PLASTIC, MICROPLASTIC, AND MICROFIBER POLLUTION AND POLICY AFFECTING MARINE RESERVES OF SOUTHERN BELIZE

by

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ABSTRACT

Plastic and microplastic pollution pose environmental and public health threats to tropical communities and ecosystems. With growing global awareness of pollution and environmental safety, the past decade has seen many nations implement legislation prohibiting the possession, manufacturing, and distribution of single use plastics (SUPs) and other plastic products like microbeads. Coral reef systems and tropical marine systems are especially vulnerable to plastic ingestion and entanglement. Caribbean countries, with a large economic reliance on environmental health, have also followed this trend. However, with limited space and infrastructure, proper waste management practices are extremely challenging in this region. The country of Belize has recently passed legislation banning single use plastics and Styrofoam, and after a delay due to the COVID-19 global pandemic, has begun a phase out in 2021. In 2019, they published national plans for increased waste management and environmental literacy to prevent marine litter under the *Belize: Blue, Clean Resilient, and Strong* plan. Belize also has several marine reserves for conservation, preservation, recreation, fishing, and tourism. The economies of these reserves, coastal areas, and the greater nation of Belize rely heavily on ecotourism and fishing - industries which are obviously harmed by the presence of plastic debris. With a closer proximity to Honduras and Guatemala, the southern reaches of the Mesoamerican Barrier Reef System are vulnerable to outputs of trash not only from the populations of Belize but also the much larger populations of other countries. This thesis seeks to outline the state of plastic pollution and perceptions of legislation in two different marine reserves of Southern Belize.

DEDICATION

This thesis is dedicated to the memory of Norman Andrew Williams, whose passion and hard work has created immeasurable and positive change in the Toledo District. He welcomed us with open arms and opened our hearts to the mission of conservation in Belize.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to the University of Alabama for providing me with the opportunity to pursue my passion and for supporting me throughout my academic journey. I am grateful for the exceptional resources and facilities that the university provides, which have allowed me to develop as a researcher and educator.

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1 INTRODUCTION

Since the popularization of plastic products in the 1950s, plastic waste and pollution has become a crucial issue within the environmental community. Plastics, microplastics specifically, impart harm to marine environments, as they can easily be ingested and travel through trophic levels; which can compromise both environmental and public health. The Caribbean region is especially vulnerable to the harmful effects of plastic, as waste disposal practices, limited geography of many countries, and ocean currents create favorable conditions for pollution and transport. This has resulted in the region's coastal litter concentration being above the global average (Diez et al. 2019). A recent analysis of marine debris found that over 77% of washed up or deposited material in the southern reaches of the Mesoamerican Barrier Reef System (MBRS) is plastic (Blanke, Steinberg, and Donlevy 2021).

This thesis seeks to examine and compare the state of plastic pollution within two marine reserves of southern Belize. The objectives include the following:

- Defining and evaluating trends in microplastic and plastic distributions in the water column, reef sediment, and beaches between and within South Water Caye and Sapodillas Cayes Marine Reserves (Chapters 1 and 2)
- Defining and evaluating social issues such as policies, programs, and perceptions that exist in relation to plastic pollution in southern Belize and Belize in general (Chapter 3)

The introductory and background sections of the study include a review of the study area and hydrologic considerations including accumulation zones and major current patterns. Past research on microplastic distributions at the global and local scale are also reviewed.

Chapter 1 addresses microplastic concentrations in water and sediment samples taken in situ within each reserve. Microscope, mapping, and statistical methods are outlined within the chapter. Pollution transport, accumulation zones, and other factors contributing to plastic material concentrations are introduced prior to the chapter for consideration in the chapter's discussion.

Next, Chapter 2 analyzes a catalogue of plastic material collected at wrack line quadrats on beaches in each marine reserve. Methods for collection and cataloging of plastic materials are outlined in the chapter, as well as trends found in the amounts and types of plastic materials found. Plastic transport and sourcing are also discussed in chapter 2.

Chapter 3 reviews relevant policies, programs, and perceptions associated with plastic pollution, including but not limited to: clean water and waste management programs, and single use plastic and microbead bans. A survey of local individuals is also included in the chapter, with a focus on environmental impacts of plastic and the recently passed Belizean ban on single use plastics and Styrofoam. Data collection for this thesis took place in the Stann Creek and Toledo districts of Belize in May and June of 2022.

1.1 STUDY AREA

1.1.1 Belize

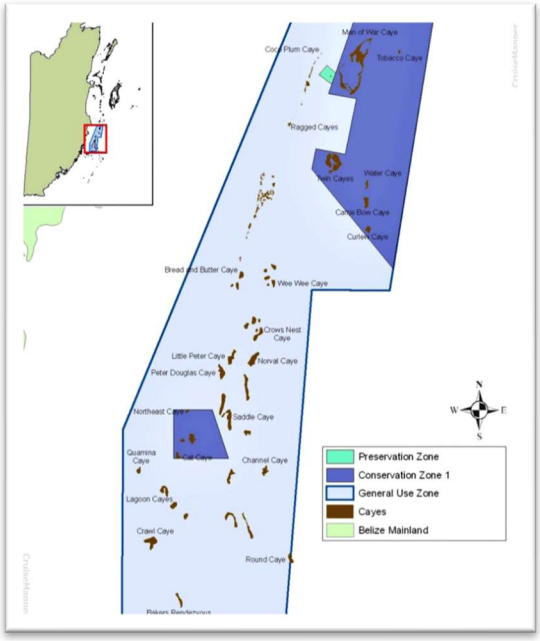
The Mesoamerican country of Belize is home to rich diversity in both its environment and human population. With a long anthropological and political history spanning from the occupation of Mayans to colonists, Belize's culture is incredibly diverse. The modern population is mostly made up of creole (mix of African and British) and mestizos (Mayan and Spanish).

With savannahs, rainforests, and deciduous tropical forests, the region's climate is classified as subtropical. The country experiences monsoon cycles of wet and dry seasons, with the wet season extending from June to November and dry conditions usually peaking in May. Inland, the country is known for its extensive forests and wildlife. Even more notable are the coastal regions and communities with access to the Mesoamerican Barrier Reef System (MBRS), which contains valuable resources for the commercial fishing, sport fishing, and tourism industries.

The economy of Belize is most reliant on the tourism industry, followed by the export of marine products. Undoubtedly, pollution has a vast impact on both markets. The close economic ties to the environment likely contribute to Belize's record of success with environmental objectives. The country has made notable strides with grassroots efforts in conservation and is now making waves throughout the Caribbean and Central America with their bold environmental policies and management practices.

Figure 1.1: Map of South Water Caye Marine Reserve

Source: CruiseMapper



1.1.2 South Water Caye Marine Reserve

The South Water Caye Marine Reserve (SWCMR) is about 47,700 hectares approximately 15 miles east of Dangriga (Figure 1). The reserve has nearly two dozen islands or "cayes", including Tobacco Caye, Carrie Bow Caye, and South Water Caye, and is the largest marine reserve in the Stann Creek District of Belize.

The reserve's economy is dominated by the tourism industry as a popular destination for fishing, cruising/sailing, and snorkeling. Multiple restaurants and resorts exist within the reserve. Carrie Bow Caye contains a Smithsonian research station, and Tobacco Caye also houses a nonprofit marine research center, the Tobacco Caye Marine Station (TCMS). Both stations conduct year-round research and educational outreach, including beach clean-ups. TCMS also pays bounties on eco-bricks turned into their station. Eco-bricks are blocks or bottles of compacted plastic waste that can be used for construction or insulation. With the aforementioned economic, research, and public interests considered, as well as the relatively close proximity to the mainland (and frequent travel by tourists and hosts between the islands and mainland), waste management in the SWCMR is generally more thorough and efficient than more remote locations within the reef system.

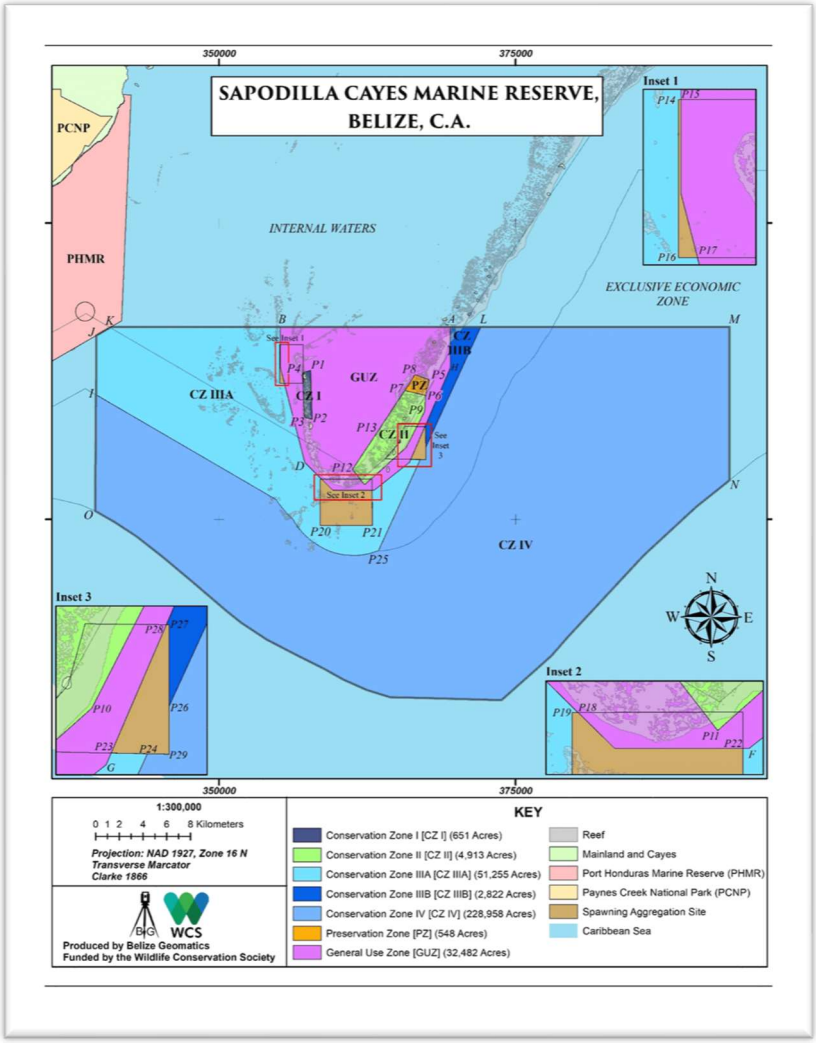
1.1.3 Sapodilla Cayes Marine Reserve

Located about 40 miles east of Punta Gorda, the Sapodilla Cayes Marine Reserve (SCMR) covers the southernmost portions of the Belize Barrier Reef. Due to its distance from the mainland and lack of development, the Belize Tourism Board claims that the reserve is one of the most remote locations in the Belize Barrier Reef System ("Sapodilla Cayes" n.d.). The reserve includes several sand and mangrove islands, including Frank's Caye, Nicholas Caye, Hunting Caye, and Lime Caye. On clear weather days, the mountains of Honduras and Guatemala can be seen from the islands.

The reserve is a hub of human and environmental activities, including turtle nesting, grouper spawning aggregations, immigration operations (foreign tourist check-ins and coast guard), sport and commercial fishing, and reef tourism. Fish species in this area include jack, parrotfish, snapper, and the rare Nassau grouper.

Recent expansion of the reserve area has increased the size by 700% (Figure 1.2). The decision was made not only to protect the marine environment of Belize but also to create sustainable systems and areas for commercial fishing and tourism ("WCS Congratulates Government of Belize On Newly Expanded Sapodilla Cayes Marine Reserve > Newsroom" n.d.). Less obvious, however, is the political undertone of the expansion. As the area's political control is contested by both Guatemala and Honduras, the declaration of the expansion supplements Belize's claim of the southern cayes (Tim Hudson n.d.).

Figure 1.2: Map of Sapodilla Cayes Marine Reserve: including different conservation zones within the reserve. Source: Belize Geomatics



Due to the combination of ecological richness and proximity to Honduras and Guatemala, the Sapodilla Cayes are threatened by illegal fishing. Hydrologically, this area is influenced by vertical coastal currents sweeping water southward from Belize, and eastward currents from Guatemala, making the reserve a convergent zone for major surface currents (Figure 1.3).

There exists little to no waste management infrastructure in these remote islands, with many individuals resorting to burning their trash instead of returning it to a disposal site on the mainland.

1.1.4 Waste management

Burning waste is common practice in much of Central America, especially in remote/rural areas lacking proper waste management infrastructure. Honduran census survey results indicate that 52% of homes burn or bury trash, while an estimated 71% of Guatemalan households burn trash (Mercedes Lu, Mark Chernaik, and Heidi Weiskel 2013; “Burning Plastic Can Affect Air Quality, Public Health (Environmental Factor, August 2022)” n.d.). Belize census reports that about 34% of households burn waste, and 50% prepare their waste for municipal collection (Mercedes Lu, Mark Chernaik, and Heidi Weiskel 2013). Other disposal information for Belize is included in Table 1. Burning trash presents many environmental and health risks, including but not limited to the release of toxic chemicals into water and air and the potential for smoke inhalation. Burning plastic waste breaks down the material into microplastics and secondary chemicals which can be easily transported throughout the local environment.

Table 1.1: Garbage disposal statistics according to the 2010 Belize Census (Source: ELAW Report)

Garbage disposal	Counts	%
Prepare it for municipal collection	26,434	50%
Public dump	4,415	8.5
Dump in own yard	2,335	4.5
Burn it	17,098	32.92
Bury it	887	1.71
Throw in river/creek/pond/sea	**247**	**0.48**
Other	427	0.82
Do not know/ not stated	102	0.2

Source: Statistical Institute of Belize. 2010 Population and Housing Census.

Other waste management practices include municipal collection or dumping. Many municipal collection sites are mismanaged or overwhelmed by the vast volume of waste, resulting in pollution coming directly from collection facilities and dumps.

1.2 HYDROLOGICAL INFLUENCES

While water quality in the northern half of the Mesoamerican barrier reef is controlled by thermohaline circulation and upwelling, the southern portions experience the strongest influence from land runoff (Carrillo et al. 2016). In the southern reaches of the reef, a dozen rivers discharge up to 1232 m^3s^{-1} (Carrillo et al. 2016). Not only does river discharge lower salinity and contribute to circulation in the Gulf of Honduras, but it also carries contaminants/pollution that can drift through the vast circulations of the Caribbean, and result in accumulation zones or "trash islands". These ephemeral amalgamations of debris occur offshore of Northern Honduras, with many disrupting tourist activities and garnering international headlines due to alarming photos being shared online (Fig. 1.3) (Leiva n.d.).

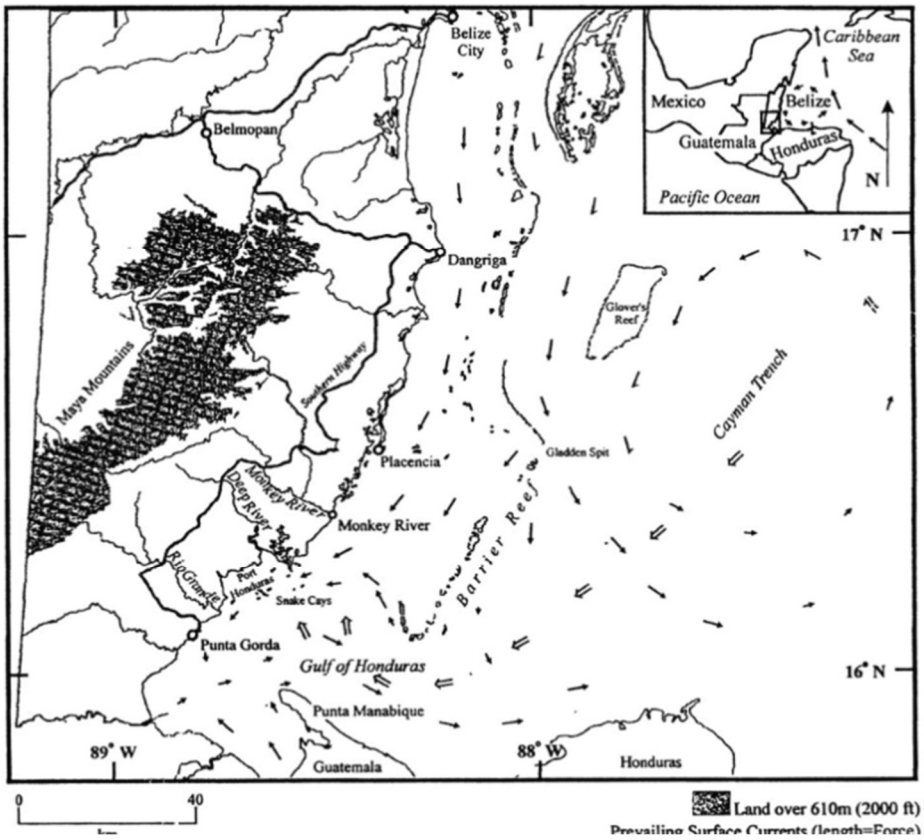
Figure 1.3: Honduran Trash Islands: Viral photos of trash islands found off the coast of Honduras in 2018. Honduras is said to blame Guatemala for the vast accumulation of debris as many of the products contained Guatemalan labels. Photos by Caroline Power

Hydrologic variability due to climate change can also affect the state of plastic pollution. With increased rainfall and wind shear modelled for the Caribbean region, there exists potential for higher intensity of monsoon seasons and more frequent development of tropical storms (Angeles et al. 2007). Extreme weather is a primary contributor to the ocean's plastic pollution, with high energy systems creating a "perfect storm" for waste transport (Nakajima et al. 2022).

1.2.1 Gulf of Honduras Oceanography

Currents in the Gulf of Honduras are primarily influenced by counterclockwise circulations in the Honduras Eddy, with currents running south down the coast of Belize toward Honduras and

Figure 1.4: Major currents in the Gulf of Honduras (Source: William Heyman, 1999)



Guatemala (Mercedes Lu, Mark Chernaik, and Heidi Weiskel 2013). Along the reef, major currents run parallel southward, until they collide with conflicting currents from the east and west in the southern reaches of the reef. The southern portions of the reef have weaker currents, and the hydrology is dominated by land run off from twelve major river systems (Carrillo et al. 2016). The northern region is controlled primarily by the Yucatan current, as well as upwelling and submarine groundwater processes, resulting in much colder and saltier conditions than the south (Carrillo et al. 2016).

1.2.2 River-Reef Connectivity

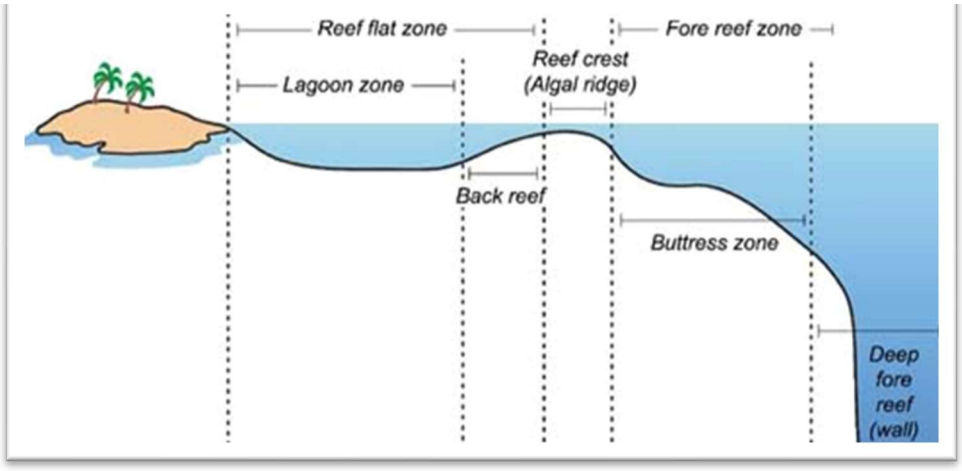
A study in 2008 evaluated connections between the MBRS and proximal river discharge from Mexico, Belize, and Honduras (Paris and Chérubin 2008). Previous studies suggested that most of the nutrients and sediment load in the gulf of Honduras originated within the borders of Honduras (Burke and Sugg 2006). The river-reef connectivity model worked with a ROMS 3D hydrodynamic model, which represents evolution through time and space of currents and oceanic variables. The ROMS model, coupled with advection modeling and coral reef "capture zones", simulated connectivity and the transport of buoyant matter between Meso-American rivers and reefs. The results of the model were plotted into a matrix to illustrate temporal and spatial trends in the transport of buoyant matter within and beyond each given country's waters. The matrix illustrates direct connectivity between Belizean rivers and reefs, with little to no buoyant matter escaping to other countries' claimed portions of the reef. Mexican rivers and reefs show a similar phenomenon. Conversely, Honduran rivers, likely due to circulating currents in the southeastern portions of the region, transport buoyant matter to not only the nation's own MBRS parcels, but also to Belizean and Mexican parcels. While Honduran rivers have a much higher index of impact on Honduran reefs, the impact on Belizean reefs is substantial.

A 2006 report utilized a reduced order model simulation to illustrate concentrations of buoyant matter along the MBRS (Burke and Sugg 2006). The results show a large area of high concentration along the coast near the border of Belize and Guatemala. This finding may be intuitive, with major rivers discharging into this location coupled with a closer proximity to population centers.

1.2.3 Reef zoning and hydrology

Barrier reefs are composed of several "zones" or reef parts, which are defined by the bathymetry and proximity to land associated with each part (Figure 1.4). Furthest from the mainland is the deep forereef, which is defined by a slope or "wall" at very high relief. Beside this is the main fore reef zone, which receives much of the wave impact and energy from the open sea. The fore reef also exhibits spur and groove formations, as well as buttressing (Cabioch 2011). Because of the variable bathymetry and amounts of energy that this zone receives, the fore reef contains the

Figure 1.5: Typical zones associated with barrier reef systems (Source: NOAA)



greatest diversity of corals (Amy Heemsoth 2014). The reef crest, or algal ridge, has the highest elevation of all of the reef zones, and is regularly exposed to the open air. The open exposure and high level of wave action makes the zone too harsh for many species and a perfect hiding place for others. Closer to the mainland from the reef crest is the back reef, which separates the reef and lagoonal area closest to the mainland. Both the back reef and lagoon zones are within the reef flat zone, which is protected from the waves and energy of the open ocean by the fore reef and reef crest. Back reef zones can contain patch reefs, which are more isolated portions of coral growth and biological activity.

Barrier reef hydrology is incredibly complex and variable. Local currents can change day to day, and even local guides and anglers have trouble predicting surface currents at a high resolution.

2 BACKGROUND: DEFINITIONS AND RELEVANT RESEARCH

2.1 TYPES OF PLASTIC

Plastic materials became popularized in the mid-1900s as an inexpensive and mass-producible consumer good. Today, plastics are ubiquitous. From food packaging to paints and clothing fibers, plastics have become a building block for much of modern human life. Definitions and descriptions of different types of plastics and their sources can be found below.

2.1.1 Macro

Macro plastics are what most people think of when hearing the term "plastic pollution". These items can be industrial or consumer waste and can also include products like medical waste. Many problematic plastics fall under the category "Single Use Plastics" (SUPs), meaning that the product is expected to last for only one use before being discarded. From a waste management standpoint, single use plastics can compose a significant load to waste production and disposal needs. With the rise of environmental movements, SUPs have been a common target for individuals to reduce their carbon footprint. Hygiene concerns and medical needs associated with the COVID-19 pandemic, however, did not help reduction measures. Since December of 2019, the start of the novel coronavirus pandemic, the production of SUPs have increased due to precautionary practices for hygiene (PPE) and medical supplies (Patrício Silva et al. 2021).

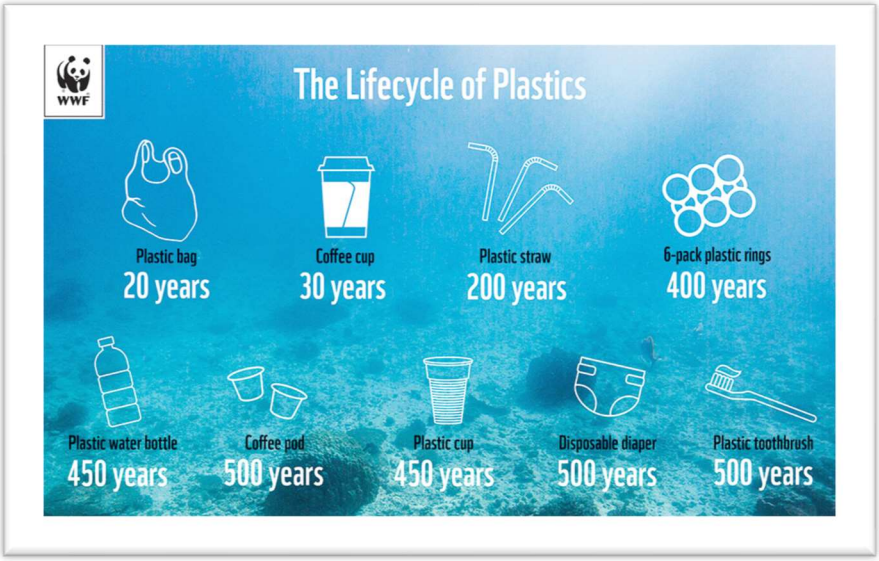
2.1.2 Micro

Objects coined as "microplastics" consist of two classifications: primary and secondary. Primaries are intentionally manufactured to be microplastics, i.e., microbeads or abrasives; while secondary microplastic occur through degradation of larger plastics, i.e., clothes and grocery bags. Microplastics are a growing concern because of their size and the fact that they are

commonly invisible to the naked eye. Microplastic waste has the potential to be an invisible invader or contaminant in much of the earth's water supply.

Many factors contribute to the degradation of plastics into microplastics, including but not limited to salinity, microbial interactions, radiation, and physical stress. This can result in the "lifetime" of a plastic being anywhere between 20 and 500 years before it is degraded down to its basic chemical components. An important aspect of plastic degradation is that even though a product may no longer be visible, the micro/nano components as well as chemical fragments can still be contaminating the system. The term "forever chemicals" has been coined for the toxic components (PFAS) included in some plastic products (E. Ryan, Kelly, and Jarenwattananon 2022).

Figure 2.1: General lifecycle of common plastic products (Source: World Wildlife Fund)("The Lifecycle of Plastics" n.d.)

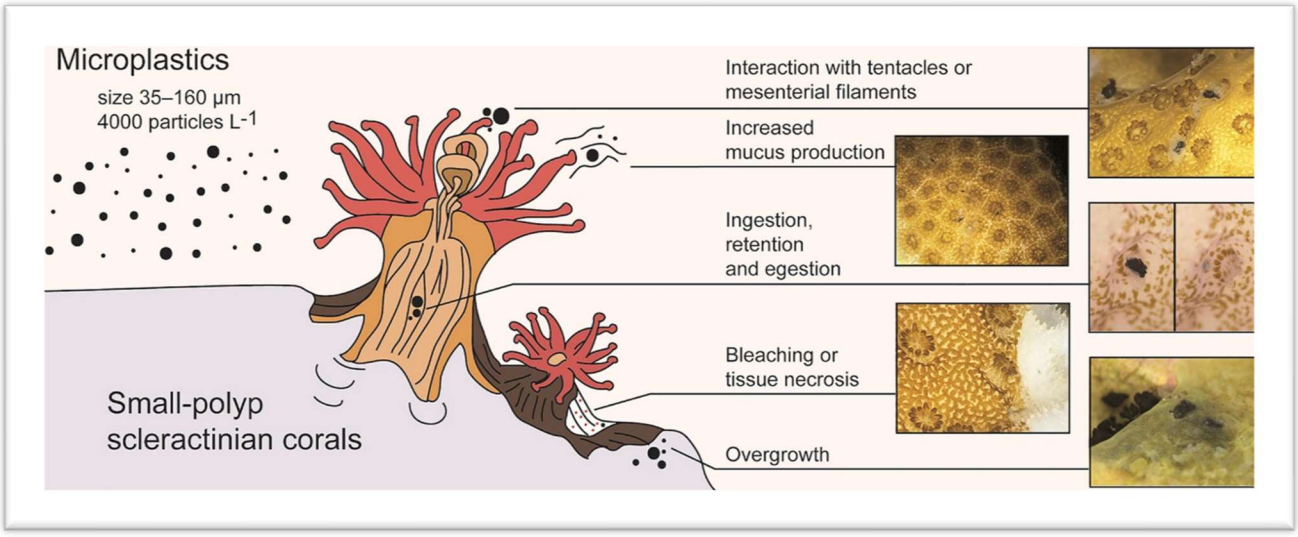


2.2 Effects of Plastic Pollution on Marine Environments

Sinks for plastic pollution include beaches, coastal waters/sediments, and the open ocean (P. G. Ryan et al. 2009). Many animals see shiny plastic debris as a potential food source; in particular, microplastics such as glitter can be easily ingested. Alarming images have surfaced on the internet depicting sea birds and fish that had mistakenly ingested plastic waste, died as a result, and became carcasses full of plastic.

With corals already stressed by climate change and ocean acidification, the effect of microplastics on reef builders potentially is profound and widespread. Like other species, corals actively ingest microplastics, mistaking it for food; but they also suffer from surface adhesion of the particles, a passive process that results in increased mucus production (Martin et al. 2019). Microplastics have also been observed to cause increased bleaching, necrosis, and unnecessary overgrowth in several coral species (Reichert et al. 2018).

Figure 2.2: illustrated effects of microplastic on coral health. (Source: Reichert et al.)



2.3 Effects of Plastic Pollution on Public Health

The microplastic contamination of many food products and basic natural resources like water and air has resulted in a daunting public health outlook. Recent studies have suggested that through the ingestion of microplastics, the average human could consume about a credit-card-size amount of plastic each week ("You Could Be Swallowing a Credit Card's Weight in Plastic Every Week | CNN" n.d.). Also, microplastics have made headlines through alarming findings of plastic in samples of human breastmilk and donated blood, meaning that the materials are working their way out of the digestive system and into other parts of the body ("Microplastics Found in Human Breast Milk for the First Time | Plastics | The Guardian" n.d.). The implications of plastic ingestion by humans have yet to be fully determined, but preliminary research suggests that plastics could lead to increased digestive problems and risk of cancer.

2.4 Global Marine Plastic and Microplastic Pollution

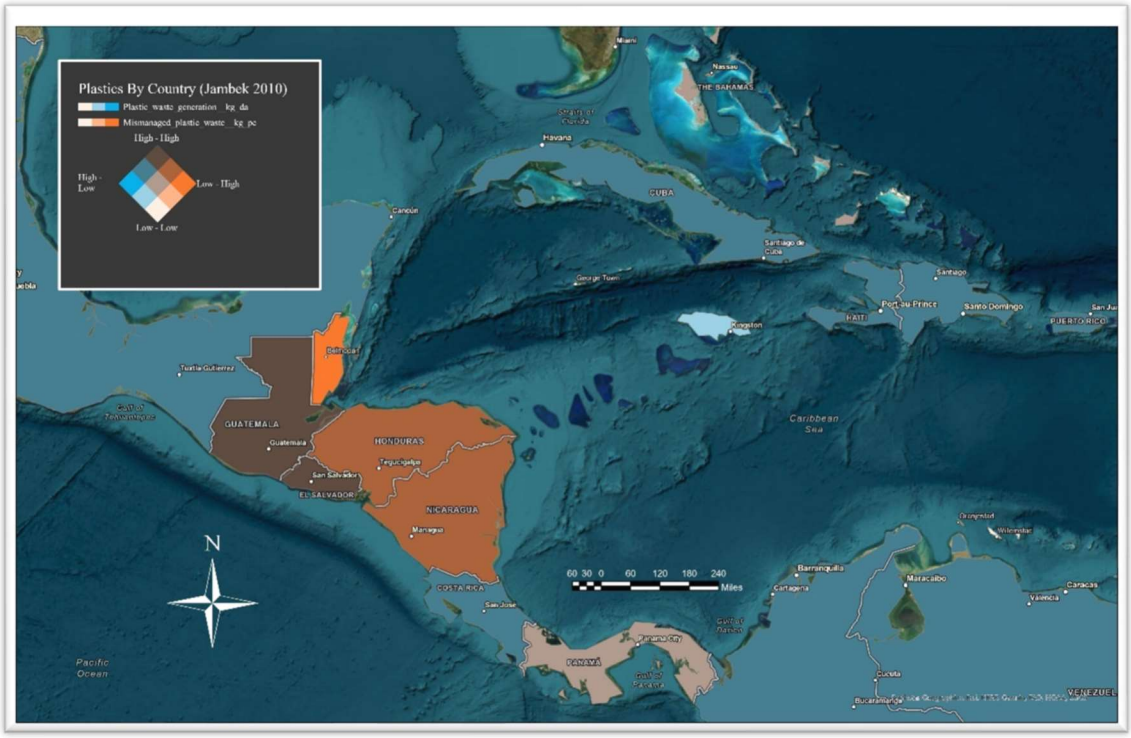
Several research cruises have set out to make global models and estimates for distributions of plastic, microplastic, and microfiber abundances. From 2015-2020 the most common unit for marine plastics data are "counts" of debris (Haarr, Falk-Andersson, and Fabres 2022). Through a meta-analysis, the highest densities of sea floor litter were located in the North Atlantic ocean, and Latin America/Caribbean beaches were reported to be the second most polluted (Haarr, Falk-Andersson, and Fabres 2022).

While waste generation is an important factor in plastic pollution, poor waste management may serve as an equally (or even more) important contributor. Recent studies suggest that while nations with high incomes produce more waste, most oceanic plastic pollution is sourced from middle to low income countries due to mismanagement and lack of proper disposal outlets (Ritchie and Roser 2018). The relationship between waste generation and mismanagement in the

Caribbean and Gulf of Honduras is illustrated in Figure 2.3, created from data collected by Jambeck in 2010 and available through ESRI online (Jambeck et al. 2015). Note that while Belize has the lowest index of waste generation (kg/day), the country also exhibits the highest index of mismanagement (kg/person/day). To the south, Honduras and Guatemala also mismanage waste at similar rates, with higher levels of waste generation.

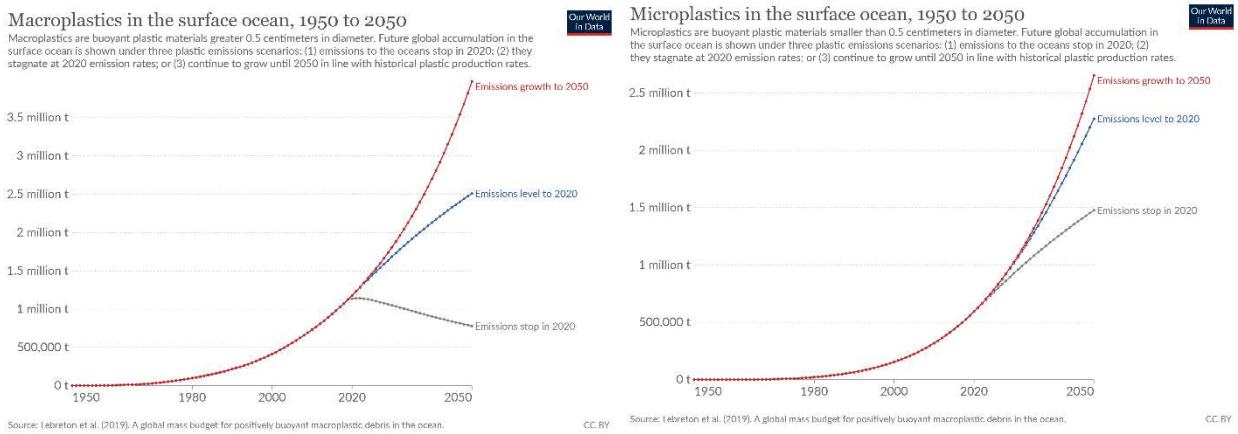
Figure 2.3: Map of countries index of waste generation and mismanaged waste. Colors denote different indices according to the legend.

Source: Jambeck (2010)



Future projections of global plastic pollution have also been created through estimating and modelling the following 3 scenarios: 1) emissions grow from 2020 2) emissions stay constant from 2020 and 3) emissions stop at 2020. The predicted amount of macroplastic in the ocean surface ranges from 778,600 tons (scenario 3) to 3.97 million tons (scenario 1), while the predicted amount of microplastics ranges from 1.48 million tons (scenario 3) to 2.65 million tons (scenario 1). Note that even if emissions were to stop at the year 2020, microplastic amounts would continue to grow as macroplastics slowly break down through time.

Figure 2.4: Timeline of predicted amounts of marine plastic and microplastic pollution to 2050 given three scenarios. Source: Lebreton et al. (2019)



2.5 PLASTIC AND MICROPLASTIC POLLUTION REPORTED IN THE MBRS

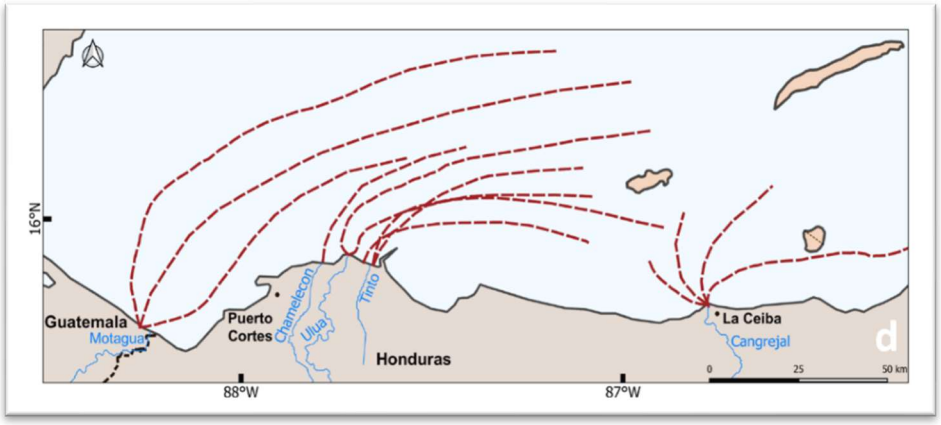
The preliminary findings of the Belize Marine Litter Action Plan suggest an urgent need for awareness programs and public trainings for NGOs and communities to engage monitoring of plastic and microplastic pollution. The authors also found that valuable natural resources like the freshwater red head cichlid *Cichlasoma Synspilum* and queen conch *Strombus gigas* exhibit the presence of microplastic contamination. Both of these species are popular for human consumption in Belize.

A recent study on queen conch found that across the Caribbean region, the species is contaminated with microplastics(Aranda et al. 2022). The sampling of feces confirmed that microplastic pollution has spread throughout the Caribbean region and is contaminating valuable resources. Belize had the highest average abundance of microplastics per conch. 98% of the microplastics found in Belizean conch were fibers.

In 2021, a breakthrough study by Oldenburg et al. found that microfiber abundance in coral varied significantly between coral species, morphology, and geography in the MBRS (Oldenburg et al. 2021). The study discovered a spatial trend in microfiber abundance, with higher levels in the southernmost corals, within the Sapodilla Caye Marine Reserve. Other sampled locations include Gladden Spit, Long Caye, and Drowned Cayes. Rayon was by far the most abundant composition, representing over 84% of the analyzed fibers.

Another technique to estimate sources and distributions of plastic debris in this region is the remote sensing of short-wave infrared reflectivity of ocean environments. Previous studies have defined spectral signatures specific to marine plastics (Garaba and Dierssen 2018). A 2020 study conducted in the Bay Islands of Honduras found that most plastic debris enters the Caribbean through continental river discharge and was able to estimate tracts of debris based on observations through time. An image of these tracts is included below (Figure 2.5)(Kikaki et al. 2020).

Figure 2.5: Tracts of marine debris sourced in Guatemala and Honduras. Source: Kikaki et al.



2.6 Population Controls on Litter Distribution

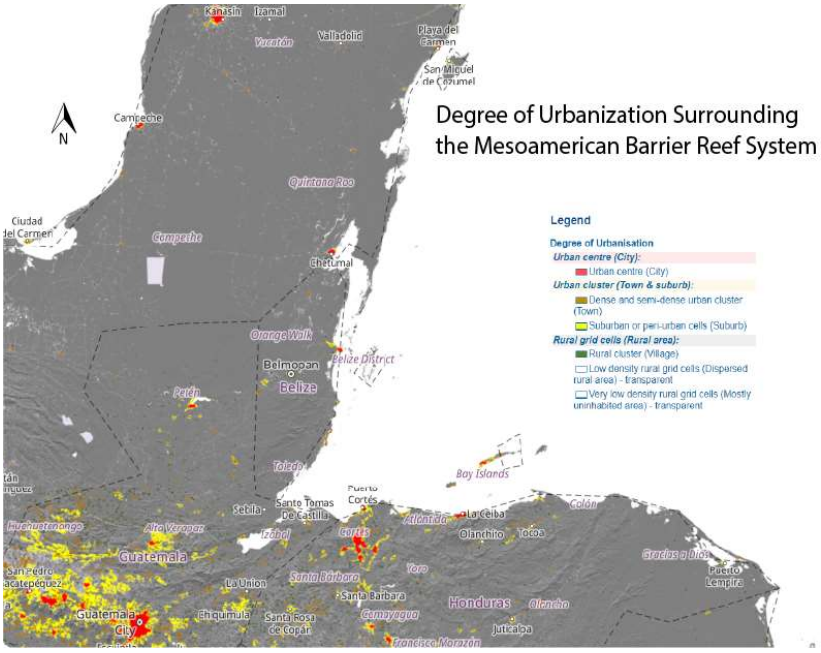
A 2010 report from the Ocean Conservancy found that more litter is found closer to larger populations due to greater inputs of consumer goods (Ocean Conservancy 2010). Previous studies have concluded that higher concentrations of microplastics exist in the southern reaches of this area, where there is also a higher population density. However, there is some disagreement as to whether this phenomenon is caused by population density, major currents/oceanography, or a combination of the two.

In 2010, Belize had a reported coastal population of 202,429 (over 50% of the total population of Belize), while Guatemala and Honduras had 2.39 million and 3.32 million respectively (Jambeck et al. 2015). With larger populations comes larger waste generation and demand for plastic products.

In addition to spatial differences in population, there are marked differences in urbanization of watersheds associated with the MBRS. Several studies have demonstrated correlations between microplastic and plastic pollution and urbanization (de Carvalho et al. 2021; 2022). Water near

urban areas is more likely to be contaminated with microplastic pollution, specifically in times following extreme weather events and hazards such as flooding (de Carvalho et al. 2022). Figure 2.5 provides an illustrative interpretation of urbanization in the study area. Notice that more urban areas with higher levels of urbanization exist to the south within the borders of Honduras and Guatemala, with more rural and low-density areas in Belize.

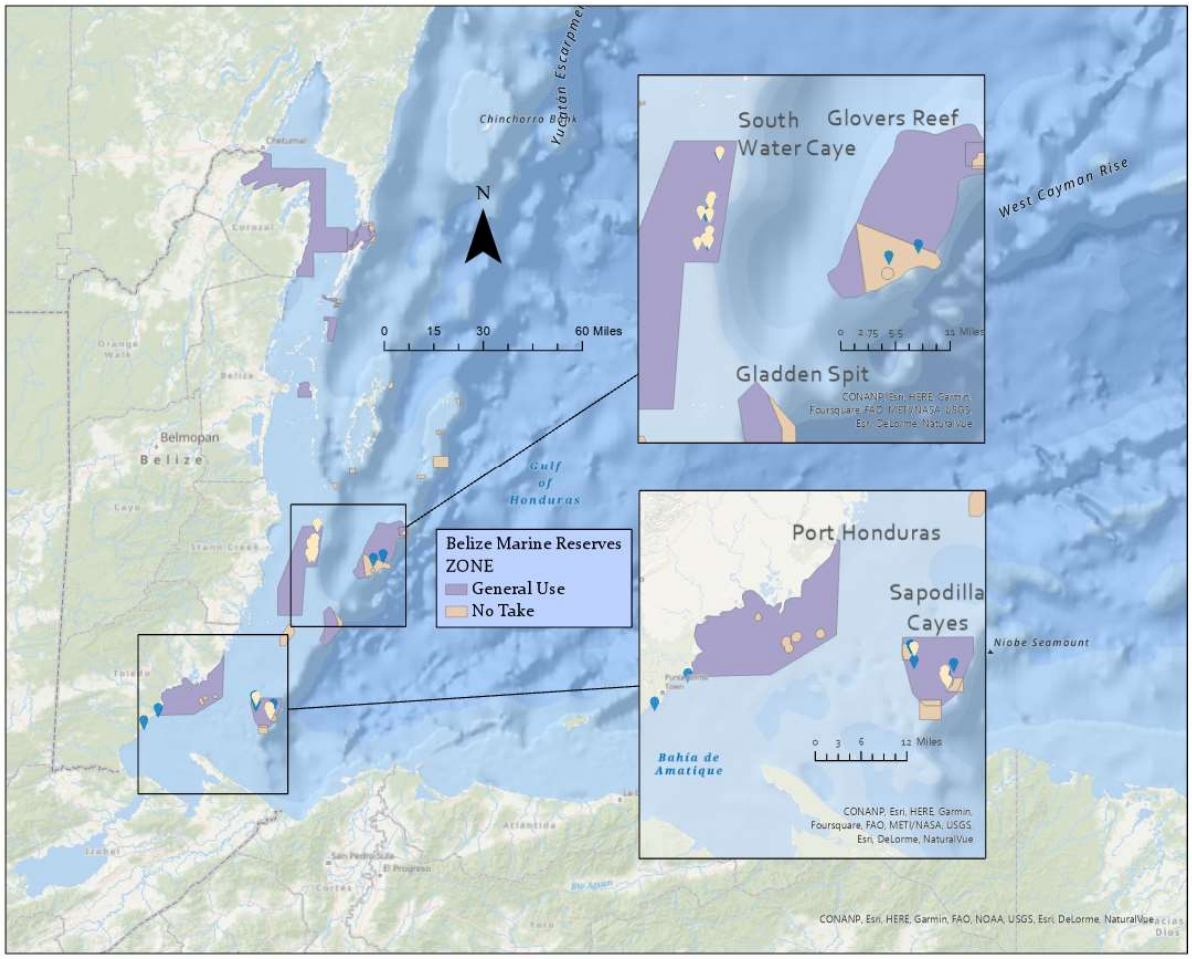
Figure 2.6: Map of degree of urbanization in the eastern Mesoamerican region. Map adapted from European Commission Joint Research Centre interactive web-map of urbanization and population density.



3 CHAPTER 1: MICROPLASTIC AND MICROFIBER DISTRIBUTIONS IN SOUTHERN BELIZE

This chapter seeks to address microplastic concentrations and distributions within the surface water and sediments of barrier reefs in southern Belize. Samples were taken across two marine reserves in southern Belize, South Water Caye Marine Reserve and Sapodilla Cayes Marine Reserve. The samples were then analyzed for counts of microplastics, and statistical analyses revealed spatial trends in the microplastic content of sediment. A map of sample locations in reference to Belize's marine reserves is included below.

Figure 3.1: Map of study area and sample sites



3.1 Surface Water Microplastic Sampling

Surface water samples were collected at points of interest along the reef by a team of students. Sample containers could hold 40-50ml of water. The sample procedure took bulk samples, without any volume-reducing measures such as a plankton net or sieve. Although volume-reducing methods may collect higher concentrations of microplastic particles, they are biased in the material they pick up. A meta-analysis of methods found that synthetic fibers are often missed in studies using plankton/manta net collection strategies (Fok et al. 2020).

A dissection/stereo microscope was employed for the analysis of each water sample. Each sample was reviewed at magnifications of 4x and 10x, and microplastics were counted and categorized according to their features. The categories include fibers, nurdles, grain-sized microplastics, and fine-sized microplastics.

3.2 Reef Sediment Microplastic Sampling

Similar to the surface water samples, reef sediment samples were taken at drop off points for snorkeling excursions. GPS coordinates were taken while a team member dove anywhere from 8-15 feet for 20-50ml of sediment. Most water and sediment samples were taken at the same coordinates so differentials in sample material could be accounted for.

The samples were then put through a density separation. Water and NaCl were added to increase the density of the solution and cause the plastics to float and sediment to sink. The solution was then decanted into a petri dish and analyzed under a stereo microscope. The samples were analyzed under the same criteria and categorical methods as the water samples.

3.3 STEREOMICROSCOPY METHODS

Microplastics were identified by using the stereomicroscopy methods as defined by Mariano et al. (Mariano et al. 2021) Many had synthetic colors and shapes, especially the microfibers. Synthetic fiber shapes lack tapering at the ends and exhibit uniform width throughout. Although materials and chemical makeup were not determined, previous studies have found that over 90% of fibers found using the aforementioned methods and identifiers are composed of synthetic material.

3.4 MICROPLASTIC DISTRIBUTION MAPPING AND ANALYSIS: METHODS

The microplastic sample data was mapped in ArcGIS and analyzed using SPSS software. Outliers and mangrove data were omitted due to the possibility of sampling error and overwhelming amounts of organic material. The data was tested for trends and relationships based on coordinate location and location in reference to the reef (i.e., reef zone). Site notes and satellite imagery were used to confirm the reef zone classifications. Analysis of Variance (ANOVA) statistics were used to examine differences within and between each zone and marine reserve.

3.5 MICROPLASTIC DISTRIBUTION RESULTS

3.5.1 Water

Microplastic concentrations in water samples showed no significant trends based on their coordinates. There were also no significant differences found between the two marine reserves. This may suggest a general homogeneity of free floating microplastics in the reef at a larger (miles wide) resolution. The only significant trend for microplastic concentrations in water was found through categorizing each sample based on its reef zone classification. The data showed

significant variance ($p=<.05$) between groups for both concentrations of microplastics and, more specifically, concentrations of fibers.

3.5.2 Sediment

On the contrary, the sediment results show no significant trends between reef zones but instead show a distinct difference between reserves. While South Water Caye Marine Reserve had an average count of .1536 microplastics/ml, Sapodillas Caye Marine Reserve had over double that amount, at a mean of .3754. Through a regression model, it was determined that microplastic concentrations significantly increased with longitude and decreased with latitude. The trend of increasing microplastic concentrations in sediment to the south supports the findings of Oldenburg et al. in synthetic microfiber concentrations in coral tissue decreasing with latitude in the MBRS.

3.6 DISCUSSION

The results found in this analysis demonstrate that not all sampling is created equal; water and sediment are very different proxies for the state of microplastics in an area. It is challenging to interpret high-resolution sampling in water because it is such an ephemeral and variable resource. Sea floor sediment samples, however, likely represent the longer time scales necessary for plastic material to bond and collect in sediment.

With southern sediments and corals demonstrating higher counts of microplastics, it is now necessary to determine which factors, or combination of factors, contributes to this phenomenon. With the southern sites having closer proximity to countries of much larger populations and no national bans on plastic, it may seem intuitive that these areas have more plastic content. However, the Gulf of Honduras is not a closed or predicable system, with variable drift models

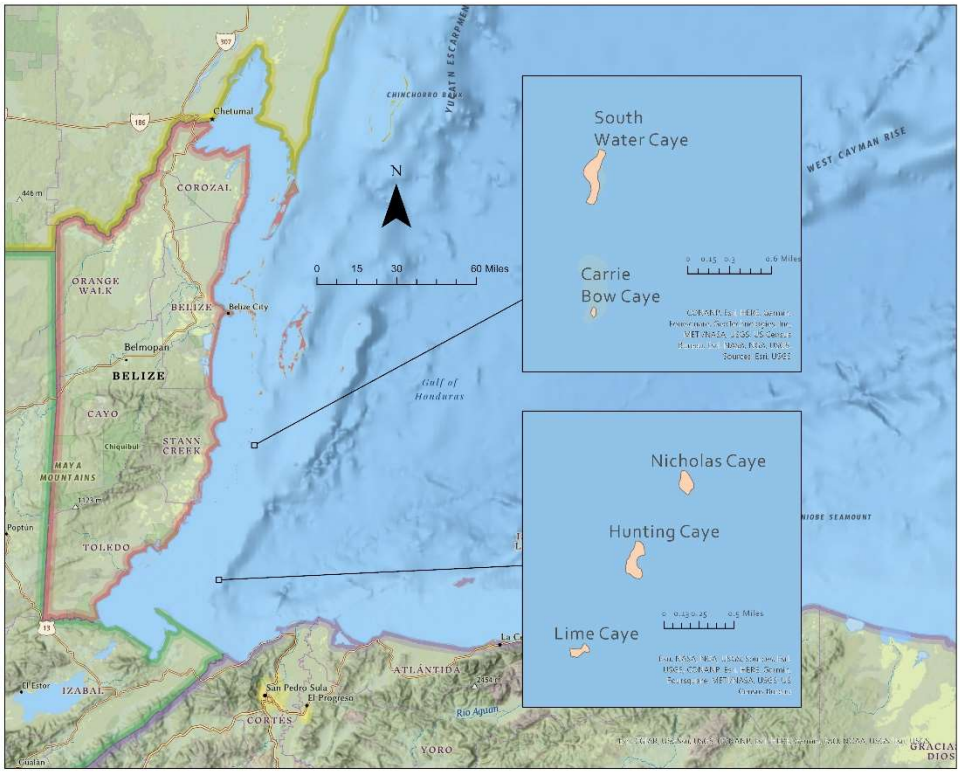
and accumulation zones throughout; cyclonic circulations could result in the mixing and transporting of plastic material from anywhere in the Caribbean, making it extremely challenging to pinpoint a specific source. These findings make the case for cross-national collaboration even stronger than before, as the fate of litter in the entire Caribbean rests on everyone's shoulders.

The successful implementation of methods in this study indicates a translation from laboratory to class-setting, a step closer to higher accessibility and dissemination of citizen science techniques. The successful engagement of students also demonstrates the educational value of implementing litter analysis into a class study. The activities/methods described in this thesis compelled students to think critically, problem solve, and closely engage with local people, effectively expanding their worldview and increasing their analytical skills.

4 CHAPTER 2: WRACK LINE CATALOGING AND ANALYSIS

This chapter discusses the methods and results of a survey of marine plastic debris found on several beaches within the Sapodillas Cayes Marine Reserve (Hunting Caye, Lime Caye, and Nicholas Caye) and South Water Caye Marine Reserve (South Water Caye and Carrie Bow Caye). The results are compared to a previous baseline study, and interpretations are discussed for any similarities and discrepancies.

Figure 4.1: Map of study area and sampling sites



4.1 METHODS

Six 1-meter square quadrats of wrack line were randomly selected for plastic collection and cataloging. The survey covered 6 beaches on 5 different islands and each wrack line faced the east (Caribbean) or west (mainland/lagoon). The selected islands were also surveyed in the

baseline study by *Blanke et al*., with the exception of Carrie Bow Caye. Each individual piece of plastic debris was counted, measured, described, and classified according to economic use or "source" in categories adapted from descriptions and findings from *Blanke et al.* (Blanke, Steinberg, and Donlevy 2021). Some items that could have fallen within a broader category but had an outstanding number of similar items were given a specific category. An example of this was the outstanding number of bottlecaps were found (Figure 4.1-D), so "bottlecaps" became a category. The following is a complete list and description of categories:

Table 4.1: Categories of Plastic Debris

Category	**Description**	**Example**	**Notes**
Consumer	Household goods and everyday use items	Highlighters, cosmetic containers	These items were examined for manufacturing information that included a place of origin
Food and Drink	Items used in the sale or consumption of food or drink	Food wrappers, plastic utensils	These items were examined for manufacturing information that included a place of origin
Bottlecaps	Loose, whole bottlecaps	Soda bottle caps	These items were originally sorted as "food and drink" but the number of items justified creating a new category
Medical	Items associated with medical applications	Covid masks, medicine bottles	Expected to find a high concentration of these items due to global pandemic
Styrofoam	Any item of Styrofoam composition	Fragments of Styrofoam	Most items in this category were heavily weathered/fragmented, making it incredibly challenging to discern

			the form of the original product
Fragment	Fragments of plastic and plastic films (excludes Styrofoam fragments) >5mm	Broken and bent plastic items	Original forms were inferred/recorded if possible
Microplastics	Fragments of plastic ad plastic films (excludes Styrofoam fragments) <5mm	Very small fragments of plastic	Original forms were extremely challenging to infer
Nurdle	Pre-production plastic product (<5mm)	Round, pea shaped plastic pellet	Some items had been misshapen/partially melted

4.2 RESULTS AND DISCUSSION

Almost two thousand pieces of plastic and Styrofoam material were found throughout the 6 beaches surveyed. The square meter with the most material, located on Hunting Caye's Ocean Facing Beach held exactly 994 pieces (over 50% of the total material found) of plastic. Styrofoam was the most abundant material, comprising over 62% percent of the total material recorded.

Of the items that had legible writing, 60% were in Spanish, 30% were English, and 10% French. A few products had manufacturing/distribution information, including a product from Arizona, USA, and another from Jamaica. Another product listed 5 Latin American countries in which it could have been manufactured. Surprisingly, only 4 out of the 1905 items were plastic bags. This may be evidence that widespread bans and phaseouts of plastic grocery bags is working to prevent marine litter. On the other hand, plastic bags are known as one of the most ingested or entangled plastic products. Most notably, sea turtles mistake the billowy film material for jelly fishes. So, the lack of bags washed up on beaches could also suggest their entanglement or ingestion elsewhere.

Spatially, the abundance and sizes of different materials varies between eastern and western facing beaches. Eastern beaches face and receive wave action from the open ocean/Caribbean Sea, while the western facing beaches receive waves from the lagoon between the reef and mainland. Although the system is not closed and litter can easily be transported between the lagoon side and ocean side of the surrounding waters, the eastern facing beaches received far more plastic and Styrofoam litter. The litter found in eastern beach quadrats was also more fragmented and weathered than that of western beaches, likely indicating a longer, rougher period at sea. These findings make sense hydrologically, with plastic pollution accumulation zones existing to the east within the Honduras eddy and other circulation patterns (Uneputty and Evans 1997).

Compared to a previous baseline study by Blanke et al. (2021), this survey found a much higher percentage of fragmented material (Blanke, Steinberg, and Donlevy 2021). This phenomena could be a result of methodological differences, with the use of a single square meter quadrant possibly producing more detailed findings than transects of 20 meters. With a smaller sampling methodology, groups could comfortable sit and found many microplastics and nurdles on the surface that may be missed with a larger task area that requires walking/standing. The discrepancy could also be a result of policy changes in the area. With a recent ban on single use plastic products and Styrofoam in Belize, it may be less likely for new, whole materials to be introduced to the reef system. Therefore, the lack of whole objects and dominance of fragmentation observed in this study may be evidence that litter washing up on the beaches of Belize entered the ocean prior to the ban, and has been deteriorating ever since. Interestingly, the survey also found that the percent of Styrofoam in the total plastic material increased from

11.68% to 62.03%. This increase is incredibly surprising considering Belize's recent ban, and may evidence of input from other countries.

Similar to Blanke's study, this survey found that Hunting Caye stands out amongst the other sample locations. However, when comparing the ocean-facing beach vs the lagoonal beach, the ocean-facing had 124 times the amount of plastic debris. Beyond its designation as an immigration office and military/defense outpost, Hunting Caye does not have tourism operations, and is inhabited by only a handful of government workers. This small population and absence of economic incentive may explain the lack of clean up efforts that are likely existent on the other surveyed islands with more robust tourism and resort operations.

Figure 4.2: Field photos of litter quadrats and sorting

A- Beach quadrat location on Hunting Caye (Sapodillas Cayes Marine Reserve)
B- Beach quadrat on Nicholas Caye (Sapodillas Cayes Marine Reserve)
C- Miscillaneous Items from Lime Caye Quadrat (Sapodillas Cayes Marine)
D- Bottle Caps from Lime Caye Quadrat (Sapodillas Cayes Marine Reserve)

5 CHAPTER 3: REVIEW OF RELEVANT POLICIES, PROGRAMS, AND PERCEPTIONS PERTAINING TO PLASTIC WASTE MANAGEMENT AND POLLUTION IN THE MBRS

5.1 HISTORY OF PLASTIC POLLUTION POLICY IN BELIZE

Belize's Department of Environment (DOE) has existed since 1989 with the ultimate goal of protecting the environment of Belize and was granted its own sovereignty as a "fully fledged" organization only 3 years later after the passage of the Environmental Protection Act (EPA) (History – Department of the Environment, n.d.). The EPA gave the Chief Environmental Officer sovereignty over the DOE and requires high penalties for environmental violations.

In the most recent amendment, many single use macroplastics and Styrofoam have been listed as Schedule 1-3 restricted products in Belize, meaning that the import, possession, and production of these products is prohibited. Forms exist for permissions for plastics for medical and pharmaceutical purposes, and applicants have the option to specify whether their product is biodegradable or not ("Belize - Environmental Protection Act. No. 22." n.d.). Although the robust list of restricted products, from Styrofoam egg boxes to drinking straws, makes huge steps in environmental advocacy, the amendment makes no mention of microplastics (or any secondary plastic debris) and their associated pollution. This leaves microplastic monitoring and prevention to be a "bottom-up", or community driven effort. This model of citizen-led conservation has had notable success in the country (Horwich, Lyon, and Bose, n.d.).

In 2018, Belize introduced a phase-out plan for single use plastics. The government's goal was to create gradual change in citizen plastic use, while also not demanding an abrupt, punctuated equilibrium. The phase-out was initially intended to start in spring of 2019, but the novel coronavirus pandemic prevented the initiative from starting on time. Belize has been forthright

with their intentions to encourage transitions to green products, while also reducing and prohibiting the use of SUPs. The government is also vocal about promoting a culture of ownership and pride of the nation's environment.

In 2008, the Organization of the Petroleum Exporting Countries loaned Belize 14.7 million USD for the development of waste disposal facilities and infrastructure. The loan set out to support a project that would increase transportability of waste, while replacing 4 major dump sites with waste transfer and recycling facilities.

In February of 2018, the CUBEL Consultancy published a controversial article in *The Belize Times* entitled: "WASTE MANAGEMENT SYSTEM IN BELIZE IS ONE OF THE WORST OF THE REGION" (Villegas Aguilar 2018). The article claims that environmental laws and regulations are not being enforced in Belize and that landfills lack on-site management. The article also includes many calls to action directed at the government of Belize, asking for better enforcements and implementation of policy, along with clean waste treatments. As of March 2020, the DOE has prohibited the burning of household and yard waste, citing air quality, environmental health, and forest fire prevention as the motivations ("Burning of Household Waste Is Prohibited – Department of the Environment" n.d.).

5.1.1 Belize- Blue, Clean, Resilient and Strong

In June 2020, Belize's Department for Environment and Center for Environment Fisheries and Aquaculture published novel policies and programs in the Belize Marine Litter Action Plan: *Belize- Blue, Clean, Resilient and Strong* ("Belize Marine Litter Action Plan – Department of the Environment" n.d.). The 5-part plan addresses waste removal, outreach and education, marine science, and both sea-based and land-based sources of pollution.

The plan's strategies include the development of long-term outreach campaigns, along with increased data collection and monitoring for more informed decision-making practices. The plan also encourages the adoption of legislation that prevents pollution at sea and reduces waste on land through standardizing waste management and increasing the capacity of the recycling sector. The plan heavily targets the sources of marine plastic debris and argues for a circular economy to ensure waste reduction.

5.2 Summary of Current/Attempted Policies and Legislation From Other Countries in the Region

Within recent years, Caribbean island countries have made landmark progress in their decisions to ban single-use plastics("TWELVE CARIBBEAN COUNTRIES HAVE SINCE BANNED SINGLE-USE PLASTICS | SKNIS" 2021). Countries like Jamaica, Barbados, and Trinidad and Tobago have stepped up to end plastic waste and pollution; the decisions were supported by the fact that many Caribbean countries lack the infrastructure for proper waste management and disposal. The following sections review larger countries that have direct inputs and impact on water quality within the study area and East Mesoamerican region.

5.2.1 Mexico

Several states such as Nuevo Leon and Nayarit have passed policy prohibiting the use of plastic consumer products like straws and bags (Griffin, Karasik, and Karasik, n.d.). Some of the laws cite a purpose of reducing environmental harm to valuable marine resources. Other localized policies have failed, like the SUP ban in Mexico City. To prevent buildup of waste, the city passed a controversial total ban the sale of single use plastics, which also resulted in a ban on many feminine hygiene products (*The Economist* n.d.). This was followed by a series of protests

from the Mexican Feminist Movement, who argued that the ban violated human rights to personal hygiene and discriminated based on gender/ability to menstruate (Ríos n.d.). Although other options to plastic menstrual products do exist, price and accessibility for disabled individuals can prevent them from being viable alternatives to some populations.

5.2.2 Honduras

The Pan-American Health Organization estimates that only 3.69% of domestic waste produced in urban areas of Belize reaches a sanitary facility (Mercedes Lu, Mark Chernaik, and Heidi Weiskel 2013). While the nation has no country wide policies or standards for the management of waste or limitation of plastic use, some small communities and islands that rely on tourism for their economy have attempted to ban some plastics (United Nations Environment Programme 2019). However, most of these bans focus on a specific product or area such as the beach. The Bay Islands of Honduras, in particular, enforce a ban on plastic bags, reflecting legislature from similar Caribbean Island communities ("Eliminating Plastic On Utila" 2014). Many Honduran communities are focusing on clean ups and recycling measures, with cities opting to creating asphalt out of plastic bottles. It is worth noting, however, that recycling methods have been identified at as a source of microplastic pollution (Suzuki et al. 2022).

5.2.3 Guatemala

The community of San Pedro introduced a local ban on the sale and distribution of some plastics and Styrofoam in 2016, likely due to their status as a "hippy" ecotourist destination. The legislation marked the nation's first ban on single-use plastic. In 2019, Guatemala announced the ban of specific plastic items like utensils and bags with a two-year phase out plan. The ban offers exceptions to individuals in need of plastic eating utensils for medical purposes. Some

communities had already adopted similar policies, but at the national level, the ban could work towards greater levels of community cooperation and awareness.

5.3 PERCEPTIONS OF POLLUTION

Not only is the environment directly impacted by the amount and distribution of plastic pollution, but people are as well. When developing responses to plastic debris through prevention and cleanup efforts, researchers and governing bodies often consider stakeholder perceptions and participation for increased awareness and policy effectiveness. To adequately respond to a problem, communities must first perceive it, but disconnects often exist between the extent of an issue and the public's perception of it. For the most part, public perceptions of the environment include cultural biases unrelated to observations or knowledge associated with a subject, with many individuals looking to "elites" for examples of appropriate response (Goebbert et al. 2012; Shao, Moftakhari, and Moradkhani 2020). Understanding the biases and characteristics associated with public perception is foundation for the development and success of environmental literacy and action.

5.3.1 Environmental Perceptions in Belize

A 2015 study surveyed populations in the Cayo District of Belize about their perceptions of the local environment (Vincent, n.d.). The results indicated that occupation has a marked effect on perception of water pollution, with a higher percentage of landowners and managers perceiving pollution as a problem in Belize than local workers. A 2016 study found that in Placencia, Belize, rapid tourism development impacts local environmental perceptions, resulting in nuanced perceptions of natural resource management, which are heavily reliant on economic and political circumstances (Wells et al. 2016).

Other studies have demonstrated positive correlations between tourism, conservation, and perceived quality of life, suggesting a positive feedback loop between tourism and environmental awareness (Diedrich 2007). Understanding local stakeholder perceptions of the rapidly changing economic and social landscape of Belize due to combined effects of tourism and conservation is paramount to the continued sustainable development of the country.

5.4 SURVEY

To get a better understanding of local perceptions of plastic pollution and the recent phase-out policy, local individuals were surveyed on their experience and opinions on plastic and plastic bans. No identifying information was collected about the individuals, so their responses could be completely anonymous. The survey was conducted throughout two weeks during June of 2022. This is a popular time for tourism in the coastal and barrier reef regions, and the month of June has fourth highest rate of tourist arrivals ("Statistics | BTB" n.d.). Because responses were collected along the course of a study abroad trip, many of the people interviewed were connected to the tourism/ecotourism industry in some way. Due to technical difficulties and remoteness of some of the areas surveyed, responses were taken both on paper and through the Google Forms website. The survey results represent 26 individuals, 61.5% male and 38.5% female, with diverse occupations and cities/countries of origin. Individuals were asked specifically about their opinions on the risks associated with plastic pollution to both the environment and their job. They were also asked about their experience of the recently passed ban on SUPs in Belize.

5.5 SURVEY ANALYSIS AND RESULTS

All respondents agreed that plastic pollution threatens both global and local marine ecosystems, while there was 16% disagreement among the respondents about plastic pollution directly

affecting their occupation. Every individual who agreed that pollution affects their job was able to give an open-ended detailed description of how or why they agreed. Some of the short answers include, “it kills the sea” and “I have to watch animals struggle”. Even though most respondents (65.4%) indicated that they were confident in their knowledge of the single use plastic ban, disagreement occurred in their collective experiences and opinions with the ban, especially when questioned about effectiveness and enforcement. When asked open-ended questions about where the trash was coming from, several individuals referenced neighboring nations, specifically Honduras and Guatemala. Through discussion with participants, most individuals were able to describe the processes in which plastic products break down and produce microplastics. Many individuals referenced land-based sources of plastic pollution, particularly river-dumping. Two respondents indicated people dump waste directly into the ocean, but it is worth noting that these individuals were referencing populations of other countries. Only one respondent mentioned the burning of waste. A few respondents mentioned climatological impacts on pollution, citing monsoon seasons and tropical storms as drivers for marine pollution.

Survey results were assigned dummy variables or binary codes based on factors in open ended responses. For example, respondents that mentioned Honduras in their open ended responses were given a value of 1 for the “Mention of Honduras” variable. Respondents who made no mention of Honduras were coded as 0. Since many questions asked respondents to use a Likert scale to indicate their level of agreement or disagreement, an ordinal regression in SPSS was used to analyze and compare results.

No trends exist between the perception of plastic pollution threats to local/global marine life and survey responses like occupation or gender. In other words, there were no characteristics or

associated perceptions that made individuals more likely to perceive plastic pollution as a threat. This is likely due to the universality of the perception that pollution has negative impacts on the environment and speaks to the success of public education and outreach about the issue.

Table 3.2 contains the results for the ordinal regression with self-evaluated confidence in Informedness of the Belize SUP ban as the dependent variable. Factors like age, gender, occupation, and threat perception had no significant impact on the respondents' level of confidence in informedness. The means by which respondents were informed, however, did impact their confidence level, with respondents who became informed through published news or word of mouth being more likely to feel confident in their knowledge of the SUP ban. Individuals who were informed through social media had no significant increase or decrease in likelihood to feel more informed.

The results of an ordinal regression using perceived effectiveness of the Belize SUP ban as the dependent variable are contained in Table 3.3. The analysis indicates that males and individuals working in the tourism industry and service industry are likely to perceive the SUP ban in Belize as effective. The level of confidence in informedness also has a positive correlation with perceived effectiveness. Interestingly, individuals that mentioned the ineffective waste management or policies of other countries were more likely to indicate their belief that the Belizean policy was effective. On the other hand, individuals who perceived other countries as a contributing entity to Belize's plastic pollution problem were less likely to indicate that the Belizean law is effective.

Table 5.1: Factors Influencing Self-Evaluated Confidence in Informedness of Belize Single Use Plastic Ban

		Estimate	Std. Error	Sig.
Self-Evaluated Informedness of National SUP Ban	Strongly Disagree (-2)	-3.658	3.766	0.331
	Disagree (-1)	-2.570	3.718	0.489
	Neutral (0)	-1.583	3.698	0.669
	Agree (1)	1.630	3.664	0.657
Variable	Age Group	-1.228	0.659	0.062
	Gender (F)	0.463	1.091	0.671
	Belize Native	-1.418	1.391	0.308
	Tourism Industry Occupation	0.781	1.256	0.534
	Service Industry Occupation	0.391	1.100	0.722
	Perceived Effects on Occupation	0.211	0.345	0.540
	Perceived Threat to Local Marine Ecosystems	0.235	1.541	0.879
	Perceived Threat to Global Marine Environment	0.436	1.296	0.736
	Informed Through Internet, Social Media	0.854	1.226	0.486
	Informed Through Published News: TV Broadcast or Newspaper *	2.607	1.049	0.013
	Informed Through Word of Mouth *	2.929	1.209	0.015

Link function: Logit. * = Null Hypoth. Probability <.05 +/- of estimate indicate positive or negative effects on the dependent variable

Table 5.2: Factors Influencing Perception of Belize Single Use Plastic Ban Effectiveness in Plastic Pollution Reduction

		Estimate	Std. Error	Sig.
Perceived Effectiveness of National SUP Ban in Reducing Pollution	Strongly Disagree (-2)	1.954	4.398	0.657
	Disagree (-1)	3.913	4.376	0.371
	Neutral (0)	6.271	4.428	0.157
	Agree (1)	8.741	4.630	0.059
Variables	Age Group	1.256	0.961	0.191
	Gender (F) *	-5.392	2.245	0.016
	Native to Belize	3.500	2.287	0.126
	Tourism Industry Occupation *	4.128	1.570	0.009
	Service Industry Occupation *	5.872	2.266	0.010
	Perceived Effects on Occupation	-0.749	0.753	0.320
	Informed Through Internet, Social Media	0.794	1.408	0.573
	Informed Through Published News: TV Broadcast or Newspaper	-0.925	1.299	0.477
	Informed Through Word of Mouth	-3.192	2.223	0.151
	Mention of Honduras	-3.024	2.178	0.165
	Mention of Guatemala	3.820	2.602	0.142
	Perception of Other Countries Lacking Management and Policy *	4.978	1.784	0.005
	Perceived Contribution of Pollution from Other Countries *	-2.867	1.351	0.034
	Perceived Population Density Issues	-4.259	2.759	0.123
	Perceived Effects of Weather and Monsoon on Plastic Input	-0.784	1.684	0.642
	Self-Evaluated Informedness of National SUP Ban *	1.808	0.723	0.012

Link function: Logit. * = Null Hypoth. Probability <.05 +/- of estimate indicate positive or negative effects on the dependent variable

NVIVO was used also to analyze word frequency in open ended questions and produce illustrative representations of commonly used words/concepts, the results of which are represented in word clouds below (Figures 3.1-3.3). The size and color of the words/phrases correlates with their frequency in the collected responses. Note that the grouping parameters included synonyms of words, i.e. “speak” and “talk” would be grouped into one classification.

Figure 5.1 Word Clouds

5.6 DISCUSSION

The concerning factor of international blame came up several times throughout this study, whether coded within literature, or informally referred to during stakeholder interviews, individuals and even communities seem to be deeply engaged in defensiveness due to "climate-shame", as defined by Aatola in 2021 (Aaltola 2021). The population of Belize is much smaller

than that of surrounding nations, and their government has been vocal and willing in support of pro-environment policies and programming, while other nations have seemingly stood-by. Collaboration on international programming and policy is likely challenging, due to residual tensions between nations from periods of colonization and boundary decisions. To this day, the boundaries between southern Belize, Guatemala, and Honduras are disputed, making it incredibly difficult to create and carry out conservation initiatives in contested waters.

The impact of perceived contribution of other countries to Belize's pollution problem on individual's perception of policy effectiveness can be interpreted in two ways. The correlation may speak to the blinding nature of blame, or it may indicate an ineffectiveness of national policy due to the lack of cooperation with surrounding entities. Further research could create an index to assess "effectiveness" from an objective standpoint, to assess whether respondents are biased in their perspective.

6 CONCLUSIONS

Proper waste management infrastructure is paramount to continued sustainable development in the east Mesoamerican region. With robust natural resources and much of the local/national economies relying on fisheries and tourism, pollution control is in the country's best interest. Looking to the future, the refreshing plans and policies developed in Belize have the potential to reduce marine litter through increased public awareness and governmental responsibility over waste management. Historically, combined and legitimate efforts between governments and informed citizens is a recipe for conservation success. Belize's rich history and willingness with resource management and conservation efforts could provide hope in light of the findings of microplastic contamination in their waters and beaches.

With its proximity to converging ocean currents, higher levels of waste generation and mismanagement, larger populations, and areas lacking policy, it may seem intuitive that Belize's southernmost marine reserve would have more sea floor microplastics than its more northern counterpart. These findings correlate with the findings of Oldenburg et al. and perhaps indicates that ingestion or attachment to coral tissues is a main driver for microplastic inclusion in sediments. The more even spatial distribution in water samples may indicate a "leveling out" of the playing field, as those samples represent more ephemeral or short-term conditions.

An element of climate change that could impact rates of pollution in the reef system is increased rainfall and storms, creating higher potential for waste transport from mainland sources. Even with SUP and other macroplastic bans, microplastic abundances are likely to continue increasing due to the degradation of plastic material. Higher temperatures and high energy conditions associated with tropical storms and climate change may increase these degradation processes. Tracking pollution abundances through cataloging quadrats and sampling is paramount to

successful monitoring of the integrative effects and feedbacks loops associated with policy and climate change.

Future policy considerations should include the engagement of stakeholders and communities, and employ the use of news and tv broadcast for the dissemination of new legislature or management plans.

7 DISCLOSURE OF LIMITATIONS AND FURTHER QUESTIONS

Limitations for this study's analysis of plastics and microplastics exist in the relatively small sample sizes. Further analysis could produce more robust results and include sampling even outside marine protected areas. One question worth exploring in the future is whether differences exist between areas within marine protected zones and areas outside of the zones. Also, an analysis between different coastal ecosystem types could show if accumulation zones occur between ecosystems. With many sea grass beds and mangroves existing near coral, further research could include samples with more organic material. This study was limited in the inability to complete a chemical digestion in the field, so mangrove and other high organic samples could not be analyzed.

Another limitation exists in the limited time associated with this study. More long-term projects could address any seasonal differences that exist within microplastic and wrack line data and have the potential to track efficacy of the recently passed legislation and management plans on the reduction of marine plastic litter in the MBRS.

Limitations of the public survey on plastic exist in the occupations represented in the sample. Most people surveyed worked within or closely to the fishing or tourism industry in Belize, which heavily relies on ecotourism. Individuals who work closely with and depend on the local environment and environmental policies are likely to be more educated on those subjects. So, responses to statements like "I am confident in my knowledge of the newly passed single use plastic policy" may not represent the population of Belize as a whole. Although this survey represented diversity in communities of origin and gender, future studies could seek out a sample of individuals in industries that better represent the greater population of Belize.

Further research should also explore the use of plastic and microplastic analysis methods in classroom study and curriculum, perhaps even with younger age groups. Exercises in sample analysis using tools such as microscopes allow students opportunities with experiential learning towards environmental literacy, especially with materials and concepts that may not be readily observable in most daily lives. For younger children, sorting, describing, and cataloging plastic materials would not only be an exercise in environmental literacy but also assist in early learning development, where similar skills are paramount to later success in science (Bulunuz 2013). Other studies could examine the history of power and shame in the study region and its effects on citizens' perception of waste management policy and litter.

8 REFERENCES

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