PREVALENCE AND SOCIOECONOMIC IMPLICATIONS OF MARINE DEBRIS IN SOUTHERN BELIZE

by

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A THESIS

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ABSTRACT

Marine debris is a global issue with acute impacts. Here, stakeholder conversations were combined with a quantitative analysis of debris to better understand the distribution and sources of marine debris in Belize. This study focused on seven islands off the southern coast of Belize, and cataloged debris present using transects along each beach. Of the 1,754 items cataloged, the majority (68.1%) were plastics. The most commonly found items were plastic water bottles, glass bottles, and Styrofoam take-out containers. Once cataloged, debris was matched to an anthropogenic source, with the majority (74.8%) of sources being recreation-related. This source-based analysis provided insight into the causes of anthropogenic pollution in southern Belize. Conversations with stakeholders highlighted the importance of mitigating solid waste pollution in the local environment, and hence the need for an improvement in Belize’s waste management system. This research can inform Belize’s policy makers as they strive to bolster their tourist-driven economy.
DEDICATION

To my grandmother, Linda Padgett.
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td>Centimeter</td>
</tr>
<tr>
<td>dF</td>
<td>Degrees of Freedom: the number of variables in the final calculation of a statistic that are free to vary</td>
</tr>
<tr>
<td>F</td>
<td>Fisher’s $F$ ratio: Determines variation between two means</td>
</tr>
<tr>
<td>m</td>
<td>Meter</td>
</tr>
<tr>
<td>m²</td>
<td>Meters squared</td>
</tr>
<tr>
<td>p</td>
<td>Probability: the measure of the likelihood an event will occur</td>
</tr>
<tr>
<td>SD</td>
<td>Standard Deviation: Measure of the variation or dispersion in a set of values</td>
</tr>
<tr>
<td>&lt;</td>
<td>Less than</td>
</tr>
<tr>
<td>≤</td>
<td>Less than or equal to</td>
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<tr>
<td>&gt;</td>
<td>Greater than</td>
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<td>≥</td>
<td>Greater than or equal to</td>
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<tr>
<td>=</td>
<td>Equal to</td>
</tr>
<tr>
<td>±</td>
<td>Plus or minus</td>
</tr>
<tr>
<td>α</td>
<td>Alpha: Refers to the significance level of a statistic</td>
</tr>
<tr>
<td>$X^2$</td>
<td>Chi-Square statistic</td>
</tr>
</tbody>
</table>
ACKNOWLEDGMENTS

I am pleased to acknowledge and thank the many people who supported this project; thank you Dr. Michael Steinberg, the committee chairman of this manuscript, who provided invaluable background knowledge of Belize and supported my passion for environmentalism. I would also like to thank my other committee members, Dr. Matthew LaFevor and Dr. Julia Cherry, for the guidance and constructive comments that shed new insights onto this manuscript. To the wonderful people from the Toledo Institute for Development and Environment, Lime Caye, and South Water Caye - your hospitality and support were more than one could ask for. I am eternally grateful for “Team Trash” (Allison Beaty, Amica Rapadas, Ashley Spiller, Molly Mabry, Deborah Olivier, Kathryn Crawford, and Connor Adams), the team of surveyors who spent hours cataloging debris on beaches. With these helping hands, this project was able to reach a much larger scope than anticipated. Lastly, I am thankful for the emotional and motivational support throughout this project from my close friends and family.
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INTRODUCTION

Environmental pollution is a complex problem in that there is no clear or readily-accessible solution. While pollution is ubiquitous across the world, regions often have unique circumstances under which they experience its consequences. Geography allows environmental pollution to be studied across different spatial scales, ranging from global to local. The study of marine debris warrants a geographical perspective, as geography offers a unique array of skills and methodologies, including the ability to measure the spatial variance of debris, the influence of physical environmental factors on pollution, and the ability to better understand human-environmental interactions. The interdisciplinary nature of geography allows social and physical components of environmental research to be combined, permitting a more thorough analysis of the problem at hand. These attributes are combined in this study to understand the problem that is marine debris.

This research project surveys marine debris on the islands along the southern coast of Belize, and includes conversations with stakeholder to gauge social perceptions of the issue. This project aims to quantify, categorize, and identify the sources of various types of debris found on beaches, as well as review the current literature regarding solid waste management in Belize. Issues regarding waste disposal systems, marine debris, and the discrepancies behind current marine debris research methods are discussed.
BACKGROUND

Marine Debris

Solid waste pollution is an issue of growing concern in today’s oceans. With the rise of single-use plastics and disposable items such as straws, Styrofoam, and plastic water bottles, litter is accumulating on coastal and marine areas around the globe at an increasing rate. A study by Jambeck et al. (2015) estimated that 275 million metric tons of plastic waste were generated by 192 coastal countries in 2010. The amount of plastic waste generated is estimated to increase by an order of magnitude by 2025 under current conditions. Litter can be found in nearly all marine environments in today’s world, ranging from shallow surface waters to the deepest parts of the sea (Barnes et al., 2009). Marine debris (“litter”; “debris”) is defined as “any manufactured or processed solid waste material that enters the marine environment from any source” (Coe & Rogers, 1997). Debris refers to a wide variety of materials but is often composed primarily of plastic (Bennett-Martin et al., 2016; Jambeck et al., 2015; Rochman et al., 2016a; Santos et al., 2009). This accumulation of debris in the environment is concerning due to its persistence; while debris is gradually weathered by natural processes (wave erosion, UV radiation, and weathering), fragments and particulates can remain in the environment indefinitely. This persistence can alter the physical environment and subsequent ecological interactions, as organisms may ingest, become entangled by, or be smothered by litter (Barnes et al., 2009). One result of this type of pollution is the Great Pacific Garbage Patch, located in the North Pacific subtropical gyre, which has a 6:1 ratio of plastic to zooplankton, or 334,271 pieces per square kilometer (Kaiser, 2010).
Marine garbage patches are amalgamations of debris from multiple sources, coastal lands primary among them.

Coastal debris is typically classified as either land-based or marine-based, but it can also be classified on the basis of pollution source and litter type (Claereboudt, 2004). As society further industrializes and expands with time, coastal debris is one of the most easily visible negative effects humans have on the marine environment (Claereboudt, 2004). It is estimated that at least 80% of marine debris originates on land (Jambeck et al., 2015). Litter producing activities include industrial and manufacturing byproducts or waste, recreational litter (e.g. cigarettes, plastic bottles, cans, straws, food wrappers), derelict fishing debris (e.g. rope, nets, fishing line), among others. The identification of potential debris sources can provide insights into debris generation patterns, allowing for more targeted mitigation efforts by policy makers.

The persistence of debris on coasts, beyond their environmental effects, can also be harmful to the local economy. A study performed by Balance et al. (2000) found as much as a 52% drop in tourism revenue due to the poor aesthetics of beaches. In addition, tourists have been found to be less likely to litter on pristine beaches as opposed to ones already filled with debris (Lu et al., 2013). Other economic areas experiencing negative impacts from marine debris include commercial shipping and aquaculture (Rochman et al., 2016b). Potential effects of litter on fishing industries and other economic areas are otherwise not widely studied yet. While the physical effects of marine debris on local economies and commercial industries warrants further research, studies investigating social perceptions of debris have attempted to understand perceived origins and sources of debris, in efforts to provide valuable waste management improvements for future debris mitigation strategies.
Previous studies have addressed public perception regarding the origins of marine debris (Liu et al., 2015; Santos et al., 2005; Uneputty & Evans, 1997), noting that human activities have a large role in the creation and persistence of solid waste pollution. For example, Liu et al. (2015) examined social perceptions pertaining to derelict fishing gear pollution, specifically regarding opinions behind the origin of this debris. In addition, informants in this study gave suggestions for future policy and management improvements of marine debris pollution. The results of this study found that improvements in environmental awareness and enhanced environmental education campaigns have the potential to substantially mitigate future marine debris. It is important to consider the human perceptions of marine debris origination to generate behavioral change; complex issues such as environmental pollution cannot be improved through human action and cooperation unless they are acknowledged as a problem (Slavin et al., 2012).

The inclusion of social perceptions allows for the priorities of stakeholders to be evaluated; if the needs and lifestyles of locals are considered they may be more likely to participate in future mitigation strategies or change their waste disposal habits. Information can then be collected regarding what is important to individuals, helping to inform more effective decisions for future waste disposal policy (Barnett et al., 2016). With enough local recognition of the harms, existing laws could be more effective in helping to limit sources of waste, guiding consumers toward environmentally-friendly and recycled alternatives, and rehabilitating affected beaches and habitats (Rochman et al., 2016a).

The marine debris literature has several inconsistencies and discrepancies, especially regarding sampling methods. It is common for marine debris studies to report debris weights and densities in order to provide comparable results for other studies. The variation of debris quantities across countries leads to the inability for direct comparisons between locations, and a
lack of unity in debris statistics. Additionally, source-based approaches to the quantification of marine debris vary in methodology (Santos et al., 2009), permitting various degrees of confidence or specificity of debris source-classification. Source-based classification of debris can provide insights into anthropogenic uses, generation patterns, and sometimes it’s geographic source (e.g. where the debris physically originated).

**Marine Debris on Islands**

Islands often offer unique perspectives into the state of the environment due to their distance from the mainland, small permanent populations (if any), and the tendency to remain stagnant (or immobile) over time. Marine debris affects islands across the world, as islands remain passive bystanders in the distribution and dispersal patterns of global debris. Due to marine debris’ transient and often lightweight nature (namely plastics), debris has the potential to float anywhere in the world as a result of prevailing wind patterns and global oceanic currents (Uneputty & Evans, 1997). Floating debris comprises a fraction of total debris in the environment, and is directly related to litter transport pathways at sea (Galgani et al., 2015). Other debris, including heavy materials that cannot float, often sink to the sea-floor, adding to the countless debris items that reside below the water’s surface.

The ability for widespread transport of litter between places has led to the accumulation of debris on offshore beaches. Numerous studies have found large amounts of debris left on beaches of islands over time (e.g. Duhec et al., 2015; Lavers & Bond, 2017; McDermid & McMullen, 2004). These islands are left as passive bystanders that accumulate debris, as they often have low permanent populations, little to zero waste disposal infrastructure, and are often
inaccessible to debris clean up campaigns (Schmuck et al., 2017). Debris on islands has been found to originate from indirect sources, where the majority of debris may have been washed ashore from a distant or foreign location. A study performed by Lavers and Bond (2017) found that Henderson Island, a remote and uninhabited island in the South Pacific Ocean, had one of the highest debris densities recorded in the world, estimated to be approximately 37.7 million debris items. In this study, it was predicted that since there was no human or industrial activity within 5,000 kilometers, the vast amount of debris must have been derived from the global disposal and dispersal patterns of waste (Lavers & Bond, 2017). A similar study conducted on the Cocos Keelings Islands, Australia, reported an estimate of 414 million pieces of anthropogenic debris on beaches, items residing both on the beach’s surface and buried below (Lavers et al., 2019). Isolated islands such as these act as marine pollution monitors, providing insights into debris mobility (or stagnancy) and accumulation trends (Lavers et al., 2019; Santos et al., 2009). With low human interference and limited local populations, distant islands are the result of long-term solid waste pollution and the most prominent visual of the negative effects humans have on the environment (Claereboudt, 2004). Islands with low human influences also tend to reflect the more natural state of debris than densely occupied areas (Lavers et al., 2019). Widespread accumulation of debris on islands also reflect the acute symptoms of the rapidly growing issue today that is single-use plastic consumption (Geyer et al., 2017; Ivar do Sul & Costa, 2007), evident on beaches worldwide (Barnes et al., 2009; Lavers et al., 2019; Santos et al., 2009).

Marine debris (plastics in particular) have been found especially prevalent in developing countries (Ivar do Sul & Costa, 2007; Santos et al., 2009), with the massive arrival of processed and packaged goods on the market leading to a pronounced influx of mismanaged wastes.
Caribbean countries are a prime example of this persistence (Schmuck et al., 2017). Numerous islands in the Caribbean have been identified as pollution hotspots (e.g. Ivar do Sul & Costa, 2007), especially those adjacent to tourism sites and urban centers (Schmuck et al., 2017). Remote, tropical beaches are especially prone to large densities of debris, which can be attributed to distance (either near or distal) from sources. The density of debris on islands can also be attributed to geographic isolation, where more isolated and remote islands have been found to have higher densities of debris compared to more frequented islands (e.g. Duhec et al., 2015; Lavers & Bond, 2017).

In addition to proximity to sources of debris, studies have found that absent or inadequate waste management systems are a major contributor to the marine debris problem in the Caribbean (Coe et al., 1997; Singh & Xavier, 1997). Insufficient waste management systems contribute to marine debris through the transfer and movement of waste. Solid waste has been found to transfer from land to oceans via inland waterways, wastewater outflows, winds, and tides (Jambeck et al., 2015). The increasing number of inputs (e.g. growing tourism industries and the continued use of plastics) coupled with inadequate waste management systems, suggests that the marine debris phenomenon will only continue to persist (Schmuck et al., 2017). This scenario is especially true in Belize, where marine debris persists on its pristine beaches.

The waste management system of Belize has been historically ineffective (Grau et al., 2014; Villegas, 2018). While there have been recent improvements in the country’s waste management infrastructure (e.g. the addition of the country’s first standardized sanitary landfill that services areas near Belize City [Belize Solid Waste Management Authority, 2014]), the southern districts of the country remain lacking sufficient municipal waste collection and disposal services. Residents are often left to dispose of waste using alternative and potentially
environmentally harmful methods, including open-air burning, the use of unregulated dump sites, or disposal into the sea or river (Lu et al., 2013; Statistical Institute of Belize [SIB] & United Nations Population Fund [UNFPA], 2012).

The government of Belize has recently focused on expanding the tourism sector; the country has seen an increase in overnight arrivals (visitors spending multiple days; excludes cruise ship “day-trip” visitors), increasing from 32,624 arrivals in 2014, to 54,551 arrivals in 2018 (Belize Tourism Board [BTB], 2020). With the continued economic development from increased tourism revenue, waste generation and waste mismanagement will increase (absent changes to the current waste management system), adding to marine debris accumulating on Belizean beaches and elsewhere. Efforts toward sustainable growth have been enacted in Belize, including the “plastic-free Belize” movement which intends to phase-out the use of commonly littered single-use plastics and Styrofoam (Department of Environment, 2019), promoting the use of biodegradable and environmentally friendly products.

The intricate relationship between solid waste generation on land and marine debris found on beaches and islands is critical in maintaining environmental integrity. When solid waste pollution is persistent on land, the waste inevitably trickles downstream and reaches the ocean. In order to combat the persistence of debris on islands, stakeholders and legislation must first combat the issue on land, where the majority of debris has been found to originate (e.g. Jambeck et al., 2015; de Scisciolo et al., 2016). Marine debris defies political boundaries, affecting not only it’s country of origin but also foreign shorelines, both near and far. Waste generated on the mainland of Belize, in both rural and urban centers, has the potential to ultimately reside on the adjacent cayes (islands) lining the eastern coast of the country.
Marine debris studies in the Caribbean commonly focus on island nations, including the Bahamas, Jamaica, Aruba, the British Virgin Islands, Panama, and the Cayman Islands (e.g. Garrity & Levings, 1993; Schmuck et al., 2017; de Scisciolo et al., 2016; Singh & Xavier, 1997). Marine debris studies are scarce in Guatemala (Tedsen et al., 2014) and Honduras (Diez et al., 2019) (both having a single known reference to solid waste accumulation throughout the literature), neighbors to Belize in the Gulf of Honduras. Few quantitative marine debris studies have been performed in Belize (e.g. Bennett-Martin et al., 2016); however, scientific marine debris studies focused on the islands of Belize are unknown. This study is the first to quantify debris on cayes in both the Sapodilla Cayes and South Water Caye Marine Reserves (see Figure 1).
OBJECTIVES AND PREDICTIONS

In this study, a baseline survey of coastal debris pollution in Belize was performed to analyze the standing stock of debris present and the social perceptions behind marine debris. Hypotheses include:

H1: Beaches with higher foot traffic will have less debris present overall.

H2: Beaches with lower foot traffic will have a higher accumulation of fragmented and worn debris.

H3: Individuals in higher foot traffic areas will be more concerned or aware of the debris issue at hand.

The degree of foot traffic refers to the number of people who regularly frequent the beaches. Willis et al. (2017) found that the quantity of debris recorded on Australian shorelines was influenced by local population size, supporting the reference of foot traffic on islands in this study. This study investigates islands that vary greatly from one another (see Table 1), so acknowledging these discrepancies in visitor frequentation helps enlighten later results. Foot traffic also serves as a proxy for recreational use, which represents the influence of humans on the island. Islands with lower foot traffic can be inferred to have a lower influence from human activity. However, the use of “foot traffic” here does not discriminate between Belizeans and foreign visitors, but describes the frequentation of people as a whole.

In addition, foot traffic tends to increase with the amount of revenue the beaches attract (e.g. how many resorts or tours visit the location if any), and the regularity with which the beach
is cleaned. Beach resorts will often have beaches that are raked daily in order to maintain visual integrity, so it is important to note if any cleaning has been performed before analysis to acknowledge the possibility of changes in debris composition.

Many studies have performed quantitative analysis of marine debris focused on overall weights and densities (e.g. Jambeck et al., 2015; Kaiser, 2010; Santos et al., 2009; Velander & Mocogni, 1999). The literature is lacking, however, in source-based quantitative analysis of marine litter. This lack of a cohesive quantitative literature is due to discrepancies among sampling methods, conservative approaches to source verification, and the lack of a comprehensive accounting of negative environmental effects (Rochman et al., 2016a). This research will provide insight into waste management and mitigation practices in marine ecosystems, as it will convey potential sources, causes, and impacts of debris accumulation. In light of new information, Belizeans will hopefully have better resources to enable more sustainable management of their waste disposal infrastructure for future generations.
METHODOLOGY

Study Area

Data collection was performed along cayes of southern Belize (see Figure 1). Study sites include islands in the Sapodilla Cayes Marine Reserve (Lime Caye, Hunting Caye, Nicholas Caye, Franks Caye) and the South Water Caye Marine Reserve (South Water Caye, Tobacco Caye, and Twin Caye). This focus on the southern coast of Belize allows for variation in data collection, as the study sites vary in population, size, and economic use. This variation can be easily seen by comparing Hunting Caye, a Coast Guard station, with South Water Caye, which lies directly north of a portion of the barrier reef and is a popular tourist snorkeling destination. Lime Caye is a family-owned island resort that can house upwards of 30 people with a small permanent population (less than 10 people). Hunting Caye, in addition to being home to a Belizean Coast Guard station and a university research outpost, attracts occasional visitors for academic and military purposes, with a low permanent population. Nicholas and Franks Cayes have somewhat degraded physical structures, suggesting that the islands are frequented less often than others and lack a permanent population. In addition, Nicholas Caye is noted as a spawning aggregation site, which is important in maintaining national and regional viability for several commercial fish species (Wildtracks, 2010). Tobacco Caye has both a tourist and non-tourist areas, with both a popular resort and the other less popular areas. While Twin Caye houses a Belizean Marine Fisheries building with few permanent occupants, the majority of the island is
said to be uninhabited. South Water Caye houses 3 popular resorts, attracting a high amount of foot traffic throughout the year. South Water Caye differs from the other sites in having the highest amount of permanent residents along with a high frequency of foot traffic, and is therefore heavily surveyed in this study. Lime Caye, Nicholas Caye, South Water Caye, and Tobacco Caye all have confirmed caretakers, meaning that the island’s beaches are cleaned and raked of washed up or littered debris. However, the frequency of beach cleaning is unknown on Nicholas and Tobacco Cayes, while South Water and Lime Caye beaches are cleaned daily.
Figure 1 Map of southern Belize on which data were collected. Sites include Tobacco Caye, Twin Caye, South Water Caye, Franks Caye, Nicholas Caye, Hunting Caye, and Lime Caye (Belize boundaries: Meerman & Clabaugh, 2017).

Table 1 below summarizes the characteristics of each island investigated, including the total area of each location, the presence of tourist resorts, economic uses, and the presence of a confirmed caretaker on each. The presence of tourist resorts refers to accommodations on each island frequently used by visitors. The presence of these resorts can then be associated with degrees of foot traffic, with tourist locations having higher frequencies of foot traffic and higher
visitation rates than locations without these resorts. The economic industry refers to the primary use of each island (as in Bennett-Martin et al., 2016), where “recreational” use refers to the people who visit the island for a short time (e.g. people visiting the beach for a few hours using personal boats). “Tourism” refers to locations with established resorts that attract foreign visitors who stay overnight, where the resort often provides guided marine tours for guests. The presence of caretakers was established either through first-hand observations or through stakeholder informants.

Table 1 Descriptors of field sites. Area of islands obtained using shape file attributes in ArcMap 10.1. Remaining information obtained through personal observations and through informants. (*Wildtracks, 2010).

<table>
<thead>
<tr>
<th>Island</th>
<th>Area of Island (acres)</th>
<th>Presence of Tourist Resorts</th>
<th>Economic Industry of Island</th>
<th>Confirmed Caretaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime Caye</td>
<td>0.86</td>
<td>Yes</td>
<td>Recreation, tourism</td>
<td>Yes</td>
</tr>
<tr>
<td>Hunting Caye</td>
<td>0.67</td>
<td>No</td>
<td>Government of Belize Research Facility</td>
<td>No</td>
</tr>
<tr>
<td>Nicholas Caye</td>
<td>1.08</td>
<td>No</td>
<td>Recreation, conservation (spawning aggregation site*)</td>
<td>Yes</td>
</tr>
<tr>
<td>Franks Caye</td>
<td>1.65</td>
<td>No</td>
<td>Unknown</td>
<td>No</td>
</tr>
<tr>
<td>South Water Caye</td>
<td>1.84</td>
<td>Yes</td>
<td>Recreation, tourism</td>
<td>Yes</td>
</tr>
<tr>
<td>Tobacco Caye</td>
<td>0.67</td>
<td>Yes</td>
<td>Tourism, fishing</td>
<td>Yes</td>
</tr>
<tr>
<td>Twin Caye</td>
<td>11.31</td>
<td>No</td>
<td>Government of Belize Marine Fisheries Station</td>
<td>No</td>
</tr>
</tbody>
</table>

Field Methodology

Given that each proposed study site varies in economic use, available beach area, and population size (see Table 1), some locations will receive more of a focus on qualitative rather
than quantitative analysis. The study sites will be compared both qualitatively and quantitatively to create an integrated analysis of marine debris. Field data was collected from May 9th-23rd, 2019.

Across 7 islands, 15 beaches were sampled (Table 1). In efforts to reduce sample bias, beach sites were chosen based on where the ship docked; once docked, a team of surveyors walked along the shore from the drop-off location until a sizable portion of the beach was found (e.g. 20 meters of un-vegetated sand). If an open area was not available, transects were shortened to the length of the un-vegetated shore. Transect lengths varied across sites, with the shortest transect being 0.05 meters long (transect area of 0.25 m²), and the longest transect being 20 meters (transect area of 100 m²). In addition, the shore’s cardinal orientation was recorded to determine if prevailing winds or currents have an effect on debris accumulation.

Approximately one hour was spent on each island, excluding Lime Caye and South Water Caye (accommodations were held on these islands during this study). For each day of field work on Lime and South Water Cayes, the team of surveyors collected data within one hour in order to stay consistent with other location’s time constraints. Sample sites varied in the amount of time required to catalog debris present, leading to differing amounts of transects on each island. For example, within one hour, 3 different beaches were surveyed on Tobacco Caye, while only one beach was surveyed on Hunting Caye. Due to this time constraint, some sites had an excessive amount of debris that could not all be accounted for, leading to conservative estimates of total debris (resulting in left-skewed data). When supplies were available, the counted litter was then picked up and disposed of properly.

At each site, 20 meter transects were used along the shore, both perpendicular and horizontal to the shoreline, allowing for fresh and accumulated debris to be measured (Velander
& Mocogni, 1999). Similar to a shore litter survey in the Gulf of Oman (Claereboudt, 2004), each horizontal transect was placed in relation to the low tidemark. If the tidemark was too variable or inconsistent, then the transect began from the location at which the sand was permanently wet or saturated (as defined in Velander & Mocogni, 1999); each perpendicular transect progressed from the tidemark to the vegetation line or end of sandy beach substrate (whichever comes first). The use of perpendicular transects was contingent on accessible beach area, which was not available at all locations. Some locations had too shallow of a beach area, dense root systems in place prohibiting access, or had unsafe conditions (e.g. an unstable rocky shoreline) for the use of perpendicular transects.

Based on a study by Araújo et al. (2006) that determined the optimal width of source-based surveys, each transect was 5 meters wide to obtain an optimal area for the categorization of litter sources. Figure 2 below diagrams the orientation of these transects, where the black lines represent horizontal and perpendicular transects, and the red lines depict the width of each transect. The consistent use of a 5 meter transect width also allows the total area surveys for each beach to be calculated, permitting the subsequent comparison of each sample site. For instance, the maximum area surveyed for one beach will be $100 \text{ m}^2$ (20 meters long and 5 meters wide). While walking along each transect, visible surface-layer debris within this transect area was counted and categorized.
Debris was categorized first based on material type (e.g. plastic, Styrofoam, paper, etc.) and object form (e.g. beverage bottles, bags, shoes, etc.) and subsequently based on economic activity (“source”) (relating to recreational, fishing, or industrial activities) (Table 2). Each source was determined through inspection of the object found (e.g. reading the label, identifying the object type); commonly known items such as tennis shoes and children toys were readily attributed to a recreational source, since they were items used in people’s households or in recreational activities. Items that are not usually used in people’s everyday life, such as cement blocks and polyvinyl chloride (PVC) pipes, were attributed to an industrial source, having been
used in the manufacturing process. Items used during fishing activities, including fishing line, large ropes, buoys, and nets, were attributed to a fishing source. Any item that was ambiguous or unrecognizable (either in its material or object form) was classified as an unknown source.

Table 2 Defining key terms used throughout this study, including material, object form, and economic use (source). *Categories presented here in decreasing orders of abundance. These categories are not exhaustive, but represent the most common of those recorded. References denote literature in which these categories were previously used.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Categories*</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Material of each debris item</td>
<td>Plastic, Styrofoam, rubber/foam, glass, metal, aluminum, processed wood, textiles, paper, rope, other (cardboard, cement, ceramic, latex), and unknown</td>
<td>Haarr et al., 2019</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Opfer et al., 2012</td>
</tr>
<tr>
<td>Object Form</td>
<td>Form that each debris items takes; the object of debris often indicates its intended use E.g. plastic straws are used for drinking</td>
<td>Beverage bottles, bottle caps/lids, containers (food and non-food), carrier bags, utensils, shoes, clothing, cigarettes, drinking straws, child’s toys, beverage cans, personal care products, and unknown</td>
<td>Opfer et al., 2012</td>
</tr>
<tr>
<td>Economic Use (“Source”)</td>
<td>The economic activities associated with waste (debris) generation. This is the perceived source use for debris</td>
<td>Recreational: Relating to common human uses and activities; commonly associated with consumer goods and are items used in daily lifestyles. Does not distinguish between Belizeans and tourists</td>
<td>Claereboudt, 2004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unknown: Related to an unknown economic activity</td>
<td>Barnett et al., 2016</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Industrial: Byproducts or materials used in the industrial or manufacturing processes; items not commonly used in everyday life</td>
<td>Liu et al., 2015</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fishing: Related to fishing activities, both personal and commercial</td>
<td>Hengstmann et al., 2017</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sheavly &amp; Register, 2007</td>
</tr>
</tbody>
</table>

Each item’s size and physical condition were also recorded. Debris size classes ranged from small (<2.5 cm), medium (≥2.5 cm; ≤10 cm), large (>10 cm; ≤1 m), and extra-large (>1
m) (Ribic et al., 1992). Each item's condition (“degree of fragmentation”) depended on its physical state, classified as either “whole”, “partial”, or “fragmented”. “Whole” items were visibly intact and easily recognizable items, while “partial” items were those that seemed to be missing a substantial portion of itself. However, “fragmented” items were small debris pieces that were often indiscernible and related to unknown objects. While micro-plastics (debris <5 mm in diameter) (Vince & Stoett, 2018) were present at these locations, they are outside the scope of this study and therefore excluded from surveys.

**Statistical Analysis**

Statistical analyses were performed using Microsoft Excel. A one-way analysis of variance (ANOVA) (as in Santos et al., 2009 and Velander & Mocogni, 1999) was used to compare the effect of transect orientation (horizontal or perpendicular) on total counts of debris found in each size class and debris degree of fragmentation (condition) (see Table 3 below). The categories of debris sizes and degrees of fragmentation were tested separately across the transect orientations. By using the total number of items for each category across horizontal and perpendicular transects, the potential variation and differences of debris sizes and conditions were compared. Across study sites, the total number of debris for each size class were combined for this analysis, which were then used as the dependent variable in the ANOVA analysis. The analysis was run using transect orientation as the grouping or independent factor. Extra-large items were excluded from this analysis due to 97% (36 out of 37 items) of these items having been found in horizontal transects. A Chi-Square analysis was also performed to investigate the statistical differences in debris quantities across various beach orientations (e.g. northern,
eastern, southern, and western facing beaches). For this analysis, the number of items per square meter for each sample site was calculated and subsequently averaged across all sites that pertained to each cardinal direction (e.g. the average number of items per square meter for all northern facing beaches). This average was used in order to address the various sample sizes (number of transects or “n”) surveyed at each island and to create a baseline average number of debris per unit area. A 95% confidence interval was used for both tests.

Table 3. Counts of debris used in the ANOVA analysis. These are total counts of debris for each size class and degree of fragmentation (condition) category.

<table>
<thead>
<tr>
<th></th>
<th>Horizontal</th>
<th>Perpendicular</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td>207</td>
<td>176</td>
</tr>
<tr>
<td>Medium</td>
<td>527</td>
<td>410</td>
</tr>
<tr>
<td>Large</td>
<td>964</td>
<td>848</td>
</tr>
<tr>
<td><strong>Condition</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole</td>
<td>1067</td>
<td>923</td>
</tr>
<tr>
<td>Partial</td>
<td>339</td>
<td>266</td>
</tr>
<tr>
<td>Fragmented</td>
<td>323</td>
<td>268</td>
</tr>
</tbody>
</table>

**Qualitative Methodology**

This study also included ethnographic conversations to understand the social perceptions of pollution. Conversations were held with stakeholders (Table 3) to understand personal perceptions of litter origination (e.g. via locals, from Honduras, fishing vessels), whether they think the debris is an issue, how they dispose of their own waste (e.g. via burning, export, recycle), perspectives on current waste disposal management and laws, and other relevant questions. Informants were chosen based upon proximity to the sample sites used during this study. Given this small sample size, the method of choosing participants, and the affinity of
participants to the tourism industry, selection bias must be considered when interpreting results and limitations. The mainland residents (Table 4) included in this study differ from the other participants in that they solely live on the mainland (e.g. in Punta Gorda), rather than living both on the islands and the mainland throughout the year; these two residents included a grocery store clerk and a bus driver. Two of the tour guides included here also lived solely on the mainland, but share stronger priorities toward the tourism industry, and are therefore classified as such.

Table 4 Summary of stakeholders, number of conversations, and location of interaction. *Note that these boat captains were also avid fishermen.

<table>
<thead>
<tr>
<th>Stakeholder Category</th>
<th>Number of Conversations</th>
<th>Location of Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boat Captain/Fishermen*</td>
<td>4</td>
<td>Lime Caye, South Water Caye</td>
</tr>
<tr>
<td>Business Owner</td>
<td>3</td>
<td>Lime Caye, South Water Caye</td>
</tr>
<tr>
<td>Resort Employee</td>
<td>2</td>
<td>South Water Caye</td>
</tr>
<tr>
<td>Mainland Residents</td>
<td>2</td>
<td>Punta Gorda, Dangriga</td>
</tr>
<tr>
<td>Tour Guide</td>
<td>3</td>
<td>Punta Gorda, South Water Caye</td>
</tr>
<tr>
<td>Traveler</td>
<td>1</td>
<td>Lime Caye</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>15</strong></td>
<td></td>
</tr>
</tbody>
</table>

Modeled from interviews performed by Liu et al. (2015), example conversation topics (see Appendix) include:

1. Do you think there is a litter problem on the beaches of Belize?

2. Can the debris be better managed under current waste laws? If not, how can these be improved?

3. Do you have suggestions for improving the current policy or creating new laws?
4. Do you believe your personal habits contribute to the litter issue? If so, how can you change your disposal habits?

Liu et al. (2015) investigated similar issues regarding marine debris in Taiwan, including social perceptions behind debris origination, opinions regarding trans-boundary pollution, and examined stakeholder perspectives of current environmental policy and debris management strategies. This study holds similar objectives to Liu et al. (2015) regarding social perceptions behind marine debris, which is a valuable model for conversations held.

These conversations were semi-structured, allowing for informants to address provided topics with supporting narratives of their personal experiences interacting with marine debris (if relevant to them). Investigating social perceptions behind debris coupled with knowledge behind waste disposal infrastructure allows for a more comprehensive understanding of the persistence of marine debris in the environment.
RESULTS

Quantitative Results

Field data were collected on 7 islands off the southeastern coast of Belize (see Table 1). A total of 15 beaches were surveyed using 24 transects, comprising 18 horizontal and 6 perpendicular transects (Table 4). The use of perpendicular transects was contingent on the geomorphology of each beach, with only the larger beaches permitting their use. Of the 7 islands surveyed, only 3 were suitable for perpendicular surveys (Lime Caye, Franks Caye, and South Water Caye), while the rest used exclusively horizontal transects. Given the large variation of area sampled on each island, some islands may be not have sufficient data (e.g. Franks Caye) to accurately portray the baseline amount of debris present.

| Number of transects and sample sites per caye. Of the 7 cayes surveyed, 18 horizontal and 6 perpendicular transects were used. |
|---|---|---|---|---|---|---|---|
| Lime Hunting Franks Nicholas South Water Tobacco Twin |
| Number of sites | 3 | 1 | 2 | 2 | 6 | 3 | 2 |
| Number of transects | 3 H, 2 P | 0 H, 1 P | 2 H, 0 P | 2 H, 0 P | 6 H, 3 P | 3 H, 0 P | 2 H, 0 P |
| Area surveyed (m²) | 286 | 100 | 53 | 200 | 600.25 | 350 | 150 |

Figures 3 and 4 below serve as examples of sample site’s geomorphology that did not permit perpendicular transects. In these photo, a distinct “edge” of the beach is visible with the presence of seaweed (Figure 3) and vegetation (Figure 4); in this case, the area covered by the
horizontal transect and it’s 5 meter width would be sufficient in assessing debris for the available beach.

Figure 3 Example of a site on Tobacco Caye that did not permit the use of a perpendicular transect. The stark "edge" to the beach area allows for the horizontal transects area to survey the available beach.

Figure 4 Example of sample site on South Water Caye that relied on horizontal transects, as the width of the transect covered the available beach area (sandy area before vegetation).
Collectively, 1,754 debris items were accounted for. Plastic was the most common material found (1,195 items, 68.13%), followed by Styrofoam (166 items, 9.46%), and foam/rubber (141 items, 8.04%) (Figure 5). Other frequently found material includes glass, metal, and aluminum (67, 45, and 34 items respectively). Among the items found, bottles were highly abundant, including 571 plastic, and 53 glass bottles. The majority of these were beverage containers with labels for soda, alcohol, and water brands.

Figure 5 The distribution of debris cataloged along offshore islands of Belize. Plastic was the most abundant material found (n=1,195, 68.1%), followed by Styrofoam (n=166, 9.5%), then foam and rubber (n=141, 8.0%). N= 1,754.
While each transect varied in material type and size distribution, 55.1% of debris present was classified as large items (967 items; >10 cm; ≤1 m), 30.5% was medium (535 items; ≥2.5 cm; ≤10 cm), 12.3% was small (215 items; <2.5 cm), and the remaining 2.1% was extra-large (37 items; ≥1 m) (Figure 6). The highest incidence of large items was found on Hunting Caye, which also had the highest amount of plastic bottles (307 items). While small debris exists at nearly all locations, small items were found most frequently on Tobacco and South Water Cayes. Of note, South Water Caye had the highest incidence of fragmented items (103 items) and Tobacco Caye had the second highest (48 items).

Table 4 provides the number of transects and sites per caye, showing high variability in the geography and accessibility of each. The number of transects per site ranges from 1 transect (Hunting Caye) to 9 transects (South Water Caye). Of the 7 cayes surveyed, 18 horizontal and 6
perpendicular transects were performed. South Water Caye had the largest number of beaches surveyed (6) with 9 total transects, and therefore had the most debris cataloged.

Horizontal and perpendicular transects were used to assess the degree of fragmentation of debris along the beaches studied. When applicable, the perpendicular transects were placed at the tide mark and ended when the vegetation created an “edge” to the beach area (e.g. the tree line or bushes). Table 5 shows the distribution of debris fragmentation for each caye. The horizontal transects contained 66.6% of the total debris (1,168 items) and perpendicular transects contained the remaining 33.4% of debris (586 items). Both orientations contained large items primarily. Hunting Caye had the highest incidence of large litter per transect, contributing substantially to the total amount of debris found in all perpendicular transects. Horizontal and perpendicular transects were found to have a statistically similar distribution in debris size [F=1.48, p=0.22, \(\alpha=0.05\)] and degree of fragmentation [F=0.33, p=0.57, \(\alpha=0.05\)]. The similar distribution of debris sizes among horizontal and perpendicular transects contradicts previous literature (Barnes et al., 2009) where smaller fragmented debris items were most commonly found away from the beach’s wrack line. Here, fragmented items were found throughout both horizontal and perpendicular transects (Table 5). However, when Hunting Caye was removed from the ANOVA analysis, both the sizes [F=2859.5, p=0, \(\alpha=0.05\)] and conditions [F=546.7, p=3.206E-110, \(\alpha=0.05\)] of debris were statistically different across horizontal and perpendicular transects.
Cataloged debris are summarized in Table 6, which describes the average number of items found per square meter, permitting the consolidation of debris quantities across locations (especially those with multiple transects). Notably, Hunting Caye had the highest average items/m², likely a result of having one transect and being heavily compromised by litter. Conversely, South Water Caye had the largest area surveyed (600.25 m² across 6 sites and 9 transects) and 0.79 items/m² (SD=22.39), the third lowest average. In addition, the three highest average items per square meter (4.09, 3.11, and 1.14) are also the only islands without confirmed caretakers (Hunting, Franks and Twin Cayes respectively).
Table 7 Summary of average number of debris per square meter for each location.

<table>
<thead>
<tr>
<th>Location</th>
<th>Total area (m²) surveyed</th>
<th>Total items</th>
<th>Average items/m² (±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime Caye</td>
<td>286</td>
<td>234</td>
<td>0.82 ± 2.15</td>
</tr>
<tr>
<td>Hunting Caye</td>
<td>100</td>
<td>409</td>
<td>4.09 ± 0</td>
</tr>
<tr>
<td>Franks Caye</td>
<td>53</td>
<td>165</td>
<td>3.11 ± 1.15</td>
</tr>
<tr>
<td>Nicholas Caye</td>
<td>200</td>
<td>90</td>
<td>0.45 ± 0.21</td>
</tr>
<tr>
<td>South Water Caye</td>
<td>600.25</td>
<td>467</td>
<td>0.79 ± 22.39</td>
</tr>
<tr>
<td>Tobacco Caye</td>
<td>350</td>
<td>218</td>
<td>0.62 ± 0.53</td>
</tr>
<tr>
<td>Twin Caye</td>
<td>150</td>
<td>171</td>
<td>1.14 ± 0.42</td>
</tr>
</tbody>
</table>

Of the 1,754 debris items found, 81.1% were identified with plausible sources (recreational activities, industrial, or fishing related) (Figure 7). The remaining 18.9% came from unknown sources, meaning that the item itself was either unrecognizable and unknown, or its source was ambiguous. Debris relating to recreational activities (e.g. home goods and personal items used in daily life) comprised 74.8% of the standing stock; commonly found recreational items include beverage bottles, shoes, clothing, bottle caps and lids, and food takeaway containers. 4.2% of the debris was linked to industrial activities, litter including large pipes, metal, and wooden construction materials. Fishing related debris was 2.1% of the standing stock, the items most often found being large nets and fishing line.
Finally, Table 7 below displays the amount of debris associated with beach orientation. During sampling, the survey team attempted to use beaches facing all cardinal directions but did not find a suitable southwest oriented beach. Northwestern facing beaches (n=4) had the largest amount of debris present (593 items), while eastern facing beaches (n=4) followed closely behind (349 items). The number of transects sampled differs as each location was different in orientation and permissible area. Therefore, the average number of items per transect was calculated to directly compare each beach orientation (Table 7). With this comparison, northwestern facing beaches still had the highest amount of debris present (148.25 items/transect; SD=89.9 items), followed closely by southern facing beaches (142 items/transect; SD=0 items). Comparing the average number of items per transect among these seven beach orientations, three (north, northwest, and south) were found significant using the Chi-Square distribution (see Table 7) ($dF=6$, $p<.05$), indicating that these beaches have significantly higher amounts of debris present.
compared to northeastern, eastern, western, and southeastern facing beaches. These statistically significant beaches had the highest (148.25 items per transect; SD=89.9) and lowest amounts (32 items per transect) of debris recorded compared to those found not statistically significant, which had the median range of debris per transect. However, given the large variance in these data, these results are widely spread out across the mean and should be interpreted with a low confidence interval.

Table 8 Distribution of debris across beach orientations. The average items per transects (±SD) was used to calculate the Chi-Square value shown here (p<0.05).

<table>
<thead>
<tr>
<th>Beach Orientation</th>
<th>Islands Included</th>
<th>Number of Items</th>
<th>Average Items per Transect</th>
<th>$X^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>North (n=1)</td>
<td>Lime Caye</td>
<td>32</td>
<td>32 ± 0</td>
<td>37.76</td>
</tr>
<tr>
<td>Northeast (n=2)</td>
<td>Franks and Nicholas Cayes</td>
<td>183</td>
<td>91.5 ± 31.5</td>
<td>0.01</td>
</tr>
<tr>
<td>Northwest (n=4)</td>
<td>Hunting, South Water, and Tobacco Cayes</td>
<td>593</td>
<td>148.25 ±89.9</td>
<td>36.95</td>
</tr>
<tr>
<td>East (n=4)</td>
<td>Lime, South Water, Tobacco, and Twin Cayes</td>
<td>349</td>
<td>87.25 ± 34.6</td>
<td>0.11</td>
</tr>
<tr>
<td>South (n=1)</td>
<td>Lime Caye</td>
<td>142</td>
<td>142 ± 0</td>
<td>29.39</td>
</tr>
<tr>
<td>Southeast (n=4)</td>
<td>Franks, Nicholas, South Water, and Tobacco Cayes</td>
<td>235</td>
<td>58.75 ± 14.8</td>
<td>11.10</td>
</tr>
<tr>
<td>West (n=3)</td>
<td>South Water and Twin Cayes</td>
<td>220</td>
<td>73.3 ± 17.8</td>
<td>3.24</td>
</tr>
</tbody>
</table>
Stakeholder Perceptions

Conversations were held with 15 stakeholders (Table 3) across the study region in addition to the analysis of debris present. These conversations were semi-structured and open-ended, modeled after methods by Liu et al. (2015). The topics used can be found in the appendix of this manuscript. Conversations were held in the course of this study with people of a variety of interests, including boat captains, fishermen, business owners, tour guides, travelers, and mainland residents (Table 3). Each person had a personal tie to marine debris, from it being visible in their area to their business relying on maintaining environmental integrity (i.e. tourist attractions). Many of the informants have lived on islands affected by washed-up debris for many years, allowing for a perspective of the change in debris over time. These conversations reflect the prevalence of debris as it pertains to Belizean cayes and the mainland, as most of the respondents (n=11; 73%) spend time in both areas.

The topics discussed in each conversation were intended to dissect personal views regarding marine debris and reflect on the management and mitigation of debris. Most respondents (60%) acknowledged that marine debris is a problem on Belizean beaches and that the issue needs to be addressed. On both the islands and the mainland, 47% of informants claimed to use the local “dump” site for primary waste disposal. While southern Belize does have one regulated waste disposal site (Mile 24 Regional Sanitary Landfill), towns and villages often have smaller disposal sites closer to the inhabitant’s residences. Several respondents (n=4; 27%) noted that while debris would be shipped from the cayes, the waste would then be transferred to the local mainland dump. This was a common practice because locals wanted to mitigate the amount of litter on their beaches, especially business owners that rely on tourist


attractions for their livelihoods. However, this movement of waste simply transfers the environmental impact from offshore to onshore.

In villages, the waste disposal habits varied. Differences between Mayan and Garifuna villages were discussed when investigating their waste disposal habits. Two respondents claimed that their Mayan villages were remarkably clean, compared to others, as the villagers take great pride in keeping their surroundings maintained. However, informants noted that this has not always been the case. These informants noted a large improvement in the frequency of litter and the amount of improper waste disposal in the past ten to fifteen years. Through non-governmental educational campaigns and an increase in civic pride, these habits have improved, leaving villagers with the thought of “my village, my garbage”. This pride has moved residents to maintain their personal domiciles while also controlling personal litter in village commons. In comparison, a respondent claimed that the ability to buy single-use plastic and convenience items are seen as wealthy, and this “wealth litter” is starting to pile up in villages, especially noting Garifuna villages. In these villages, the burning of waste is commonplace while other villages have banned the burning of non-biodegradables. 60% of respondents claimed that waste burning still exists in some areas today, but not nearly as frequently (e.g. in villages). While Belizeans seem to acknowledge the harm of burning processed goods such as plastic, 55% (n=6) of the respondents living on the islands (which were 11 out of 15 informants) claimed to burn biodegradables (e.g. palm leaves, sargassum, cardboard, and paper; to limit how much waste is transferred back to the mainland). While open-air burning is less common than it used to be due to increased accessibility of collected garbage disposal, it was claimed that burning remains the only viable option for some locations (e.g. smaller villages and reportedly on Hunting Caye).
During this study, however, some burn piles were found on the cayes to have non-biodegradable items (South Water Caye).

In Punta Gorda and Dangriga, respondents discussed issues with waste collection, which is often a provided service via the town council. 40% of informants expressed issues with the dependability of waste collection vehicles, as the services would sometimes lag for weeks at a time, allowing waste to accumulate in the streets and leaving waste collection bins overflowing. One respondent noted that they were instructed by town leaders to remove a custom-built waste collection container from their personal yard, with the complaint that the bin “creates more trash”, infringing upon personal efforts to contain waste. 27% of participants also noted the lack of waste disposal bins in public areas (e.g. around the town park or shopping centers), which could incentivize people to litter as it is the most convenient disposal option. Informants (n=2; 13%) also noted that while the town council employs people to clean major roads and drains, the “real issue lies outside the center” in smaller villages and towns.

When prompted for potential causes behind the debris, informants had mixed responses. While 60% of respondents acknowledged that there is a debris issue across Belize, they also often (60%) suggested that a substantial portion of debris is carried into Belize from neighboring countries, including Honduras and Guatemala. This was mentioned more frequently near the Sapodilla Cayes (Lime, Hunting, Franks and Nicholas Cayes) where a major shipping lane and oceanic current runs between these countries along the eastern edges of the cayes. An informant from Hopkins, a coastal Belize town, supported this notion regarding washed up debris; stressing that their personal beachfront property was constantly inundated with debris originating from the ocean. They claimed to often find “thousands of bottle caps washed up at once,” emphasizing the degree of difficulty of continuously cleaning up the beach. Rivers were also noted as a source of
debris, as the influx of solid-waste polluted water affects downstream regions. While rivers have been used as waste disposal sites in the past, informants (n=2; 13%) noted that that practice is much less common in recent times. In addition, 13% of informants referenced cruise ships as a major source of debris, as the ships illegally dump large amounts of debris into the ocean. In recent years, Belize has become a popular cruise ship destination, contributing to 15.4% of the country’s gross domestic product in 2014 (Diedrich, 2010), increasing the amount of ocean-based debris that washes up on Belizean beaches (Belize Development Trust, 2000; Center on Ecotourism and Sustainable Development, 2006; Grau et al., 2014). In addition to these potential ocean-based sources of debris, several informants (n=3; 20%) also claimed that the growth of “Chinese-owned grocery and convenience stores” are a large cause behind the issue.

Respondents claimed that before the introduction of these foreign-owned businesses, markets and stores often required one to provide their own containers for items; with the presence of these shops, Belizeans have more access to single-use plastics and other commonly littered convenience items (e.g. food wrappers and beverage bottles) than ever before. The introduction of these stores and single-use plastics also correlates to the “wealth litter” previously discussed.

Respondents (47%) often discussed the historical lack of environmental education of Belizeans; multiple (n=4; 27%) respondents claimed that from a young age, Belizeans were taught that littering was normal and acceptable, contrary to current policy movements. One respondent claimed that this issue is “not Belizeans’ fault” because it is how people were raised. Throughout these conversations, several environmentally conscious organizations were mentioned, including Oceana, Belize Tourism Industry Association, the Wildlife Conservation Society and the Toledo Institute for Development and Environment (TIDE), whose goals are said to inform the general public about environmental issues; respondents often (n=6; 40%) stated the
need for increased civic pride, permitting more widespread action against environmental pollution.

Participants proposed a variety of potential solutions to the environmental pollution issues at hand. All informants agreed that the current level of environmental management policies and campaigns were insufficient and in need of improvement (Appendix, Questions 8 and 9). Respondents (47%) repeatedly discussed the need for improved environmental education around the country, emphasizing a focus on impressionable schoolchildren. Respondents (n=4; 27%) noted that in their experience, children have been taught improper waste disposal habits, such as littering on sidewalks and out of bus windows. In efforts to combat these learned behaviors, one respondent described a recent program that informs schoolchildren of proper solid waste disposal habits, emphasizing anti-littering, in hopes that the children would return home and share this information with their parents. Other debris mitigation suggestions include greater accessibility to recycling (recycling is reportedly absent from most areas), consistent enforcement of littering fines, and greater personal conviction against improper waste disposal.

Respondents also noted the need for improved environmental regulations, especially since the economy is focused on the growth of sustainable ecotourism (Tourism and Leisure Europraxis Consulting and BTB, 2011). While participants noted that pro-environmental behaviors have improved recently (within the past five to ten years), such as limiting the amount of waste dumped into rivers and open-air burning of waste, they also noted that proximity to the coast was seen as a driving factor for environmental consciousness. Those who are closer to the coast are more likely to personally witness or be impacted by solid waste pollution (e.g. tourism), and therefore are more likely to engage in pro-environmental behaviors. Several participants (n=7; 47%) suggested an increase of focus on community-level environmental awareness
campaigns; respondents noted that local beach cleanups have been implemented with community members, allowing residents to engage in pro-environmental campaigns while positively impacting the environment and community. It was noted that while these small-scale beach cleanups are improving the state of the ocean, they do not offer long-term solutions to the persistence of marine debris. Several respondents (n=4; 27%) asserted that even though beaches are cleaned, the debris returns regularly, suggesting a more fundamental “cleanup” or improved policies and regulations are necessary. Collaborations among businesses and the community were also suggested to promote environmental consciousness while appealing to certain demographics. A respondent referenced the Professional Association of Diving Instructor’s (PADI) annual clean-up event, which collaborates with community members interested in maintaining oceanic integrity to clean local beaches. Collaborations oriented toward the tourism industry would largely benefit from these environmental awareness campaigns.

The “plastic-free Belize” movement was relatively new at the time of data collection (enacted April 22nd, 2019; DOE, 2019) and signs promoting the initiative were somewhat evident throughout the region. When asked about the impact and scope of phasing out single-use plastics, respondents (n=4; 27%) claimed that while the movement is an important step forward, it is not yet widely enforced. A local grocery store clerk seemed proud of their plastic bag refusal sign, claiming that few other shops in town are following the new regulations. Stores such as this offer biodegradable options and plastic bags for a fee. The clerk noted that the movement “takes a while to implement,” suggesting that other stores will follow suit given enough time. These respondents suggested that the plastic-free movement needs more publicity to increase awareness in communities for a larger effect. With raised awareness, 47% of respondents (n=7) ensured that Belizeans would be swayed against single-use plastics and reduce the amount of marine debris.
reaching the environment. Noted throughout this research were similar steps toward sustainability, including the implementation of deposit-refund systems. The most common of these systems include the use of refillable five gallon containers of water throughout tourist areas and the return of empty glass coke bottles and plastic crates to the factory.

It is important to note that seaweed in the genus *Sargassum* was discussed in association with environmental pollution during this study. While the Caribbean *Sargassum* epidemic (e.g. Schell et al., 2015; van Tussenbroek et al., 2017) is outside the scope of this study, it is a widespread problem around Belize (BTB, 2020; The San Pedro Sun, 2019). Some informants (20%) associated *Sargassum* with marine debris, suggesting that the two issues have similar but fundamentally different environmental connotations. Both issues are visually displeasing, potentially harmful to wildlife, and seen as a nuisance. The presence of *Sargassum* on beaches warrants unpleasant odors upon decay (Doyle & Franks, 2015), can enhance the transport of invasive species (Franks et al., 2016), and can prove harmful to ecosystems (van Tussenbroek et al., 2017). The causes and impacts of *Sargassum* on the environment should be further investigated to understand its prevalence and effects in the Caribbean.
DISCUSSION

Interpreting the Standing Stock of Debris

Large (>10 cm; <1 m) plastic items were the most common across the region, with plastic beverage bottles being one of the most heavily observed objects. The majority of these items were linked to recreational sources, having likely originated from people’s day-to-day activities (e.g. from personal hygiene routines, used children’s toys, discarded beverage bottles). These results suggest that there likely exists a heavy anthropogenic influence on marine pollution, as most of the debris cataloged can be associated with consumer goods.

Cataloging debris materials, sizes, and frequently found objects allows for insights into potential causes and sources of marine pollution in the region, as these debris items can then be linked to anthropogenic pressures (or sources of debris generation) such as urban populations, industry and manufacturing materials, fishing activities, and tourism. Evidently, single-use plastics dominate the environment in this study and needs to be addressed.

Hunting Caye stands out in this study as a display of a heavily polluted area from recreational and urban sources, having had the highest abundance of large plastic items (307 items) with only one transect sampled. This northwest-facing beach was heavily littered beyond the surface layer, causing the total amount of debris cataloged to be a conservative estimate. Hunting Caye is sparsely populated, having few permanent residents from the Belize Coast Guard station and research station for the University of Belize. This lack of permanent urban
influence suggests that the majority of debris cataloged likely floated onto the beach over time via prevailing winds and currents (Hengstmann et al., 2017; Lavers & Bond, 2017). While efforts to clean certain beaches on Hunting Caye were evident, there is no permanent caretaker or tourist resorts on this island. This lack of foot traffic could be attributed to the high amount of debris left in the environment for longer periods of time, as the motive for clean beaches to attract tourists revenue is lacking (Botero et al., 2017). In addition, the presence of such heavy inundation of debris on this beach reflects the degree to which ocean-based debris is increasing, constantly washing ashore, and accumulating on remote islands (Lavers & Bond, 2017).

Conversely, small items (<2.5 cm) were found most frequently on Tobacco and South Water Cayes, South Water Caye having the highest occurrence of fragmented items. The presence of small and fragmented items suggests that debris may have been worn and degraded in transit or disposal, before being discarded or washed ashore on these beaches. It was hypothesized that a majority of small and fragmented items would be found in perpendicular transects and away from the beach’s wrack line (near the horizontal transect), as found in Barnes et al. (2009). However, Tobacco Caye had only four items cataloged in the perpendicular transect while the remaining items were all cataloged in horizontal transects. While drivers of waste movement may include the influx of waste from rising tides, delivery or removal of waste via storms or high winds, or stagnancy of debris over time, they were not apparent at the time of sampling. However, both of these islands have observed caretakers, which likely accounts for the variance of debris composition at the time of sampling. This discrepancy in debris sizes among islands highlights the outcome of raked (cleaned) beaches; while raking beaches changes the composition of debris present (e.g. debris size and fragmentation), it does not necessarily change the overall quantity (Santos et al., 2009; Somerville et al., 2003). The process of raking beaches
removes larger items, but can leave behind smaller fragmented items; raking can also further break down debris, creating a higher quantity of small items left behind. This cleaning process often fails to remove these smaller items of debris (Somerville et al., 2003), therefore changing the composition of debris present rather than the overall quantity. This is supported further in that heavily trafficked islands still had ample fragmented debris (e.g. South Water Caye) despite being cleaned daily.

When all islands were including for analysis, the orientation of transects (horizontal or perpendicular) did not have statistical differences in debris size or degree of fragmentation, contrary to previous literature (Velander & Mocogni, 1999). However, both sizes and conditions of debris were shown statistically significant across transect orientations when Hunting Caye was excluded, suggesting the skewed influence of Hunting Caye on these analyses. The purpose of using both horizontal and perpendicular transects was to distinguish between fresh and accumulated litter at each site. However, widespread debris was consistent across the region despite significant differences in degradation across transect orientations. With the heavy presence of whole, large items on Hunting Caye, the statistical analyses failed to support the hypothesis of characteristic differences between horizontal and perpendicular transects. Various degrees of fragmentation were evident across both transect orientations, suggesting varied rates of weathering or debris breakdown across the region. Horizontal transects were more accessible throughout this study due to the presence of thick vegetation and limited beach areas across the region.

The average number of debris items per square meter was calculated to directly compare the standing stock of debris present across and between each island, as seen in Haarr et al. (2019). Hunting Caye had the highest average number of items per square meter, despite having
one transect. South Water Caye had the largest area surveyed but had the third lowest average number of items per square meter. These results further support the hypothesis that the amount of foot traffic an island receives is inversely related to the amount of debris present. Islands, and more specifically those with tourist resorts, have the economic incentive to maintain their beach’s visual aesthetics to attract tourist revenue (Somerville et al., 2003). Therefore, there will be more daily cleaning of beaches and maintained waste management at heavily trafficked locations as opposed to the islands without these tourist attractions (Botero et al., 2017). Recent literature has shown that the amount of litter on beaches is directly correlated with beach occupation (Santos et al., 2005; Tourinho & Fillmann, 2011), but the opposite has been found with this study (e.g. Hunting Caye and South Water Caye). Similarly, in discussions with respondents it was noted that individuals in close proximity to the coasts are more likely to be personally impacted by marine debris (e.g. tourist locations dependent on aesthetics) and are more inclined to sway toward environmentally conscious behavior. Informants who share time between the coast and inland support this notion through the description of waste disposal habits in villages lacking tourist attractions. Therefore, it would be beneficial to focus environmental awareness campaigns not only on coastal populations but on inland communities as well. This branching of knowledge could help maintain the delicate relationship villages and towns have with downstream coastal locations.

Of the 1,754 items cataloged, 81.1% were identified with plausible sources. These sources were broad categories relating to recreational activities, industrial and manufacturing byproducts or waste, and derelict fishing gear. A large portion of debris was readily identifiable (e.g. having intact product labels or having a recognizable object shape), allowing for a greater degree of identification than expected. Commonly found objects across all beaches include
beverage bottles, bottle caps and lids, shoes, clothing, and food takeaway containers - items commonly associated with everyday human activities. Previous literature lacks a unifying methodology for the source-based classification of debris (Rochman et al., 2016a), resulting in varying degrees of confidence in identification. However, while this study attempts to fill this gap through the categorization of debris in three source categories (recreational, industrial and manufacturing, or fishing), these source categories do not distinguish among different types of recreational influences (e.g. foreign versus local inhabitants; intentional littering versus accidental littering, etc.), providing a larger scope of recreational influences than other studies and therefore a larger percentage of debris categorized. This recognition of debris sources can provide insights for Belize policymakers, permitting more targeted mitigation efforts to stop solid waste pollution at its generation point. The abundance of recreational goods identified in this study reflect the consumer nature of society, highlighting the intricate relationship between human activities and the environment. Steps toward source-oriented solutions, such as plastic bag taxes, would have a chance in mitigating solid waste pollution on beaches.

The remaining 18.9% of debris cataloged were categorized as having an unknown source. Debris from unknown origins was either unrecognizable or extremely worn and fragmented. The persistence of debris in the environment often leads to conditions that make the identification of debris difficult (Slavin et al., 2012), leading to higher rates of categorization as unknown.

While the majority of the debris was able to be associated with an economic activity (also described as sources) (recreational, industrial, or fishing), the country or precise location of origin is much more difficult to pinpoint. Conversations highlighted the fact that residents of Belize often claim that a large portion of marine debris originates from neighboring countries (Honduras and Guatemala). While this may be true to an extent (due to physical factors,
including wind patterns, ocean currents, and the buoyant nature of debris), it is difficult to quantify the extent of marine debris that washes onto Belizean beaches from other countries.

Out of the seven beach orientations examined, northwestern and eastern facing beaches stood out as having the highest amount of debris present (593 and 349 items respectively). Northwestern and southern oriented beaches had the highest average number of items per transect (148.25 and 142 items/transect respectively). Using a Chi-Square analysis, northern, northwestern, and southern orientated beaches had significant amounts of debris relative to their counterparts (see Table 7). This higher presence of debris may be attributed to prevailing wind and oceanic current patterns. The northeast trade winds affect this region and a major warm oceanic current dominates the Caribbean, rising up off the coast of South America and traveling north toward Mexico. Figure 5 depicts the movement of currents in the Caribbean, where the thicker arrows represent stronger currents (>30 miles/24 hours), and the thinner arrows represent slower moving currents (Map obtained from Sverdrup et al., 1942). Based on Figure 5, these currents have the ability to influence Belizean beaches on the northern sides of islands (via smaller currents) and from the southern edges of islands (via the faster current). Based on these results and the persistence of these physical factors, there may be a positive influence from oceanic currents in marine debris accumulation patterns. However, due to the high variance in these data (see Table 7), further sampling of beach orientations with these significant quantities is necessary to support this argument. These data provide insights into accumulation patterns on cayes sampled, but may not prove consistent with other islands of Belize. The effects of prevailing winds and currents on the movement, accumulation, and composition of debris is further supported both in the literature (Hengstmann et al., 2017; Sheavly & Register, 2007;
Uneputty & Evans, 1997) and through informant claims of trans-boundary movement of debris (e.g. from neighboring countries).

![Map of Caribbean currents](image)

*Figure 8 Map depicting currents in the Caribbean. Thick arrows represent faster moving currents (the Caribbean Current), while thin arrows depict slower currents. The currents surrounding Belize largely flow from the east, moving north, while smaller currents flow south. The red star represents Belize (Map from Sverdrup et al., 1942).*

When discussing the potential origins of debris, many respondents claimed that cruise ships contribute substantially to the mismanagement of debris. Respondents from the Sapodilla Cayes (Lime, Hunting, Nicholas, and Franks Cayes) noted that a major shipping land exists along the eastern coasts of the islands, suggesting additional outside influence from discarded waste via ships. Hengstmann et al. (2017) also supports the notion that sea-side sources of debris may originate from cruise ships, causing higher rates of debris on the eastern sides of the islands. Here, eastern orientated beaches had the second highest abundance of debris recorded (349 items), reflecting that both land and ocean-based sources influence this region.

The illegal disposal of waste into the ocean from ships is noted throughout the literature (Hengstmann et al., 2017; Leous & Parry, 2005; Monteiro et al., 2018; Sheavly & Register, 2007), leaving adjacent beaches as casualties. While there is legislation in place to prevent this
illegal disposal, such as the International Convention for the Prevention of Pollution from Ships (MARPOL), implementation and enforcement of these regulations continue to be an international issue (Leous & Parry, 2005). While MARPOL Annex V restricts at-sea disposal of solid waste, emphasizing a ban on the discharge of plastics at-sea (Leous & Parry, 2005), individual countries are responsible for implementing alternatives to at-sea disposal (e.g. proper disposal mechanisms at ports) and enforcing the dumping ban. International legislation against marine pollution is a promising step, promoting collaboration and co-management among the environmental protection sector and government officials (Liu et al., 2015), but further initiative and compliance from participating countries to enhance positive change are needed.

**Marine Debris Legislation**

Marine debris legislation aimed at citizens have been found to have positive outcomes on mitigating the amount of debris that enters the environment. Market-based instruments and economic incentives have been found to influence people’s behavior toward using less plastic (Löhr et al., 2017). An example of these economic incentives includes plastic bag taxes, where plastic carrier bags are taxed and users are encouraged to use alternatives, such as reusable or biodegradable bags. While studies have found that this plastic bag tax succeeds in reducing the amount of plastic bags used by customers (Convery et al., 2007; Martinho et al., 2017), single-use plastic alternatives must be accessible and provided by establishments for successful dissuasion. Other economic incentives are already in action in Belize, including widespread deposit-refund systems. Visible throughout the regions were refillable 5 gallon water jugs and stacks of empty coke bottles waiting to be returned to the factory for a refund of the container’s
deposit. This system promotes sustainability by rewarding patrons for proper disposal of these common containers, as opposed to disposing of the containers in landfills, rivers, or other, less desirable, locations. The utilization of closed-systems such as these reduces the volume of materials entering the consumer waste stream (Convery et al., 2007), and therefore reduces the magnitude of mismanaged waste.

As of January 15th, 2020, Belize has passed legislation (Environmental Protection [Pollution from Plastics] Regulations) banning the importation, manufacturing, sale, and possession of single-use plastics and Styrofoam (e.g. plastic carrier bags, Styrofoam and plastic take-away containers, plastic drinking straws, plastic cutlery, etc.), aiming to reduce the number of plastics and Styrofoam that reach the terrestrial and marine environment (DOE, 2020). During this study, the beginning stages of this legislation were taking effect. Informants were aware of these impending regulations and were hopeful of potential improvements. While respondents promoted the departure from single-use plastics, they claimed that there was little enforcement implemented in shopping centers. Respondents urged for an increase in awareness that would promote the new legislation and environmental implications of plastic pollution. Respondents highlighted the necessity for an improvement in environmental awareness among Belizeans, especially young children. People must recognize the issue at hand in order for positive changes (both legislative and behavioral) to proceed. Therefore, widespread awareness campaigns regarding marine debris should be implemented simultaneously with the introduction of new legislation or market-based instruments in order to adequately inform the public (Martinho et al., 2017). While the creation of laws does not guarantee compliance (Sheavly & Register, 2007), progressive social changes stem from understanding the downstream effects of one’s behavior (here, personal littering), leading to eventual participation in environmental stewardship. While
this legislation does not solve all present environmental problems, the departure from single-use plastics serves as a valuable step in invoking public behavioral change (Martinho et al., 2017). Solutions such as the introduction of these laws combat the source of marine debris directly: humans. Source-oriented solutions to this wide-scale phenomena serve as more practical and effective methods in reducing the breadth and volume of marine debris, preventing the introduction of potential waste into the environment from the consumer standpoint (Rochman et al., 2016b). With enough collective action and participation, people have the power to reduce their impact on the environment while maintaining their livelihoods.

Similar actions toward sustainability should be taken to refine the waste management and collection systems across Belize. The majority of respondents discussed issues with personal waste being collected in an untimely fashion, as they remain dependent on unreliable municipal garbage collection trucks. Over time, with the addition of more garbage collection vehicles, standardized collection bins across towns, and the introduction of recycling centers (which are said to be absent), the amount of mismanaged solid waste has the potential to drastically diminish. Through the improved collection of waste from households and individuals, debris is prevented from reaching the environment by controlling its source (Rochman et al., 2016b).

The anecdotal feedback given by this study’s informants provide insights into personal experiences with waste management issues. While these opinions and perspectives of marine debris are from a small sample of Belizeans, they provide a valuable starting point into the investigation of waste management infrastructure and policies in the country. Further conversations should be held with stakeholders to create a representative viewpoint behind solid waste pollution, as other Belizeans with dissimilar interests may hold vastly different opinions of environmental pollution (if any).
LIMITATIONS

Although marine debris studies often report the total weight and density of debris recorded, this study chose against weighing debris for the sake of accessibility and ease of transportation. Therefore, the results of this study cannot be directly compared with other literature focused on the density of debris present. However, the average number of debris items per square meter can serve as a comparable variable for future studies.

This study attempted to fill the gap of source-based classification of debris, which lacks cohesive methodology. This study reports a broad range of source categories and does not discriminate among the different types of human influences (e.g. tourist or local), attributing to the high degree of sourcing reported. It is difficult to pinpoint human-based sources beyond the level of recreational, industrial, or fishing related, as sources of debris can be ambiguous.

A one-time sampling of these Belizean cayes provides a baseline of debris present, providing a foundation for future data collection. There are a limited number of studies focusing on marine debris in Belize, and even fewer reporting a source-based analysis. The methodology of this project is readily usable for Belizeans in a future investigation if needed, permitting citizen science participation for debris mitigation efforts (Bennett-Martin et al., 2016). Further sampling should be performed on cayes in this study that had limited areas sampled (e.g. Franks Caye) in order to accurately portray the amount of debris present. Future analyses should also investigate debris accumulation rates (e.g. is debris frequently removed naturally or remains in
place over time) and should extend to additional islands along the Belize reef system, in addition to the mainland. Mainland debris sampling would provide insight into the effectiveness of the waste management system due to the proximity of potential debris sources. Long-term monitoring and waste audits would also be necessary for assessing the effectiveness of the single-use plastic ban across the country.

Manual beach clean-ups are cost-effective and commonly rely on volunteer labor, and are therefore used prominently in the country to tackle the ongoing marine debris crisis. However, clean-up events on islands may be difficult to coordinate due to logistics (e.g. cost, time, fuel, and the eventual dumping of collected debris in landfills) (Lavers et al., 2019). Therefore, a focus on debris prevention mitigates the amount of waste reaching the environment (Löhr et al., 2017) and evades costly clean-up events.

Lastly, the conversations reported here highlight a small portion of Belizeans, most of whom hold interests in the tourism industry. Further conversations should be held with stakeholders in more economic sectors (including the exports and fishing industries, and in more rural communities) in order to create a more representative sample of Belizean interests and opinions on solid waste pollution.
CONCLUSION

In an effort to illuminate potential sources, causes, and effects of marine debris, this study quantified the standing stock of marine debris found along a sample of Belizean beaches and investigated social perceptions surrounding marine debris from various stakeholders. Through the use of field survey transects across various beaches, debris was cataloged by type and related to a possible source when possible. Stakeholder perceptions regarding marine debris were also investigated to understand how Belizeans perceive environmental pollution and mismanaged waste.

Large plastic items were the most abundant items found, commonly including plastic and glass beverage bottles, Styrofoam containers, clothing, and shoes. Items such as these are assumed to have originated from recreational sources, meaning that the majority of debris present was related to everyday human activities. Qualitative results revealed that stakeholders are aware of the marine debris phenomena and are interested in changes in environmental policies, regulations, and educational initiatives that can mitigate the amount of waste reaching the environment.

The results of this investigation supported the hypotheses that beaches with higher foot traffic would have less debris present overall, and that beaches with less foot traffic would have a
higher accumulation of worn and fragmented debris. This conclusion is supported in that the three islands with the highest average number of items per square meter (Hunting, Franks, and Twin Cayes) also have low degrees of foot traffic. The prediction that beaches with lower amounts of foot traffic will have the highest accumulation of worn and fragmented debris is not supported due to the observation that South Water Caye had the highest occurrence of fragmented debris. This conclusion can be further attributed to the daily cleaning of beaches on heavily trafficked locations, leading to changes in debris composition (e.g. higher presence of smaller items after raking) rather than overall quantities. Further investigation on remote or sparsely habited islands is necessary to solidify this argument. Individuals in close proximity to coastal environments have serious concerns regarding the persistence of marine debris in the environment. Discussions with stakeholders highlighted the discrepancy between individuals near the coasts and that further inland, as waste disposal habits varied greatly between locations. This could be attributed to the historical lack of environmental education throughout the country, which needs improvement in order to mitigate marine debris.

This study aimed to address the gap in the source-based analysis of marine debris, contributing unique analyses and quantitative methods to the scientific community. Few marine debris investigations have been performed in Belize, making this study important in contributing information regarding the standing stock of debris present on Belizean islands. Most of the literature focusing on marine debris in Belize maps debris present, largely focusing on the mainland. These results offer a glimpse into the magnitude of debris present offshore, providing novel information for policy makers and local government. The qualitative investigation here makes clear that inhabitants of Belize both recognize the issue, and are willing to change their behavior in order provoke positive change. The communication of these scientific results with
local policy makers can enhance mitigation issues, backing new regulations with evidence of the issue at hand (Rochman et al., 2016b).

Further sampling is necessary to gain a longitudinal understanding of marine debris on Belize beaches. In addition, surveys of debris accumulation rates would provide insight into the mobility (or lack thereof) of debris; this baseline study could serve as a comparison for future studies to investigate the effects of recent legislation against single-use plastics and Styrofoam.

While the results of this study are concerning in terms of the damage already done, the qualitative section reflects a distinct possibility of social mobilization to reduce future waste. Through persistent community participation, collaboration, and environmental stewardship, countries impacted by marine debris have the chance to regain valuable environmental integrity and flourish through sustainable growth.
REFERENCES


Center on Ecotourism and Sustainable Development (2006). Cruise tourism in Belize:


Lavers, J. L., & Bond, A. L. (2017). Exceptional and rapid accumulation of anthropogenic debris on one of the world’s most remote and pristine islands. Proceedings of the National Academy of Sciences, 114(23), 6052-6055.


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APPENDIX

Topics of stakeholder conversations:

1. Do you believe the beaches of Belize have a debris problem?
2. How do you normally dispose of waste? (e.g. via dumping, burning, or recycling?)
3. What do you think is the biggest generator or source of debris?
4. What do you think is the greatest threat of debris is if any?
5. In your opinion or experience, has the abundance of debris worsened over time? If so, is this due to tourism?
6. Do you believe your personal habits contribute to the debris issue? If so, how can you improve these?
7. Do you have issues with mainland accessibility for waste disposal?
8. Do you believe current environmental management policies are sufficient for litter control?
9. Do you have any suggestions for improved management strategies for solid waste disposal?