A PROPOSED METHOD TO ANALYZE MESO- AND MICROPLASTIC POLLUTION ON BEACHES IN OREGON

by
Sage Losh

A PROJECT

submitted to

Oregon State University

University Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Environmental Science
(Honors Associate)

Presented March 5, 2015
Commencement June 2015

AN ABSTRACT OF THE THESIS OF

Sage Losh for the degree of Honors Baccalaureate of Science in Environmental Science presented on 03/05/2015. Title: A proposed method to analyze meso- and microplastic pollution on beaches in Oregon.

Abstract approved: ____

Dr. Angelicque White

Meso- and microplastic debris is becoming a rising coastal issue as more research highlighting the detrimental impacts this material has on marine organisms and the environment is performed. This research, however, continues to be conducted in a non-standardized manner meaning that the data being collected cannot be compared spatially or temporally. In this thesis, the need for standardized meso- and microplastic debris sampling protocols is stressed and a protocol developed by The 5 Gyres Institute, which has been modified to suit Oregon, is suggested. The 5 Gyres Institute has been performing pilot studies in Southern California using college student interns to collect data at several beaches; it is the purpose of this thesis that pilot studies begin here in Oregon. By doing so, we can finally begin to collect data that can be compared and analyzed over time in an effort to create a baseline for meso- and microplastic debris loads on beaches along the West Coast of the United States of America. Hopefully, this thesis will lead to a discussion of standardized methodology for marine debris beach surveys and the detection of change.

Key Words: Marine debris, mesoplastic, microplastic, 5 Gyres, NOAA

Corresponding e-mail address: loshs@onid.oregonstate.edu

A PROPOSED METHOD TO ANALYZE MESO- AND MICROPLASTIC POLLUTION ON BEACHES IN OREGON

by
Sage Losh

A PROJECT

submitted to

Oregon State University

University Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Environmental Science
(Honors Associate)

Presented March 5, 2015
Commencement June 2015

Honors Baccalaureate of Science in Environmental Science project of Sage Losh presented on March 05, 2015.

APPROVED:

Dr. Angelicque White, Mentor, representing Earth, Ocean and Atmospheric Sciences

---

Dr. Robert Wheatcroft, Committee Member, representing Earth, Ocean and Atmospheric Sciences

---

Dr. Skip Rochefort, Committee Member, representing School of Chemical, Biological and Environmental Engineering

---

Toni Doolen, Dean, University Honors College

I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

Sage Losh, Author

Table of Contents

I. INTRODUCTION

Since their introduction in consumer products, first as 'Bakelite' in 1907 (Cole et al., 2011), plastics have been transformed into a material of necessity for everyday life. Large-scale production of plastic consumer goods began in the 1950s, and reports of plastic marine debris (PMD) in beach environments appeared by the 1970s (Cundell, 1973; Gregory, 1978). In response to this, and many other coastal PMD sightings across the globe (Dixon & Cooke, 1977; Federal Republic of Germany, 1986; Henderson et al., 1987; Johnson & Merrell, 1988; Willoughby, 1986) Ribic and Johnson (1989) created guidelines for the design of beach debris surveys. These guidelines were created to standardize beach survey methods to detect change after the Marine Pollution Act (MARPOL) Annex V, prohibiting dumping of plastic waste from ships while at sea, was passed in 1988. Despite this law, PMD has continued to infiltrate the coastal environment, but still no baseline exists because survey methods have not been standardized.

So why are beach surveys important? Not only do beach surveys show what PMD accumulates on beaches, it also points the types and amounts of PMD in coastal and marine environments. Accumulating this data over time, or creating a baseline of data, allows for the detection of change (Ribic and Johnson1989). This is why a baseline of data is important. By knowing the types and quantities of PMD currently occupying beach environments, informed decisions can be made regarding mitigation, either politically or environmentally. The National Oceanic and Atmospheric Administration (NOAA) is currently the organizing force behind macrodebris (>2.5cm) surveys; they created a standardized protocol in 2012 (Opfer et al., 2012). Through their Marine Debris Shoreline Survey Field Guide, utilized by dedicated volunteers, they are beginning to compile PMD data. This field guide for collecting PMD data during beach cleanups has been adopted by non-profit organizations (NPO's) including Surfrider and The 5 Gyres Institute (5 Gyres). NOAA has yet to create an official meso- (2.5cm-5mm) and/or microplastic (<5mm) survey field guide.

5 Gyres is a non-profit organization operating out of southern California and aimed at research on plastic pollution in the world's oceans. In a recent paper they claim that the annual production of plastic has more than quintupled over the last 60 years, reaching 288 million tons per year in 2012. A significant fraction of this debris ends up in the surface ocean. Current estimates of the mass of plastic in the open ocean range from 7,000-35,500 metric tons (Cozar et al. 2014; Eriksen et al., 2014). Beaches are another, more obvious, repository for plastic debris, however these environments have not been carefully surveyed to date. To mitigate this data gap, the 5 Gyres' program has developed a beach survey methodology based upon NOAA's field guide. These beach surveys are part of a separate program called the Plastic Beach Project. Here I suggest adopting a modified version of the 5 Gyres Plastic Beach Project methods for surveying the abundance of meso- and microplastic debris on Oregon beaches. The purpose of this thesis, therefore, is not only to suggest a standardized beach survey method, but to also include the public, by way of citizen science, so they too can become educated in the

topic of PMD. This will also allow for data to be collected at a faster rate and at more locations than by marine debris scientists alone.

II. PLASTIC DEGRADATION

Degradation reduces the total molecular weight of the plastic polymer, causing the compound to break down. There are numerous ways that plastic can degrade; however, photodegradation by sunlight is primarily responsible. This process is initiated as soon as plastic debris enters the marine environment, causing the exposed surfaces to fracture and become brittle (Figure 1). When plastic is at sea, the photodegradation is retarded due to reduced temperatures and relatively low oxygen content. On beaches the process is more efficient, as the material is exposed to high levels of both oxygen and UV radiation (Andrady, 2011). In fact, this is thought to be the likely mechanism for the generation of a majority of meso- and microplastics in the environment. Over time, this brittle and fractured plastic is broken into many fragments, becoming what is known as secondary plastics (Cole et al., 2011).

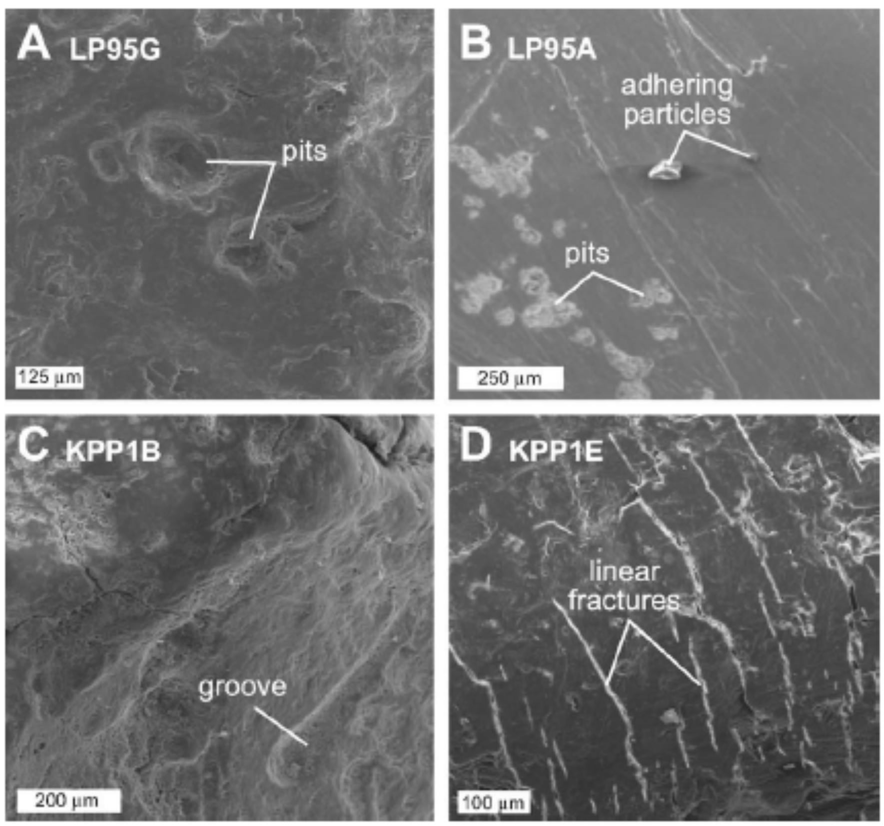

Figure 1. Examples of surface textures on sampled plastic particles taken from Corcoran et al., 2009. (A) Pitted surface on rounded sample. (B) Adhering particles and pits on angular sample. (C) Groove in rounded, highly oxidized sample. (D) Linear fractures in subangular sample.

III. MESO- AND MICROPLASTIC CLASSIFICATION

Meso- and microplastic debris can be classified into a few different categories (Figure 2); however two main types are found most often on beaches: pre-production pellets and fragments (Barnes et al., 2009). Pre-production pellets or plastic resin pellets, familiarly known as nurdles, and previously known as nibs, are primary plastics, i.e. those plastics, which were manufactured in small sizes (Cole et al., 2011). They can be spherical or cylindrical in shape and are usually clear or white but can also be yellowed due to photo-oxidation (Cole et al., 2011; Ogata et al., 2009). As their name suggests, these pellets are the feedstock for a wide range of industrial and consumer plastic products (Ogata et al., 2009). Pellets enter the aquatic environment mainly through accidental spillage at processing plants but can also be lost during transport at sea (Gregory, 1996; Doyle et al., 2011; Ogata et al., 2009; Cole et al., 2011). Once in the ocean, resin pellets are known to persist over long periods of time, on the order of hundreds to thousands of years (Barnes et al., 2009), and have been observed in marine systems worldwide (Ogata et al., 2009; Cole et al., 2011). These pellets are also becoming recognized for their adsorption of organic micro-pollutants or persistent organic pollutants (POPs), which include polychlorinated biphenyls (PCBs), Dichlorodiphenyldichloroethylene (DDE) and nonylphenol; all of which have been detected on nurdles collected from beaches worldwide by an international program (Ogata et al., 2009).

Fragments, as explained above, are known as secondary microplastics, meaning they are derived from the breakdown of larger plastic debris (Cole et al., 2011). They are irregular in shape and vary greatly in color due to their parent material. The most common color tends to be white due to photodegradation of incorporated pigments. However, it is not uncommon to find colored pieces: red, green, black and, most commonly among the colored pieces, blue. It is believed that pigment richness can help reveal exactly how long individual fragments have been exposed to the marine environment, but this is a relatively new area of study (Cole et al., 2011).

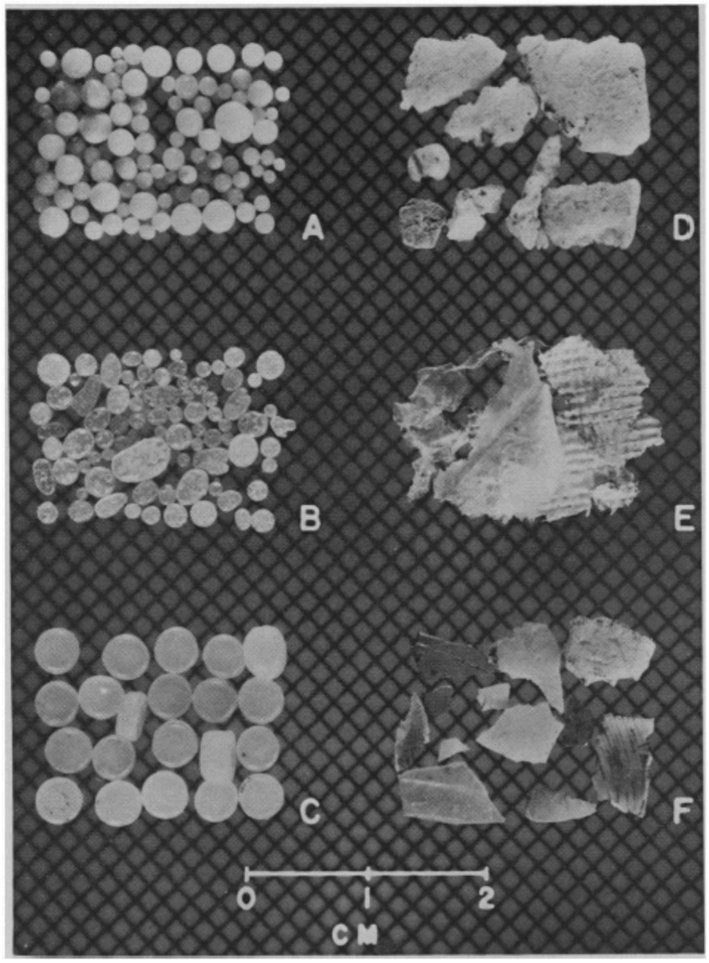

Figure 2. Typical plastic particles: (a) opaque polystyrene spherules, (B) clear and translucent polystyrene spherules, (C) opaque and translucent polyethylene cylinders, (D) Styrofoam, (E) plastic sheets and (F) plastic pieces. Figure and description taken from Colton et al., 1974.

IV. EFFECTS PLASTIC MARINE DEBRIS ON MARINE ORGANISMS

Plastic marine debris is becoming an area of intensive study as its negative effects on marine life start to surface. What used to be only an aesthetic eyesore on beaches now results in the accidental ingestion of and entanglement (sometimes leading strangulation) in marine debris, by marine organisms including seals, sea turtles, sea birds, etc. (Wright et al., 2013). Ingestion of PMD affects at least 267 species worldwide including 86% of sea turtle species, 44% of seabird species and 43% of all marine mammals (Laist, 1997). These numbers are likely to be underestimates, as most PMD ingestion victims are likely to die over open ocean environments and either sink or are eaten by predators (Wolfe, 1987). Entanglement in PMD while affecting seabirds and turtles is a particular problem for marine mammals (Derraik, 2002). Young fur seals are one of the better-known victims, as they are both playful and curious. The debris becomes entangled around the neck of the seal, and as it grows the plastic tightens, eventually severing arteries, strangling the animal, or both (Derraik, 2002). Another risk is the potential for PMD to desorb persistent organic pollutants (POPs) when ingested by marine organisms, becoming toxic (Ogata et al., 2009); however, little is known about the toxic effects of plastic ingestion. Perhaps more ominous, because of their size, is the degradation of larger PMD objects into meso- and microplastic debris, defined by Lippiatt et al. (2013) as pieces of debris 5mm-2.5cm and <5mm, respectively.

a. EFFECTS OF MESO- AND MICROPLASTIC DEBRIS ON MARINE ORGANISMS

Ingestion of PMD has been documented in many marine organisms including mussels and other bivalves, copepods, sea cucumbers, sea stars and sea urchins. Once ingested, these smaller plastics can be retained in the digestive tract, egested in the form of feces or absorbed into the lining of the gut and in some cases can result in starvation and physical deterioration (Browne et al., 2007). Ultimately, meso- and microplastic ingestion can lead to reduced fitness, diminished predator avoidance and death, whether it is from drowning or the inability to feed (Wright et al., 2013). Along with ingestion, recent research has suggested that the seafloor is likely a sink for meso- and microplastics (Eriksen et al., 2014; Wright et al., 2013), potentially posing threats to benthic marine animals. Figure 3 depicts the likely pathways meso- and microplastic debris can follow in the oceanic environment.

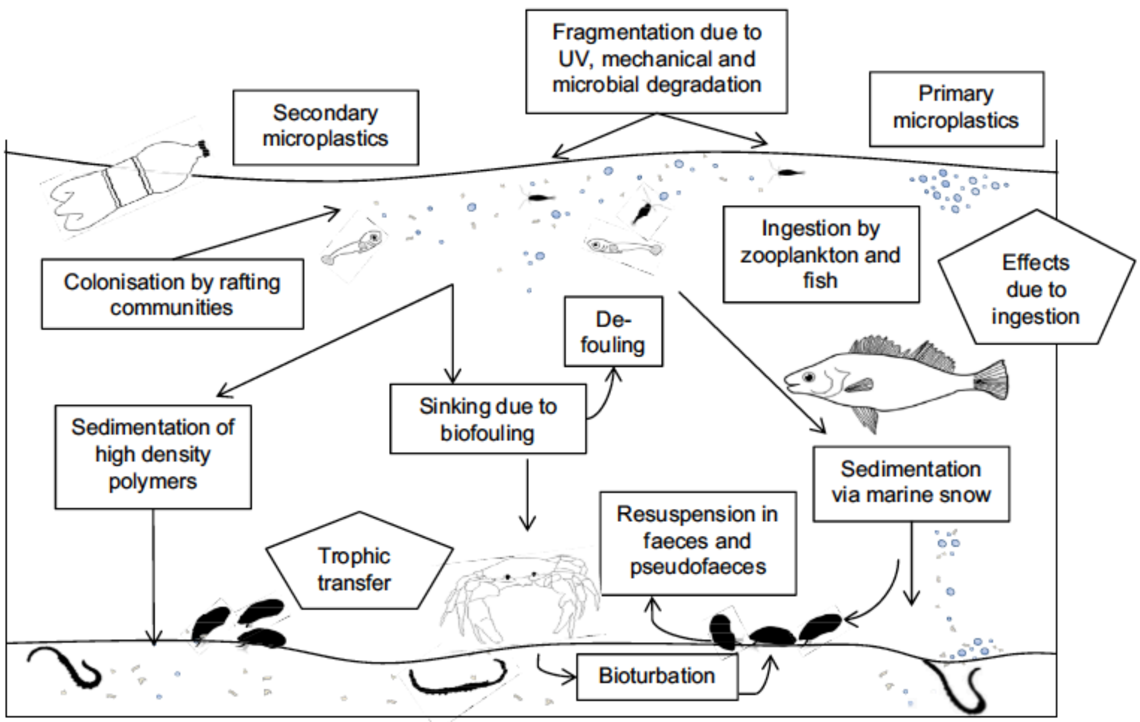

Figure 3. Potential pathways for the transport of microplastics and their biological interactions. Figure and description taken from Wright et al., 2013.

V. REVIEW OF MESO- AND MICROPLASTIC SAMPLING METHODS

Many sampling methods exist to quantify the abundance of meso- and microplastics on beaches; yet, none have been widely accepted as being the 'best' method (Velander and Mocogni, 1999). Not only does this lead to confusion when studying the topic, but it also creates a barrier in comparing studies to create a baseline of data (Eriksen et al., 2014). Hidalgo-Ruz et al. (2012) reviewed 44 studies concerning microplastics on beaches, and identified three main sampling strategies: selective sampling, bulk sampling and volume-reduced sampling. Selective sampling refers to the direct extraction of items from the environment that is recognizable by the naked eye. This is the sampling method most commonly used by volunteers. Bulk sampling in the field consists of extracting the entire volume of the sample, whereas volume-reduced sampling means the sample has been reduced by some fractionation procedure before processing. These methods are most commonly used for samples taken at depth in the sediment. Volume-reduced sampling was not included in the table below as it can be categorized under bulk sampling. Each of these methods was then broken down into various aspects such as the number of beaches, specific beach zone sampled, tools used and depth of sample. The various methods that were comparable are detailed in Table 1 below.

Table 1. Comparison of microplastic sampling methods on beaches.

Paper	Size Analyzed	Sample Depth	Selective Sampling	Bulk Sampling	Beach Zone Analyzed	Principal Objective	Tools Used?	No. Beaches Sampled
Gregory, 1978	<5mm	Surface	X		High tide line	Presence of debris	No	300
McDermid and McMullen, 2004	1-15mm	5.5cm		X	High tide line + storm tide line	Presence of debris + spatial distribution	Yes	9
Thompson et al., 2004	<5mm	Does not specify		X	Estuarine and subtidal	Abundance of debris	Yes	17
Corcoran et al., 2009	0.8-6.5mm	1cm and 10cm		X	Does not specify	Spatial distribution + relationship between composition and degradation	Yes	18
Browne et al., 2010	<1mm	3cm	X	X	High tide line	Spatial distribution due to wind	Yes	1
Browne et al., 2011	<1mm	1cm	X	X	High tide line	Presence of debris	Yes	18

Each paper included in the table reported a different method for sampling microplastic debris from beaches. The methods are distinguished by many factors of which this section will explain in detail. The size of debris analyzed changes from one author to another. However, this column also has another meaning; the size listed is also what the author believes the term microplastic should be. This lack of standardization is common among microplastic studies, as yet there is no consensus about a specific size nomenclature (Hidalgo-Ruiz et al., 2012). Another disparity among studies is the depth of sampling. It is not well known whether microplastic debris can be buried in beaches, but collecting samples at depth has yet to be decided upon and usually depends on the objectives of the study. Likewise, while most studies claim that the majority of microplastic debris can be found along the high-tide line, the area sampled and the tools used vary depending on the objectives of the study. Some studies require few or no tools, as they are focused around volunteer efforts, often on a number of beaches; that was the case in the Gregory (1978) study, which took place in New Zealand at 300 different beaches. Other studies have focused on one beach and required tools such as sieves and density separators, with sample evaluation with sophisticated methods like Fourier Transform infrared spectroscopy (FT-IR) and scanning electron microscopy.

There is a serious lack of standardized sampling procedures for beaches, the environments where the most visible and accessible PMD accumulations occur (Barnes et al., 2009). Thus, plastic loads cannot be compared over time or between sites (Cheshire et al., 2009; Smith and Markic, 2013). While much effort has been expended by volunteer organizations, such as SOLVE and The Surfrider Foundation (Surfrider), to remove this debris from beaches, the focus is usually large debris, not smaller particles (Thompson et al., 2004). This effort, while beneficial, is rarely accompanied by rigorous data collection, and even then the debris is usually quantified by its weight alone. The accepted notion among these organizations involves a tradeoff: you can have either many volunteers collecting a lot of debris or a few trained volunteers collecting data, not both. Much of the PMD sampling research available is limited in spatial and temporal coverage as each organization and/or scientist uses a different sampling method. As a result, the magnitude and variability of PMD in beach environments remains badly defined. This uncertainty can be traced to a lack of standardized procedures for the assessment of the distribution and composition of PMD.

The following sections contain two sets of methodologies. The first is the Plastic Beach Project, written verbatim, with permission from 5 Gyres. The second is a modified Plastic Beach Project to accommodate Oregon beaches. This modified method is intended to be utilized by volunteer organizations, universities and citizen science groups in an effort to establish a baseline of data for PMD on Oregon beaches.

VI. 5 GYRES PLASTIC BEACH PROJECT

a. MISSION STATEMENT AND GOALS

The 5 Gyres Institute's (5 Gyres) mission is to conduct research on and promote awareness of the impact of plastic pollution in the world's oceans and ultimately help reduce the accumulation of plastic pollution in the five subtropical gyres (main oceans of the world). Plastic pollution is plastic litter that is found on beaches and throughout the oceans and other water bodies worldwide. It continues to be an important environmental concern locally, nationally and globally.

The Plastic Beach Project aims to better understand the distribution of plastic pollution on beaches all over the world. This information helps designate "Plastic Beach Hotspots" to better focus coastal management efforts, understand the sources of plastic pollution and help others comprehend the vast scale of plastic pollution in the world's oceans.

The goal of the Plastic Beach Project is to gather information on plastic pollution on an international level. 5 Gyres Staff will focus on the West Coast of the United States in 2013 and 2014, with the intention of creating a West Coast Report Card for Plastic Pollution.

All data collected for the Plastic Beach Project will be displayed on an online mapping program that will allow comparison between beaches and highlight the most plastic beaches. The report card will grade each beach and help create stronger policies to limit plastic pollution on the beach. Stronger policies may include more local plastic bag bans, more laws that require catchment basins on storm drains, more laws that require materials that companies use to be recyclable. The project will also raise awareness to the general public and get more people involved in cleaning up our beaches.

For more information and to get involved, contact 5 Gyres Staff:
Carolynn Box, 5 Gyres Environmental Coordinator, carolynn@5gyres.org
Marcus Eriksen, 5 Gyres Executive Director, marcus@5gyres.org

b. BEACH SELECTION

Ideally, two beaches should be selected in each community included in the Plastic Beach Project. If the community is a 'beach community', know of the more frequented beaches (most popular tourist destinations) should be selected as one of the two beaches for that community. The other should be a beach that is less frequented, a more "natural" or "remote" beach. Many times there are beaches known in the community to gather an abundant amount of debris, such as logs, driftwood, seaweed and plastic pollution. If possible, one of these beaches should be included in the project. Beaches can be sandy or rocky.

Beaches should be clearly described on the "Plastic Beach Information Sheet". Maps and/or GPS locations for each beach should be included as part of the background information for each beach.

If just a single beach is selected, a sandy beach with the most beach-use should be selected. The results from a well-known beach will generate the most discussion and attention. For example, in San Francisco, a section of Ocean Beach should be included in the research. Specifically, the southern section of Ocean Beach (at Sloat Blvd) should be included in the project because this section of Ocean Beach is highly used and known to have a significant amount of plastic pollution deposited from wave and tidal action.

c. BEACH INFORMATION

Once the beach is selected, three to 12 beach quadrants should be analyzed to evaluate beach litter and plastic pollution. The results may vary depending on many factors, at different times of the year and after storms. Research documenting plastic pollution at different times of the year is ideal. All beaches included in the Plastic Beach Project should be evaluated at least two times, including quadrats collected in the summer and winter months.

Prior to conducting the quadrats, some background information on the beach should be documented: any storm drains and/or rivers or stream, wind and wave direction, last high tide, current weather and beach type should be described for each beach. Also note if there is significant beach or cliff erosion in the area and the current and general beach-use. If statistics on beach-use are available through the city, it would be helpful to know about how many people use the beach annually. Furthermore, some cities and counties and local environmental groups clean local beaches regularly; if this is the case, try to document as much information on cleanups as possibly. Also include information on whether the beach was recently cleaned (if known).

To evaluate beach litter and plastic pollution at a beach over time, the beach transect should start from a point on the beach that is permanent, such as the edge of a seawall, sidewalk, parking lot, or large rock. The starting point should be described and the latitude and longitude documented, so that transects can be done in the same spot in the coming years.

d. EQUIPMENT

- 1-m by 1-m square or rope
- 5-gallon bucket
- 4.75mm sieves and 1mm sieves and magnification tools
- Shovel or scoop
- Data sheets
- 4-8 sample bags or jars (please reuse sample bags if plastic and use alternatives, such as glass jars, if possible)
- Ruler scaled in mm
- 2+ 100-meter tape measure
- Clipboard or folder for data sheets
- Pens (to write on data sheets) and sharpies (to write on bags)

e. QUADRANT ANALYSIS

To better evaluate microplastic pollution in the area, you will first randomly select four **transects** from within a 100-meter section. You will then analyze four 1-square meter **quadrats**, three along each transect line. Transects should be placed on the **wrack** line, the line on the beach that represents where the last high tide reached, mid beach and back beach. Often the wrack line is covered in seaweed and other material (i.e. plastic pollution and beach litter). If there are multiple wrack lines all details describing which wrack was evaluated should be included in the notes. If there were a storm wrack line on the beach, it would be good to conduct some of the quadrant research in this area. It is important to describe all of the locations in the notes and include GPS coordinates if possible. Figure 4 shows the set up.

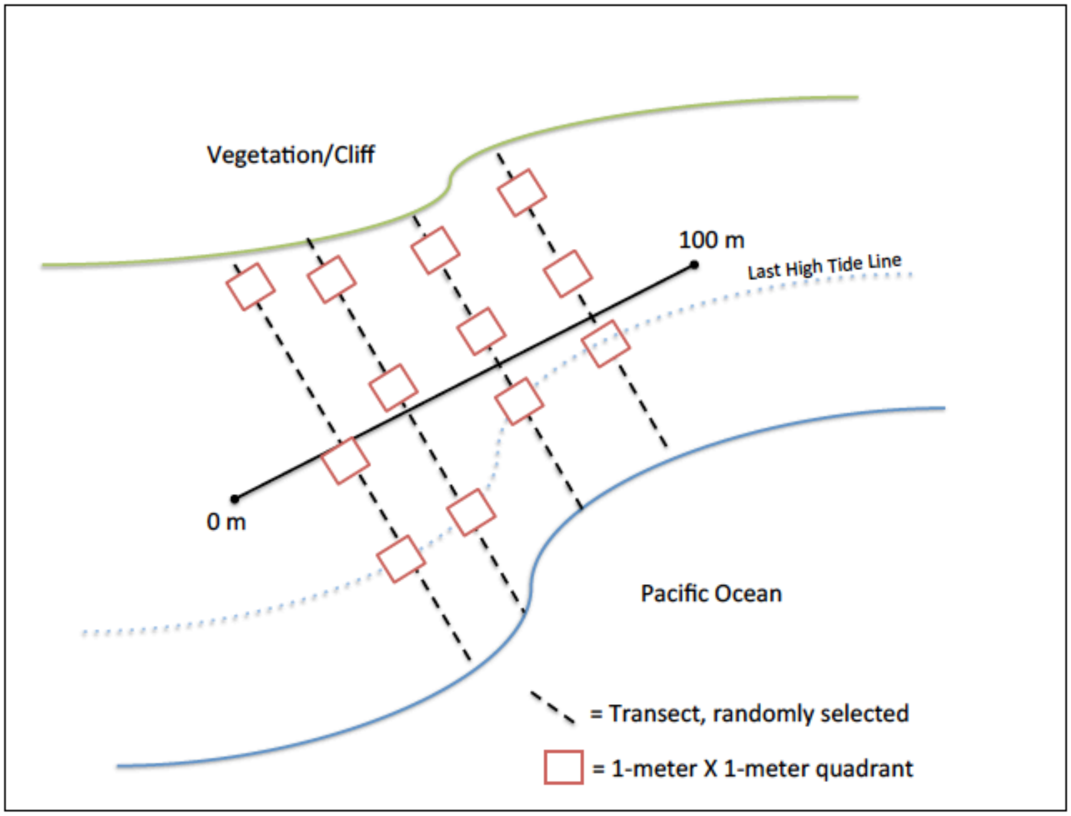

Figure 4. Setup protocol for The 5 Gyres Institute's Plastic Beach Project microplastic sampling methodology.

f. METHODS

The quadrant protocol was developed by 5 Gyres. Here are the step-by-step methods that should be followed:

1. Fill out the **Beach Characteristics** on the <u>Plastic Beach Data Card</u> (Appendix B) for each beach. This includes Beach Name, contact information for the person/s conducting the quadrant, GPS coordinates, tidal range, time of high tide, sediment type, wave and wind direction, recreation details (public or private beach, how many people using the beach, etc), nearest town, nearest river, and location of any outfalls.
2. **Photograph** the beach and the starting location of the transect.
3. **100-meter section of beach.** Lay out one 100-meter tape measure to select the area of beach to be analyzed. The tape measure should be placed in the middle of the beach parallel to the shoreline.
4. **Select 4 transects**. Choose 4 random numbers between 0 and 100 (divisible by 5). If 5 is selected, the 5 – 10 meter section of the transect should be analyzed. Appendix C of the NOAA Marine Debris Shoreline Survey Field Guide also has a good method to use.
5. **Transect placement**. Lay another 100-meter tape measure on one of the selected transect areas. The tape measure should be stretched perpendicular to the existing tape measure and run from the back beach (bottom of dunes, sea wall, vegetation, etc) to the ocean/bay. Record the length between the back beach and the water on the data sheet.

6. **Quadrant placement.** Place three quadrants along the transect, in the wrack line, mid beach and back beach. Table 1 indicates where each quadrant should be placed. This will be repeated on each transect line.
7. **Record GPS** for each quadrant.
8. **Draw a map** of the beach that shows where each transect is located and identifies any important features or any storm drains or rivers in the region.
9. **At each Quadrant, remove big pieces of natural debris**, like seaweed, leaves and wood. Brush them off and throw them away.
10. **Remove sediment from the surface** evenly with a scoop or shovel and put in 5-gallon bucket. Fill bucket half way. This will be approximately 3cm of the surface. The sediment should be scraped off the surface as evenly as possible.
11. **Sieve** the sediment through the 4.75mm and 1mm sieves, if available. If sieves are not available, mesh colanders can be used (note the size of the openings). Use a ruler to document the size of the fragments.
12. **Record** any fragments found (by size and type) on the data sheets (Appendix B)
13. Record the total **number of fragments** and **weight** of the fragments. Weighing is best done in an area with little to no wind.
14. Transfer the fragments into **collection bags** for further analysis. The material collected for each quadrant should be kept separately. Once weighed and analyzed, the plastic can be discarded.

g. DATA ENTRY AND SUBMISSION

Data should be consolidated into an Excel Worksheet and submitted to 5 Gyres Staff for inclusion on the Plastic Beach Project webpage and map. Please send data to carolynn@5gyres.org.

VII. ASSESSMENT

This section will assess the 5 Gyres protocol as it stands now. Any suggestions described here have been incorporated into the modified Plastic Beach Project in the next section.

a. EQUIPMENT

The 5 Gyres protocol calls for 2-3+ sets of the equipment list because they recommend carrying out this survey with a group of volunteers rather than just a single volunteer. The modified protocols below have been changed to show only one set of equipment because showing “3+” sets of an item is confusing. When first reading the Plastic Beach Project’s equipment list I assumed there was a specific purpose for having multiples of each item, beyond just having enough equipment for several volunteers.

Sieves

The sieves are the most difficult item to procure because there are so many different types, styles and price tags. An important consideration for these methods is cost and so the sieve had to be something that could be easily purchased by the volunteer or volunteer coordinator.

Professional grade sieves in either stainless steel or brass would be the obvious choice as it’s easy to buy and gets the job done easily; however, these sieves cost around $150 a piece and therefore are not feasible for this study. Do-it-yourself sieves could potentially work well; however, it was difficult to find the necessary materials to construct a sieve that would hold up to the weight of wet sand.

Some volunteer organizations, such as Surfrider and SOLVE use kitchen colanders or mesh strainers to separate out plastics. Again, there are many different varieties with price tags ranging from $1-$30. A few of these were tested with fluctuating levels of success. Plastic kitchen colanders come in various shapes, sizes and hole-opening patterns. Usually, the holes are sized differently depending on where they are located. For example, holes at the bottom of the colander are usually smaller than on the sides. This size disparity proves troublesome for meso- and microplastic debris because it doesn't yield uniform results. Metal mesh kitchen strainers (Figure 5) work much better because the openings are uniform and the whole basket can be utilized for sifting. There are generally three types, the difference being in the handle. At first glance, this might not seem like such an important feature, but testing confirmed that a two-handled mesh strainer works better than a single-handle or no-handle strainer. This is simply because it's easier to shake the strainer if there are two handles, and shaking is an important part of the sieving process, especially if the sand is wet. A stainless steel mesh kitchen strainer as described above is easily purchased online or at retail stores (e.g. Marshalls, TJ Maxx, Ross, Fred Meyer, Walmart, etc.) for around $10.

Figure 5. Stainless steel mesh colander by Cook Pro Inc.

Another option that costs a little more ($10-$20 each), but might yield more consistent results, is stacking garden sifters, which can be purchased online (e.g. Amazon.com). These sifters fit inside a 5-gallon bucket, and for ease of sampling, two mesh sizes should be purchased. The bigger mesh size, ½-inch (Figure 6), is used to remove any large pieces of natural or unnatural debris. A 1-inch mesh size would be preferable as this is the upper limit for sampling, but sieves of this size are either not available for purchase, or not easily found for purchase. Instead, if volunteers are unsure of the debris size, they should use a ruler to double check. This procedure can be seen in the modified methods below.

Figure 6. Stackable sifting pan, mesh size ½-inch.

The smaller mesh size, 1/30-inch (Figure 7), converts to ~0.85mm and was the closest mesh size to 1mm that could be found in this style.

Figure 7. Stackable sifting pan, mesh size 1/30-inch.

It is highly recommended that volunteers and/or the volunteer/program coordinator purchase these stackable sifting pans for this survey. These sieves are lightweight and affordable, they fit inside a 5-gallon bucket and because they are stackable, they will allow for a quick and easy sieving process.

Collection Bags
5 Gyres recommends using reusable containers, such as glass jars, for debris collection. While the idea of using a material, such as glass, is a refreshing change from plastic, it is just not practical. Glass is a heavy material, and these volunteers already have quite a lot of equipment to carry around. Glass is also prone to breaking and is therefore not recommended in the modified equipment list below. Plastic zipper baggies are recommended as they can be reused, are inexpensive and take up very little space.

Collection Bag Labels
Appendix D includes a sheet of labels to be included in the collection bags. This ensures the volunteer will include all of the pertinent information about the survey in each collection bag. It also allows for the bags to be reused more easily than if using a marker to write on the outside of the bag. It is highly recommended that volunteers and/or the volunteer /program coordinator print datasheets on Rite in the Rain™ paper to withstand environmental conditions.

Trundle Wheel
Measuring the width and length of beaches is always a difficult task, but especially in Oregon, where beaches never seem to end and, at low tide, can be over 100 meters wide. 5 Gyres suggests using 100-meter tape measures to measure the length of the survey area as well as the width of the beach. While this works great for the survey area, the width of an Oregon beach is usually greater than 100 meters, making measuring the width in this way difficult. 100-meter tape measures are not included in the modified equipment list below for two other reasons: 1) they are expensive, usually costing $30 each and 2) they are difficult to operate with only one volunteer and requires the volunteer to place the tape measure and then go and collect it once done measuring, thereby adding unnecessary time. The modified equipment list below suggests using a trundle wheel instead to measure both the 100-meter survey area and beach width. While a bit more cumbersome than a tape measure, these devices are easier to operate and can cost less than 100-meter tape measures (priced $15-$50 depending).

b. DATASHEETS

One of the most important additions to the modified datasheets concerns past and current the weather conditions. 5 Gyres does not recommend collecting very thorough weather and environmental conditions. However, it is important to gather and record weather observations on the day of sampling, as well as note any recent storms, to get a sense of how the environment could have affected the data. Much of this information can be collected from the Internet (e.g. tidal height, wind speed/direction, temperature, recent storms, etc.). It is also important to understand that while the Internet is a great source of information, it is no substitute for in situ observations. Make sure to verify the weather information collected from the Internet with what you experience during sampling. If the weather happens to change during sampling, make a note on the Meso- and Microplastic Sampling Datasheet.

Included in Appendix B are the datasheets for the Plastic Beach Project. Appendix C contains the modified datasheets, which include pieces from the Plastic Beach Project datasheets, COASST datasheets, NOAA Marine Debris Survey Field Guide and personal experience. It is highly recommended that volunteers and/or the volunteer/program coordinator print datasheets on Rite in the Rain™ paper to withstand environmental conditions.

c. VOLUNTEER METHODS TESTING

To test the effectiveness of these modified methods, a "best case scenario" situation performed by volunteers took place on Tuesday February 24, 2015 at Nye Beach and South Beach. Only steps 10-13 of the methods were performed because only the effectiveness of sieving was being tested. Adding the rest of the steps would have only wasted the volunteer's time.

Each volunteer was given an instruction sheet (Appendix C), the same quadrant set up and materials. For the quadrants, a 1-meter by 1-meter plot was constructed and roughly the first 3cm of sediment was removed to ensure no prior meso- or microplastic debris was present. Once the plot was established, 100 pieces of previously collected meso- and microplastic debris was counted and earmarked for testing. Dry sand from a nearby dune was used for the test instead of the original sediment. This was done for two reasons: 1) It's easier to sieve dry sand and remove any meso- or microplastic debris which may have been present, and 2) This test is supposed to represent a "best case scenario" and dry sand personifies that. The dry sand was then distributed about the quadrant and the 100 fragments were mixed in. The volunteers were timed for comparison.

Table 2. Results of volunteer method testing.

	Time	No. Fragments Collected	Feedback
Volunteer A	16 minutes	88	• "Make sure to tell volunteers not to fill the sieve all the way up. It's impossible to operate with this much sand." • "Please include a picture of what "typical meso- and microplastic debris looks like." • "It would help to explain how far to "dig" down in the sediment."
Volunteer B	24 minutes	88	• "Provide best known techniques in the methods. • "It would have been useful to know how deep I was supposed to dig down into the sand."
Volunteer C	10 minutes	100 + 4 fragments	• "I noticed some of the fragments broke as I was sieving them."
Averages	**17 minutes**	**92**	

Table 2 shows how each of the volunteers compared with regard to the time it took them to complete the activity as well as the number of fragments they found during the activity. It should be noted that while the volunteers were timed, they were not restricted on time. It was made clear to them that the timer would only stop once the volunteer was satisfied that all of the meso- and microplastic debris had been collected. Also included in the table are any comments made during or after the activity.

Volunteer A

Volunteer A performed the activity at Nye Beach in Newport, Oregon around 12:30pm. The weather was sunny and a bit cloudy with a NNW wind speed of 13.8mph with gusts up to 18.4mph. Volunteer A had never done any sort of meso- or microplastic debris collection before and was given no hints about technique. They were apprehensive about how deep to dig into the sediment and instead only barely scraped the surface using the shovel. They attempted to sieve it all of the sediment at once and realized that this was not efficient. They then transferred the sediment into the 3-gallon bucket and sieved small batches of sediment, counting each fragment they encountered before placing it in the plastic bag. While using seawater to separate sand from plastic was included in the instructions, Volunteer A chose to ignore this step. The biggest issues they ran across were: 1) Not knowing what "typical" meso- and microplastic debris looked like, 2) Not knowing how deep to dig down in the sediment and 3) Not knowing what technique works the best when collecting debris.

Volunteer B

Volunteer B performed the activity at Nye Beach in Newport, Oregon around 1:30pm. The weather was sunny and a bit cloudy with a NNW wind speed of 15mph. Volunteer B had extensive experience picking up marine debris but did not have a solid technique for collecting meso- and/or microplastic debris. Volunteer B was given no hints about technique. They started by handpicking any fragment that was not buried by sand. They then proceeded to collect fragments by using their shovel but chose to sieve the sand over the quadrant, thereby adding back all of the sand and covering up any additional fragments. This volunteer also took quite a bit longer than Volunteer A because they were questioning each fragment they found, asking if it was indeed plastic. After about 18 minutes they had collected 56 fragments and stated that they felt the plot was "clean" and that if they were completing the survey that they would move on. It was at this moment that they thought of another way to collect and sieve the sediment. They scraped all of the sediment into the middle of the quadrant and then used this pile to run through the sieve. Within 6 minutes they had collected another 32 fragments bringing the total up to 88. They suggested adding this "centering" technique into the methods as it works very well. Again, while using seawater to separate sand from plastic was included in the instructions, Volunteer B chose to ignore this step. They did add that collecting water would be a "pain in the neck" due to the low tide and distance required to carry almost 3 gallons of water.

Volunteer C

Volunteer C performed the activity at South Beach in Newport, Oregon around 2:45pm. The weather was sunny and a bit cloudy with a NNW wind speed of 11.5mph. Volunteer C also had extensive experience picking up marine debris but did not have a solid technique for collecting meso- and/or microplastic debris. Volunteer C was told to use the "centering" technique and encouraged to use water separation if sieving took too long. From the start, Volunteer C was much more methodological than either Volunteer A or B. They started at one side, scraping sediment into piles and then sieving each pile for debris. They completed the activity much faster than either Volunteer A or B and also collected 104% of the total debris located in the quadrant. The volunteer noted that during the sieving process some of the debris fragmented, leading to the higher than possible result.

Looking at the last row in Table 2 containing the averages, this test demonstrated that in a "best case scenario", a volunteer should be able to complete one quadrat in 17 minutes while being 92% effective. Some simple math reveals that 17 minutes per quadrat multiplied by 12 quadrats equals 3 hours 24 minutes. However, this only includes steps 10-13 of the methods and does not take into account normal beach conditions. With that being said, volunteers should be aware of the time required to complete this survey.

VIII. MODIFIED METHODOLOGY

a. MISSION STATEMENT AND GOALS

These modified methods aim to better understand the distribution of plastic pollution on beaches in Oregon. The goal of this project is to develop meso- and microplastic debris survey methods that are practical for volunteers to perform on a regular basis. Therefore, the volunteers only have to survey one transect, instead of four, with two quadrats, instead of three. The methods were split into two parts: debris collection and data analysis. Debris collection volunteers will be responsible for going to a beach, establishing the transect and collecting debris from a 1-meter by 1-meter quadrat. The data analysis volunteers will be responsible for filling out datasheets and arranging the debris on, and taking a picture of, the chalkboard as well as submitting all data to program coordinator. The project will also raise awareness to the general public and get more people involved in cleaning up our beaches.

b. BEACH SELECTION

Ideally, volunteers should "adopt" one beach to survey monthly, quarterly or biannually (winter and summer) at the very least. Research documenting plastic pollution at different times of the year is ideal. It is also important that volunteers survey the same 100-meters each time. This way, consistent data will be coming in on the same location, which can then be looked at over time to establish a baseline. Beaches can be sandy or rocky but should be clearly described on the Beach Characteristics Datasheet (Appendix C). Maps and/or GPS locations for each beach should be included as part of the background information for each beach.

c. BEACH INFORMATION

Once the beach is selected, at least one random transect (but not more than four) will be surveyed, with two 1-meter by 1-meter quadrats. The quadrats will change each time the 100-meter transect is surveyed depending on where the high tide line is situated, the width of the beach, if a storm tide line is present, etc. Three quadrats are no longer necessary as the 5 Gyres protocol suggests as most PMD is deposited in the high tide line or is wind-blown to the backshore (pers. obs.). Figure 8 below gives a general overview of what the 100-meter survey area may look like, keeping in mind only one transect must be established. The results may vary depending on many factors, at different times of the year and after storms.

Prior to conducting the quadrats, some background information on the beach should be documented on the appropriate datasheets: any storm drains and/or rivers or stream, wind and wave direction, last high tide, current weather and beach type should be described for each beach. Also note if there is significant beach or cliff erosion in the area and the current and general beach-use. If statistics on beach-use is available through the city, it would be helpful to know about how many people use the beach annually. Furthermore, some cities and counties and local environmental groups clean local beaches regularly; if this is the case, try to document as much information on cleanups as possibly. Also include information on whether the beach was recently cleaned (if known).

d. PRELIMINARY INFORMATION

To evaluate beach litter and plastic pollution at a beach over time, the 100-meter survey area should start from a point on the beach that is permanent, such as the edge of a seawall, sidewalk, parking lot, or large rock. The starting point should be described and the latitude and longitude documented, so that transects can be done in the same spot in the coming years.

Before arriving at the site, select four numbers from the Random Number Table (Appendix B), by first choosing a number between 1 and 5, and then a number between 1 and 4. The corresponding number in the table (1-20) is the transect you will survey. You will then analyze two 1-meter by 1-meter quadrats along the transect, Figure 8 shows the set up. Quadrats should be placed on the wrack line (the line of the beach that represents where the last high tide reached) and the back beach. Often the wrack line is covered in seaweed, woody debris and other material (including plastic pollution and beach litter). If there are multiple wrack lines, all details describing which wrack line was evaluated with a quadrat should be included in the notes. If there were a storm wrack line, similar to a normal wrack line but one that has been created by a storm event, on the beach, it would be good to conduct some of the quadrant research in that area.

e. EQUIPMENT

Most of the materials can be purchased at a home-improvement/hardware store (e.g. Ace Hardware, Lowes, Home Improvement) craft store or retail store (e.g. Dollar Tree).

Debris Collection

- Smartphone (must have camera and GPS capabilities)
- 1-m by 1-m square frame (cemented PVC pipe works well), 4 m of rope with pegs along each meter to mark out quadrats also works and can be transported in a very small space
- 5-gallon bucket
- ½-inch sieve
  - Can be purchased online (e.g. Amazon.com)
- 1/30-inch sieve (~1mm)
  - Can be purchased online (e.g. Amazon.com)
- Handheld shovel or scoop
- 1-meter trundle wheel

Data Analysis

- Data sheets printed on Rite in the Rain™ paper (Appendix B)
- No. 2 Pencils (to write on data sheets)
- Chalkboard (can be made, buy 1ftx1ft piece of wood + chalkboard paint at craft store, or bought)
- Ruler scaled in mm
- Clipboard (for data sheets)
- Chalk

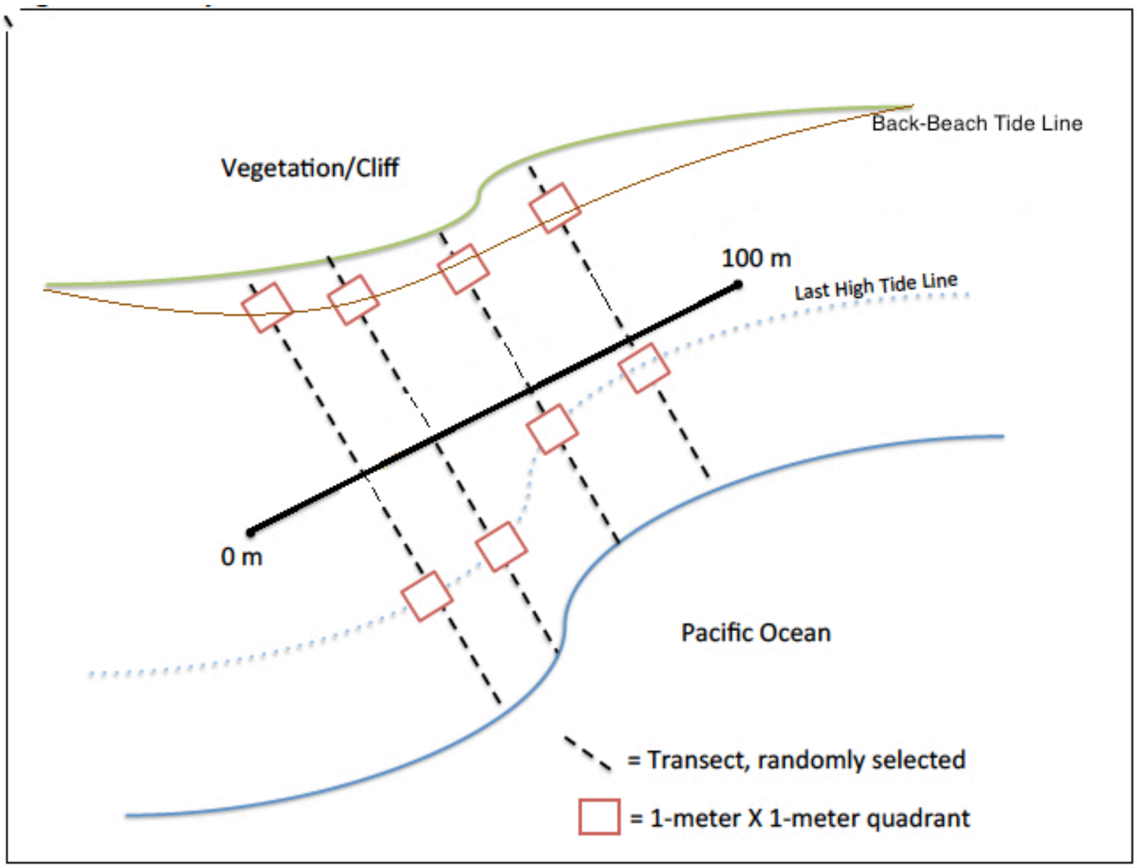

Figure 8. Modified setup protocol for the microplastic sampling methodology.

f. METHODS

These methods work best if broken up into two parts: debris collection and data analysis.

Debris Collection

1. **Write beach name**, date and names of volunteers on Transect and Quadrat Datasheet (Appendix C).
2. **Photograph** the beach and the starting location of survey area.
3. **Record GPS** for start of sampling area.
    a. Record on Transect and Quadrat Datasheet
4. **Establish transect.** Use the methods described in the preliminary information section and the Random Number Table in Appendix A.
    a. Transect will be perpendicular to the existing 100-meter plot and run from the water line to the back beach (bottom of dunes, sea wall, vegetation, etc.).
    b. It is easiest to establish transect by starting from the water line.
5. Using the trundle wheel, **measure length of transect** from the water to the back beach.
    a. Fill out transect information as you go on **Transect and Quadrat Datasheet** (Appendix C).
6. **Quadrat placement.** Place two quadrants along each transect; in the last high tide line and back beach. Figure 10 (above) indicates where each quadrant should be placed.

    a. The back beach is usually defined by vegetation, dunes, cliff, seawall or structures. Place the quadrat 1 meter from the farthest extent of the beach. Do not place quadrat in vegetation or on dunes.
7. **Record GPS** for each quadrat on Transect and Quadrat Datasheet (Appendix C).
8. **Remove big pieces of debris**, like seaweed, leaves, wood and plastic debris. The natural debris can be thrown aside, but the plastic debris should be collected to be disposed of properly.
9. **Scoop or shovel by scraping sediment from all sides into the center** creating a pile.
    a. The sediment should be scraped off the surface as evenly as possible.
10. **Remove sediment from the pile** using the scoop or shovel and sieve through the ½-inch mesh sieve over the 5- gallon bucket.
    a. **The bucket should only be filled about half way.** This will be approximately 3cm of the surface.
11. **Measure** any pieces of plastic debris that could not pass through the ½-inch sieve.
    a. If greater than or equal to 2.5 cm (1 inch), dispose of properly.
    b. If less than 2.5 cm (1 inch), include in survey (place with the rest of the now sieved sand in the 5-gallon bucket.
12. **Sieve** the sediment in the 5-gallon bucket through the 1/30-inch sieve.
    a. It is okay for the sediment to be sieved over the ground, we are trying to empty the 5-gallon bucket.
    b. Sieve small portions at a time so as not to overload the sieve.
13. **Fill the now empty 5-gallon bucket halfway with seawater**.
    a. This is NOT optional.
14. **Dump the collected PMD** from the 1/30-inch sieve into the seawater.
    a. The remaining sand will sink, effectively cleaning the PMD. Other natural debris may sink as well, but any woody debris will float and will need to be separated out.
15. **Transfer the fragments into collection bags** for further analysis.
    a. The material collected for each quadrant should be kept separately.
16. **Fill out a collection bag label** and place it in the collection bag.
    a. Use pencil.
17. **Repeat steps 7-16** for remaining quadrat.
18. **Give collection bags to volunteer/program coordinator.**

Data Analysis

NOTE These steps should be done at the same time of debris collection for best results.

1. Fill out the **Beach Characteristics Datasheet** (Appendix C) for your beach.
    a. You only need to fill out this datasheet once for each beach. Use pencil.
2. Fill out the **Meso- and Microplastic Sampling Datasheet** (Appendix C) for your beach.
    a. You need to fill out this datasheet every time you survey this 100-meter section of this beach. Use pencil.
3. **Write the site information on the chalkboard.**
    a. Site information includes: beach name, date, transect and quadrat number.

4. **Place PMD on chalkboard** so that no pieces are overlapping.
    a. **NOTE:** If conditions are unfavorable (e.g. too windy) to place PMD on the chalkboard wait until indoors to finish.
5. **Take a picture of the chalkboard** using your smartphone.
    a. Make sure to include the ruler for scale. See Figure 11 for an example of how this should look.
6. **Upload pictures to Instagram.** Must use #mesomicrosurvey so the photo is added to the collection.

Figure 11. Example of how to take a picture of the fragments on a chalkboard. Photo taken by Sage DeLuna, January 29, 2015.

g. DATA ENTRY AND SUBMISSION
Datasheets and debris collection bags should be given to program coordinator (Appendix C) for inclusion in the project. Please email all pictures (site, chalkboards, etc.) to loshs@onid.oregonstate.edu.

IX. INTENDED USE
This thesis was written with the intention that volunteer and other organizations/institutions would adopt it for use during beach cleanups, regular surveys

and other activities. Below is a list this thesis had in mind including an explanation of how each would implement the methods into their existing programs.

a) *SOLVE*
SOLVE is a non-profit organization (NPO) based in Portland, Oregon best known for their coast-wide Spring Beach Cleanup and their statewide Beach and Riverside Cleanup in the Fall. Thousands of volunteers from all across the state come together for these events making it one of the most promising organizations for data collection. Implementing this procedure would be difficult on such a large scale and so the success, as well as the reliability, of the data would be a major issue. But SOLVE is not against data collection. In fact, they do provide data cards for volunteers at each of these cleanup events in the hope of understanding what types of debris is being collected. The down side that not every volunteer records their data, and others may recall their data incorrectly. Either way, the data being collected on these cards only just begins to paint a picture of the situation. There is a lot more we can do and a partnership with SOLVE using these methods may in fact have a promising future.

b) *The Surfrider Foundation*
The Surfrider Foundation, hereafter referred to as "Surfrider", is a global NPO with headquarters in California and volunteer-run-chapters all around the world. Surfrider focuses on many aspects of coastal protection ranging from campaigns to cleanups to recreational events, such as surfing competitions. They generally work on smaller scales, but have a large impact on their communities by partnering with local groups and stakeholders as well as politicians and decision makers. Each chapter is run by volunteers and it is up to them to decide what campaigns or issues they tackle each year. In Oregon, there are six chapters with varying levels of involvement. Data collection is not a new idea within Surfrider; however, because each chapter is different, the amount and frequency of data collected varies greatly. While this might seem like a big hurdle, it is in fact, not. As long as the methods are clear and easy to follow, it doesn't matter that some chapters may collect more data than others. Over time, this data will accrue and we can begin to see a baseline for beaches being surveyed on any sort of basis. Although, it will be recommended that volunteers survey a beach once a month for accuracy of results.

c) *Oregon Shores/CoastWatch*
Oregon Shores is a NPO with many different programs including land use, coastal law, an ocean and climate program and their volunteer program, CoastWatch. CoastWatch consists of nearly 1,300 volunteers who keep watch over mile-long segments of Oregon's shoreline, the only such program in the nation. CoastWatchers monitor for and report a wide range of natural changes and human impacts. An activity that currently takes place on these adopted miles are marine debris surveys using NOAA's Marine Debris Shoreline Survey Field Guide. A possible partnership with Oregon Shores/CoastWatch could be developed to include the meso- and microplastic debris survey methods developed in this thesis on adopted miles along the Oregon coast.

d) *COASST*
The Coastal Observation and Seabird Survey Team (COASST), while based in Seattle, Washington, has an up-and-coming marine debris survey team who is developing their own methods for marine debris collection. While the procedures may not overlap exactly, it is important to collaborate and share best practices. COASST also has another shared trait that can be used to our advantage; they operate, and are a part of, the University of Washington (UW). This is important because it almost guarantees a volunteer base. Communication about how COASST partners with UW should be started to start the same type of program at Oregon State University.

e) *Oregon State University*
Because this thesis is being written through The University Honors College at Oregon State University (OSU) it is convenient to include them in the list of partner organizations. To better engage the students of OSU in coastal issues, this thesis could be turned into an unpaid internship opportunity for undergraduates. It would be open to all, but of course be solicited mainly to the College of Earth, Ocean and Atmospheric Sciences and the College of Fisheries and Wildlife, as they have a strong marine program.

f) *National Oceanic and Atmospheric Administration*
The National Oceanic and Atmospheric Administration (NOAA) developed the parent document these methods are based on. The Marine Debris Shoreline Survey Field Guide was revised and made available to the public in 2012 and is the first step in collecting standardized data during marine debris surveys. Currently, this field guide does not include debris smaller than 2.5cm (1 inch). The survey methods developed here could easily be integrated into the larger field guide so that data can begin to be collected for meso- and microplastic debris. Communication with NOAA's Marine Debris Program will be initiated for this purpose.

X. CONCLUSION

The unending use of plastic has revolutionized our world both positively, by providing life-saving products, and negatively, by accruing on our beaches, polluting our waterways and harming aquatic organisms. Conscious effort has been made since the early 1970's to survey the abundance of PMD in beach environments; however, the methods used have not been consistent and a baseline of data has yet to be established. The National Oceanic and Atmospheric Administration created a Marine Debris Shoreline Survey Field Guide and have begun collecting data through volunteer organizations, such as The Surfrider Foundation, and citizen science. However, their focus remains on macrodebris (>2.5cm), thereby ignoring meso- (2.5cm-5mm) and microplastic (<5mm) debris.

Only as of last year has an estimate of plastic pollution in the world's oceans been identified (Cozar et al., 2014; Eriksen et al., 2014). Beaches are more accessible and cheaper to survey; however, due to the lack of standardized methods the debris load on beaches has yet to be established. The modified methods presented here, as well as the intended use of those methods, were created to fill that gap.

XI. RECOMMENDATIONS

It is the recommendation of this paper that the methodology created by The 5 Gyres Institute, and modified here, be adopted and implemented by those organizations outlined in the "Intended Use" section to begin standardizing the data collected and establish a baseline for Oregon beaches.

XII. ACKNOWLEDGEMENTS

I would like to acknowledge The National Oceanic and Atmospheric Administration for their work in creating the Marine Debris Shoreline Survey Field Guide, which has put us one step closer to estimating the amount of debris on beaches. I would also like to acknowledge The 5 Gyres Institute for the permission to use and modify their microplastic survey methodology. This paper would not have been possible without either of these organizations. Lastly, I would like to acknowledge my thesis mentor Dr. Angelique White and the rest of my thesis committee Dr. Rob Wheatcroft and Dr. Skip Rochefort as well as those who helped review this thesis, Dr. Kim Bernard, Dr. Charlie Miller and Hillary Burgess of COASST. I am truly grateful for all of the input I received, the experiences I had and the knowledge I have gained over the course of writing this thesis.

XIII. REFERENCES

Andrady, A.L., 2011. Microplastics in the marine environment. Marine Pollution Bulletin 62, 1596–1605. doi:10.1016/j.marpolbul.2011.05.030

Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B: Biological Sciences 364, 1985–1998. doi:10.1098/rstb.2008.0205

Browne, M.A., Crump, P., Niven, S.J., Teuten, E., Tonkin, A., Galloway, T., Thompson, R., 2011. Accumulation of Microplastic on Shorelines Woldwide: Sources and Sinks. Environmental Science & Technology 45, 9175–9179. doi:10.1021/es201811s

Browne, M.A., Galloway, T., Thompson, R., 2007. Microplastic--an emerging contaminant of potential concern. Integrated Environmental Assessment and Management 3, 559. doi:10.1897/1551-3793(2007)3[559:LD]2.0.CO;2

Browne, M.A., Galloway, T.S., Thompson, R.C., 2010. Spatial Patterns of Plastic Debris along Estuarine Shorelines. Environmental Science & Technology 44, 3404–3409. doi:10.1021/es903784e

Carpenter, E.J., Smith, K.L., 1972. Plastics on the Sargasso Sea Surface. Science 175, 1240–1241. doi:10.1126/science.175.4027.1240

Cheshire, A., Adler, E., Barbière, J., 2009. UNEP/IOC guidelines on survey and monitoring of marine litter. United Nations Environment Programme, Regional Seas Programme ; Intergovernmental Oceanographic Commission, Integrated Coastal Area Management and Regional Programme, Nairobi; Paris.

Cole, M., Lindeque, P., Halsband, C., Galloway, T.S., 2011. Microplastics as contaminants in the marine environment: A review. Marine Pollution Bulletin 62, 2588–2597. doi:10.1016/j.marpolbul.2011.09.025

Colton, J.B., Burns, B.R., Frederick D. Knapp, 1974. Plastic Particles in Surface Waters of the Northwestern Atlantic. Science 185, 491–497. doi:10.1126/science.185.4150.491

Corcoran, P.L., Biesinger, M.C., Grifi, M., 2009. Plastics and beaches: A degrading relationship. Marine Pollution Bulletin 58, 80–84. doi:10.1016/j.marpolbul.2008.08.022

Cundell, A.M. 1973. Plastic materials accumulating in Narragansett Bay. Mar. Pollut. Bull. 4:187-188.

Derraik, J.G., 2002. The pollution of the marine environment by plastic debris: a review. Marine pollution bulletin 44, 842–852.

Dixon, T.R., Cooke, A.J., 1977. Discarded containers on a Kent beach. Marine Pollution Bulletin 105–109.

Doyle, M.J., Watson, W., Bowlin, N.M., Sheavly, S.B., 2011. Plastic particles in coastal pelagic ecosystems of the Northeast Pacific ocean. Marine Environmental Research 71, 41–52. doi:10.1016/j.marenvres.2010.10.001

Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, J.C., Galgani, F., Ryan, P.G., Reisser, J., 2014. Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea. PLoS ONE 9, e111913. doi:10.1371/journal.pone.0111913

Federal Republic of Germany, 1986. Degree and effects of environmental pollution of the German Bight and its coasts caused by synthetic material and other litter discarded by ships.

Gregory, M.R., 1978. Accumulation and distribution of virgin plastic granules on New Zealand beaches. New Zealand Journal of Marine and Freshwater Research 12, 399–414. doi:10.1080/00288330.1978.9515768

Gregory, M.R., 1996. Plastic "scrubbers" in hand cleansers: a further (and minor) source for marine pollution identified. Marine Pollution Bulletin 32, 867–871. doi:10.1016/S0025-326X(96)00047-1

Henderson, J.R., Austin, S.L., Pillos, M.B., 1987. Summary of webbing and net fragments found on Northwestern Hawaiian Islands beaches, 1982-86. Southwest Fisheries Center; Honolulu Laboratories; National Marine Fisheries Service; NOAA 15.

Hidalgo-Ruz, V., Gutow, L., Thompson, R.C., Thiel, M., 2012. Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification. Environmental Science & Technology 46, 3060–3075. doi:10.1021/es2031505

Johnson, S.W., Merrell, T.R., 1988. Entanglement debris on Alaskan beaches, 1986. U.S. Department of Commerce, NOAA Technical Memo 26.

Laist, D.W., 1987. Overview of the biological effects of lost and discarded plastic debris in the marine environment. Marine Pollution Bulletin 18, 319–326. doi:10.1016/S0025-326X(87)80019-X

Lippiatt, S., Opfer, S., Arthur, C., 2013. Marine Debris Monitoring and Assessment, NOAA Technical Memorandum.

McDermid, K.J., McMullen, T.L., 2004. Quantitative analysis of small-plastic debris on beaches in the Hawaiian archipelago. Marine Pollution Bulletin 48, 790–794. doi:10.1016/j.marpolbul.2003.10.017

Nelson, J., 1985. The Oregon experience. U.S. Department of Commerce, NOAA Technical Memo, Proceedings of the Workshop on the Fate and Impact of Marine Debris 154–159.

Ogata, Y., Takada, H., Mizukawa, K., Hirai, H., Iwasa, S., Endo, S., Mato, Y., Saha, M., Okuda, K., Nakashima, A., Murakami, M., Zurcher, N., Booyatumanondo, R., Zakaria, M.P., Dung, L.Q., Gordon, M., Miguez, C., Suzuki, S., Moore, C., Karapanagioti, H.K., Weerts, S., McClurg, T., Burres, E., Smith, W., Velkenburg, M.V., Lang, J.S., Lang, R.C., Laursen, D., Danner, B., Stewardson, N., Thompson, R.C., 2009. International Pellet Watch: Global monitoring of persistent organic pollutants (POPs) in coastal waters. 1. Initial phase data on PCBs, DDTs, and HCHs. Marine Pollution Bulletin 58, 1437–1446. doi:10.1016/j.marpolbul.2009.06.014

Opfer, S., Arthur, C., Lippiatt, S., 2012. NOAA Marine Debris Shoreline Survey Field Guide. NOAA draft protocol.

Smith, S.D.A., Markic, A., 2013. Estimates of Marine Debris Accumulation on Beaches Are Strongly Affected by the Temporal Scale of Sampling. PLoS ONE 8, e83694. doi:10.1371/journal.pone.0083694

Thompson, R.C., Olsen, Y., Mitchell, R.P., Davis, A., Rowland, S.J., John, A.W.G., McGonigle, D., Russell, A.E., 2004. Lost at Sea: Where Is All the Plastic? Science 304, 838–838. doi:10.1126/science.1094559

UNESCO, 1994. Marine Debris: Solid Waste Management Action Plan for the Wider Caribbean. IOC Technical Series 41, Paris.

Velander, K., Mocogni, M., 1999. Beach litter sampling strategies: is there a “best”method? Marine Pollution Bulletin 38, 1134–1140.

Wolfe, D.A., 1987. Persistent plastics and debris in the Ocean: an international problem of Ocean disposal. Marine Pollution Bulletin 18, 303–305. doi:10.1016/S0025-326X(87)80015-2

Willoughby, N.G., 1986. Man-made litter on the shores of the Thousand Island Archipelago, Java. Marine Pollution Bulletin 17, 224–228.

Wright, S.L., Thompson, R.C., Galloway, T.S., 2013. The physical impacts of microplastics on marine organisms: A review. Environmental Pollution 178, 483–492. doi:10.1016/j.envpol.2013.02.031

XIV. Appendix A: Random Transect Selection

BEFORE arriving at the site, select four numbers from the Random Number Table, by first choosing a number between 1 and 5, and then a number between 1 and 4. The corresponding number in the table (1–20) is one of the four transects you will survey. Complete this exercise four times to choose four random transects (each transect can be used only once per survey).

Random Number Table

	1	2	3	4	5
1	4	8	17	9	1
2	7	19	2	12	20
3	18	14	6	16	11
4	3	5	15	10	13

Transect ID and distance along shore from start of 100-m shoreline section

Transect ID	Meters (m)
1	0-5
2	5-10
3	10-15
4	15-20
5	20-25
6	25-30
7	30-35
8	35-40
9	40-45
10	45-50
11	50-55
12	55-60
13	60-65
14	65-70
15	70-75
16	75-80
17	80-85
18	85-90
19	90-95
20	95-100

XV. Appendix B: Plastic Beach Project Datasheets

THE PLASTIC BEACH PROJECT

5 GYRES BEACH INFORMATION

Beach Name	
City, County	
Number of volunteers/Origin	
Weather/wind direction and speed	
Date	
Start Time	
End Time	
Last High Tide (time)	
GPS - start of transect (0m)	
GPS - start of transect (100m)	
Length of Shoreline (meters)	
Average Width of beach (Avg T1:T4)(m)	
Direction of Transect when facing water	
Public or Prive Beach	
# of beach users at time of transect	
Site Usage: High/Medium/Low	
Parking lot adjacent?	
Describe any pipes, channels, outfalls etc?	
Describe beach type and details	
Notes:	

THE PLASTIC BEACH PROJECT

5 GYRES MICRO DEBRIS DATA CARD

Beach Name:	Quad 1		Quad 2	
Transect Section Analyzed (ex. 20-25m)				
PLASTIC				
NOTE: Analyze what is on surface prior to carrying out the full analysis	SURFACE	BELOW SURFACE	SURFACE	BELOW SURFACE
Plastic Fragments >4.75mm				
Plastic Fragments 1mm to 4.75mm				
Foam Fragments >4.75mm				
Foam Fragments 1mm to 4.75mm				
Plastic Film >4.5mm				
Plastic Film 1mm to 4.5mm				
Plastic Food Wrappers >4.75mm				
Plastic Food Wrappers 1mm to 4.75mm				
Plastic Bottle Cap >4.75mm				
Plastic Bottle Cap 1mm to 4.75mm				
Plastic Pellets/nurdles >4.75mm				
Plastic Pellets/nurdles 1mm to 4.75mm				
Plastic Fillament (fishing line, rope) >4.75mm				
Plastic Fillament (fishing line, rope) 1-4.75mm				
Plastic jugs or containers >4.75mm				
Plastic jugs or containers 1mm to 4.75mm				
Cigar tips >4.75mm				
Cigar tips 1mm to 4.75mm				
Cigarettes >4.75mm				
Cigarettes 1mm to 4.75mm				
Personal Care Products >4.75mm				
Personal Care Products 1mm to 4.75mm				
TOTAL PLASTIC WEIGHT (g)				
PAPER and METAL				
Paper and Cardboard				
Metal (aluminum foil)				
TOTAL PAPER AND METAL (g)				
OTHER				
Balloons				
Glass				
TOTAL OTHER DEBRIS (g)				
TOTAL WEIGHT of all CATEGORIES (g)				

THE PLASTIC BEACH PROJECT

5 GYRES MICRO DEBRIS DATA CARD

Beach Name:	Quad 3		Quad 4	
Transect Section Analyzed (ex. 20-25m)				
PLASTIC				
NOTE: Analyze what is on surface prior to carrying out the full analysis	SURFACE	BELOW SURFACE	SURFACE	BELOW SURFACE
Plastic Fragments >4.75mm				
Plastic Fragments 1mm to 4.75mm				
Foam Fragments >4.75mm				
Foam Fragments 1mm to 4.75mm				
Plastic Film >4.5mm				
Plastic Film 1mm to 4.5mm				
Plastic Food Wrappers >4.75mm				
Plastic Food Wrappers 1mm to 4.75mm				
Plastic Bottle Cap >4.75mm				
Plastic Bottle Cap 1mm to 4.75mm				
Plastic Pellets/nurdles >4.75mm				
Plastic Pellets/nurdles 1mm to 4.75mm				
Plastic Fillament (fishing line, rope) >4.75mm				
Plastic Fillament (fishing line, rope) 1-4.75mm				
Plastic jugs or containers >4.75mm				
Plastic jugs or containers 1mm to 4.75mm				
Cigar tips >4.75mm				
Cigar tips 1mm to 4.75mm				
Cigarettes >4.75mm				
Cigarettes 1mm to 4.75mm				
Personal Care Products >4.75mm				
Personal Care Products 1mm to 4.75mm				
TOTAL PLASTIC WEIGHT (g)				
PAPER and METAL				
Paper and Cardboard				
Metal (aluminum foil)				
TOTAL PAPER AND METAL (g)				
OTHER				
Balloons				
Glass				
TOTAL OTHER DEBRIS (g)				
TOTAL WEIGHT of all CATEGORIES (g)				

XVI. Appendix C: Modified Plastic Beach Project Data Forms

Beach Characteristics Datasheet

Only needs to be filled out once per beach

Beach Name: Date:

Start Time: End Time:

City, County:

GPS - Start of sampling area (0m):

GPS - End of sampling area (100m):

Direction of transect when facing water (N, S, etc.):

Parking lot adjacent? (circle) Yes No

Sediment Type (sand, pebble, intertidal, etc.):

Nearest River (name and delta):

Nearest Town:

Major recreational use (surfring, kites, general, clamming, etc.)

Notes: (Describe an pipes, channels, outfalls, or other beach details)

Meso- and Microplastic Sampling Datasheet

Needs to be filled out once per 100-meter survey area

Beach Name: Date:

Start Time: End Time:

City, County:

Number of Volunteers/Origin:

Weather Information

Weather Condition (sunny, cloudy, rainy, etc.); Be as detailed as possible:

Beach Slope:

Wind Direction & Speed:

Wave Direction:

Tidal Range:

Last High Tide (time):

Width of beach (average = sum of transect widths/no. transects):

Site usage: High Med Low

No. of beach users at time of transect (best estimate)

Notes:

Transect and Quadrat Datasheet

Beach Name:

Date:

Start Time: **End Time:**

Start of Sampling Area GPS:

Transect 1

Transect Location (ex. 10-15m):

GPS - near water:

GPS - back beach:

Length of transect (m):

Quadrat 1 - High Tide Line

GPS:

Quadrat 2 - Back Beach

GPS:

Transect 3

Transect Location (ex. 10-15m):

GPS - near water:

GPS - back beach:

Length of transect (m):

Quadrat 1 - High Tide Line

GPS:

Quadrat 2 - Back Beach

GPS:

Transect 2

Transect Location (ex. 10-15m):

GPS - near water:

GPS - back beach:

Length of transect (m):

Quadrat 1 - High Tide Line

GPS:

Quadrat 2 - Back Beach

GPS:

Transect 4

Transect Location (ex. 10-15m):

GPS - near water:

GPS - back beach:

Length of transect (m):

Quadrat 1 - High Tide Line

GPS:

Quadrat 2 - Back Beach

GPS:

Notes:

XVII. Appendix D: Volunteer Test Methodology

Volunteer Test Methodology

****Please read this document carefully. I will offer no additional assistance.****

You will be sampling a 1m by 1m quadrant that has been staged with meso- (5mm-2.5cm) and microplastic debris (>5mm). It is your job to follow the procedure below and report the abundance of debris you found in your sample.

Materials Provided:

- 1mm stainless steel mesh sieve
- 3-gallon bucket
- Tweezers
- Plastic collection bag
- 1-meter by 1-meter quadrant
- Shovel

Methods:
Please note that these are abbreviated methods. They start in the middle and completely ignore the beginning. This is done for two reasons: 1) it drastically reduces required volunteer time and 2) we're only concerned with this section of the methods for assessment.

1. Use the shovel, or your hands (whichever you prefer), to scrape the top layer of sediment into the sieve.
    a. *NOTE* You should not be digging into the sediment. Try to not penetrate more than a few millimeters into the sediment.
2. Shake the sieve back and forth, forcing the sediment out of the openings.
3. Using the 3-gallon bucket, collect seawater and bring it back to your quadrant.
4. Dump the debris in the sieve into the seawater.
5. Using the tweezers, or your fingers (whichever you prefer), separate the meso- and microplastic debris from the organic debris.
    a. **IMPORTANT:** Keep count as you separate the debris. This is to see how well you did following these procedures. In the "real" procedure volunteers are not required to count the debris.
6. Place the separated meso- and microplastic debris in the plastic collection bag.
7. Report your count to me.

Thanks for all your help!

XVIII. Appendix E: Collection Bag Labels

These labels need to be printed on Rite in the Rain™ paper so they stand up in the environment. Please make sure to fill out these labels with pencil, as normal pens do not work.

Site Name: Date: Transect (circle): 1 2 3 4 Quadrant (circle): HT Mid Back	Site Name: Date: Transect (circle): 1 2 3 4 Quadrant (circle): HT Mid Back
Site Name: Date: Transect (circle): 1 2 3 4 Quadrant (circle): HT Mid Back	Site Name: Date: Transect (circle): 1 2 3 4 Quadrant (circle): HT Mid Back
Site Name: Date: Transect (circle): 1 2 3 4 Quadrant (circle): HT Mid Back	Site Name: Date: Transect (circle): 1 2 3 4 Quadrant (circle): HT Mid Back
Site Name: Date: Transect (circle): 1 2 3 4 Quadrant (circle): HT Mid Back	Site Name: Date: Transect (circle): 1 2 3 4 Quadrant (circle): HT Mid Back
Site Name: Date: Transect (circle): 1 2 3 4 Quadrant (circle): HT Mid Back	Site Name: Date: Transect (circle): 1 2 3 4 Quadrant (circle): HT Mid Back