PARTICIPATORY SENSING MARINE DEBRIS: ESTIMATES FOR AMOUNTS, TYPES, AND DISTIBUTION USING MARINE DEBRIS TRAKCER DATA

by

KATHERINE E. SHAYNE

(Under the Direction of Jenna Jambeck)

ABSTRACT

Marine Debris Tracker (MDT) is a mobile app and citizen science program originally sponsored by the NOAA Marine Debris Program and launched in 2011. At the time, MDT was the first app of its kind, allowing users to report litter anywhere in the world. In its more than 6-year timeframe of use, the app and program has helped collect data on over 1.1 million debris items across the globe. Besides collecting data, the app itself serves as an outreach and education tool, creating an engaged participatory sensing instrument. Also, important to Marine Debris Tracker is open data and transparency. A web portal provides data that users have logged allowing immediate feedback to users. The MDT community and dataset continues to grow daily. This thesis presents current usage and engagement, participatory sensing data distributions, areas of active tracking, and, for the first time, a statistical analysis of the MDT opportunistic data through the development and use a Poisson model for Jekyll Island, Georgia.

INDEX WORDS: Marine debris, citizen science, mobile applications, opportunistic data modeling, Poisson distribution, plastic pollution

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KATHERINE E. SHAYNE

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KATHERINE E. SHAYNE

Major Professor:	Jenna Jambeck
Committee:	Kyle Johnsen
	Lan Mu

Electronic Version Approved:

Suzanne Barbour
Dean of the Graduate School
The University of Georgia
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CHAPTER 1

INTRODUCTION

1.1 Overview

The identification of the problem of marine debris partly came from people noticing litter accumulating in their local environments. Although anecdotal at the time, these observations became data collection initiatives, and have helped to inform marine pollution science and policy; they give a voice to the people confronted with trash on their beaches, in their waterways and accumulating in their local environments. Much of the marine litter observed from land-based sources is mostly plastic (Schuyler et al., 2018). The history of marine litter research is closely linked to the development of plastics.

There was an estimated 2.5 BMT (billon metric tons) of municipal solid waste generated in 2010 by 6.4 billion people living in 192 countries world wide (Jambeck et al. 2015). Of this, 31.9 MMT (million metric tons) was classified as mismanaged waste and an estimated 8 MMT of plastic waste eventually reaches the ocean each year from mismanaged sources (Jambeck et al., 2015). Plastic is a prevalent anthropogenic material in the marine ecosystem, and raises concerns due to its effects on wildlife and potentially humans. Plastics do not naturally biodegrade, rather they fragment into microscopic pieces and stay in aquatic environments for yet undefined time periods.

Citizen science initiatives can help curb the input to plastics and debris into the ocean. Clean ups and actions by citizens inform the public, and can influence decision makers to act on policy (Thiel et al., 2017). The Marine Debris Tracker is a participatory sensing citizen science application where data is collected by human "sensors" around the world at a scale, speed, and efficiency that was not previously possible before the application existed (Jambeck and Johnsen, 2015). The MDT data is opportunistic, requiring advanced statistical modeling to understand trends and make informed conclusions about debris accumulation and possible sources.

1.2 Objectives and Scope

The objectives of this research were to:

1. Characterize the Marine Debris Tracker (MDT) data for types and amounts of marine litter at a global scale.
2. Conduct a regional assessment of MDT data based on the 10 NOAA Regions characterizing and comparing the regions for types and amounts of marine litter.
3. Conduct a site specific investigation into the MDT data for types and amounts on Jekyll Island, Georgia.
4. Develop models that can assess MDT opportunistic data in communities worldwide via communities' geographic features and infrastructure.

1.3 Thesis Organization

This thesis is organized in the following way: Chapter 2 is a literature review of current studies and reports on marine debris, plastics in the ocean, opportunistic data and statistical modeling. Chapter 3 encompasses the initial investigation into the MDT data, and assessment of the MDT data in NOAA MDP regions. Chapter 4 consists of a paper draft for the truncated Poisson model developed to analyze opportunistic MDT data in

Jekyll Island, Georgia. And lastly, Chapter 5 is a summary and proposed future work to continue to analyze citizen-based marine debris data.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter includes historical research relevant to marine debris, citizen science, opportunistic data and statistical methods. It provides an overview of the issue associated with marine debris and plastics in our oceans, how citizen science has been used to educate, engage and inform research and policy, and the Marine Debris Tracker data, as well as is opportunistic data in general.

2.2 Plastics in the Ocean

The effects of marine debris are numerous. From harming wildlife to affecting the food chain, marine debris does more than impact tourism through unsightly beaches. Concerns over marine debris have been raised since it was discovered impacting albatross chicks in the Hawaiian Islands in 1966 (Kenyon and Kridler, 1969). It is not a new issue; however, we are continuing to see an increasing amount of plastic enter the ocean every year (Jambeck et al., 2015). Plastic production has increased from 1.7 million metric tons/year in 1950 to more than 322 million metric tons/year in 2015 (PlasticsEurope, 2016). This steep increase in plastic production has been accompanied by an increase of plastic in the waste stream. 40% of the plastic produced is used for packaging, which can add significantly to the waste stream (PlasticsEurope, 2016). In 1960, plastic accounted for 0.4% of the waste stream; whereas in 2012, plastic accounted for 12.7% in the USA

(Ryan, 2015). Plastic is an increasing concern in litter streams and collections of marine debris as they have a high percentage of presence in both, e.g., 19.3% and 60-95%, respectively (Shultz and Stein, 2009)(Moore, 2008).

Plastics come in many shapes, colors, and textures, and, have properties that include flame retardation and antimicrobial surfaces. These property enhancements are from additives. (Deanin, 1975). The addition of additives results in a wide variety of plastic materials for various uses. The plastics eventually, when exposed to sunlight and other environmental factors, will fragment into microscopic pieces over time, lingering in environments rather than biodegrading (van Sebille et al., 2015).

Plastics can harm wildlife and potentially human health. In Wilcox et al., 2016, experts provided a ranking of the top three most harmful debris items to wildlife; they were fishing gear, followed by balloons and plastic bags – all of those items are made of plastic. In a recent study, the number of marine species with reports of fatal entanglement and ingestion increased from 260 to nearly 700 in fewer than 15 years (Wilcox et al., 2016). In a critical review by Rochman et al., 2016, 83% of the 296 threats of debris to wildlife tested were proven threats, and 82% were from plastic. Not only is there evidence that there are threats, but these threats have been observed first hand. When fishing nets and other equipment get lost, they drift and continue to trap fish, invertebrates, and other wildlife.

This type of threat is called “ghost fishing,” and in a study in Puget Sound, they recovered and analyzed 870 gillnets lost from fisherman. Among these gillnets they found 31,278 invertebrates, 1,036 fishes, 514, birds, and 23 mammals. Of the wildlife caught, 56% of invertebrates, 93% of fish, and 100% of birds and mammals perished (Good et al., 2010).

Marine debris can affect human health and well-being. It can present hazards to the shipping and boating industry, as well as tourism. Debris can entangle propellers, clog water intake, alter navigation systems, and stop pumping systems. In the tourism sector, marine debris can pose a potential decline in beachgoers and tourists due to unsightly, unclean beaches. In Orange County, California, where NOAA Marine Debris Program preformed a study in 2014, residents reported being concerned about marine debris, and what impacts it had to the beach systems. They thought that clean beaches were the most important beach characteristics (NOAA, 2014). Decreases in tourism come at steep costs. According to UNEP, plastics carry a $13 billion financial burden to the marine ecosystem globally (UNEP, 2014).

Marine debris and plastic waste can enter the ocean from inputs on land. A recent study estimated that 275 million metric tons of plastic waste was generated in 192 countries. Of the 275 MMT, 99.5 MMT was generated 50 kilometers from the coast, and a percentage of that was mismanaged (31.9 MMT). It was then estimated that between 4.8 and 12.7 MMT reached the oceans annually (**Figure 1**) (Jambeck et al., 2015). Once this plastic is in our oceans it becomes a global issue. There are both economic and logistical issues to attempting to clean plastic from the ocean. Mitigation strategies are needed for upstream preventative acts to reduce debris going into the ocean. And while more research may be needed to assess exposure, cleanup efforts should still take place, as a last chance effort to both keep debris from entering the ocean and in some areas that are deposition sites (plastic washing up onto shorelines), it may even clean the ocean.

Figure 1. Plastic inputs from land into the ocean (Jambeck et al., 2015 with permission).

2.3 The Importance of Citizen Science and Data Collection

Collection efforts for marine litter are a last chance effort to prevent litter from entering the ocean. Clean ups and actions by citizens inform the public, and can influence decision makers to act on policy (Thiel et at., 2017). Working together on marine litter projects enhances awareness and participation in solutions (Veiga et al. 2016). Citizen science and volunteer programs can be powerful tools in generating scientific information in regions where no or little information about marine debris abundances, composition, and impact exists (Thiel et al., 2017). Using volunteers to bring awareness to litter issues and collect valuable data through citizen science initiatives, information can be collected on a spatial scale rarely achieved through professional studies alone. Citizen Science poses a unique position in bringing together people from many different backgrounds and nationalities to raise environmental awareness about marine litter and provide much needed data (Thiel et al., 2017).

The use of citizen scientists and decentralized groups of nonprofessionals to gather information predates the internet and has long been embraced by community projects. In producing environmental data, citizen scientists become agents in decision making and policymaking processes. In robust citizen science projects, the redundancy of data and information can serve as a peer-reviewing, self-correcting mechanism, thus improving the reliability of such information (Connor, Lei, and Kelley 2012). When citizen science projects utilize technology such as GPS recording devices which are imbedded in many phones and tablets, they can voluntarily give geographic information that allows them to be a network of human functioning as technicians and sensors in real time. The concept of using citizens to monitor issues, especially environmental ones, can be seen in the numerous projects that are active (**Table 1**).

Table 1. Various active citizen science projects.

Project	**Disciplines**	**Began**
Reef Environmental Education Foundation (REEF)	Marine Conservation, Marine Biology	1990
Georgia Adopt-a-Stream	Water Quality	1995
Frog Watch USA	Conservation, Ecology, Herpetology	1998
eBird (Bird Watch)	Infectious Disease Ornithology	2013
Zooniverse	Various	2007
Go Viral Study	Infectious Disease Ornithology	2013

The rise of marine litter is closely coupled with the development and production of plastics. In regards to plastic, if we implement citizen science efforts to collect data and clean areas contaminated with litter, it can inform upstream solutions to plastic pollution issues. Clean-up efforts by citizen scientists can be seen as a "last chance" to stop debris from entering the ocean.

If our goal is zero input of plastic (or other materials) into the ocean, then our mitigation strategies can start upstream and go all the way to the end of this value chain, while taking an integrated approach (**Figure 2**). First, if production was reduced, it would decrease the amount of plastic in the waste stream, leaving a smaller percentage to potentially be mismanaged. In the next step, product design and materials substitution could allow products to last longer, have a simpler recyclable design, have substantial reuse capabilities or biodegrade. Next, as products enter the waste stream, improved waste management infrastructure can be developed, especially where it is currently lacking. Then finally, in a "last chance" effort, marine debris can be captured before it enters the ocean, or cleaned from coastlines after it has been deposited onto shorelines. Capture methods range from floating river booms, to beach cleanups and surveys, such as the Marine Debris Tracker. The data collected during beach cleanups can then inform upstream solutions, e.g., what items are found most frequently in particular areas? Is there an awareness and behavior issue to address there? Or, are there ways to redesign the packaging, or the system of delivery to reduce the problematic materials or items? These are questions that can be explored and addressed with data collected from litter and beach cleanups.

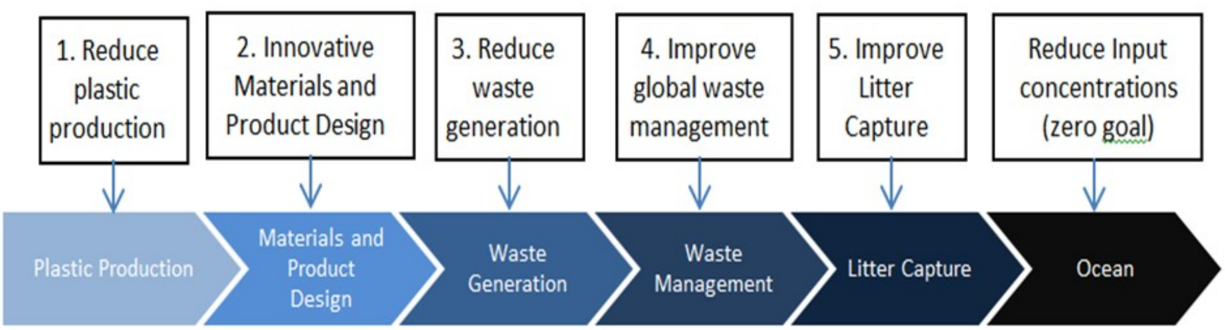


Figure 2. Marine plastics value chain for interventions for marine plastic debris before reaching the oceans (US Senate Committee on Environmental and Public Works, 2016).

2.3.1 Citizen Science Data Collection and Challenges

Citizen science efforts to curb marine litter have been seen across the globe. Studies have been conducted on the local (one sampling site), regional (several sampling sites), and even international scale. Research on marine debris has focused on six main areas: (1) Distribution and composition of marine litter, (2) interaction with marine biota, (3) toxic effects, (4) horizontal and vertical transport, (5) social aspects, and (6) degradation of marine plastic litter. The majority of citizen science studies available, however, have only focused on spatial distribution and composition of marine litter where intertidal zone environments were the only sampling zone (Hidalgo-Ruz and Thiel, 2015). Degradation of marine litter was not addressed by citizen scientists. The majority of citizen science studies cover time periods ranging from less than 1-2 years. Marine litter is a wide spread, global issue, but little is known about it on this scale because most of citizen science studies have been performed in the northern hemisphere (Hidalgo-Ruz and Thiel, 2015; Goodchild, 2007).

One of the major concerns of citizen science data, no matter how it was collected, is whether it is a reliable source of data, and if it can be compared to professional studies. There are four major criteria on assessing the quality of data: (1) the preparation of protocols, (2) training of volunteers, (3) *in situ* supervision of experts, and (4) validation of data and samples (Bonney et al. 2009).

2.4 Marine Debris Tracker and Opportunistic Data

The Marine Debris Tracker was developed as the first participatory sensing application to collect marine debris data worldwide in 2011. Marine Debris Tracker allows users to log data on the local, regional and international scale, all through the same application using smartphones and tablets. The application has multiple lists from which to choose from to log items (**Figure 3(a) and 3(b)**). The categories of materials that can be logged include plastic, metal, cloth, lumber and paper, glass, fishing gear, rubber, and other (items not listed in any category). Within each materials category are numerous items. For example, within the metals material category of the NOAA Marine Debris Items list, the items consist of aerosol cans, aluminum or tin cans, and metal bottle caps (**Figure 3(c)**).

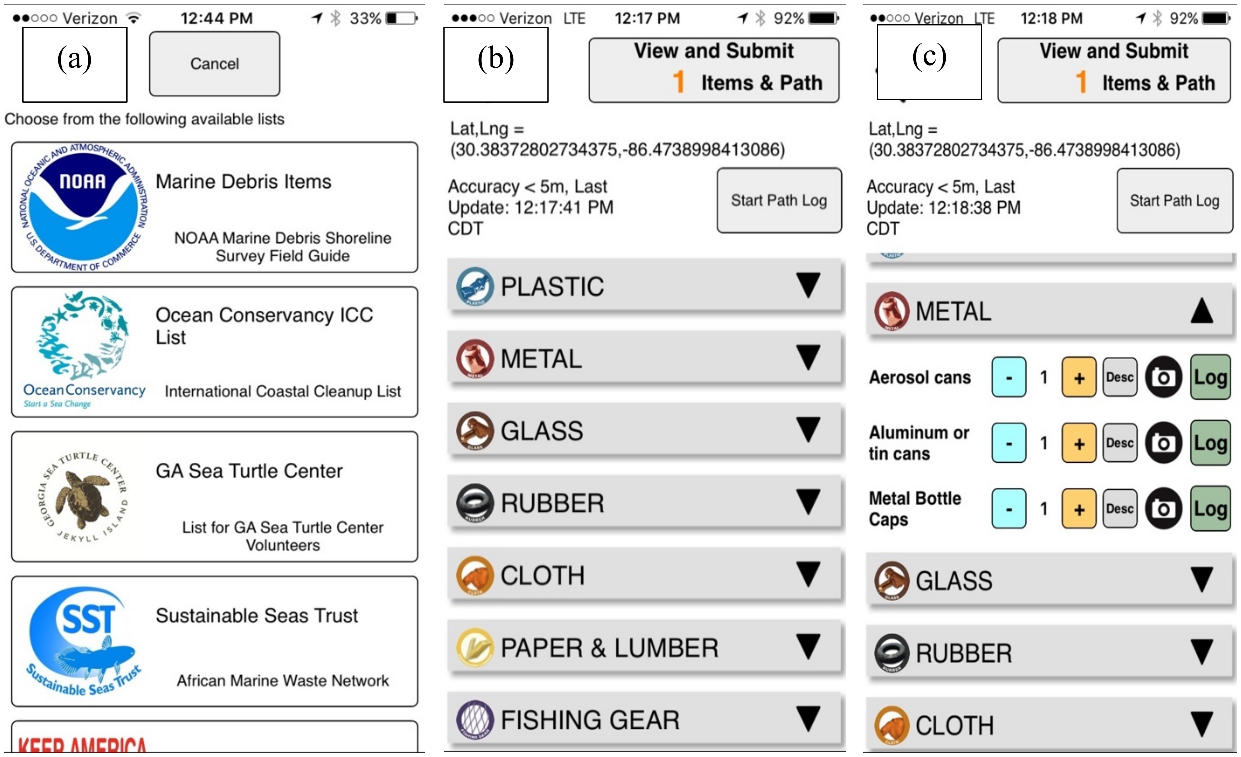


Figure 3(a), (b), and (c). Images of the MDT application on an iPhone 6. (a) is a partial list of specific item lists from various organizations. (b) is a partial list of materials categories, and (c) is the item list under the metal material category from the NOAA MDP's list.

Not only are the materials and items recorded by the app, but multiple other variables are also logged. The latitude and longitude of each entry is captured, collected through GPS signaling in the WGS_1984 geographic coordinate system. The latitude and longitude can be used—and have been for this project—to map in software like Geographic Information Systems (GIS) or other mapping programs. The error radius of the GPS latitude and longitude point is recorded in meters, as well as altitude. The time and date are captured for each entry as well, which can be used for temporal analysis. A description can be added to a logged item, and a photo can be taken too.

The data is stored in a MySQL database, which provides data security, storage, access, and backup. The database in overseen by two professors in the College of Engineering at UGA. A PHP-based web service allows for any programmable, internet-capable device to securely log marine debris items by accepting the debris data collected, user identification data, and metadata about the upload itself (Jambeck and Johnsen, 2015). Data are posted on a publicly available web portal (http://marinedebris.engr.uga.edu) , with open source data available for download to anyone. Data is also viewable and filterable on an interactive map. The application has over 15,000 downloads and over 1,400 registered users. (**Figure 4**).

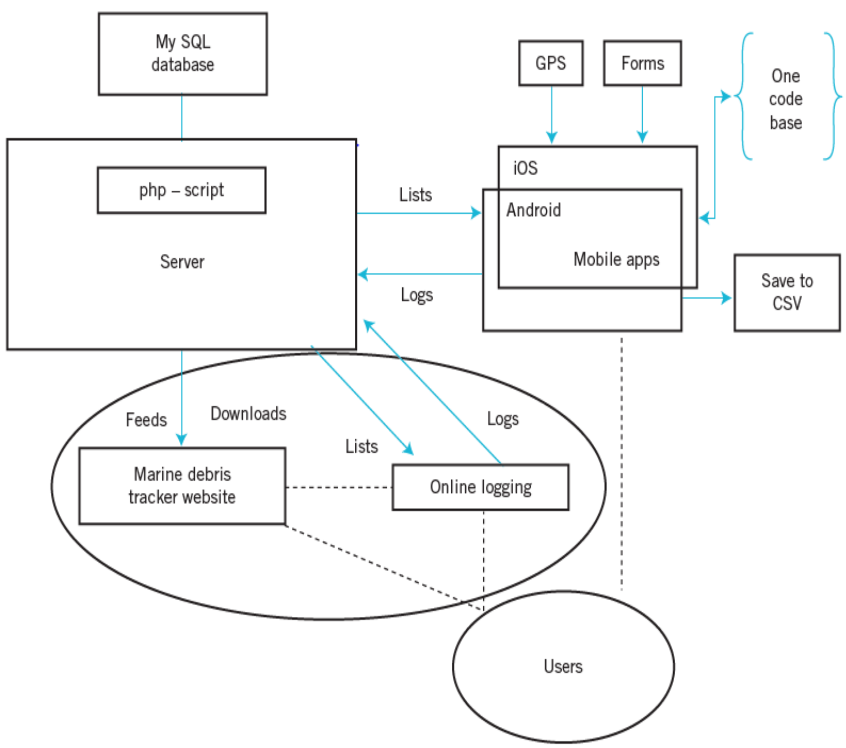


Figure 4. Marine Debris Tracker database and application architecture (Jambeck and Johnsen, 2015).

The Marine Debris Tracker was developed in partnership with the National Oceanic and Atmospheric Administration (NOAA) Marine Debris Program and the Southeast Atlantic Marine Debris Initiative at UGA's College of Engineering. The vision of the NOAA MDP is to have the global ocean and its coasts free from the impact of marine debris. Its mission is to investigate and prevent the adverse impacts of marine debris. For NOAA's MDP's research, the MDP monitors the amount and types of debris on shorelines and supports projects to help understand debris baselines, chemicals in plastics, debris detection, plastic ingestion by wildlife, economic implications, and how to minimize the impacts of derelict fishing gear (Marinedebris.noaa.gov, 2017).

Within the program, there is regional coordination that supports local marine debris initiatives through ten regions across the United States, including the Pacific Islands and the Caribbean. Regional coordinators guide action planning and provide expertise to ensure that stakeholders have the best information available. The NOAA regions include the Southeast, Northeast, Mid-Atlantic, Great Lakes, Gulf of Mexico, California, Pacific Northwest, Alaska, Pacific Islands, and the Caribbean (**Table 2**) (**Figure 5**) (Marinedebris.noaa.gov, 2017).

Table 2. NOAA Marine Debris Program regions by state or territory (Marinedebris.noaa.gov, 2017)

Region	**Areas Involved (Marinedebris.noaa.gov,2017)**
Southeast	North Carolina, South Carolina, Georgia, Florida (Atlantic Coast)
Northeast	Main, New Hampshire, Rhode Island, New Jersey, New York (Atlantic Coast)
Mid-Atlantic	Virginia, Maryland, Washington DC, Delaware, Pennsylvania (Atlantic Coast)
Great Lakes	Ohio, Michigan, Indiana, Illinois, Wisconsin, Minnesota, and Western Pennsylvania and New York
Gulf of Mexico	Texas, Louisiana, Mississippi, Alabama, Florida (Gulf Coast)
California	California
Pacific Northwest	Oregon and Washington
Alaska	Alaska
Pacific Islands	Hawaii, Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands
Caribbean	Puerto Rico and U.S. Virgin Islands

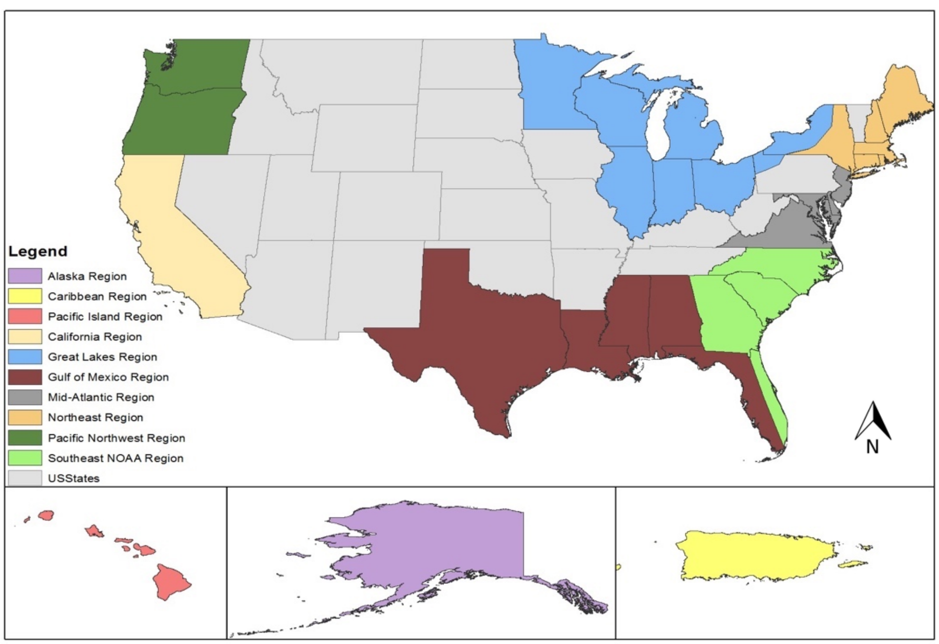


Figure 5. NOAA Marine Debris Program regions mapped in GIS (Marinedebris.noaa.gov, 2017)

2.4.1 Opportunistic Data

The Marine Debris Tracker is a participatory sensing citizen science application where data is collected by human "sensors" around the world at a scale, speed, and efficiency that was not previously possible before the application existed (Jambeck and Johnsen, 2015). In opportunistic data collection with citizen scientists, multiple biases exist in the collection process. These biases are explained in van Strien's Opportunistic citizen science data analysis of animal species, which produced reliable estimates of distribution trends if analyzed with occupancy models (2013). Quantifying animal densities and distributions are heavily reliant upon participatory sensing opportunistic data, and therefore, similar methods can potentially be used to analyze Marine Debris Tracker data.

The first bias that is prevalent in citizen science data is geographical bias. Because opportunistic data are rarely collected through a designed scheme, they suffer from uneven geographical distribution of surveyed sites. Second, the lack of standardization of observer efforts within sites leads to variable search efforts, which may bring an observational bias into the data. Third, observers often do not report all species observed, but only those they find interesting. This is known as a reporting bias, and can be a possible bias in MDT data as well, some people may only report plastic and not glass or other organic items. Lastly, observers are unable to detect all species occurring at a site. This is known as a detection bias. Although most marine debris is visible along flat sandy beaches, some beaches may be rocky, covered in vegetation or other components that may hide coastal litter (van Strien et al., 2013).

Opportunistic data is difficult to analyze as well due to the nature of data collection. For opportunistic data, large datasets are needed to preform analysis. Volunteers who use the Marine Debris Tracker to collect data opportunistically. Therefore, their survey areas, duration of tracking and effort is unknown. This tends to make tracking user effort and areas surveyed relatively difficult to understand from a data analysis perspective. Therefore, understanding the accumulation of debris and sources, such as points of litter leakage, have to be considered from a large data set in boundaries set but the analyzer.

2.4.2 Statistical Methods for Opportunistic Data Analysis

Opportunistic data has been used to build models and predict animal densities in ecology and biology fields. Models used in quantifying these are called occupancy models. A common occupancy model called "unmarked" has been used for statistically analyzing opportunistic surveys of unmarked animals. The focus of these models is on hierarchical models that separately model latent state or states and an observation process. Unmarked provides methods to estimate site occupancy, abundance, and density of animals that cannot be detected with certainty. Numerous models are available that correspond to specialized survey methods such as temporally replicated surveys, distance sampling, removal sampling, and double observer sampling. These data are often associated with metadata related to the design of the study. For example, distance sampling, the study design (line or point transect), distance class break points, transect lengths and units of measurement need to be accounted for in the analysis (Fiske and Chandler, 2011).

Although occupancy modeling is a chosen method for opportunistic animal distributions and density analysis, there are other available statistical distributions that can be used for modeling opportunistic data. Two such models that are utilized for analysis of the MDT data are the Truncated Poisson and Hurdle models, both of which are based upon the Poisson distribution.

The Poisson distribution gives the probability of a given number of events happening in a fixed interval of time or space (**Figure 6**). This distribution can be derived from assumptions about what happens in a very small amount of time (Hilborn and Mangel, 2013). The events occur with a known constant rate and independently of the time since the last event. The Poisson distribution can be useful to model events such as the number of patients arriving in an emergency room in a given hour or the number of phone calls received by a call center per hour (Frank, 1967).

The probability of events for the Poisson distribution follows **Equation 1**.

$$P(k\ events\ in\ interval) = e^{-\lambda \frac{\lambda^k}{k!}}$$

Equation 1. Poisson probability equation (Hilborn and Mangel, 2013).

Where λ is the average number of events per interval and *k* is the event count. Also, the average number of events per interval, λ, can be interpreted as the time rate *r* for the events to happen times time (**Equation 2**) (Hilborn and Mangel, 2013). Therefore

$$P(k\ events\ in\ interval\ t) = e^{-(rt) \frac{(rt)^k}{k!}}$$

Equation 2. Poisson probability equation expanded (Hilborn and Mangel, 2013).

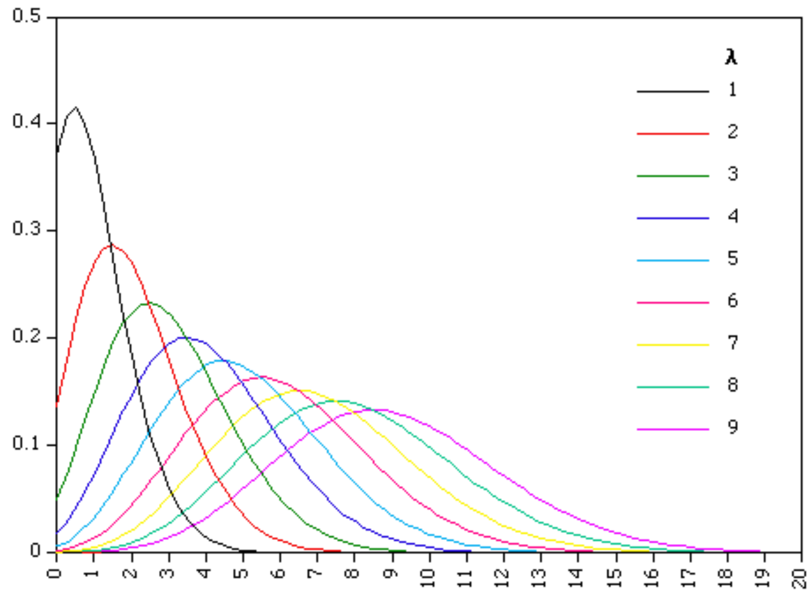


Figure 6. Poisson distribution as λ increases (UMASS, 2007).

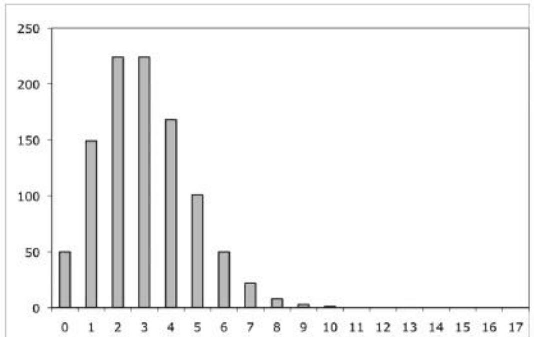
A characteristic of the Poisson distribution is that its mean is equal to its variance. The Poisson regression is a generalized linear model form of regression analysis used to model count data and contingency tables with the logarithm as the link function, and the Poisson distribution function as the assumed probability distribution of the response (Cameron, 2013). A common problem with the Poisson regression is excess zeros (Berk, 2008). This is also an issue with determining areas of debris accumulation is areas, since areas that haven't been visited by trackers when data is gridded are zeros. Since this is true for the MDT data as well, we can investigate the Zero-Truncated Poisson distribution as a way modeling this type of data (**Figure 7(a) and (b))** (Berk, 2008; Hu, Pavlicova, and Nunes, 2011; Cameron, 2013) .

The zero-truncated Poisson distribution is a certain discrete probability distribution whose data is a set of positive numbers. This model can be thought of in terms of grocery shopping. Consider the variable in question is the number of items is a shopper's basket in the checkout line. The assumption is that the shopper does not stand in line with nothing to buy, so the minimum purchase is one item (Hu, Pavlicova, and Nunes, 2011). Here, since k>0 the formula takes the form of

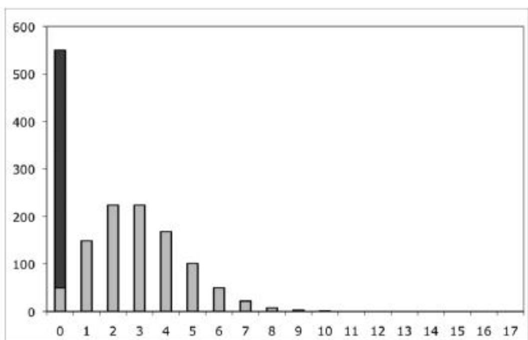
$$P(k \ events \ in \ interval \ t) = \frac{\lambda^k}{(e^\lambda - 1)k!}$$

Equation 3. Zero-truncated Poisson probability function. (Hu, Pavlicova, and Nunes, 2011; Cameron, 2013)

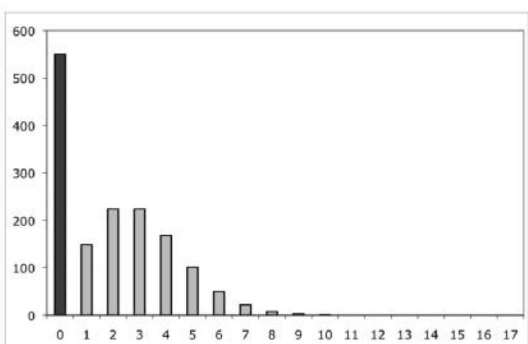
a) Data appropriate for Poisson model (n=1000, Mean=3, Variance=3)



b) Data appropriate for Zero-Inflated Poisson model (n=1500, with 500 "structural" and 50 "sampling" zeros)



c) Data appropriate for Poisson Hurdle model (n=1500, with 550 "structural" and no "sampling" zeros)



Figures 7(a), (b), and (c). Data distributions appropriate (a) Poisson Distribution, (b) truncated Poisson model, and (c) Hurdle model (Hu, Pavlicova, and Nunes, 2011).

CHAPTER 3

MARNIE DEBRIS TRACKER DATA ASSESSMENT

3.1 Introduction

The Marine Debris Tracker is a global application. Marine debris data is recorded from around the world (**Figure 8**). This chapter is the initial investigation into the data collected between 2011 and 2017.

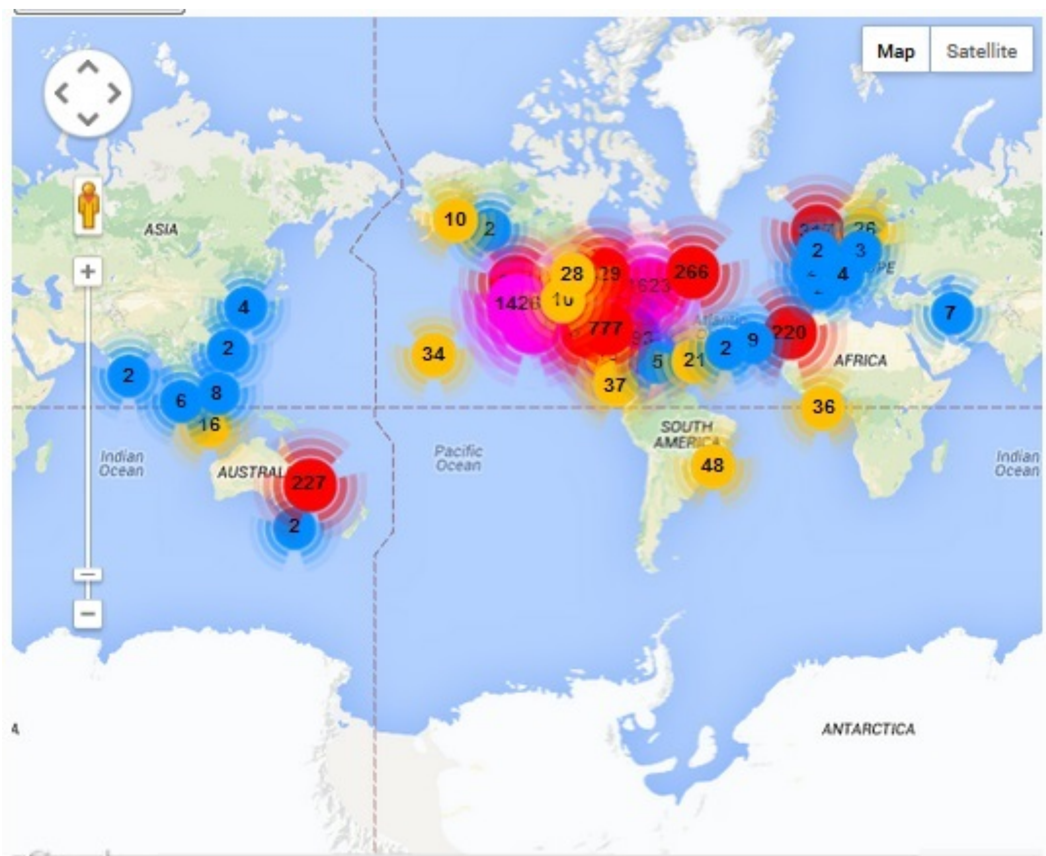


Figure 8. Marine Debris Tracker data displayed on an interactive web map located on the MDT website (http://www.marinedebris.engr.uga.edu).

3.2 Initial Investigation

The initial investigation into the Marine Debris Tracker data began with the raw, unfiltered data from its MySQL database. The MDT application records variables based on location and user input. From MySQL, where the data is stored, spreadsheets of variables can be exported and used. However, a spreadsheet with the combination of all variables was beyond the programs capabilities. Therefore, initial manual quality assurance and control was preformed to combine all variables needed for analysis. In the end, a usable, populated dataset was produced to be used for the remainder of this project (**Table 3**). In doing so, it was discovered that some of the categories had multiple indexes. For example, the material and material index numbers were not congruent throughout. In some instances, the material "PLASTIC" would be indexed to number 4, 8, and 10. These common indexes were combined through manual recoding of materials based on the item reported.

Table 3. Marine Debris Tracker attributes used for analysis.

Variable	Description
id	Number identifier for individual entries
item_index	Number associated with item
item	Items registered to organization lists within application
user_index	Number associated with usernames
username	Names of users for tracking, top trackers list, and login purposes
effort_index	Number recorded for a user's effort
latitude	Latitude coordinate in degrees
longitude	Longitude coordinate in degrees
altitude	Altitude of report in meters
radius	GPS error radius in meters
time	Time of report
description	User added description of debris item
additonal_info	Additional information about report
qunatity	Amount of the item found
location	Geotagged location based on GPS coordinates
dt	Date of report
month	Month of report
image	User uploaded image
material_index	Number associated with material category
material	Material category of items
entrytype	How the coordinates for the report were recorded (e.g. GPS)

The MDT data used in this project encompassed data from 12/30/2010 through 06/12/2017. Each entry (can be one or multiple items) contains a latitude and longitude coordinate as well as a radius of GPS accuracy and altitude. According to the US Government's GPS site, GPS in smartphones and other capable devices are accurate up to a radius of 15 meters (gps.gov). GPS error radii for each MDT report follows the distribution seen in **Figure 9**. Approximately 85% of the recorded MDT reports' GPS locations are below 1,000 meters in radius error. Within the 0-20 meter GPS radius range, 62% of the MDT reports sit. The majority (51%) of the MDT reports have GPS error radii between 5-10 meters, where the median of the overall distribution is 5 meters.

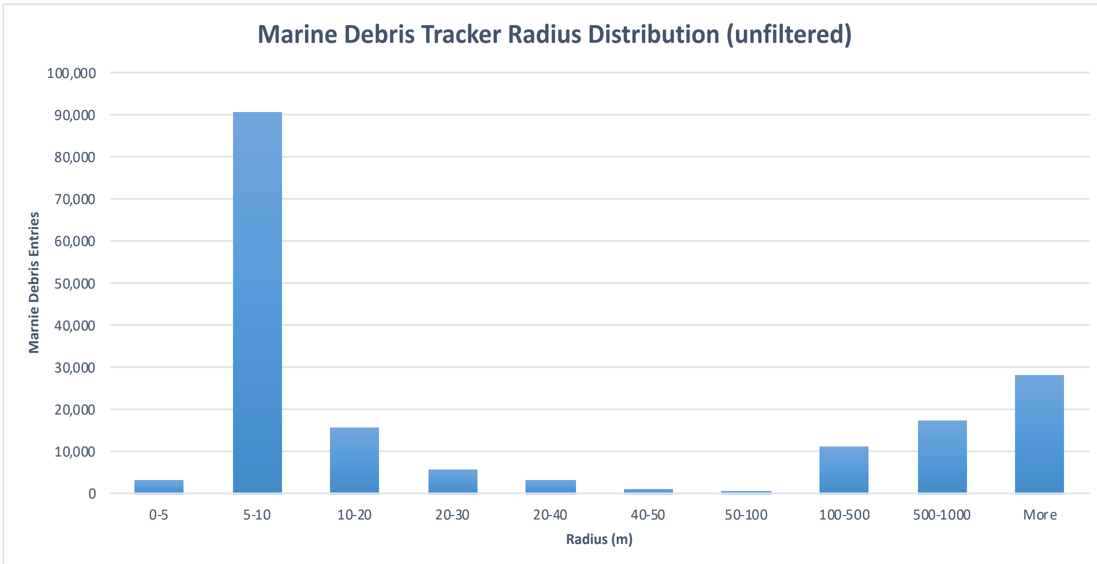


Figure 9. Distribution of MDT reports' GPS radius of error.

Global reports for marine debris total 176,502 entries and 1,191,760 items (**Table 4**). The various categories—plastic, metal, paper and lumber, fishing gear, glass, rubber, and other items—were split up and relative totals were taken from each of these categories. These main categories make up 99.3% of the items tracked, whereas microplastics and cleanup input data make up roughly 1% of the of the total reports. Therefore, the lesser-used categories do not have a significant influence on the analysis of the data, and the main categories will be the only material categories used for analysis.

Table 4. Total materials and percent of total in each category for unfiltered global data (MDT, 2017)

Material Category Characterizations (unfiltered)		
Material	**Reporting Frequency**	**Percent of Total Reports**
Plastic	118,566	67.18%
Other Items	15,830	8.97%
Paper & Lumber	13,675	7.75%
Metal	9,744	5.52%
Fishing Gear	7,603	4.31%
Glass	4,594	2.60%
Cloth	4,201	2.38%
Rubber	1,059	0.60%
Microplastics	640	0.36%
Cleanup	590	0.33%
Total	176,502	

The top 10 and 20 items reported globally accounted for 62% and 79% of the data respectively (**Figure 10**). Of the 10 top items reported, plastic accounts for the top 6 items, making up 76%. In the top 20 items reported, plastic accounted for 13 out of the top 20, approximately 75% of the top 20 items (**Appendix A**). The top 10 locations for reporting were in cities located in the United States, and mostly in the Southeast (**Figure 11)**. The top 10 locations account for 33% of the total reported locations. It is noted that within the top location analysis, "unknown, unknown" and [blank] locations ranked amongst these cities, accounting for 34% of the total reports. Combined with the top 10 cities, this data accounts for 67% of the total data based on location. A way to minimize the unknown and blank reported locations is to map their latitude and longitude coordinates through a program like GIS, and extract that information separately. Another way would be to find the site specific latitude and longitude attributes and filter for these location is R.

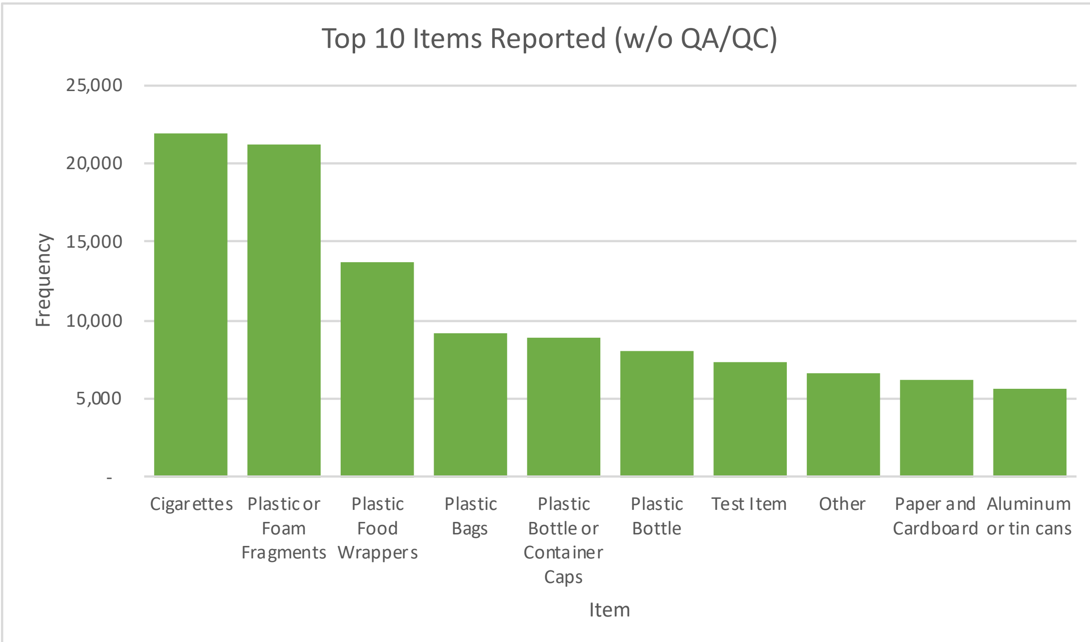


Figure 10. MDT top 10 items reported by users globally (unfiltered).

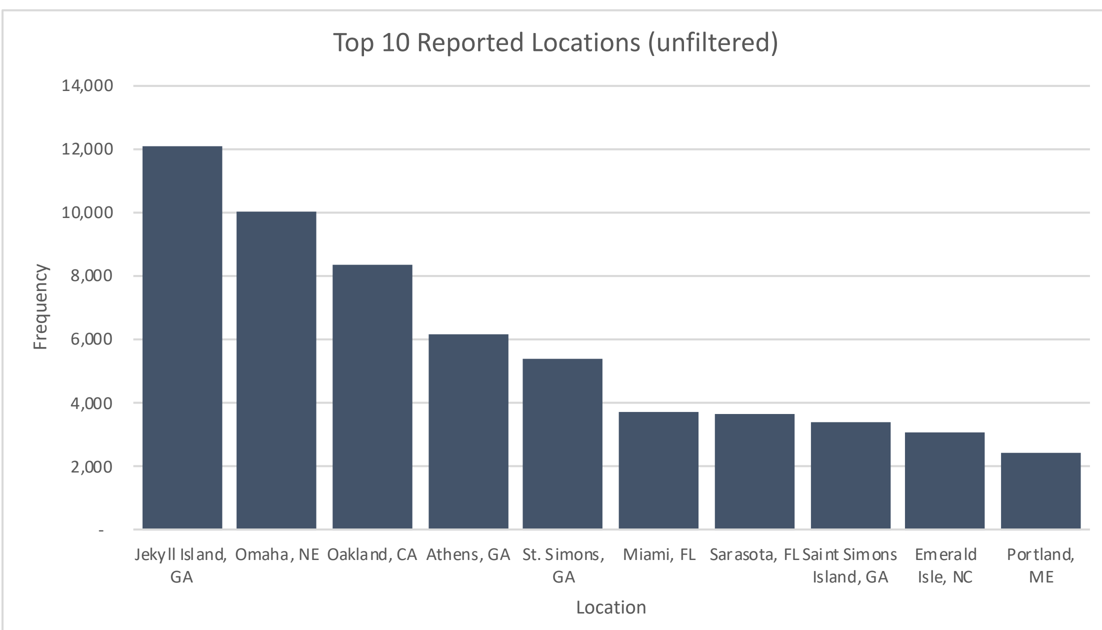


Figure 11. MDT top 10 reported locations globally (unfiltered).

The MDT attributes have a quantity input for the items collected. Therefore, the amount of entries and items logged are different. Globally, the MDT has 1,191,760 items reported. Plastic accounts for approximately 67% of the quantity of debris reported, which congruent with the findings on reports alone (also 67%). However, the top 10 items based on quantity differ slightly from reports only (**Figure 12**). Plastic or foam fragments are the highest item in quantity tracked, whereas cigarettes were the top item tracked based on reporting alone.

To compare quantities of items by top locations, a comparative study was performed between Jekyll Island, Georgia and Omaha, Nebraska (**Figure 13**). Jekyll Island is the home the Georgia Sea Turtle Center, who is a frequent tracker on MDT. They are an organization that uses volunteers to track debris under the same username. Whereas, in Omaha, Nebraska, an individual tracker frequently records debris under a single username. This is an example of the range of user profiles that MDT houses. These top 1 and 3 trackers are on opposite spectrums of the user base, however, are recording relatively the same top items. On Jekyll Island, there appears to be an abundance of plastic bags being tracked, whereas in Omaha, straws are the top item. However, we see that 7 out of the 10 top items tracked are plastic, which is congruent with overall trends in collection data.

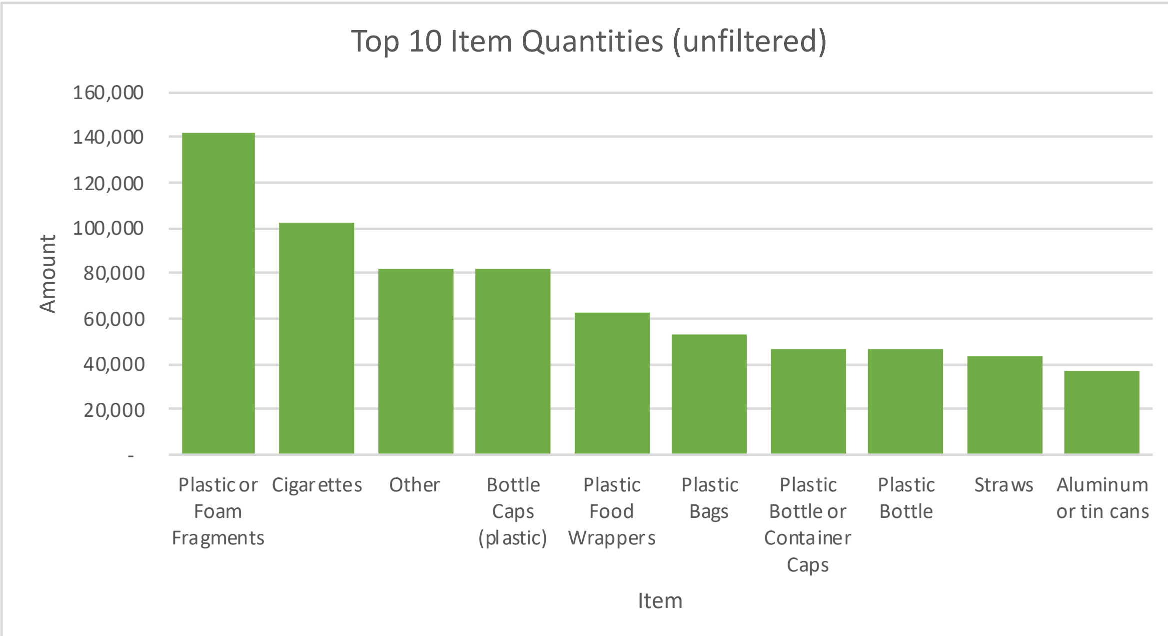


Figure 12. MDT global top 10 items based on quantity (unfiltered).

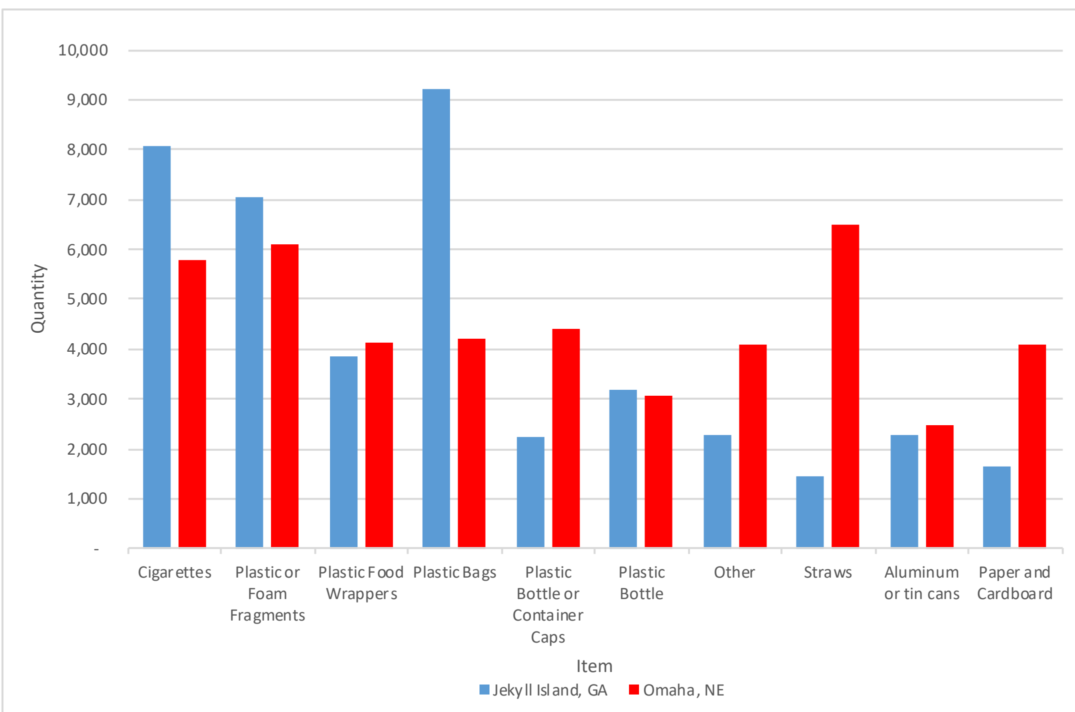


Figure 13. MDT top items by location comparison between Jekyll Island, GA and Omaha, NE (unfiltered).

There are a little over 1,400 usernames registered with the MDT application. Some are organization with many volunteers and others are individuals who feel apart of a larger initiative while they pick up litter. The top 10 trackers' reports of debris account for approximately 65% of all reported debris (**Figure 14**). As mentioned before, the top trackers range from individuals (OldMarketPhoto) to organizations (GSTC Citizen Science).

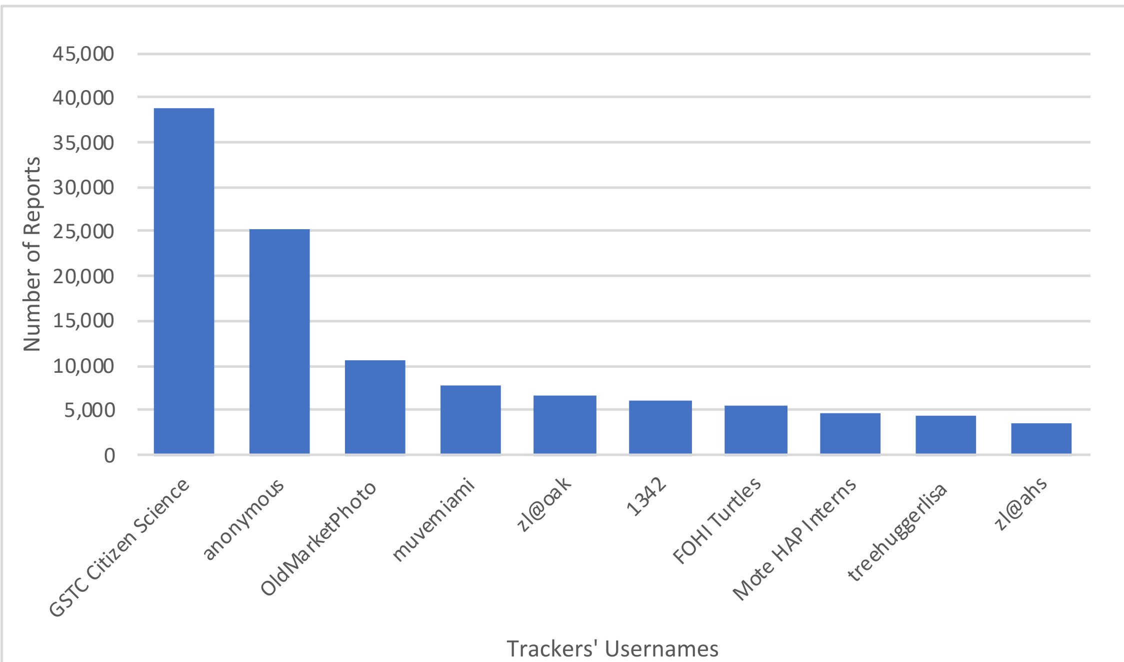


Figure 14. MDT global top trackers (unfiltered).

In investigating how trackers use the MDT application, a survey (under UGA IRB approval) was sent out to the top trackers. Survey questions were based on information that would be useful in assessing and analyzing opportunistic data collected by groups and individuals (**Appendix B**). Nine surveys went out and three responses were returned.

The survey encompassed the areas in which the users surveyed, the number of participants in a typical survey, and how a typical clean-up was conducted, along with disposal methods. Since only 3 survey responses were returned, no conclusions could be made about survey effort, however, data about surveying methods on Jekyll Island were returned. Jekyll Island is the target site for a statistical model described in Chapter 4. Surveying methods can be expanded to reach other users in future studies.

3.3 GIS Mapping Investigation

The initial dataset containing unfiltered marine debris data points from around the world was uploaded into ArcGIS. Once the table was in GIS, a custom coordinate system was developed under the Geographic coordinate system of WGS_1984 and Projected Coordinate System Mollweide with a central meridian at -96.00 degrees (centered on the US). After the coordinate system was established, the X and Y coordinates of each marine debris point were displayed on a map of the world's countries (**Figure 15**). Points were queried for the USA through selection within GIS. After selected, the data was exported into a new layer and a text file, which was converted into an excel file for analysis of just USA data.

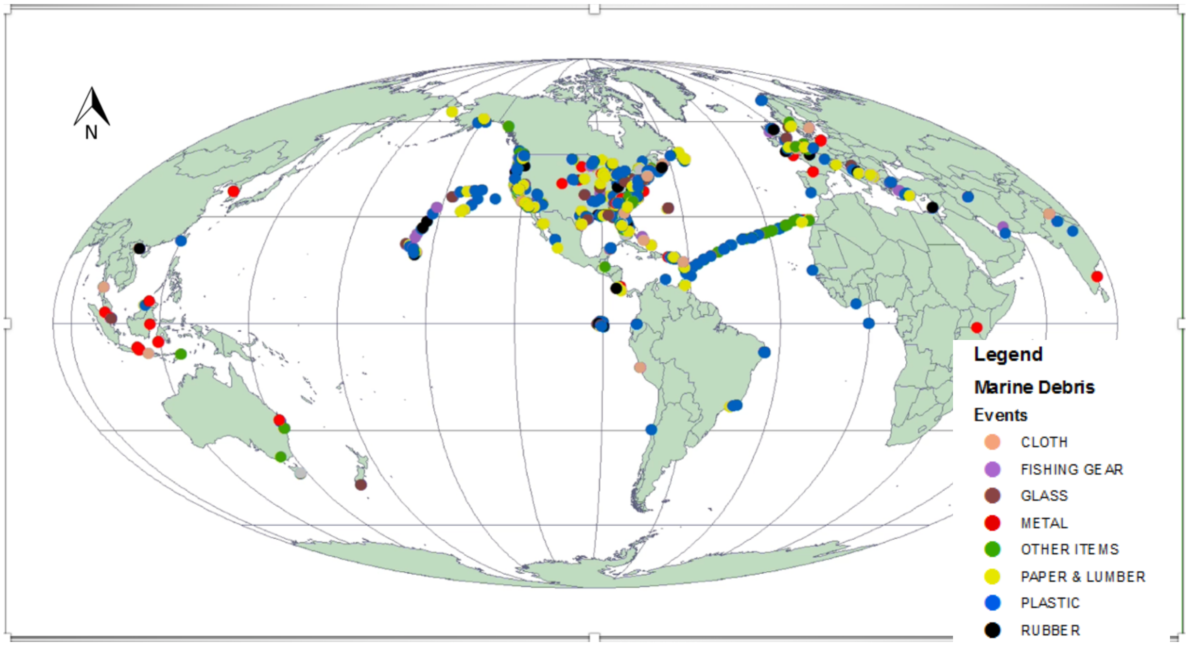


Figure 15. Tracker analysis of global marine debris reports with Mollewide projection (CM: -96.00).

To assess the marine debris data in GIS, quality assurance and control measure were taken to insure that accurate geographical depictions of the data were present. The global data was condensed, with "test items" being removed, as well as GPS error radii over 15 meters (**Table 5**) (gps.gov).

Table 5. Data QA/QC (filtered) metrics for items and reports. (MDT, 2017).

Data Description	**Data points (items)**	**Data Points (reports)**
All data as downloaded	1,127,990	152,549
Data with error radius 15 meters or less	718,552	90,569
Data with Test Items Removed and Quality Assurance/Quality Control Complete	713,356	86,027
Data for the USA	637,346	77,213

Polygon features of the 10 NOAA regions (Southeast, Mid-Atlantic, Northeast, Great Lakes, California, Pacific Northwest, Alaska, Pacific Islands, and Caribbean) were created through a file geodatabase. The point feature data of the USA points (637,346 total items and 77,213 total point entries) were then selected per region and exported into separate layer shapefiles and excel files to analyze further for characterization of the data for quantity, items, and materials.

The total US marine debris items tracked are 631,278 (89% of the total items tracked globally) and entries logged are 76,662 (90% of the total entries globally). The US Marine Debris Tracker data, only accounting for main marine debris categories, is summarized in **Table 6 (Appendix C)**.

Table 6. US MDT data items and reports (filtered) (MDT, 2017).

Material Category	Items Tracked	Entries Logged
Plastic	536,354	52,392
Glass	14,467	2,246
Metal	17,942	4,766
Paper & Lumber	32,852	7,024
Fishing Gear	9,193	2,876
Cloth	4,943	2,142
Rubber	1,048	478
Other Items	14,479	3,738
Total	**631,278**	**75,662**

The main marine debris categories—plastic, glass, metal, etc.— account for 99% of the total items tracked and 98% of the total entries logged. Marine microplastics and other categories logged only account for 1% of the items tracked and 2% of the entries logged for the USA data. Therefore, they did not have a significant influence over the total US marine debris data.

3.4 NOAA Marine Debris Regional Characterizations

The NOAA Marine Debris regions consist of the Southeast, Mid-Atlantic, Northeast, Great Lakes, Gulf of Mexico, California, Pacific Northwest, Alaska, Pacific Islands, and the Caribbean. Each region is characterized by total items and entries, as well as types of materials found. The total entries and items per region can be seen in **Table 7** and **Figures 16** and **17.** Characterizations of material quantities show that plastic is the most tracked material type in NOAA regions (**Figure 18** and **Appendix D**).

Table 7. NOAA Marine Debris Program Region characterization by MDT data items and reports (filtered).

NOAA Region	Entries Logged	Items Tracked
Southeast	35,035	263,982
Mid-Atlantic	1,475	3,711
Northeast	2,059	24,440
Great Lakes	1,184	6,556
Gulf of Mexico	7,685	20,111
California	17,205	131,387
Pacific Northwest	1,012	111,022
Alaska	12	13
Pacific Islands	131	5,223
Caribbean	3,708	1,811
Total	**69,506**	**568,256**

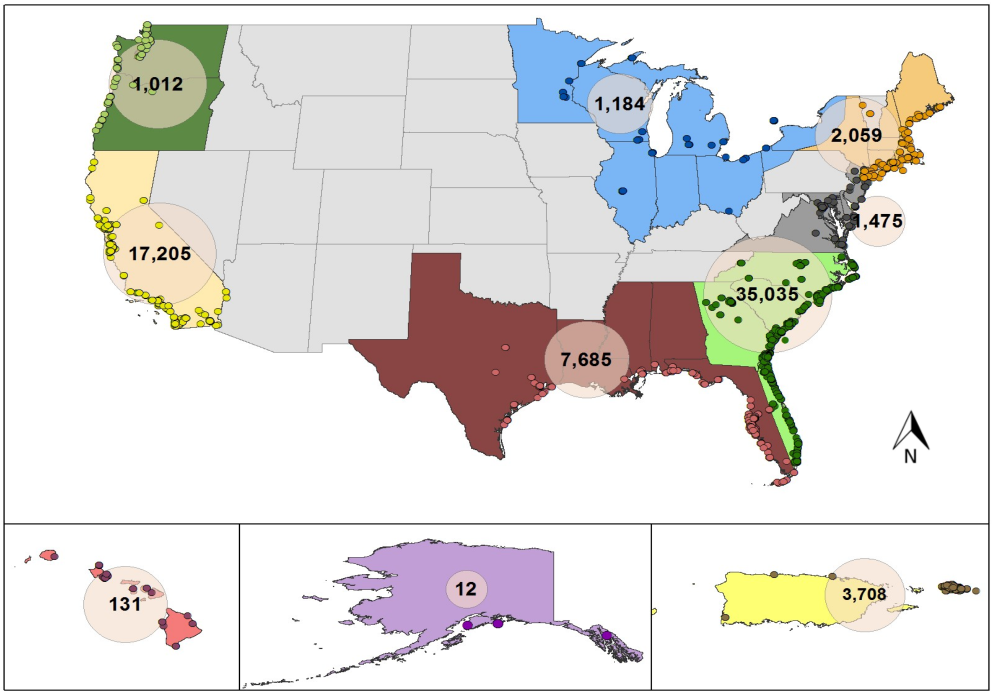


Figure 16. NOAA MDP regions by MDT entries (filtered).

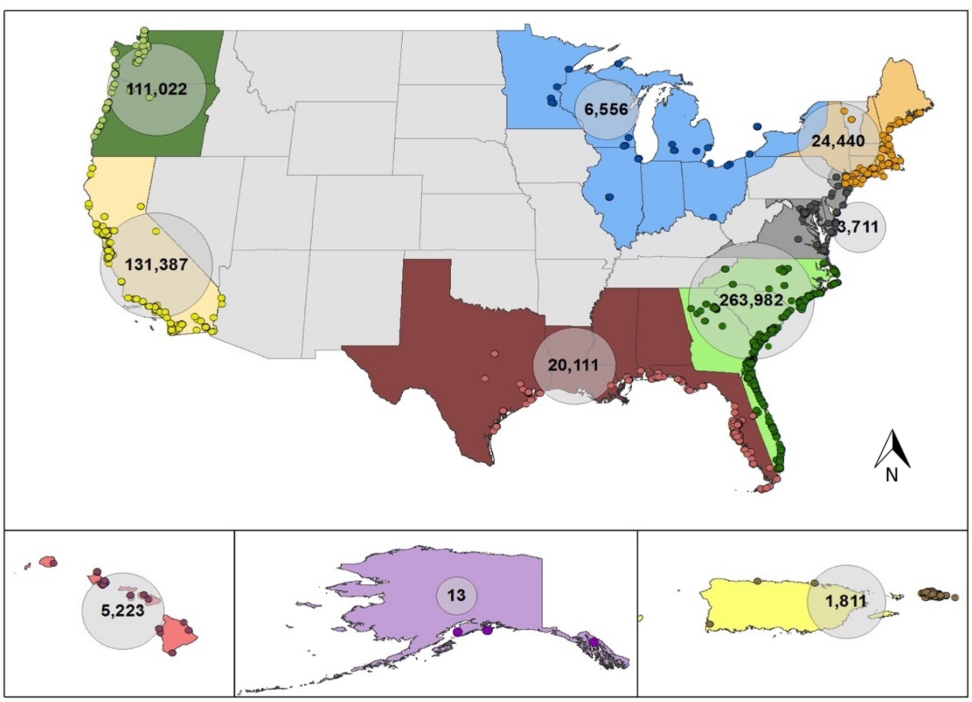


Figure 17. NOAA MDP regions by MDT items tracked (filtered).

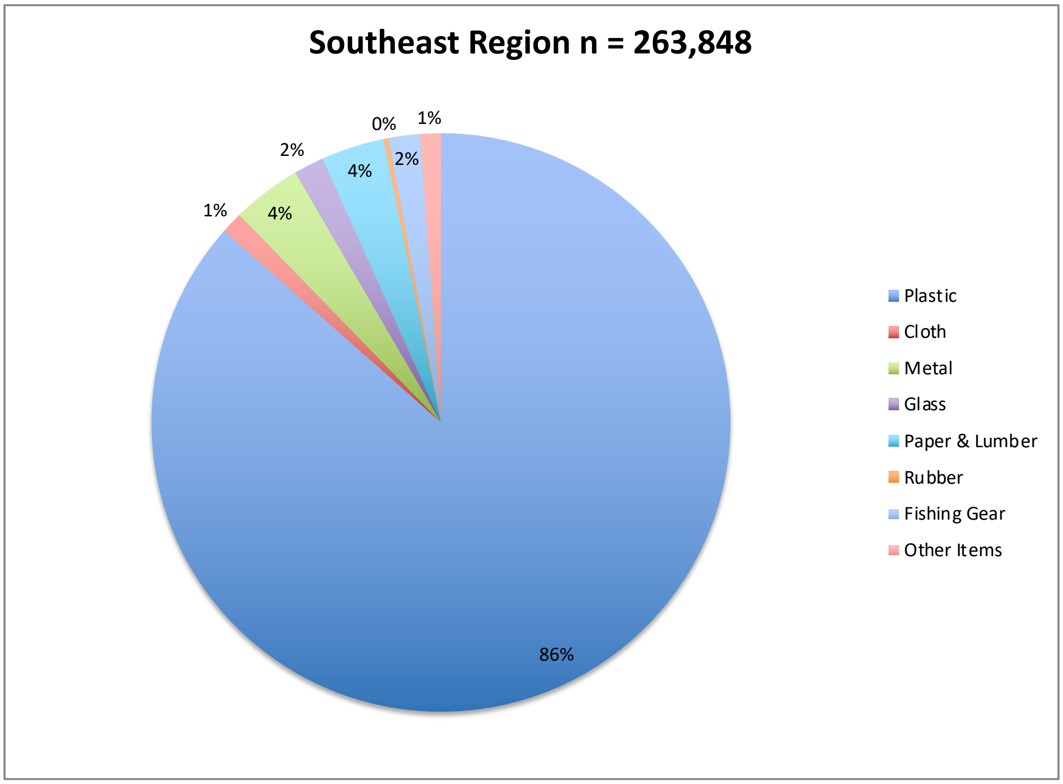


Figure 18. NOAA MDP Southeast region material characterizations (filtered).

3.4.1 Jekyll Island Investigation

Jekyll Island was chosen as a site-specific area in which to do an in-depth, community assessment. It was chosen because the area is the top MDT location for reported marine debris in the world, it are home to a frequent user, Georgia Sea Turtle Coalition, who use the app for data collection regularly, and the fact that data has been collected over nearly the entire island (**Appendix E**). The island is a little over 11 kilometers long and 2.4 kilometers wide. The total main marine debris items— plastic, metal, glass, etc—on the island totaled 77,655 (**Table 8**).

Table 8. Jekyll Island material characterizations (filtered).

Material Category	Items Tracked	Entries Logged
Plastic	65,974	9,732
Glass	800	359
Metal	3,059	921
Paper & Lumber	2,841	770
Fishing Gear	2,864	710
Cloth	1,138	522
Rubber	127	77
Other Items	852	389
Total	**77, 655**	**13,480**

The initial investigation on the island was for possible areas of debris accumulation. A density assessment and mapping of debris hot spots was done on the island to gauge areas of debris collection (**Figure 19**). However, the density analysis does not give a full or accurate picture of true areas of debris accumulation. The data from MDT is opportunistic, so other areas on the island are left looking as though they have less debris, when in fact those areas could have more debris accumulation, but no tracking activity. Therefore, the density analysis can only illustrate the areas in which users actively reported debris.

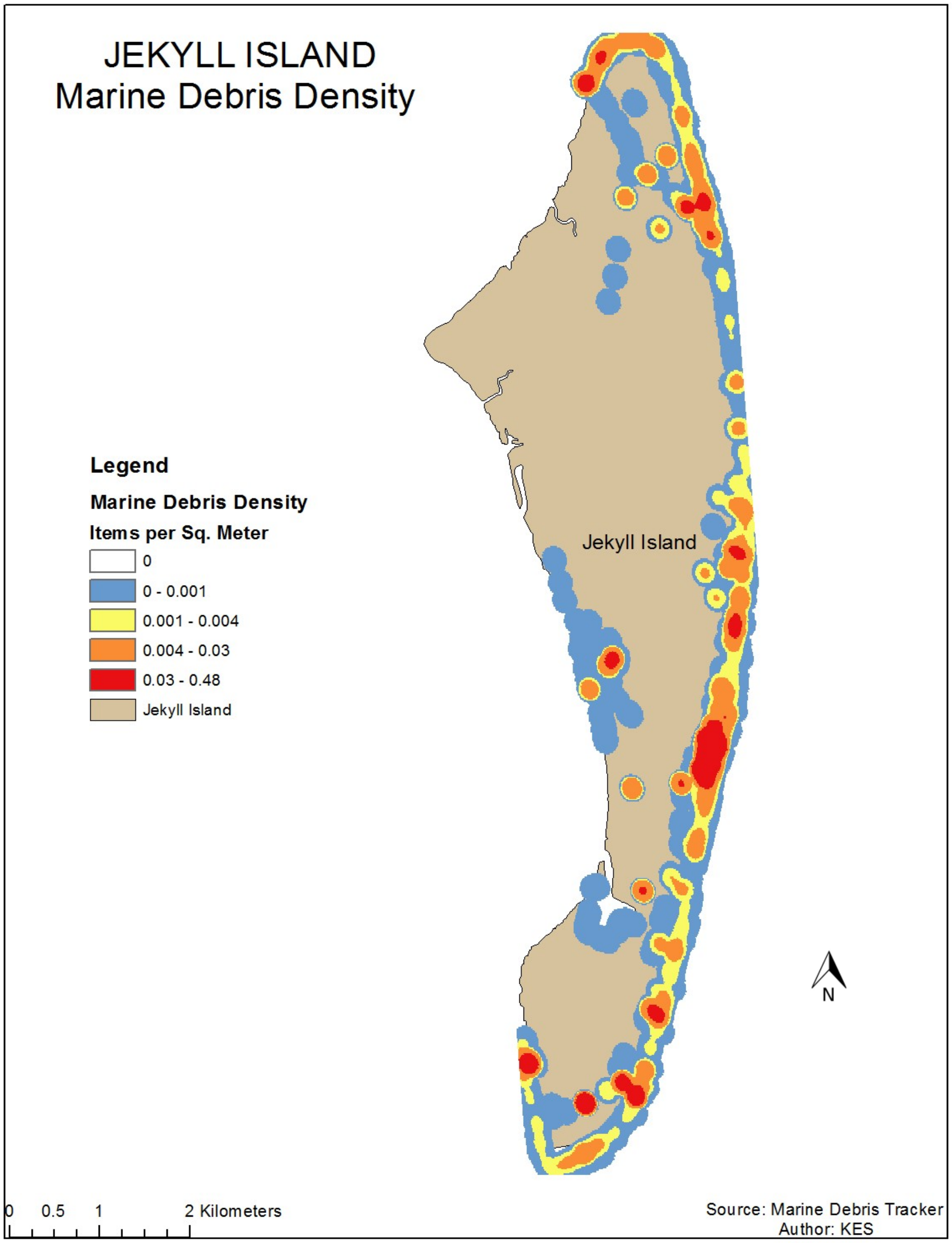


Figure 19. Jekyll Island debris item densities per square meter.

To understand where debris was truly accumulating, a model was developed in partnership with CSIRO to assess the MDT opportunistic data for Jekyll Island. The model evaluates the importance of different explanatory variables, identify hot spots of debris accumulation and possible sources, as well as predict loads of unsampled areas based relationships with different driving variables.. Since MDT data is count data, it was appropriate to use a model based on the Poisson distribution. For model variables, geographic features and infrastructure on the island were necessary to understand where debris was ending up and where users were tracking (**Figures 20 and 21**) (https://www.glynncounty.org/656/GIS-Mapping, 2017). The model will be discussed in depth in Chapter 4.

Figure 20. Jekyll Island census blocks, topology, and major and minor road systems (https://www.glynncounty.org/656/GIS-Mapping, 2017).

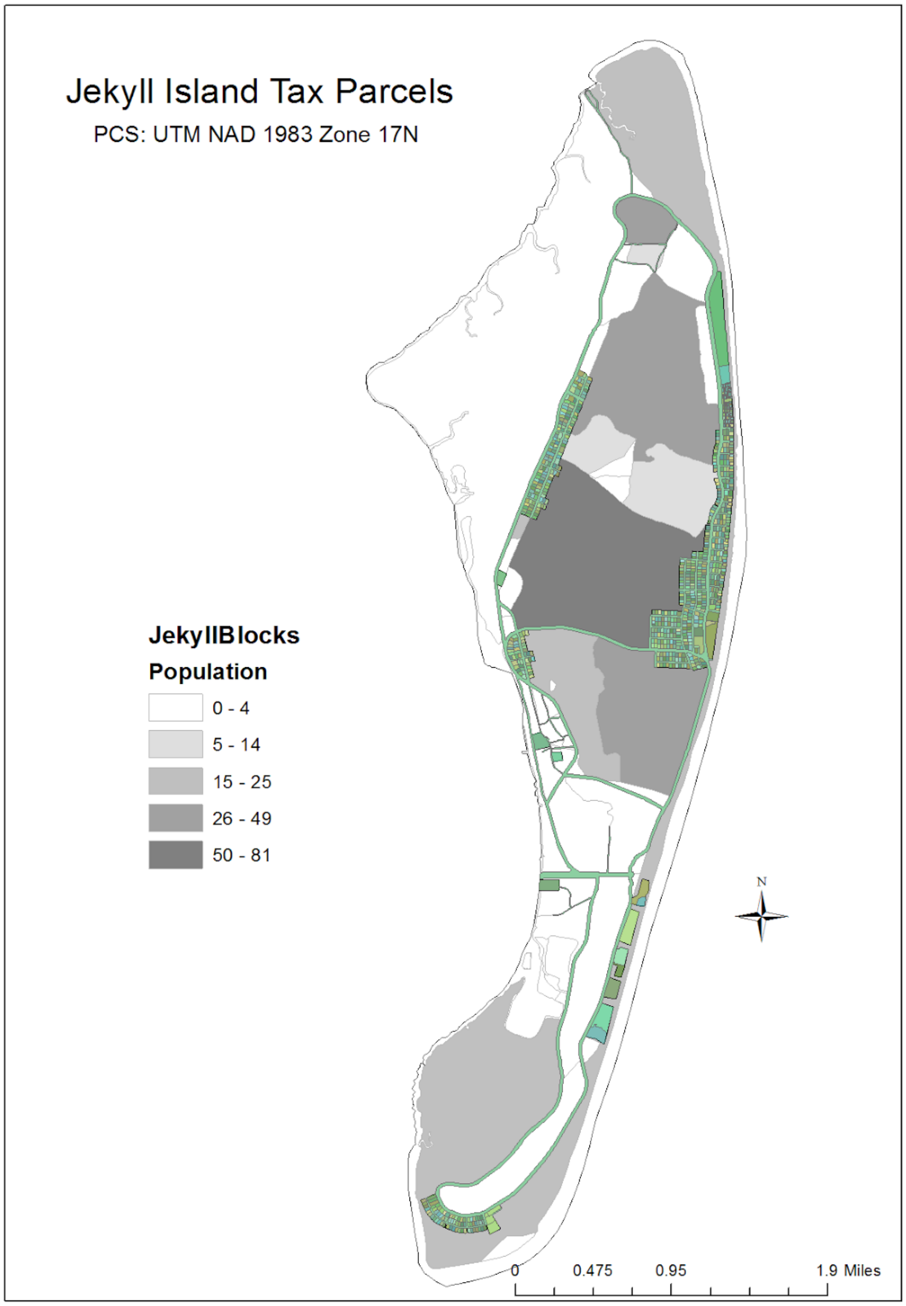


Figure 21. Jekyll Island tax parcels and population densities per census blocks (https://www.glynncounty.org/656/GIS-Mapping, 2017).

CHAPTER 4

TRUNCATED POISSON MODEL

4.1 Background

The identification of the problem of marine debris partly came from people noticing litter accumulating in their local environments. Although anecdotal at the time, these observations became data collection initiatives, and have helped to inform marine pollution science and policy; they give a voice to the people confronted with trash on their beaches, in their waterways and accumulating in their local environments. Much of the marine litter observed from land-based sources is mostly plastic (Chris's paper). The history of marine litter research is closely linked to the development of plastics. Most litter entering the sea has done so from diffuse, land-based sources that are difficult to control (Ryan, 2016).

There was an estimated 2.5 BMT (billon metric tons) of municipal solid waste generated in 2010 by 6.4 billion people living in 192 countries world wide (Jambeck et al. 2015). Of this, 31.9 MMT (million metric tons) was classified as mismanaged waste and an estimated 8 MMT of plastic waste eventually reaches the ocean each year from mismanaged sources (Jambeck et al., 2015). Plastic is a prevalent anthropogenic material in the marine ecosystem, and raises concerns due to its effects on wildlife and potentially humans. Plastics do not naturally biodegrade, rather they fragment into microscopic pieces and stay in aquatic environments for yet undefined time periods.

Through the use of technology, we've been able to give anecdotal observations a scientific backbone. The Marine Debris Tracker serves as a citizen science mechanism to collect valuable geographic and observational data about marine litter. MDT was developed as the first participatory sensing application to collect marine debris data worldwide in 2011. The MDT application allows users to log data on the local, regional and international scale, all through the same application using smartphones and tablets. Data is collected by human "sensors" around the world at a scale, speed, and efficiency that was not previously possible before the application existed (Jambeck and Johnsen, 2015).

Citizen science and data collection are important tools for tackling the problem of marine litter. The use of citizen scientists and decentralized groups of nonprofessionals to gather information predates the Internet and has long been embraced by community projects. In producing environmental data, citizen scientists become agents in decision making and policymaking processes (Connor, Lei, and Kelley 2012). However, one of the major concerns of citizen science data, no matter how it was collected, is whether it is a reliable source of data, and if it can be compared to professional studies (Hidalgo-Ruz and Thiel, 2015).

Within science data, a smaller subset of data is opportunistic in nature. MDT utilizes data collected opportunistically. Opportunistic data is accompanied by biases that challenges evaluation and analyzation of the data. In robust citizen science projects, such as MDT, the redundancy of data and information can serve as a peer-reviewing, self-correcting mechanism, thus improving the reliability of such information (Connor, Lei, and Kelley 2012).

4.2 Methods

The objective of the MDT evaluation model was to develop a mechanism to identify areas of marine debris accumulation and possible sources in communities through different contributing variables. The study site was Jekyll Island, Georgia. Jekyll Island is the home of the Georgia Sea Turtle Center, who is a frequent user of Marine Debris Tracker and has accumulated over 34,000 items tracked on the island. Jekyll Island is approximately 11 kilometers long and two and a half kilometers wide.

Raw Marine Debris Tracker data was input into ArcGIS and selected for data points that only occurred on Jekyll Island, including the tide lines. Once this data was selected, it was exported, and uploaded into R. In R, we organized the reported items based on presence of data per day in a 100 square meter (10 by 10 meter) grid cell. This grid provided unique identifiers to apply a count function to each cell, so that counts of reported debris were given for each 100 square meter cell. The data was then exported back in ArcGIS describe various geographic indicators.

Geographic variables for Jekyll Island were extracted from the Glynn County GIS clearinghouse (https://www.glynncounty.org/656/GIS-Mapping, 20-17). The variables of concern for developing the model were: major and minor road systems, vegetation types, parcels, census blocks, and the ocean tide lines. The spatial data for these variables was input into ArcGIS map with the gridded MDT data for Jekyll Island. In GIS, the gridded data were spatially joined with the each geographic variable, calculates the distance from the gridded data to the nearest geographic attribute **(Figure 22).**

A new data set was created from the MDT data and geographic features joined data sets in excel. The new dataset became the Jekyll Truncated Poisson Model Input dataset, which contained the complete MDT data, distances to geographic feature (distance to census blocks, parcels, vegetation, roads, and the ocean) as well as the geographic categorical features (major and minor roads, vegetation type and population of census blocks).

The Jekyll Truncated Poisson Model Input was used to develop the truncated Poisson model. The inputs for the model were the distances from each unique survey ID (reported MDT data on a given day in the gridded 100 square meter cell) to geographic features and the categorical variables associated (**Eq. 1**)

$$zerotrunc(formula = Count \sim Dist_{OceanM} + Dist_{ParcelM} + Parcel_{ID} + Dist_{BlocksM} + Population + Dist_{RoadsM} * Type_{Road} + Dist_{VegM} + Type_{Veg}$$

Equation 1. Truncated Poisson global model

From this global model, which accounted for all variables, a best fit model was produced.

To account for variation in the data that might be due to factors at the parcel level such as high levels of pedestrian traffic near hotels, or behaviors by individual homeowners, a random effect for parcel ID was included. An ANOVA test was performed for parcel effect. The test allowed us to measure the significance of the random effect on the best fit model; the more debris accumulation, the larger the positive number. A best fit model to analyze debris distribution and on geographic features as potential sources of the debris was produced.

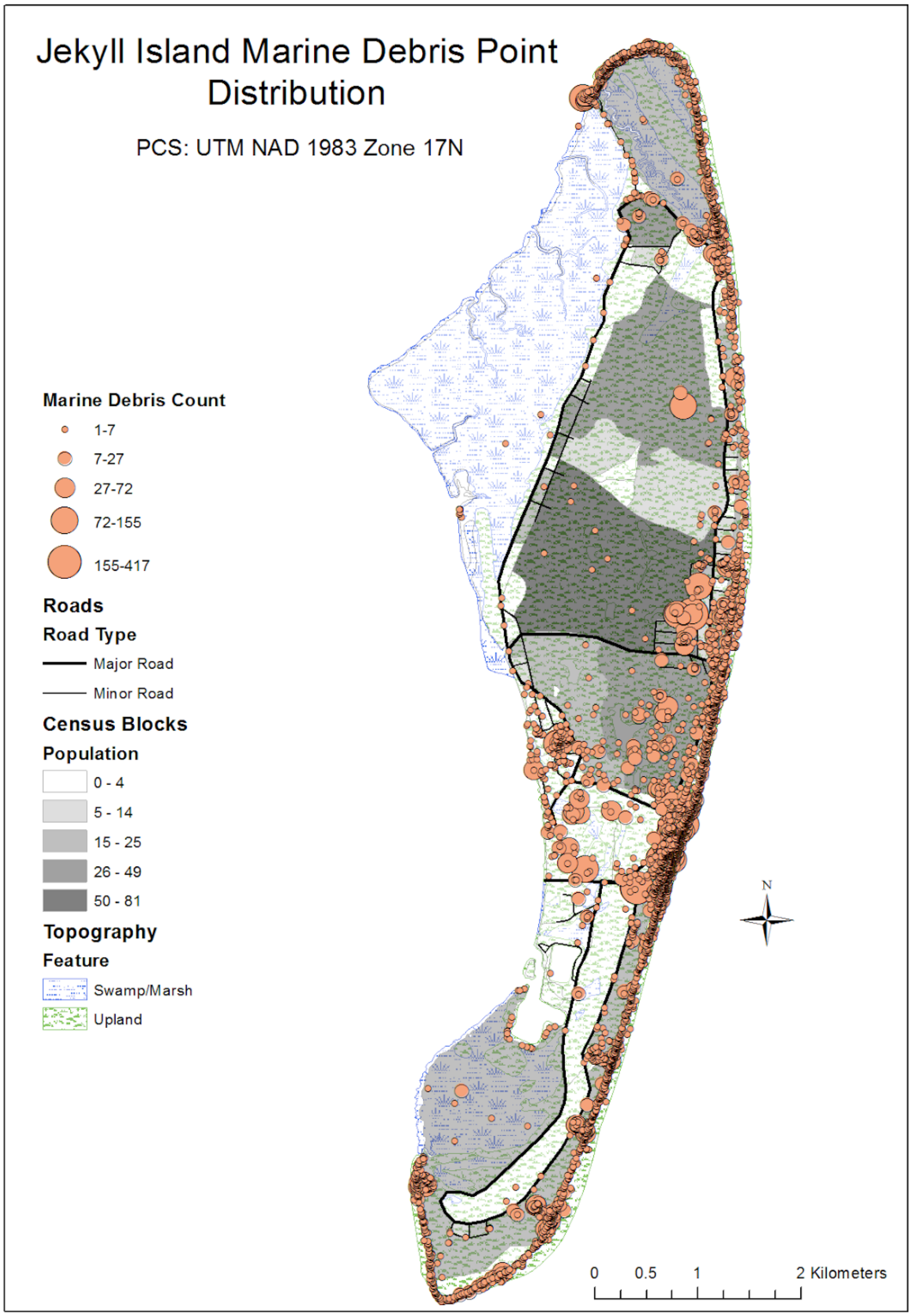


Figure 22. Jekyll Island debris counts per 100 square meter cells.

4.3 Results

The model was applied to data in which users saw at least one item in a given grid cell. It accounts for the Marine Debris Tracker data only being presences and aggregating at 100 square meter cells (**Figure 23**). From a global model, which incorporated all of our input variables, there were four models that came within two units of AIC of the best model, so these four are within a 95% confidence set of the best fit model. The distances to residential, commercial and residential property, ocean tide lines, major and minor roads, and vegetation type were all a part of the top models. Differences in the models occurred for the population density per census block and distances to parcels. Distances to parcels was kept as an input variable in the model, with an additional random effect test for nearest parcel through an applied ANOVA.

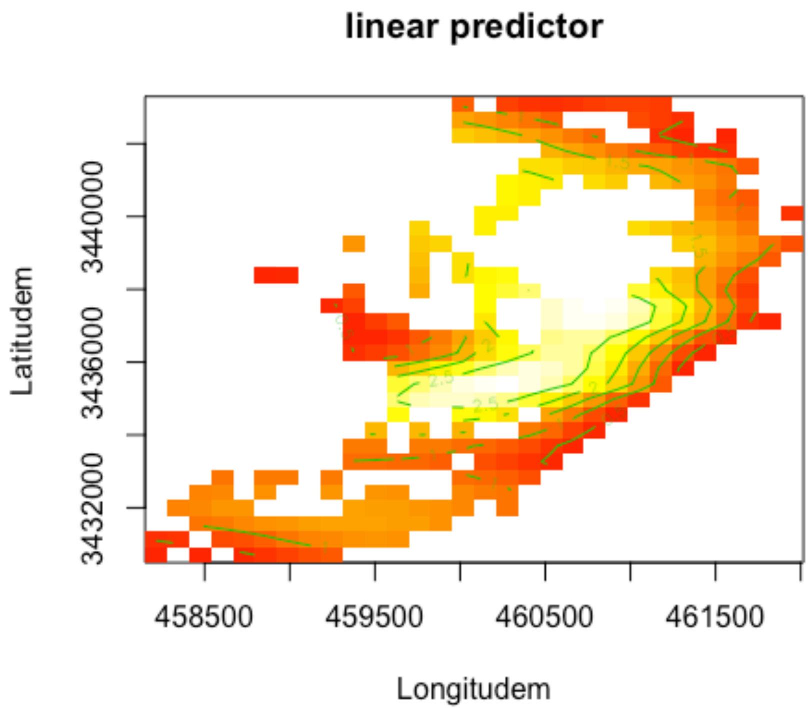


Figure 23. Visual gam predictor of debris counts for of MDT gridded data on Jekyll Island.

The random effect for parcels on Jekyll Island showed that they are significantly different from each other in their effect. A large positive effect means that there is more debris accumulation close to that particular parcel (**Figure 24**). The opposite is true for large negative effects (less debris accumulation). The random effect for parcels shows that the lowest amount of debris is found near parcel 19-E Oakgrove S/D (-1.387), whereas near parcel 7.073 AC Jekyll Beach (3.163) and 13-D Oakgrove (4.697) high levels of debris accumulate (**Figure 24** and **Appendix F**). This is true even accounting for all other factors in our models.

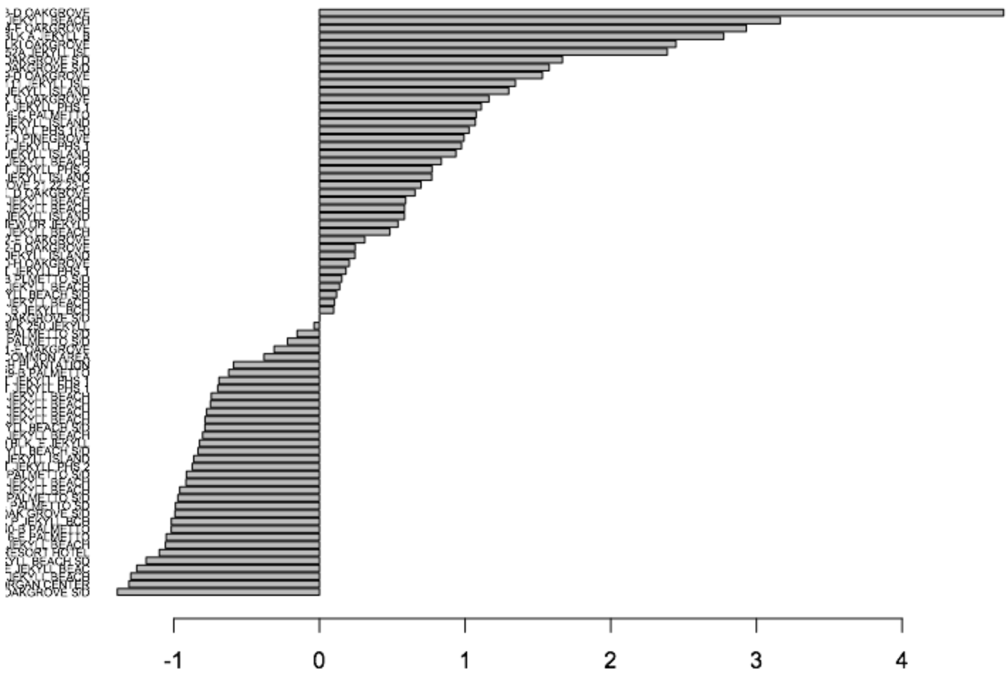


Figure 24. Difference in debris accumulation by parcel.

The other factors considered for the model show trends in the distribution of reported debris on the island. In general, debris tends to accumulate near census blocks and parcels (**Table 9**). The model suggests that for Jekyll Island, there is less debris near the ocean. Major roads on the island have higher levels of debris. Moving away from roads, the amount of debris decreases (**Figure 25**). The interaction of type of road and distances is positive; therefore, debris tends to increase as distance from minor roads increases. Debris also tends to accumulate in or near upland vegetation rather than in wetlands on the island, according to the model (**Figure 25**).

Table 9. Truncated Poisson geographic variables effect outputs.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.167506325	0.07221116	16.1679494	8.49E-59
Dist_OceanM	0.001664536	3.66E-05	45.4590038	0
Dist_BlocksM	0.024818062	0.00252186	9.84116199	7.48E-23
Dist_RoadsM	-0.002249146	0.00018194	-12.362067	4.19E-35
RoadSize	-0.11087947	0.02599182	-4.2659379	1.99E-05
Dist_VegM	0.000911989	0.0006752	1.35068898	0.176795083
Veg_TypeUpland	0.227274027	0.06188244	3.67267414	0.000240025
Dist_RoadsM:RoadSize	0.000436691	9.14E-05	4.77664819	1.78E-06

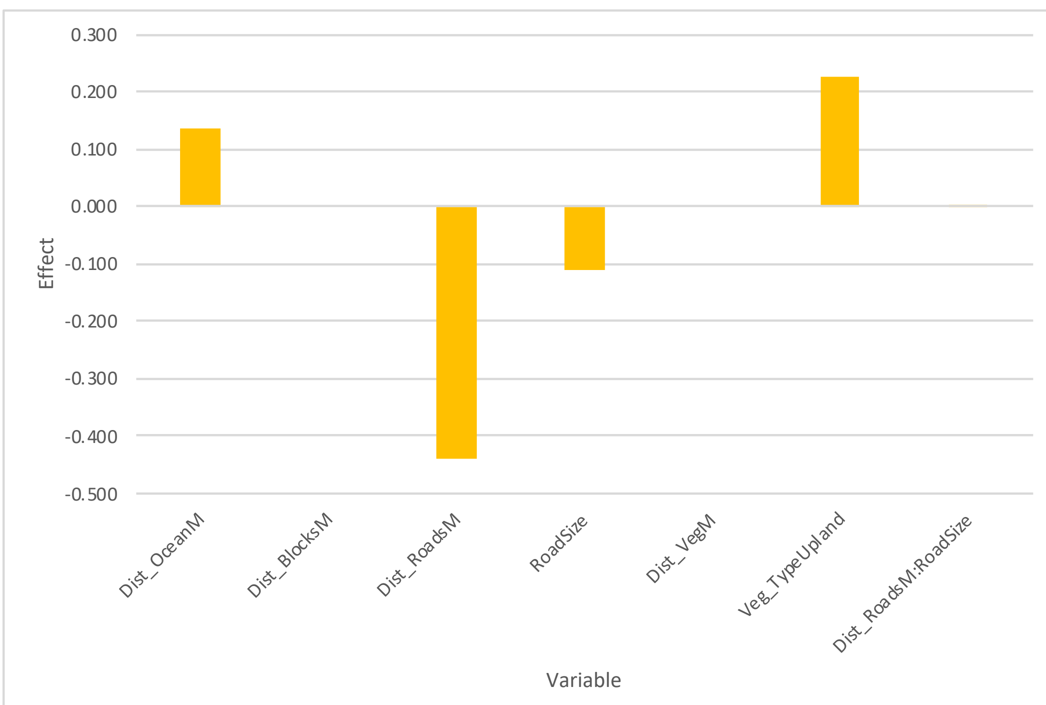


Figure 25. Truncated Poisson model output for geographic variables' effects.

4.4 Discussion and Conclusions

Our model allowed us to statistically analyze and map the distribution of opportunistically reported marine debris sourced from the mobile application Marine Debris Tracker. The best models developed were based on the Poisson distribution truncated for presence only data, allowing us to analyze marine debris that was reported. Following this method, we can conclude the distribution of debris and possible sources associated with areas of accumulation beyond anecdotal findings. The model allowed for the evaluation of the importance of different explanatory variables, identification of hot spots for debris accumulation and littering sources, and predictions of loads in unsmapled areas based on relationships with driving variables. The analysis yielded that debris tends to accumulate near major roads, in close proximity to hotels, and in areas near construction on Jekyll Island, but away from beaches and wetland areas.

The random effect for parcels shows that debris distribution is a product of parcel type. For example, near hotels, but not on the property, debris tends to accumulate. This may be due to the high volumes of people pedestrian traffic. Furthermore, it gets cleaner closer to beaches and wetland areas. This could suggest that local littering may be a driver of debris in the Jekyll Island community. This also suggests that Jekyll Island is may not be a major deposition area for debris from the ocean. On other parcels with high debris accumulation, construction projects were occurring next to undeveloped land close to the ocean and major roads (7.073 AC Jekyll Beach parcels). This suggests there might be littering activity near active construction.

The use of the truncated Poisson model helped to overcome user effort biases because the model only accounts for areas of active tracking. The model is conditional on seeing at least one debris item per day. The model is also based upon the sampling effort being a “group or person” tracking during the same “sampling interval,” i.e. daily counts of debris per 100 square meter cells. When the MDT data is mapped, it looks as though hot spots and more debris accumulation would occur along the beaches, however, the model concludes that debris decreases near the ocean. Future research can investigate the path of trackers and user effort that contribute to biases more in depth through other statistical models, such as the Hurdle model, which accounts for areas where zero litter is reported.

CHAPTER 5

SUMMARY AND FUTURE WORK

Marine debris and littering are pollution issues that are attributed to unsightly beaches, decreases in economic viability of localities, and harm to wildlife and potentially humans, while being a problem that is predominately sourced from land. This means that people on land are behind many of the issues that are associated with marine debris; however, people are also the drivers of change. Marine Debris was partly realized as a problem by citizens in communities who noticed their natural environments littered with trash, especially plastic waste. Through projects based in citizen science, community members have been able to inform the public and policy about pollution problems.

Marine Debris Tracker is one of the tools to help educate the public about litter and collect valuable information about the types and locations. MDT continues to grow, adding users and debris items every day. The initial investigation into the data illustrated areas of tracking were predominantly in the Southeastern United States, however, tracking does happen globally. The top users of the application range from individuals to large groups of people surveying their local environments.

The MDT data is opportunistic, therefore, challenging to analyze with simple statistical analysis methods. Instead, a more sophisticated statistical approach was taken through the development of a Poisson distribution based model. The model's feature inputs were geographic features of the study site, Jekyll Island, Georgia and MDT data counts per day in 100 square meter cells. The outputs concluded that debris accumulation on Jekyll tends be higher near major roads and less near beaches. As distance away from major roads increases, debris decreases; whereas, as distance from minor roads increases, litter also increases. Parcels are significant in reference to their activities. Parcels near hotels and active construction tend to have higher debris counts. Also, wetland did not tend to have a significant amount of data accumulation where tracked.

For future work, user effort should be examined more closely. Understanding the places surveys take place or boundaries for trackers, as well as time started and stopped tracking would help in understanding the distribution of data where less tracking. Also, the amount of data it takes to have significant results per community should be evaluated through data replications. The model can be replicated in other communities who use MDT.

A Hurdle analysis would be beneficial to the future research for evaluating user effort in unsampled areas. The Hurdle model is based in the Poisson distribution, and is a two part model that specifies one process for zero counts and another process for positive counts. The idea is that positive counts occur once a threshold is crossed, or put a "hurdle" is cleared (Cameron, 2013). This would be beneficial in evaluating MDT data for areas that go untracked, or "zero" areas. Therefore, when an item is tracked in a particular area, the threshold is crossed. Future work on models to understand and evaluate opportunistic citizen science will be beneficial to the overall work being conducted in finding solutions to marine debris and litter problems around the world.

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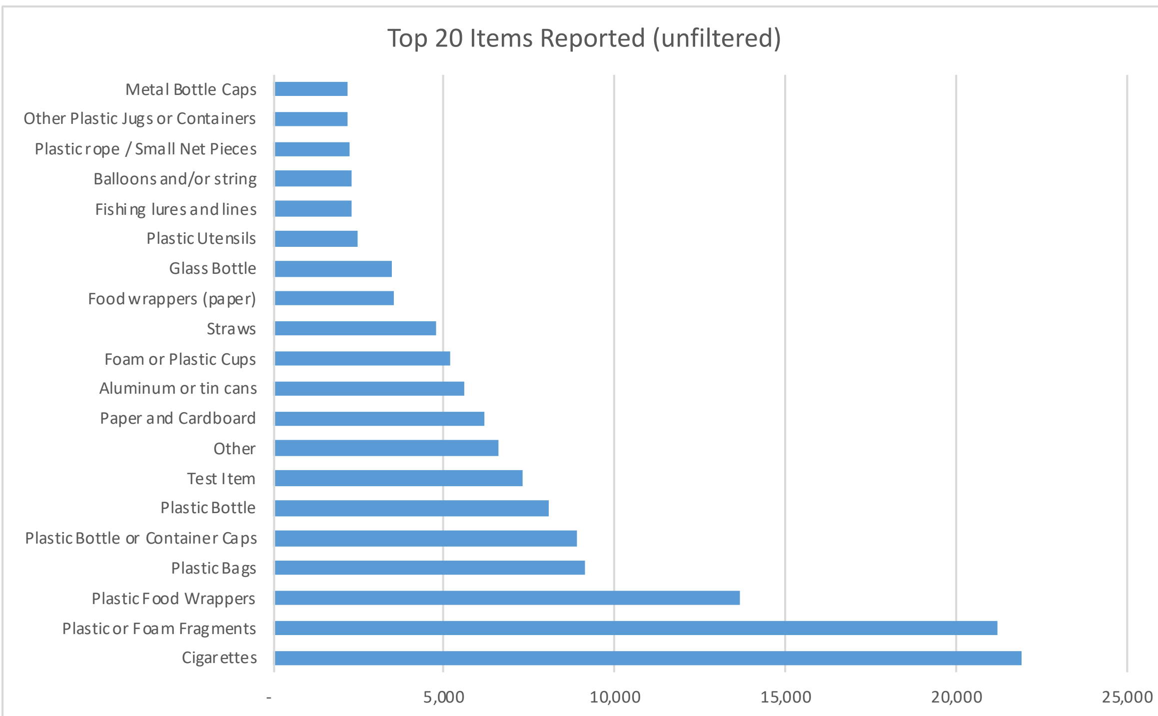
APPENDIX A

Global top 10 and 20 Items by Reporting Frequency

Top 10 Items Reported (unfiltered)		
Item	**Reporting Frequency**	**Percent of Total**
Cigarettes	21,933	12.43%
Plastic or Foam Fragments	21,193	12.01%
Plastic Food Wrappers	13,663	7.74%
Plastic Bags	9,115	5.16%
Plastic Bottle or Container Caps	8,875	5.03%
Plastic Bottle	8,091	4.58%
Test Item	7,310	4.14%
Other	6,622	3.75%
Paper and Cardboard	6,199	3.51%
Aluminum or tin cans	5,586	3.16%
Top 10 Total	108,587	61.52%
Total reports	**176,503**	

Top 20 Items (unfiltered)		
Item	**Reporting Frequency**	**Percent of Total Reports**
Cigarettes	21,933	12.43%
Plastic or Foam Fragments	21,193	12.01%
Plastic Food Wrappers	13,663	7.74%
Plastic Bags	9,115	5.16%
Plastic Bottle or Container Caps	8,875	5.03%
Plastic Bottle	8,091	4.58%
Test Item	7,310	4.14%
Other	6,622	3.75%
Paper and Cardboard	6,199	3.51%
Aluminum or tin cans	5,586	3.16%
Foam or Plastic Cups	5,160	2.92%
Straws	4,758	2.70%
Food wrappers (paper)	3,525	2.00%
Glass Bottle	3,480	1.97%

Plastic Utensils	2,451	1.39%
Fishing lures and lines	2,292	1.30%
Balloons and/or string	2,288	1.30%
Plastic rope / Small Net Pieces	2,238	1.27%
Other Plastic Jugs or Containers	2,203	1.25%
Metal Bottle Caps	2,182	1.24%
Top 20 Totals	139,164	78.85%
Total Reports	176,502	



APPENDIX B

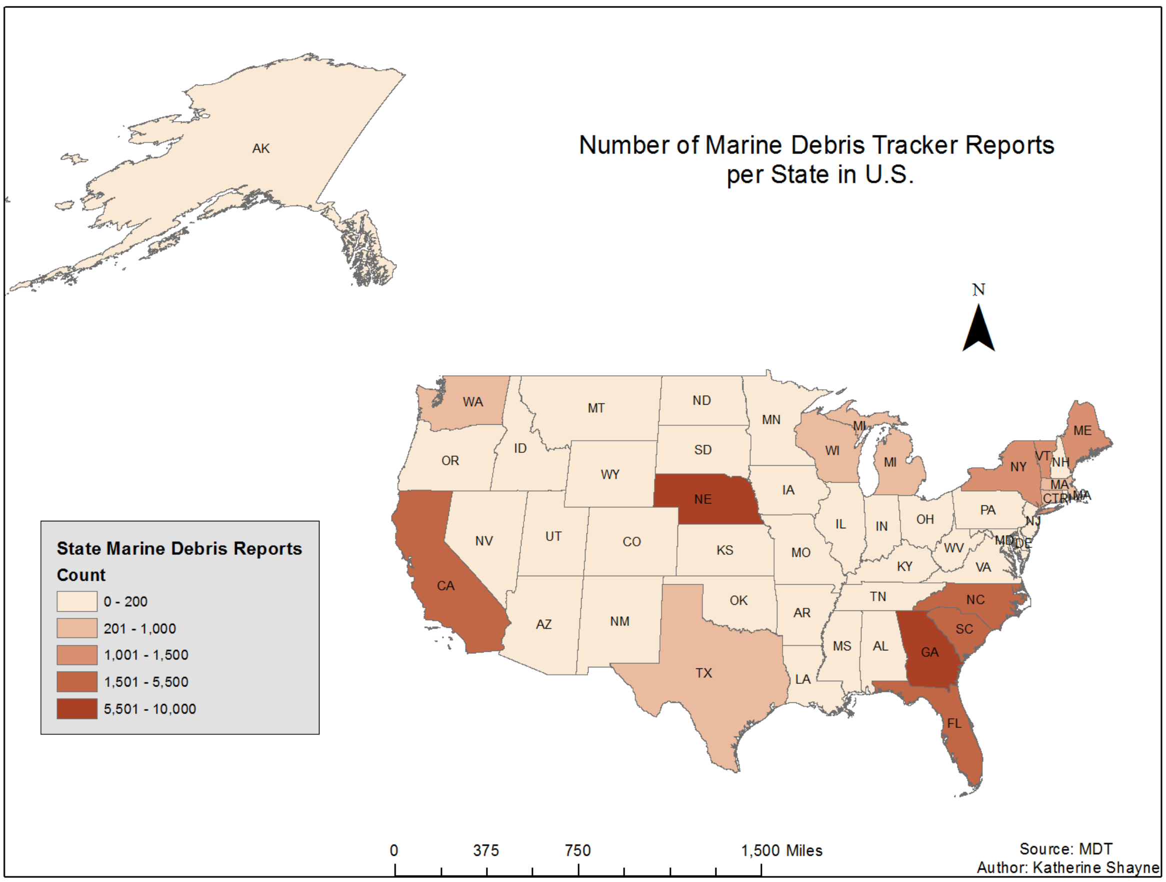
Marine Debris Tracker user survey and responses.

Marine Debris Tracker Survey about Usage			
Questions	**Response 1**	**Response 2**	**Response 3**
What is the name of your organization (if applicable)?	Georgia Sea Turtle Center	Not affiliated with an org	Rozalia Project
Where are you/your organization based geographically?	Jekyll Island, GA	San Diego County, CA	Vermont and New England
How many people are apart of your organization? (If you are the only contributor, please put 1).	~50	1	4 plus hundreds of vounteers
How many people log debris with your organization's Marine Debris user login information?	30-50	1 to 10	50+
How many times per week do you/your organization use the Marine Debris Tracker to track debris in your area?	Daily to multiple times a week	2 to 4	Multiple times per week during the summer/expeditions
Are there certain areas that are visted more often than others in your/your organizations clean-up area? If yes, explain where these areas are.	Jekyll Island Beaches and East beach on St. Simons Island	I think all areas visted roughly same amount	Coastal Maine
What is done with the debris after a clean-up takes place?	We recycle what we can, send rigid beach plastics to Terracycle and dispose of the rest	I recycle anything recycleable, then balance goes to landfill via city trash svc. Occasionally I find batteries, I recycle those as well	Ideally upcycled, then recycled and landfilled if necessary
If planned clean-ups have occurred within your organization, how many times a year do they occur?	More than 30; Monthly clean ups, community clean ups, and then groups that come	A planned clean-up hasn't taken place; I do take part in	1 to 10

		clean ups held by others	
If planned clean-ups have occurred, please give a brief description of your organizations procedures and if the Marine Debris Tracker was used for the clean-up.	We send tracker information before clean ups begins, do an introduction to our project to our project and the tracker on meeting day. During the clean up we have a couple folks as designated trackers and everyone brings their debris to them to be logged and bagged	The (organized by others) clean ups I have participated in did not use the app. But I logged my data	We like to do a central sort so passers-by can see what we are doing and eveyone gets a sense of the scale of the problem. After the sort, we record first on paper, then transfer to the app

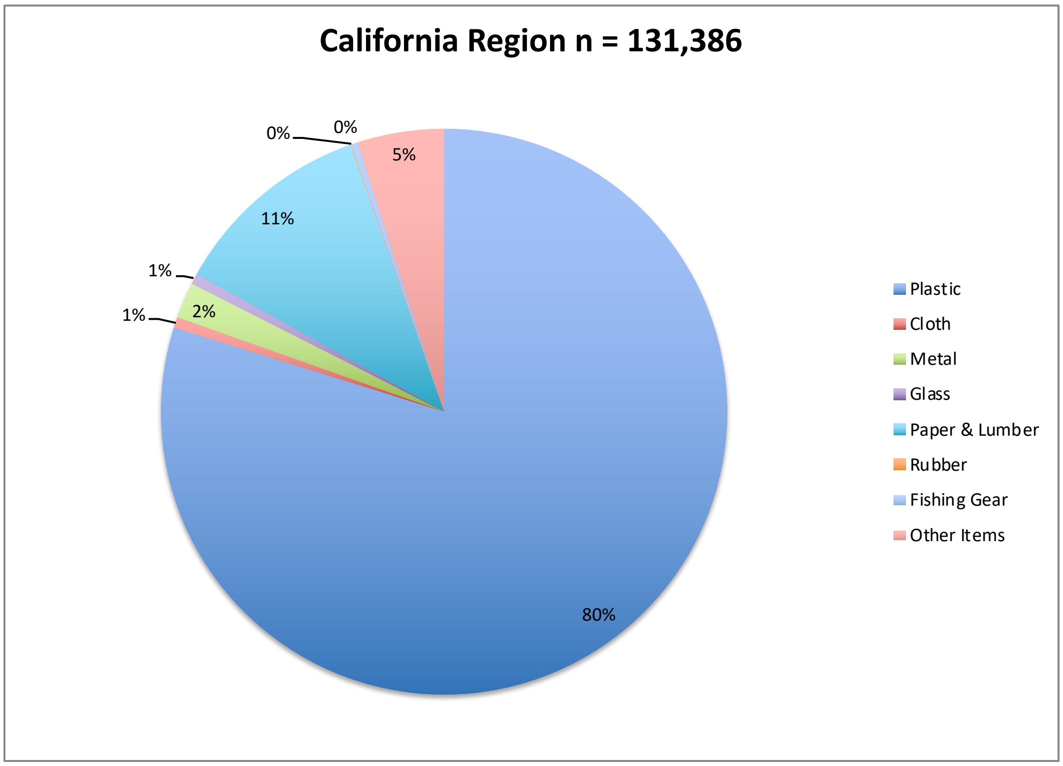
APPENDIX C

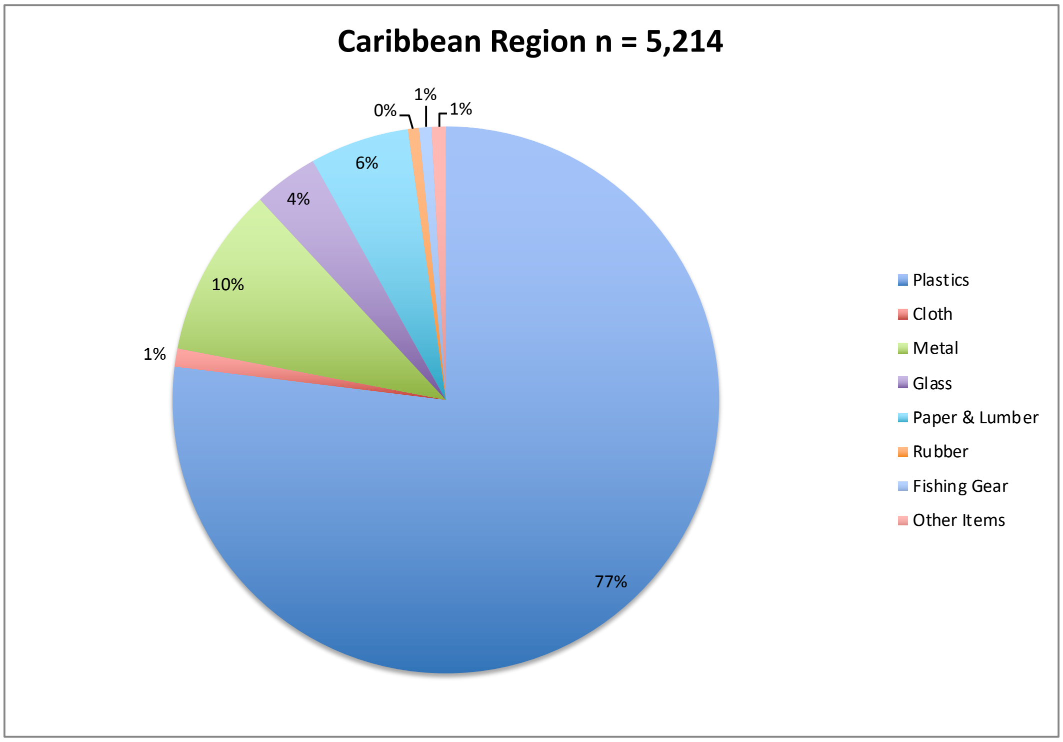
United States marine debris counts by state.

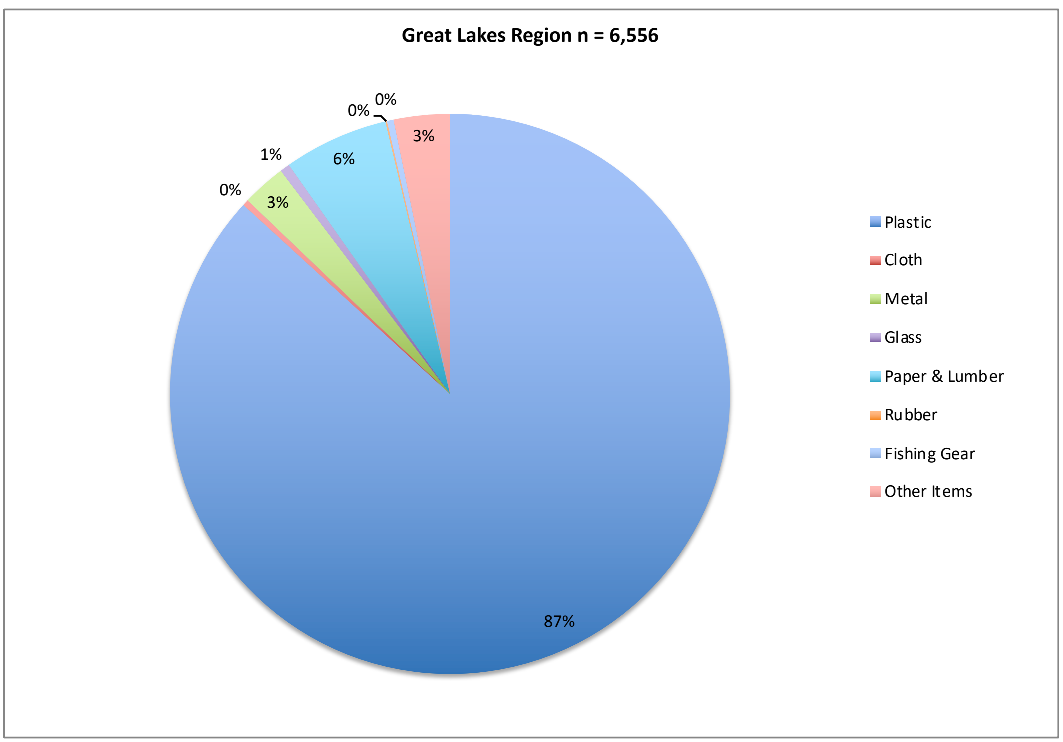


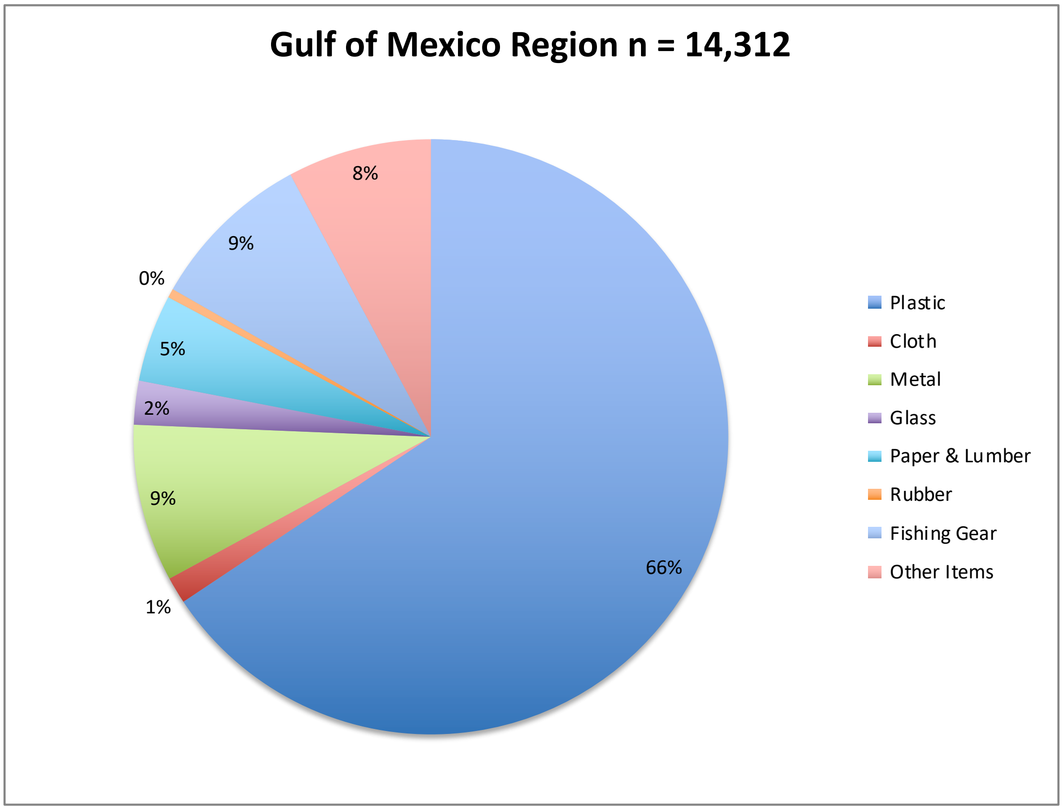
APPENDIX D

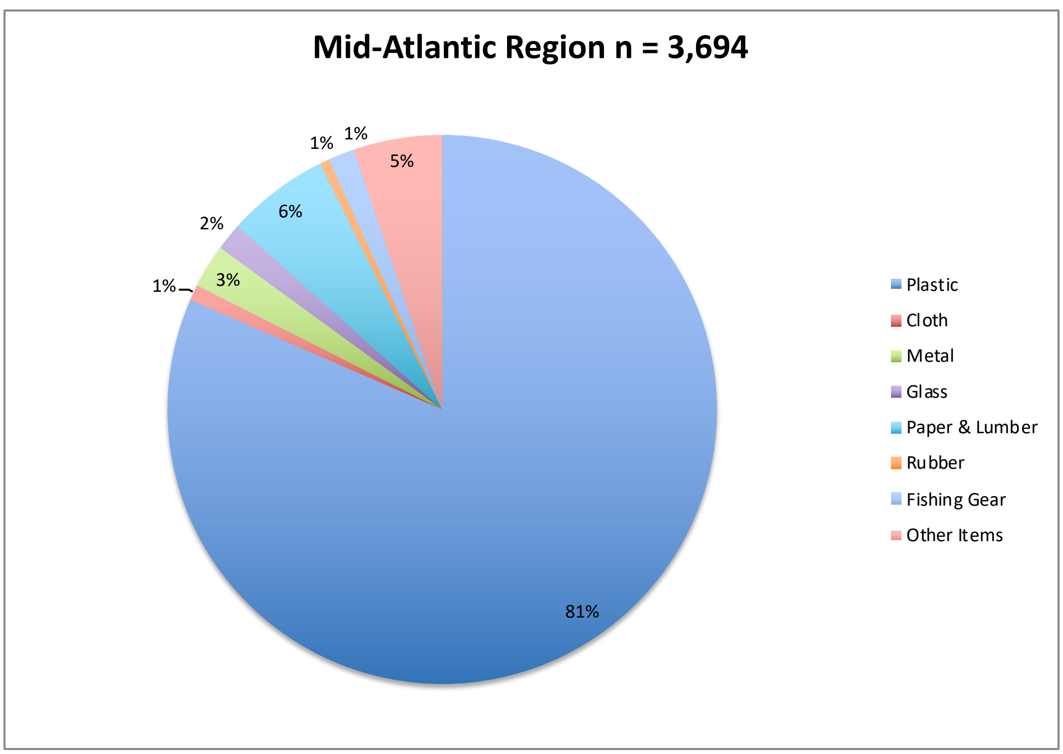
Material Characterizations for NOAA Regions.

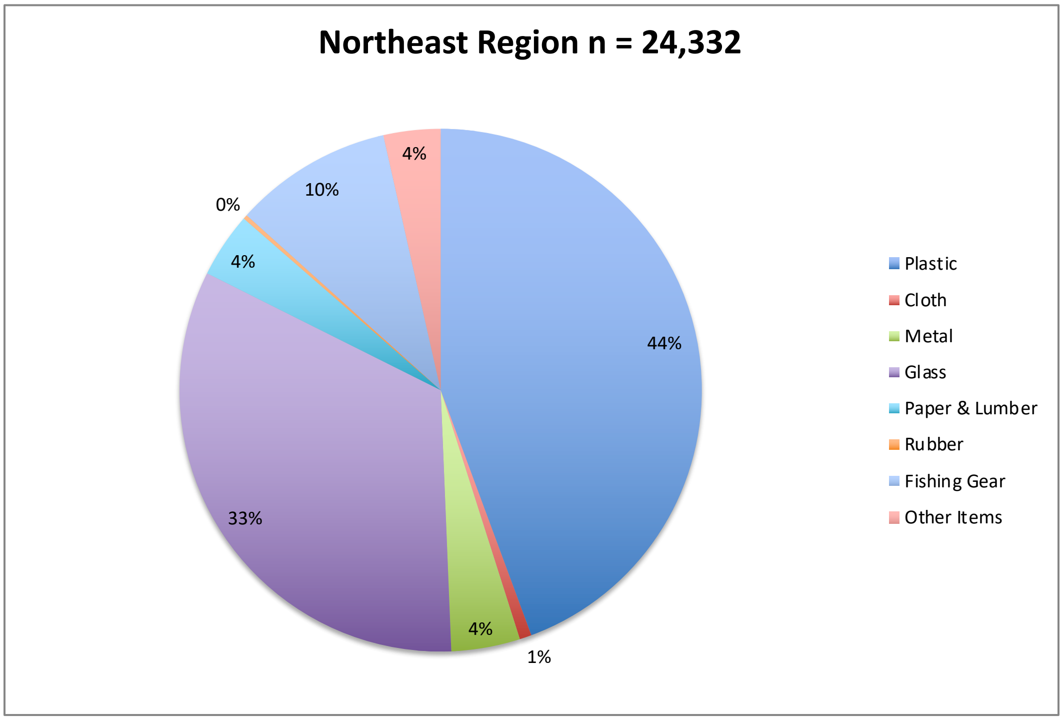


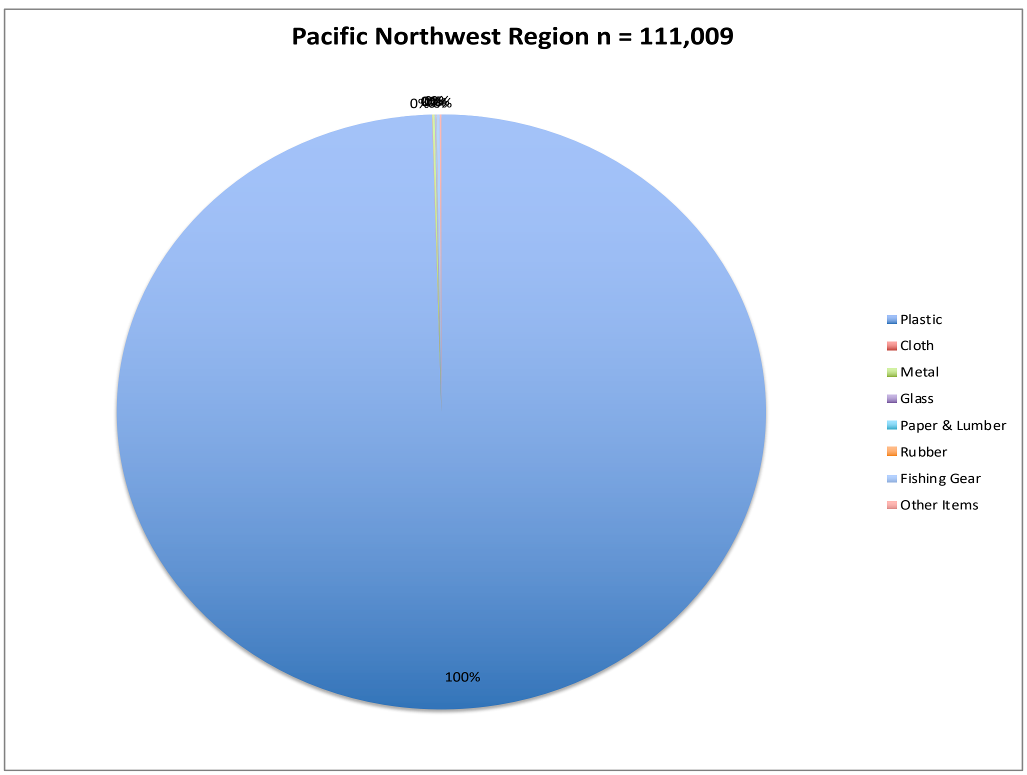

Caribbean Region n = 5,214
0%
1%
1%
6%
4%
10%
1%
77%
Plastics
Cloth
Metal
Glass
Paper & Lumber
Rubber
Fishing Gear
Other Items

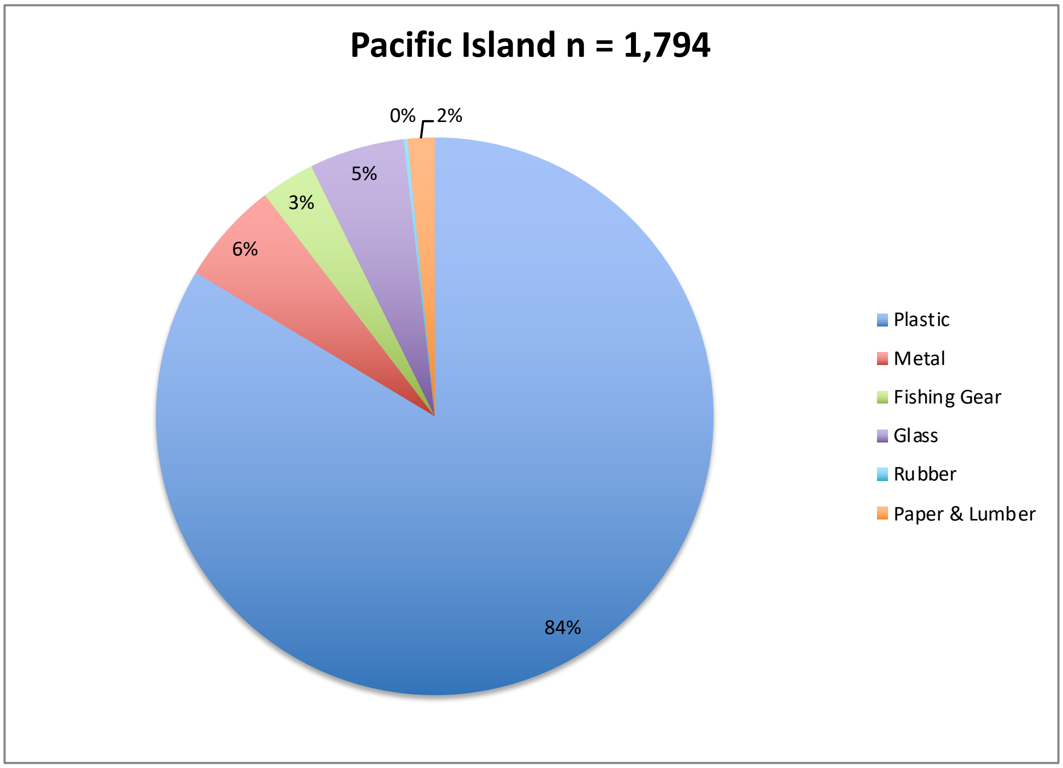

Great Lakes Region n = 6,556
0%
0%
3%
1%
6%
0%
3%
87%
Plastic
Cloth
Metal
Glass
Paper & Lumber
Rubber
Fishing Gear
Other Items

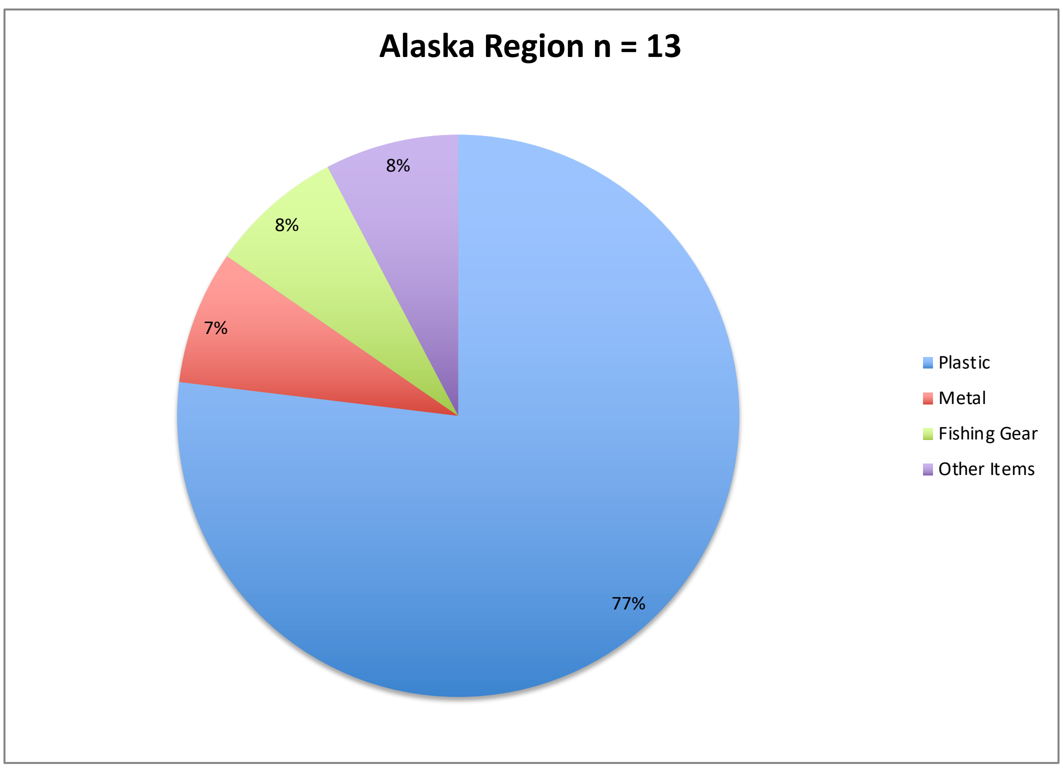

Gulf of Mexico Region n = 14,312
8%
9%
0%
5%
2%
9%
1%
66%
Plastic
Cloth
Metal
Glass
Paper & Lumber
Rubber
Fishing Gear
Other Items


Mid-Atlantic Region n = 3,694
1%
1%
5%
6%
2%
1%
3%
81%
Plastic
Cloth
Metal
Glass
Paper & Lumber
Rubber
Fishing Gear
Other Items


Northeast Region n = 24,332
4%
10%
0%
4%
44%
33%
4%
1%
Plastic
Cloth
Metal
Glass
Paper & Lumber
Rubber
Fishing Gear
Other Items


Pacific Northwest Region n = 111,009
100%
Plastic
Cloth
Metal
Glass
Paper & Lumber
Rubber
Fishing Gear
Other Items

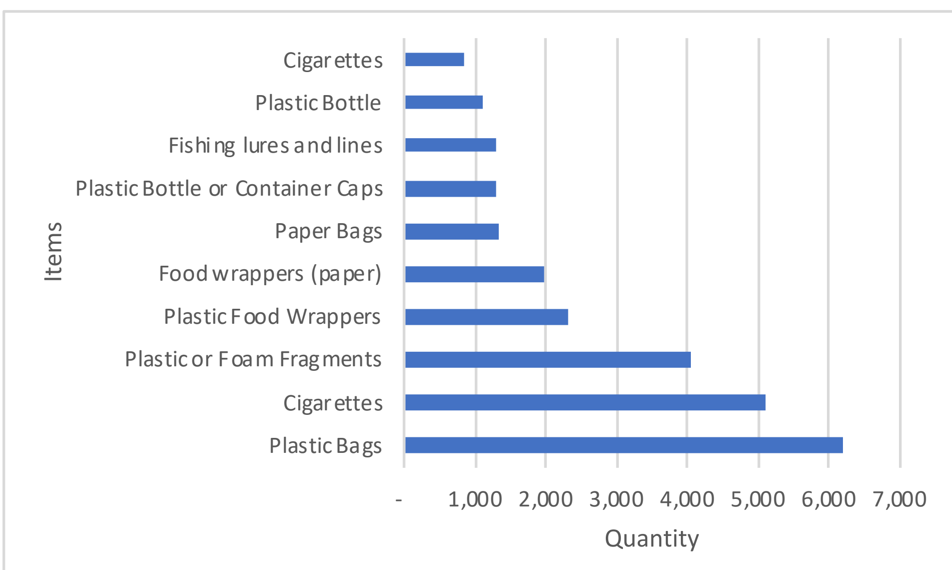

Pacific Island n = 1,794
0%
2%
5%
3%
6%
84%
Plastic
Metal
Fishing Gear
Glass
Rubber
Paper & Lumber


Alaska Region n = 13
8%
8%
7%
77%
Plastic
Metal
Fishing Gear
Other Items

APPENDIX E

Georgia Sea Turtle Center Jekyll Island tracking activity – top 10 items in quantity

Top 10 Items	Quantity
Plastic Bags	6,182
Cigarettes	5,116
Plastic or Foam Fragments	4,065
Plastic Food Wrappers	2,328
Food wrappers (paper)	1,990
Paper Bags	1,317
Plastic Bottle or Container Caps	1,313
Fishing lures and lines	1,298
Plastic Bottle	1,109
Cigarettes	856
Total top 10	**25,574**
Total by GSTC on Jekyll	**34,806**



APPENDIX F

ANOVA random effect for parcel ID output.

19-E OAKGROVE S/D	-1.387297944
JEKYLL ISLAND MORGAN CENTER	-1.307905147
12-O JEKYLL BEACH	-1.29531559
LOT 10-E JEKYLL BEAC	-1.254581183
11-E JEKYLL BEACH SD	-1.189779815
RADISON RESORT HOTEL	-1.099680704
1-P JEKYLL BEACH	-1.057478257
6-E PALMETTO	-1.052199244
40-B PALMETTO	-1.017856001
3 BLK P JEKYLL BCH	-1.017055252
16-G OAK GROVE S/D	-0.992143056
LOT 21-B PALMETTO SD	-0.988539684
30-B PALMETTO S/D	-0.972331928
4 BL O JEKYLL BEACH	-0.959445798
10-N JEKYLL BEACH	-0.916235
12-C PALMETTO S/D	-0.913476864
LOT 32 THE COTTAGES AT JEKYLL PHS 2	-0.87372115
.915 AC OF LOT 110 JEKYLL ISLAND	-0.862718263
3-C JEKYLL BEACH S/D	-0.833995094
LOT 9 BLK. E JEKYLL	-0.823540868
4-E JEKYLL BEACH	-0.801861326
5-D JEKYLL BEACH S/D	-0.786647092
COMMON AREA 6-A JEKYLL BEACH	-0.786128087
1-K JEKYLL BEACH	-0.774754483
16-N JEKYLL BEACH	-0.748389075
5,6-K JEKYLL BEACH	-0.742605887
LOT 55 THE COTTAGES AT JEKYLL PHS 1	-0.698727798
LOT 53 THE COTTAGES AT JEKYLL PHS 1	-0.689830585
29-B PALMETTO	-0.623131144
8-H PLANTATION	-0.589840739
CONVENTION/REST VILLAS BY THE SEA-COMMON AREA	-0.380904519
1-E OAKGROVE	-0.310853795

28-A PALMETTO S/D	-0.219835306
20-A PALMETTO S/D	-0.153269323
BLK 250 JEKYLL	-0.037363846
14-F OAKGROVE S/D	0.001579997
5 BL B JEKYLL BCH	0.097466003
7-D JEKYLL BEACH	0.103278849
6-H JEKYLL BEACH S/D	0.117401692
LOT 8-N JEKYLL BEACH	0.138204859
20 BL B PLMETTO S/D	0.153358296
COMMON AREA 1 THE COTTAGES AT JEKYLL PHS 1	0.182111122
10-H OAKGROVE	0.204339326
5.347 AC JEKYLL ISLAND	0.243887438
LOT 22-D OAKGROVE	0.244955104
LOT 2-E OAKGROVE	0.311031739
8-E JEKYLL BEACH	0.483608015
BEACHVIEW DR JEKYLL	0.539126625
8.743 AC JEKYLL ISLAND	0.583553375
7-A JEKYLL BEACH	0.583746148
7-E JEKYLL BEACH	0.591842612
4 BL D OAKGROVE	0.656021175
2-6 INC OAKGROVE 21,22,23-C	0.697526674
ROADS LOCATED ON JEKYLL ISLAND	0.771017654
LOT 30 THE COTTAGES AT JEKYLL PHS 2	0.772930555
LOT 4-A JEKYLL BEACH	0.836530799
7.091 AC OF LOT 108 & 110 JEKYLL ISLAND	0.936935849
LOT 25 THE COTTAGES AT JEKYLL PHS 1	0.974926948
LOT 1-J PINEGROVE	0.992380315
JEKYLL ISLAND	1.070186443
16-C PALMETTO	1.075999289
LOT 26 THE COTTAGES AT JEKYLL PHS 1	1.111083965
LOT 9 BLK G OAKGROVE	1.163622008
4.78 AC JEKYLL ISLAND	1.299260021
LOT 111 JEKYLL ISL.	1.345154812
19-D OAKGROVE	1.530468931
LOT 3-E OAKGROVE S/D	1.577031013
LOT 1-J OAKGROVE S D	1.667930873
LOT 252A JEKYLL ISL	2.387863695
1BLKI OAKGROVE	2.447326735

8&9 BLK A JEKYLL B		2.77548561
4-F OAKGROVE		2.930593691
7.073 AC JEKYLL BEACH		3.163255812
13-D OAKGROVE		4.697135341
PRIVATE ROADS WITHIN THE COTTAGES AT JEKYLL PHS	1(R)	1.027094274