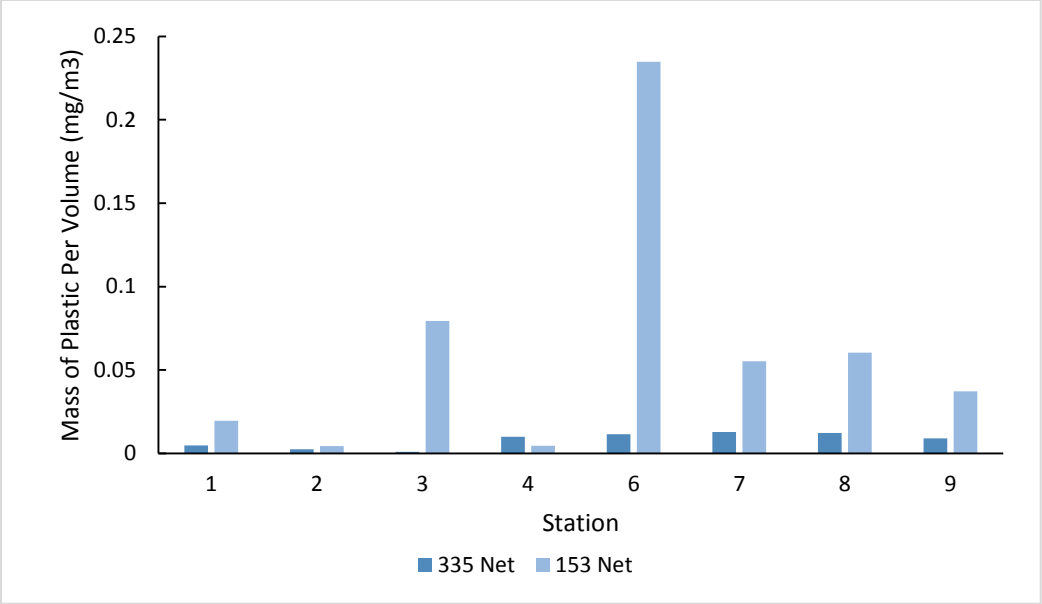

Figure 9. A comparison of the mass of plastics per volume collected using the 335 μm net and the 153 μm of Sampling Route One conducted on August 15, 2016. Stations 1 through 5 represent stations in the Winyah Bay estuary and stations 6 through 9 represent stations in the Waccamaw River.

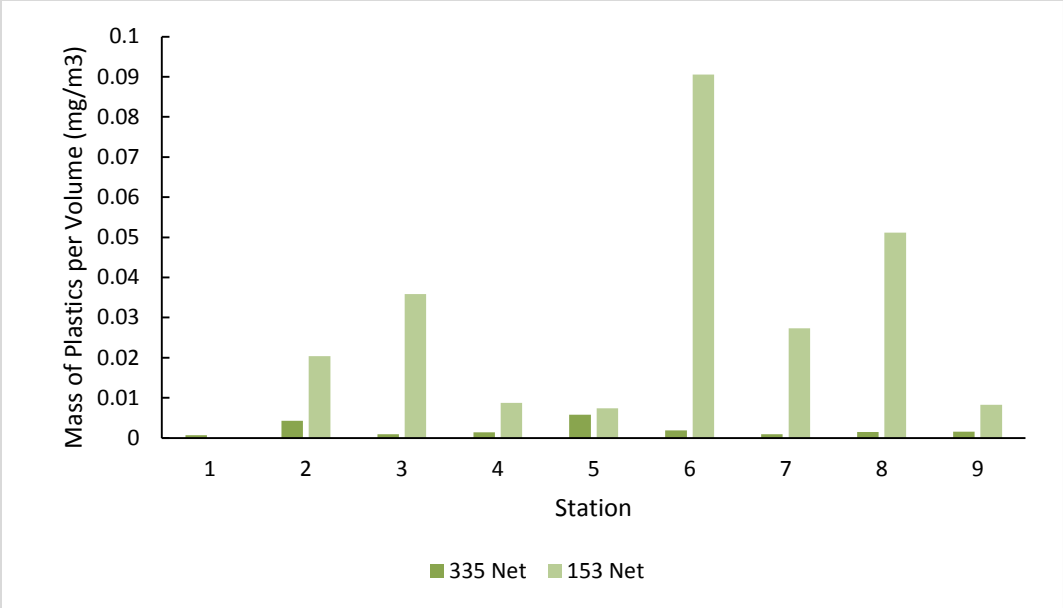

Figure 10. A comparison of the mass of plastics per volume collected using the 335 μm net and the 153 μm of Sampling Route Two conducted on May 6, 2016. Stations 1 through 3 represent the Black River, while stations 4 and 5 represent the Great Pee Dee River. Stations 7 and 8 represent the Sampit River, and stations 6 and 9 represent the mixing zone of the Sampit and Great Pee Dee Rivers.

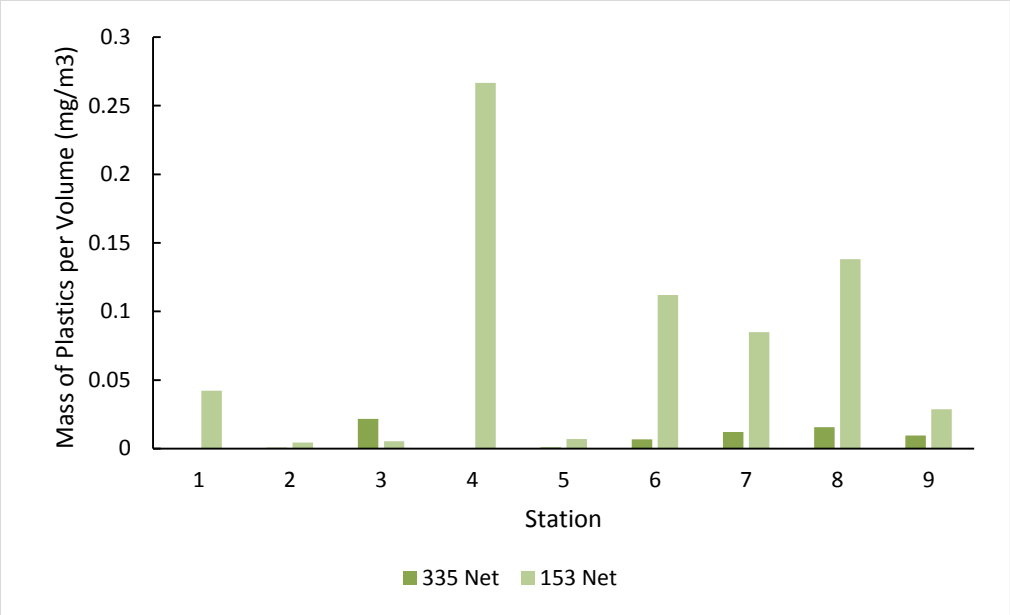

Figure 11. A comparison of the mass of plastics per volume collected using the 335 μm net and the 153 μm of Sampling Route Two conducted on August 20, 2016. Stations 1 through 3 represent the Black River, while stations 4 and 5 represent the Great Pee Dee River. Stations 7 and 8 represent the Sampit River, and stations 6 and 9 represent the mixing zone of the Sampit and Great Pee Dee Rivers.

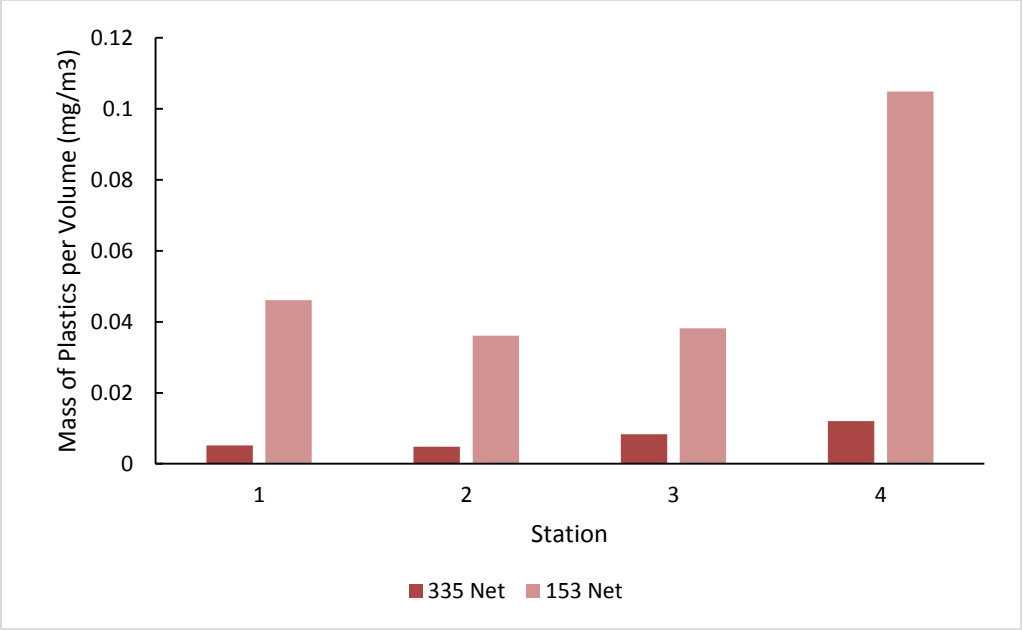

Figure 12. A comparison of the mass of plastics per volume collected using the 335 μm net and the 153 μm of Sampling Route Three conducted on November 6, 2016. The route includes a 10-mile long transect off the coast of Winyah Bay, S.C. Station 1 is located 10 miles off shore and station 4 is located at the mouth of the bay.

Literature Cited

Ashton, K., Holmes, L., Turner, A. Association of metals with plastic production pellets in the marine environment. *Mar Pollut Bull* 2010; 60:2050-2055.

Baldwin, A.K., Corsi, S.R., Mason, S.A. Plastic debris in 29 Great Lake tributaries: relations to watershed attributes and hydrology. *Environ Sci Technol* 2016; 50: 10377-10385.

Browne, M.A., Crump, P., Niven, S.J., Teuton, E., Tonkin, A., Galloway, T., Thompson, R. Accumulation of microplastic on shorelines worldwide: sources and sinks. *Environ Sci Technol* 2011; 45: 9175-9179.

Browne, M.A., Niven, S.J., Galloway, T.S., Rowland, S.J., Thompson, R.C. Microplastic moves pollutant and additives to worms, reducing functions linked to health and biodiversity. *Curr Biol* 2013; 23:2388-2392.

Carr, S.A., Liu, J., Tesoro, A.G. Transport and fate of microplastic particles in wastewater treatment plants. *Water Res* 2016; 91: 174-182.

Classens, M, De Meester, S., Van Landuyt, L. De Clerk, K., Janssen, C.R. Occurrence and distribution of microplastics in marine sediments along the Belgian Coast. *Mar Pollut Bull* 2011; 62: 2199-2204.

Cole, M., Lindeque, P., Fileman, E., Halsband, C., Goodhead, R., Moger, J., Galloway, T.S. Microplastic ingestion by zooplankton. *Environ Sci Technol* 2013; 47:6646-6655.

Denuncio, P., Bastida, R., Dassis, M., Giardino, G. Plastic ingestion in Franciscana dolphins, *Pontoporia blainvillei* (Gervais and d'Orbigny, 1844), from Argentina. *Mar Poll Bull* 2011; 62:1836-1841.

Derraik, J.G.B. The pollution of the marine environment by plastic debris: a review. *Mar Pollut Bull* 2002; 44: 842-852.

Desforges, J-P. W., Galbraith, M., Dangerfield, N., Ross, P.S. Widespread distribution of microplastics in subsurface seawater in the NE Pacific Ocean. *Mar Pollut Bull* 2014; 79: 94-99.

Devriese, L.I., van der Meulen, M.D., Maes, T., Bekaert, K., Paul-Pont, I., Frere, L., Robbens, J., Vethaak, A.D. Microplastic contamination in brown shrimp (*Crangon crangon*, Linnaeus 1758) from coastal waters of the Southern North Sea and Channel area. *Mar Pollut Bull* 2015; 98: 179-187.

Dris, R., Gasperi, J., Saad, M., Mirande, C., Tassin, B. Synthetic fibers in atmospheric fallout: a source for microplastics in the environment? *Mar Pollut Bull* 2016; 104: 290-293.

Engler, R.E. The complex interaction between marine debris and toxic chemicals in the ocean. *Environ Sci Technol* 2012; 46: 12302-12315.

Eriksen, M., Maximenko, N., Thiel, M., Cummins, A., Lattin, G., Wilson, S., Hafner, J., Zellers, A., Rifman, S. Plastic pollution in the South Pacific subtropical gyre. *Mar Pollut Bull* 2013; 68: 71-76.

Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, J.C., Galgani F., Ryan, P.G., Reisser, J. Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. *Plos One* 2014: 9: 111913.

Fendel, L.S., Sewell, M.A. Contributing to marine pollution by washing your face: Microplastics in facial cleaners. Mar Pollut Bull 2009; 58: 1225-1228.

Goni, M.A., Voulgaris, G., Kim, Y.H. Compositions and fluxes of particulate organic matter in a temperate estuary (Winyah Bay, South Carolina, USA) under contrasting physical forcings. *Estuar Coast Shelf S* 2009; 85: 273-291.

Graham, E.R., Thompson, J.T. Deposit-and suspension-feeding sea cucumbers (Enchinodermata) ingest plastic fragments. *J Exp Mar Biol Ecol* 2009; 368:22-29.

Jemec, A., Horvat, P., Kunej, U., Bele, M., Krzan, A. Uptake and effects of microplastic textile fibers on freshwater crustacean *Daphnia magna*. *Environ Pollut* 2016; 219:201-209.

Keller, A.A., Fruh, E.L., Johnson, M.M., Simon, V., McGourty, C. Distribution and abundance of anthropogenic marine debris along the shelf and slope of the US West Coast. *Mar Poll Bull* 2010; 60: 692-700.

Law, K.L., Moret-Ferguson, S., Maximenko, N.A, Proskurowski, G., Peacock, E.E., Hafner, J., Reddy, C.M. Plastic accumulation in the North Atlantic Subtropical Gyre. *Science* 2010, 329: 1185-1188.

Lusher, A.L., McHugh, M., Thompson, R.C. Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. *Mar Pollut Bull* 2013; 67: 94-99.

Maso, M., Garces, E., Pages, F., Camp, J. Drifting plastic debris as a potential vector for dispersing harmful algal bloom (HAB) species. *Sci Mar* 2007; 67:107-111.

Masura, J., Baker, J., Foster, G., Arthur, C., Herring, C. Laboratory methods for the analysis of microplastics in the marine environment: recommendations for quantifying synthetic particles in waters and sediments. 2015. NOAA Technical Memorandum NOS-OR&R-48.

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

Murray, F., Cowie, R. Plastic contamination in the decapod crustacean Nephrops norvegicus (Linnaeus, 1758). *Mar Pollut Bull* 2011; 62: 1207-1217.

Hartline, N.L., Bruce, N.J., Karba, S.N., Ruff, E.O., Sonar, S.U., Holden, P.A. Microfiber masses recovered from conventional machine washing of new or aged garments. *Environ Sci Technol* 2016; 50:11532-11538.

Patchineelam, S.M., Kjerfve, B., Gardner, L.R. A preliminary sediment budget for the Winyah Bay estuary, South Carolina, USA. *Mar Geol* 1999; 162:133-144.

Rochman, C.M., Kross, S.M., Armstrong, J.B., Bogan, M.T., Darling, E.S., Green, S.J., Smyth, A.R., Verissimo, D. Scientific evidence supports a ban on microbeads. *Environ Sci Technol* 2015; 49:10759-10761.

Tanaka, K., Takada, H., Yamashita, R., Mizukawa, K., Fuckwaka, M., Watanuki, Y. Accumulation of plastic-derived chemicals in tissues of seabirds ingesting marine plastics. *Mar Pullut Bull* 2013; 69:219-222.

Taylor, M.L., Gwinnett, C., Robinson, L.F., Woodall, L.C. Plastic microfiber ingestion by deep-sea organisms. *Sci Rep* 2016; 6:33997.

Thompson, R.C., Swan, S.H., Moore, C.J., vom Saal, F.S. Our Plastic Age. *Phil. Trans. R. Soc. B.* 2009; 364: 1973-1976.

Wagner, M., Scherer, C., Alvarez-Munoz, D., Brennholt, N., Bourrain, X., Buchinger, S., Fries, E., Grosbois, C., Klasmeier, J., Marti, T., Rodriguez-Mozaz, S., Urbatzka, R., Vethaak, A.D., Winther-Nielsen, M., Reifferscheid, G. Microplastics in freshwater ecosystems: what we know and what we need to know. *Environ Sci Eur* 2014; 28:12.

Wright, S.L., Thompson, R.C., Galloway, T.S. The physical impacts of microplastics on marine organisms: A review. *Environ Pollut* 2013; 178: 483-492.

Zettler, E.R., Mincer, T.J., Amaral-Zettler, L.A. Life in the “plastisphere”: microbial communities on plastic marine debris. *Environ Sci Technol* 2013; 47:7137-7146.

Zhao, S., Zhu, L., Wang, T., Li, D. Suspended microplastics in the surface water of the Yangtze Estuary system, China: First observations on occurrence, distribution. *Mar Pollut Bull* 2014; 86: 562-568.