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Let's Talk Takataka: Impacts of Plastic in the Stone Town Harbor Area, Zanzibar

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SIT Study Abroad

Let's Talk *Takataka*:
Impacts of Plastic in the Stone Town Harbor Area, Zanzibar

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Abstract:

Plastic pollution has become an anthropogenic crisis worldwide. In the Stone Town Harbor area in particular, consumerism, population growth, tourism and a deficient municipal waste management system contribute to alarming amounts of mismanaged plastic that enter the ocean. This is devastating for the diverse marine ecosystem that provides valuable resources to its flora and fauna and to it human inhabitants. In this study, micro-plastic at the sea surface as well as plastic on coastal beaches was quantified to determine the effects of plastic pollution in the area by use of a standard plankton net methodology. This study contributed to the first set of baseline information regarding plastic at this location. It was determined that there are approximately 172,061.01 micro-plastic floating particles at the sea surface in the Stone Town Harbor area. Micro-plastic was found in 94% of sea surface samples and plastic was found in 64.76% of coastal beach survey quadrats. Results suggest that the population size in this coastal environment is proportional to the micro- and macro-plastic abundance in the area. Furthermore, if the population of Stone Town limited single-use plastic, it would greatly mitigate plastic waste concentration, including by up to 43%. This study will contribute to plastic waste awareness as well as offer recommendations for more successful waste management strategies the help conserve the marine ecosystem.

Ufupisho Wa Utafiti:

Uchafuzi wa plastiki umekuwa ni mgogoro mkubwa duniani kote unaosabaishwa na mwanadamu. Katika eneo la bandari ya mji mkongwe Zanzibar kwa ujumla kuna matumizi ya plastiki, ongezeko ya idadi ya watu, utalii na mfumo wa usimamizi wa ukuanyaji wa taka taka wa manispaa unakabiliwa na change moto mbali mbali, na kutishia baadhi plastiki kuingia baharini. Hali hii ni mbaya kwa mazingira ya baharini na mfumo mzima wa ekologia ya bahari. Bahari ambayo hutoa rasilimali muhimu wanyama na mimea ya baharini. Katika utafiti huu, “micro-plastiki” za juu ya bahari pamoja na plastiki za fukweni zote zilifanyiwa uchunguzi ili kujua athari za platiki katika mazingira kwa kutumia net maulum (standard plankton net) Utafiti huu umechangia kwenye msingi mkuu wa utafiti wa taka taka za plastiki Zanzibar . Inakisiwa kuna takriban 172,061.01 chembechembe za plastiki zinazozunguka katika eneo la bandari ya mji mkongwe. Micro-plastiki (Plastiki ndogo ndogo) zilizopatikana katika utafiti huu mdogo ni asilimia 94 ya sampuli za uso wa bahari na plastiki ilipatikana katika fukwe za mwambao wa bahari ni asilimia 64.76 ya “quadrats” ya utafiti wa pwani ya pwani.
Matokeo yanaonyesha kwamba ongezeko la idadi ya watu katika mazingira ya pwani ni yanaenda sambamba na wingi wa micro na macro-plastiki katika eneo hili.
Zaidi ya hayo, ikiwa wakazi wa mji mkongwe watapunguza matumizi ya plastiki kwa mara moja tu (single use) ingeweza kupunguza kiwango cha taka taka za plastiki kwa asilimia 43, Utafiti huu utachangia kuongeza ufahamu wa taka ya plastiki pamoja na kutoa mapendekezo kwa mikakati ya ufanisi zaidi ya usimamizi wa taka kwa matumaini ya kuongeza uhifadhi wa ikologia ya baharini.

1.0 Introduction

Global plastic production is proportional to the overwhelming increase in population. While plastic has become a ubiquitous resource due to its durability and convenience, it has caused an environmental catastrophe. The lifespan of plastic is infinite and the degradation process is gradual, therefore, making it a persistent pollutant of concern. Plastic waste is particularly apparent in developing coastal countries where solid waste awareness and proper practice are insufficient. “It was calculated that 4.8 to 12.7 million metric tons of waste entered the ocean generated by coastal countries in 2010” (Jambeck et al. 2015). This study quantified marine microplastics at the sea surface (top quarter meter of the water column) and assessed the effects of plastic along the coast of Unguja, a part of the Zanzibar Archipelago. Being the first of its kind, this study is significant because it provides baseline knowledge that will in turn promote marine conservation and mindfulness about solid waste in the marine ecosystem.

The accumulation of mismanaged plastic waste leads to the high amount of plastic that enters the marine habitat, which has detrimental socioeconomic and ecological impacts. Plastic varies in size within the marine environment. However, small pieces or micro-plastic have are understood to be devastating. Macro- and micro-plastics can introduce toxic chemicals from additives, monomers, and other chemical by-products (Teuten et al, 2009) or can be ingested by marine organisms or cause entanglement and death (Gall and Thompson 2015). These impacts have negative implications for fisheries, eco-tourism, food production, and human livelihoods in the harbor. Many studies have been conducted quantifying marine plastic debris, but little is known about marine plastic abundance along East Africa’s coastline. This study evaluated the degree of plastic presence in the Stone Town Harbor area.

2.0 Background

The story of plastic pollution worldwide is complex. The tale is horrific and the solution remains a mystery. What began as a synthetic polymer produced for human convenience has become a material over-produced due to population increase. In areas such as the Stone Town harbor the lack of waste awareness and proper disposal practices only amplify plastic in the environment. It is now coming to attention in the scientific community that plastic never fully degrades, but only reduces over time. The resultant micro-plastic has serious socioeconomic and environmental impacts. Prior to understanding the quantitative data on micro- and macro-plastic in this study, the topic must be contextualized.

2.1 What is plastic?

Plastic has become an omnipresent resource due to its cost efficiency, convenience, durability and high demand. Plastic is defined as a synthetic organic polymer produced by polymerization of monomers extracted from gas or oil (Derraik, 2002). For the past 50 years, plastic production has continued to increase; 299 million tons of plastic were produced in 2013 alone (Gourmelon, 2015). The heightened production of plastic has allowed high quantities of macro-plastics (>5mm) and micro-plastics (<5mm) to accumulate in coastal and marine environments.

2.2 Plastic in Coastal Countries

Nearly 10% of annual production of plastics ends-up in the oceans (Barnes et al., 2009). Plastic enters the ocean in many ways including littering, discarded fishing gear, drainage, sewage outfalls, and illegal dumping (MCS, 2005; cited in Browne, 2010). It was calculated that 275 million metric tons (MT) of plastic waste was generated in 192 coastal countries in 2010, with 4.8 to 12.7 million (MT) entering the ocean (Jambeck et al., 2015:768). Since macro-

plastics cannot be completely degraded, they break down by UV radiation, chemical degradation, wave mechanics, and grazing marine life (Sebille et al., 2015). Commonly found micro-plastics include fragments from larger debris and nearly microscopic particles that are used in cleaning products, plastic powders, pellets, and synthetic fibers from textiles (Browne et al., 2011).

2.3 Waste Management in Zanzibar

Zanzibar Municipality is the primary urban setting on Unguja island, with a population of about 230,000 citizens. Stone Town in particular generates about "120 tons per day of solid waste of which only 40% is collected for disposal by the municipality facilities" (ZMC, 2000b:21; cited in Mohammed, 2002:204). Although there is one formal landfill called "Kibele", its infrastructure is inadequate. The solid waste component in Zanzibar Municipality is primarily "biodegradable organics (86%) followed by recyclable materials or plastics (4%)" (ZMC, 2013; cited in Biubwa et al., 2014:8). Even though plastic waste is a miniscule component of the waste produced, plastic litter is very apparent on the beaches and in the streets. The only initiative taken on plastic pollution in Zanzibar is the ban of plastic bags which, if violated, could result in a fine or jail time. The management process of waste is poor and there is only one private recycling company (Zanrec Plastics, Limited) that initiates the separation of plastics as well as recycling.

2.4 Plastic Pollution in the Stone Town Harbor Area

Plastic could have amplified negative ecological and economic effects on Zanzibar due to the government and population's high dependency on coastal ecosystems. The Zanzibar Archipelago contains diverse ecosystems including coral reefs, mangroves, sea grass beds, beaches, estuaries, rocky shores, and coastal forests (Khamis et al., 2017). Even though this area is a home to rich natural resources, these habitats continue to be plagued with human

degradation. Assuming no waste management infrastructure improvements are implemented, the cumulative quantity of plastic waste available to enter the marine environment from land is predicted to increase by an order of magnitude in 2025 (Jambeck et al., 2015). Without healthy coastal environments, tourism, fisheries, and other socioeconomic activities will be impacted. Marine ecosystem services account for 30% of GDP, 77% of investment, and a large amount of foreign exchange and employment (Jiddawi and Glenn-Marie, 2009). If no plastic management is implemented on Zanzibar in the near future, natural resources as well as the economy will face decline.

2.5 Wind Patterns in the Stone Town Harbor

The fate and transport of plastic marine debris is governed by poorly understood geophysical processes, such as ocean mixing within the surface boundary layer (Kukulka et al., 2012). To understand how plastics move it is important to understand wind patterns in the Stone Town Harbor area. The region faces a clockwise wind system over the Indian Ocean from April to September and reverses during southern summer months (November to March). In addition, the wind system has an almost clockwise ocean current system that changes according to the winds. Southeast monsoon winds are from April to October (Mahondo, 2011). They are usually strong and predominantly southerly (Iverson et al., 1984).

2.6 Study Area

This study was conducted in the Stone Town Harbor area, off of the primary urban setting on the west side of Unguja Island in the Zanzibar Archipelago. The study area is illustrated in Figure 1. The Zanzibar Archipelago is approximately 32 kilometers off the coast of Tanzania, East Africa and includes Unguja and Pemba Islands. This harbor area is framed by Unguja and many small islands, including but not limited to Pange Sandbar, Bawe Island, and

Changuu Island. This is an area with heavy boat traffic for shipment of cargo, fishing, and tourism.

Figure 1. Map of the Stone Town Harbor Area including Stone Town, Pange Sandbar, Bawe Island, and Changuu Island.

2.7 Sites of Microplastic Sampling in the Aquatic Space of the Harbor

Marine micro-plastic samples were taken at five locations within the harbor area depicted by Figure 2. The first site is located along the immediate western coast of Stone Town on Unguja Island. This coast is home to a dense urban setting. The second site is located along the northern coast of Pange Sandbar. Pange Sandbar is 4 km southwest of Stone Town with a length of 800 m. It runs east to west. The third site is along the east coast of Bawe Island. Bawe Island is 10 km west of Stone Town with a length of 1 km. The fourth site is along the southern coast of Changuu Island. Changuu Island is located 5.6 km northwest of Stone Town with a length of

800m. The fifth site is located in the middle of the harbor. This location provided information on plastic that gathered in the middle of the harbor area.

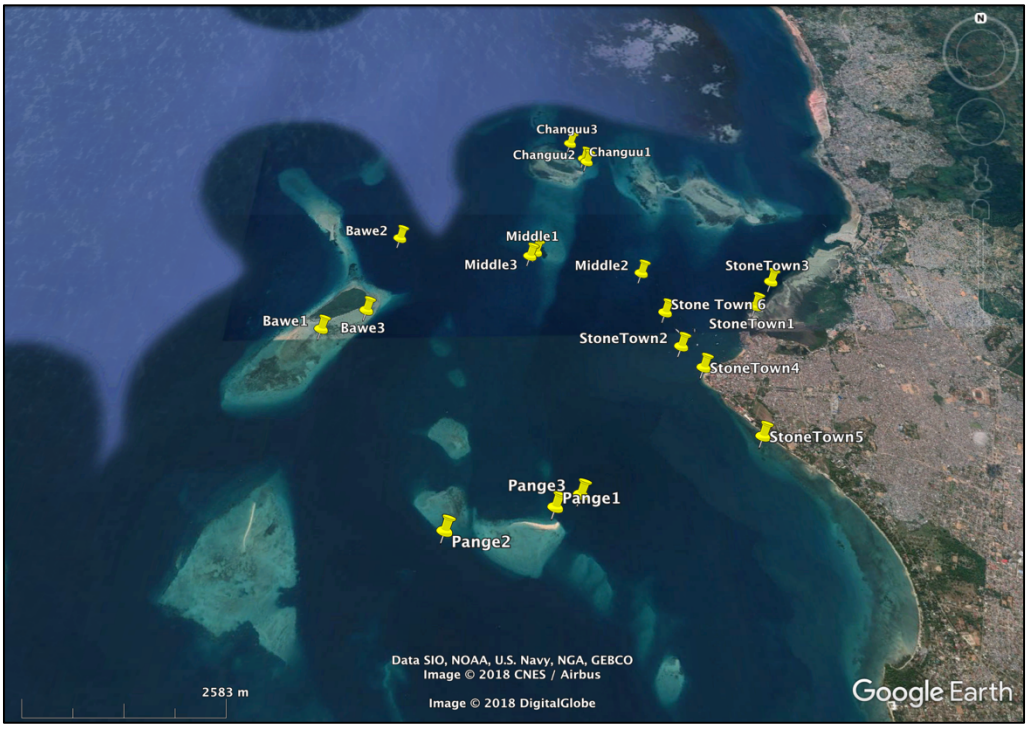

Figure 2. Map of micro-plastic GPS waypoints taken at the study site.

2.8 Sites of Plastic Sampling in the Terrestrial Space of the Harbor

Terrestrial plastic observations were taken at three beaches within the harbor area to serve as a supplemental information in the study. Each site was selected based on its high population or high tourist activity. The first site includes the northern side of the Pange Sandbar shown in Figure 3. Even though this sandbar has no permanent residents, tourist vendor's set-up tents daily that produce substantial plastic pollution. The second site, as illustrated in Figure 4, is on the western side of Stone Town, Unguja Island located in front of Tembo Hotel. The third site, also in Figure 4, is on the western side of Stone Town but nearer to Forodhani Park. Being

the primary urban setting, having high tourism, and weak waste management, these beaches have substantial plastic pollution.

Figure 3. Map of GPS waypoint taken at the first terrestrial plastic sampling site on Pange Sandbar.

Figure 4. Map of GPS waypoints taken at the second and third terrestrial plastic sampling sites on two beaches in Stone Town.

3.0 Methodology

For this study, two primary methods were employed to analyze the impacts of plastic in the Stone Town Harbor area. The first method comprised two-thirds of the project schedule: the quantification of marine micro-plastics at the sea surface. The second component covered one-third of the project schedule: visual surveys of plastic on Pange Sandbar and Stone Town's coastline. Both methods contributed to an overall view of the abundance of plastic in the harbor. This study was conducted between April 5 to May 2, during the southeast monsoon season of heavy rainfall.

3.1 Micro-plastic Sampling in the Aquatic Space of the Harbor

Micro-plastic samples were taken at the sea surface because "plastic items are usually found at the sea surface or washed up on the shoreline" (Barnes et al, 2009). The sea surface in this study includes the top quarter meter of the water column. Most micro-plastic marine debris is measured at the sea surface by surface-towing plankton nets. In previous studies net mesh ranged from 150 μm to 300 μm (Sebille et al. 2015:3). Net tows are primarily conducted at the sea surface for between 15-60 minutes outside the vessel's wake to avoid down welling debris (Erikson et al. 2014:3). To remain consistent with standardized methods, a plankton net (150 μm) was used. The net length was 2.5m long and the diameter of the mouth opening was 50cm.

Figure 5. Photograph of plankton net (150 μm) used for micro-plastic sampling. Photograph taken by CJ O'Brien.

For this study, the plankton net was towed 11m behind the boat, on the outside of a boat's

wake for 20 minutes at approximately 4.8 km/h in a straight line covering an average of 3km linearly. A GPS waypoint path was recorded. Three transects were completed at each of the following locations: Pange Sandbar, Bawe Island, Changuu Island, and the middle of the harbor. Six transects were completed along the Stone Town coastline. All near shore transects hugged the coast, subsequently moving approximately 20 meters towards the interior of the harbor to at transect 2 and transect 3. All transects were conducted during high tide so transects could be taken close to shore without entangling the plankton net on coral. Once transects were completed, the net's contents were dumped from the net's cup collecting apparatus and placed into a small labeled container. This process was repeated for each site. tide, weather conditions, flow rate, and other observations were recorded as well.

Later, samples were filtered using a 100μm sieve, which collected organic and plastic materials at the surface of the filter. Sieved samples were moved into a small labeled container with 5% formalin to be preserved. The preserved samples were analyzed under a microscope at 40x magnification, counted and measured. The micro-plastics were separated into four sizes in order to organize data. This study quantified micro-plastics, extrapolating micro-plastic amounts for the harbor.

Figure 6. Photograph of sieve (100 μm) used for plankton and micro-plastic separation. Photograph taken by CJ O'Brien.

3.2 Quantification Methods

The total amount of floating plastic particles in the harbor was calculated. Data determined that there were 1.353 plastic particles/linear km. This number was multiplied by

2000 to extrapolate km^2 [net diameter (0.5m) determined transect width]. Thereafter, this calculation was multiplied by the estimated harbor area:(πr^2) = 63. 585km2. In total, it is estimated that 172,061plastic particles are at the sea surface in the Stone Town Harbor area.

3.3 Plastic Sampling in the Terrestrial Space of the Harbor

Terrestrial visual plastic surveys were completed using standard line transects. Each transect was deployed along the low, middle, and high tide lines of the site's beach, where plastic accumulates. All transects were conducted during low tide. A 0.5 m square quadrat was placed every 10m along the transect and plastic presence and abundance was determined. Plastics were counted, measured, and their known uses recorded (e.g. water bottle, clothing, or fork). The plastic was separated into four size classes to organize the data. The frequency of plastic was quantified as well as its types. Other observations, such as tide, weather conditions, and human presence were also recorded. This supplementary study quantified plastic on human impacted islands. The total amount of plastics found on coastal beaches was not extrapolated to the entire harbor coastline.

Figure 7. Photograph of quadrat (0.5m) used to quantify terrestrial plastic. Photograph taken by CJ O'Brien.

4.0 Results

Micro-plastic surveys produced quantitative data for overall floating plastic particle estimations, while coastal terrestrial beach surveys produced supplementary data to strengthen project interpretations. Additionally, the leader of an NGO seeking to reduce plastic waste in Stone Town was interviewed to investigate potential plastic mitigation strategies. This interview examined the challenges and successes. The three data sets contribute to a thorough preliminary assessment of plastic in the Stone Town Harbor area.

4.1 Micro-plastic Sampling in the Aquatic Space of the Harbor

Table 1 illustrates the sites, transect numbers, distances covered, and particle counts for each transect. The mean of all samples was 1.353 plastic particles/linear km. Figure 8 illustrates the abundance of micro-plastic found at each site. Plastic was found in 94% of the 18 samples taken. As illustrated in Figure 8, both Stone Town sites had the highest amount of micro-plastic followed by Pange Sandbar. Stone Town Site 1 contained 23 plastic particles, Stone Town 2 Site (14 plastic particles), Pange Sandbar (14 plastic particles), Bawe Island (7 plastic particles), Changuu Island had (11 plastic particles), and the middle of the harbor contained

Site	***Sample***	***Length (km)***	***Particle Count***
Pange	1	3.42	10
Pange	2	4.77	1
Pange	3	3.03	3
Bawe	1	5.82	2
Bawe	2	5.30	3
Bawe	3	5.18	2
Changuu	1	4.77	4
Changuu	2	4.69	5
Changuu	3	5.26	2
Middle	1	3.17	0
Middle	2	1.79	7
Middle	3	3.18	2
Stone Town	1	1.69	12
Stone Town	2	.16	10
Stone Town	3	2.29	1
Stone Town	4	.439	4
Stone Town	5	1.88	2
Stone Town	6	.876	8
Average		3.20	4.33

Table 1. Table illustrating micro-plastic site, number, distance covered, and particle count of each transect.

9 plastic particles. Island (7 plastic particles), Changuu Island had (11 plastic particles), and the middle of the harbor contained 9 plastic particles.

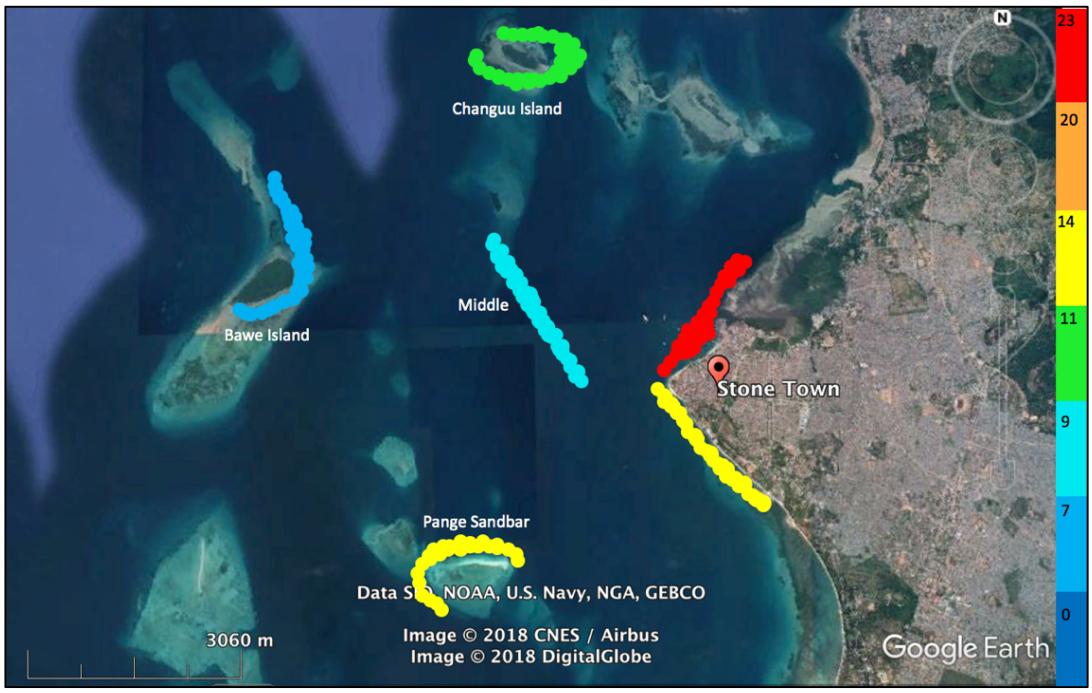

Figure 8. Color coated map illustrating micro-plastic abundance at each site.

Figure 9 illustrates the size class distribution of plastic particles collected. Sizes ranged from <0mm to >5.1mm. The size class ranging from 2mm-5.1mm was highest in abundance (35%) followed by nearly microscopic plastic ranging from <0mm-0.5mm (27%). Particles greater than 5mm considered macro-plastics consisted of 20% of plastics found, subsequently particles ranging from 0.51mm-1.99mm consisted of 18%.

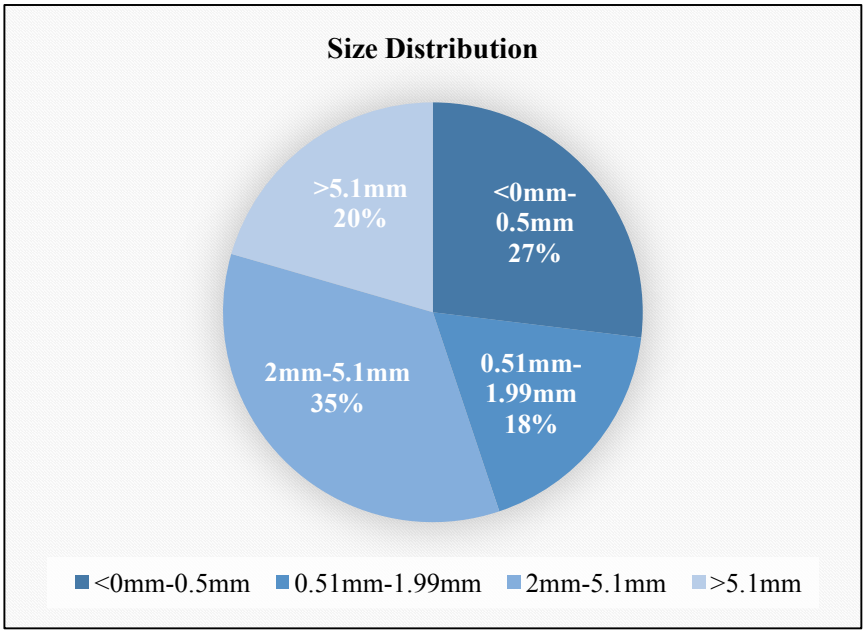

Figure 9. Graph illustrating size class distribution of micro-plastic particles found at the sea surface.

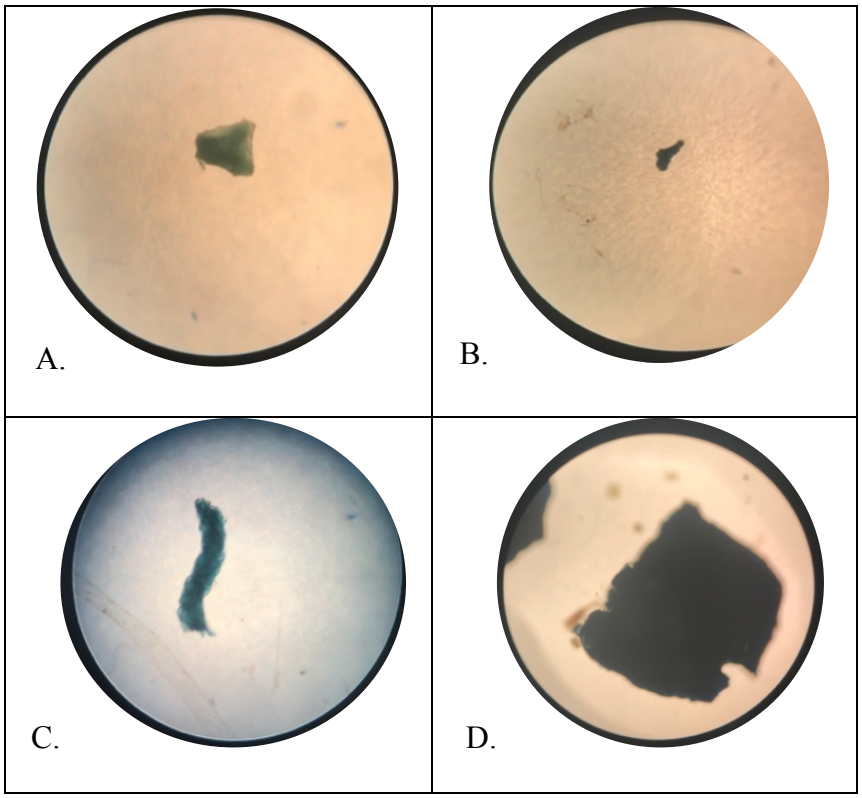

Table 2. Table illustrating various plastic particles under the microscope (40x magnification). A (2mm), B (0.5mm), C (1.8mm), D (4.1mm). Photographs taken by CJ O'Brien.

Table 2 illustrates various plastic sizes under the microscope. While some were determined to be macro-plastics, most were micro-plastics. Pictures A, B, and D are plastic fragments, while C is a fragment of plastic rope material.

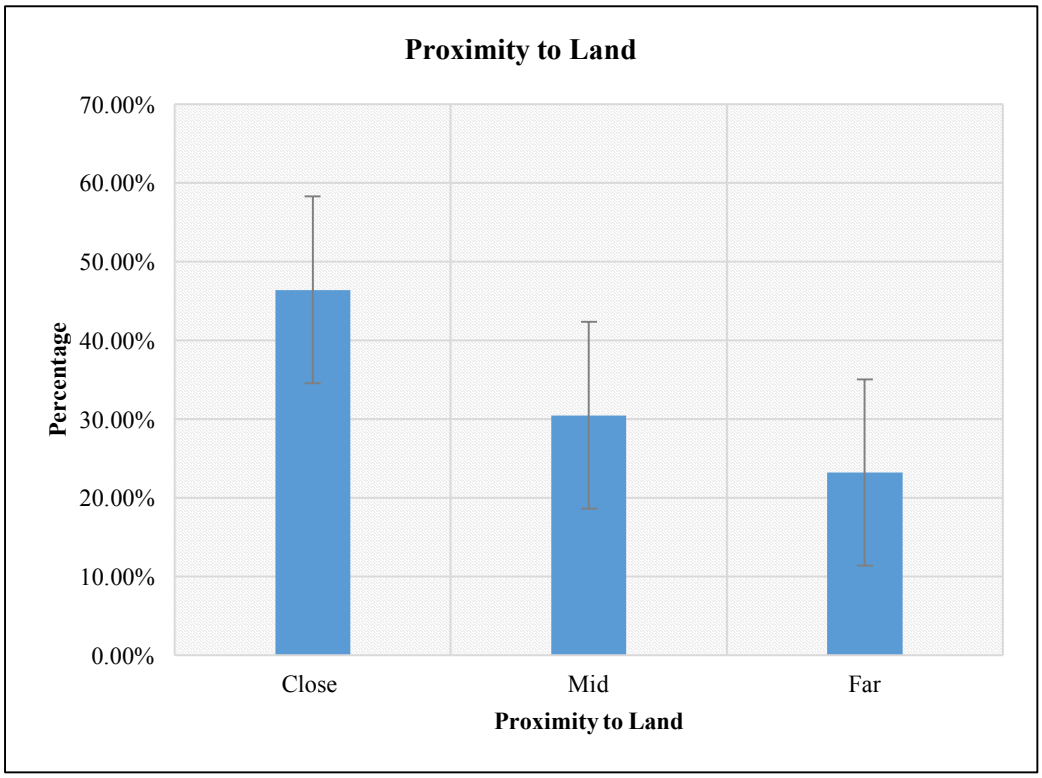

Figure 10. Graph illustrating the abundance of plastic in correlation with proximity to land. (+/- standard error bars are included)

Figure 10 illustrates the abundance of plastic in correlation to proximity of land in samples. The samples taken in the middle of the harbor are not represented in from this figure because no landmass was in proximity. Plastics that accumulated close to land consisted of 46.38%, 30.43% accumulated mid-distance from land, and 23.19% accumulated far from land. Although a small sample size and lack of normal curve prevented a t-test, the bar graph indicates a meaningful variance. There was a noteworthy difference in plastic abundance from samples

close to land and samples mid-distance. However, there was an even greater difference of plastic abundance in samples close to land compared to those farthest from land.

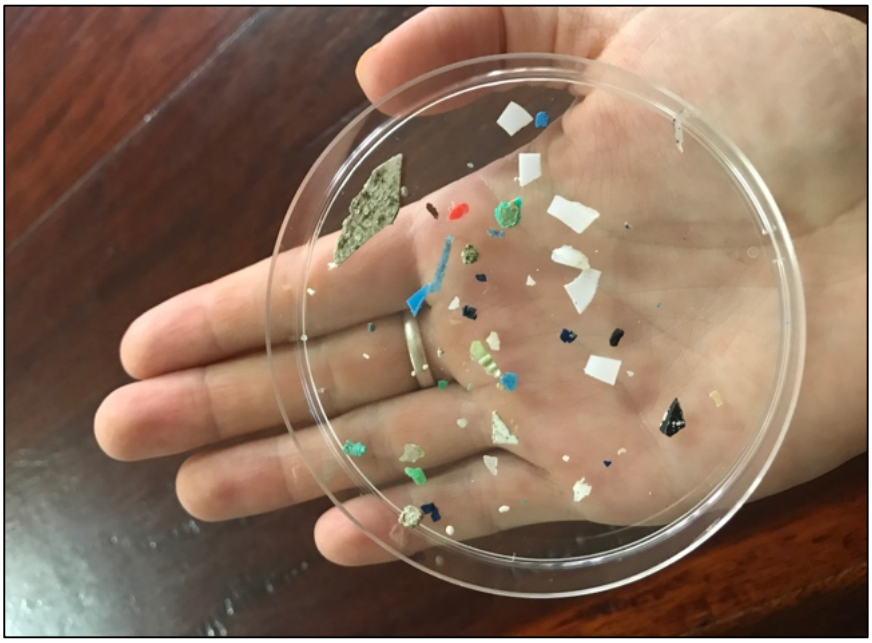

Figure 11. Photograph illustrating micro-plastic particles taken from the Stone Town Harbor area. Photograph taken by CJ O'Brien.

4.2 Plastic Sampling in the Terrestrial Space of the Harbor

Figure 12 illustrates the abundance of plastic at each site. Plastic was found in 100% of sites but found in 64.76% of the 210 quadrats surveyed. As illustrated by figure 12, Pange Sandbar and Stone Town Tembo site showed the greatest plastic pollution in terms of number of pieces of plastic. Pange Sandbar contained 134 plastic particles, Stone Town Tembo site contained 133 plastic particles, and Stone Town Forodhani site contained 123 plastic particles.

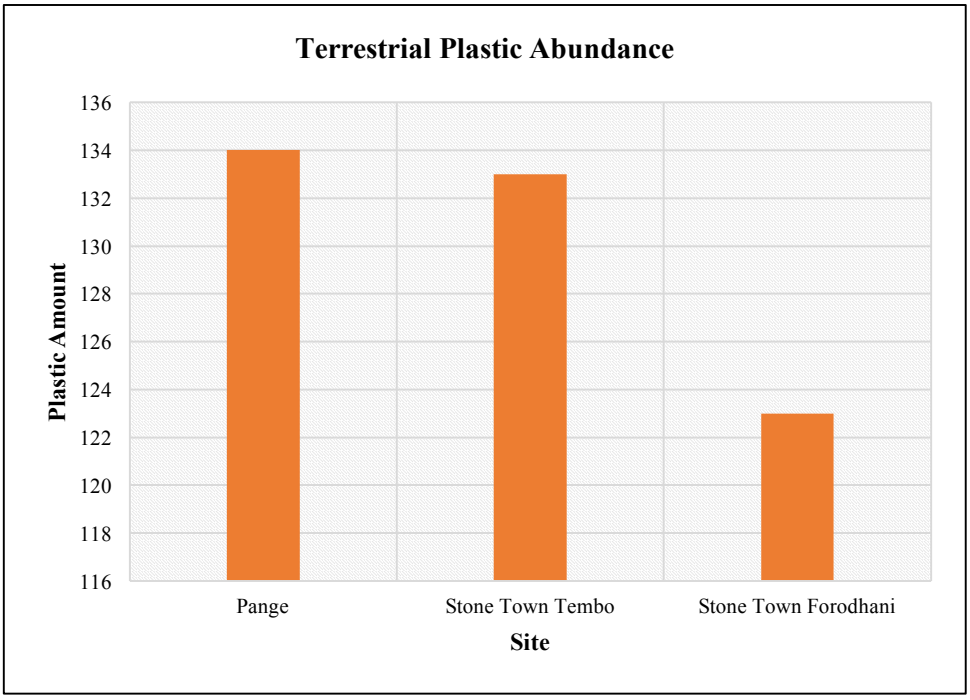

Figure 12. Graph illustrating the abundance of terrestrial plastic at three beaches in the Stone Town Harbor area.

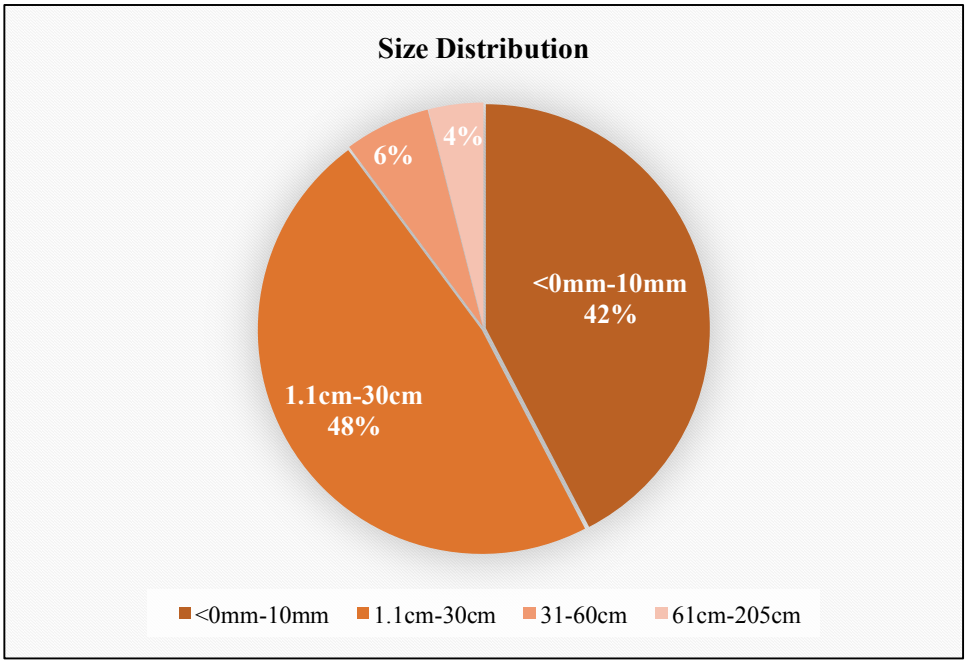

Figure 13. Graph illustrating the size class distribution of terrestrial plastic found at three beaches in the Stone Town Harbor area.

Figure 13 illustrates the size class distribution of plastic particles collected. Sizes ranged from <0mm-205cm including both micro-plastic and macro-plastic. The micro-plastic and small macro-plastic size classes (<0mm-10mm and 1.1cm-30cm) were in highest abundance with 42% and 48%, respectively. The large size classes (31-60cm and 61-205cm) yielded fewer plastics: 6% and 4%, respectively.

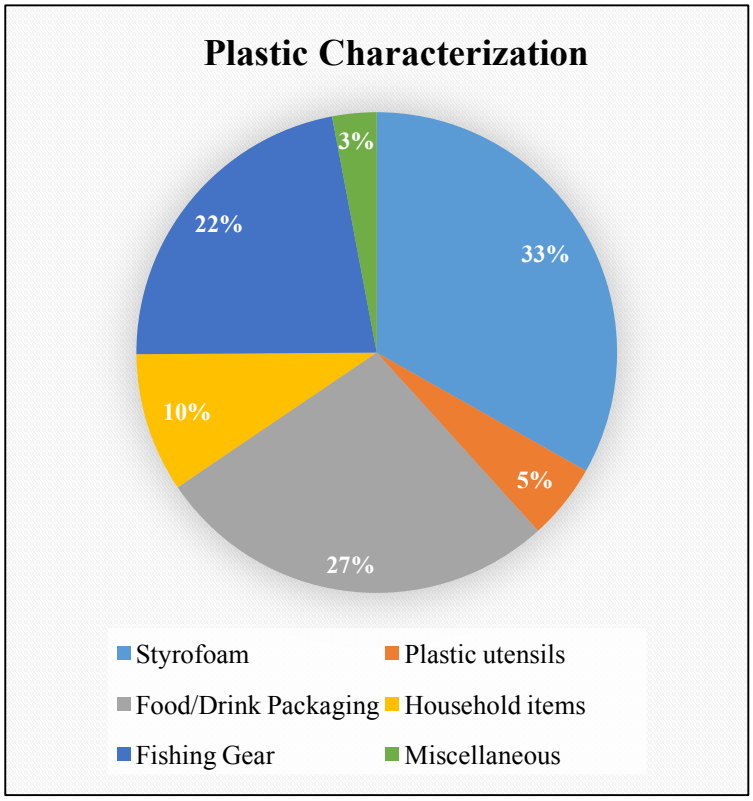

Figure 14. Graph illustrating the commonly found plastic types separated into six classes.

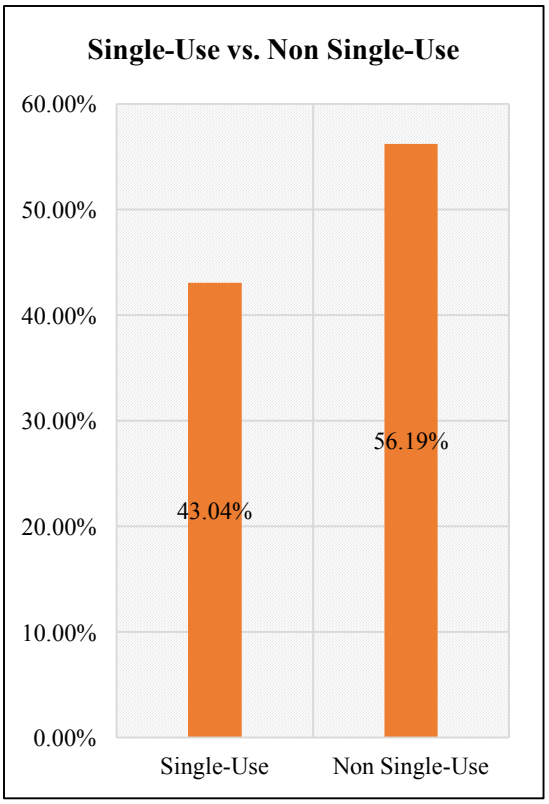

Figure 15. Graph comparing single-use and non-single-use plastic items.

Figure 14 illustrates 26 specific categories, broken down into six classes.: Styrofoam (33.19%), food/drink packaging (27.23%), fishing gear (22.13%), household items (9.36%), plastic utensils (5.11%), and miscellaneous (2.98%). Figure 15 illustrates a comparison of single-use to non-single-use items. The total amount of plastic within the three sites included 388

plastic pieces, from which 170 single-use items were found. Single-use items constituted 43.81% of plastic found, while non-single-use items comprised 56.19% of plastic found.

Figure 16. Photographs illustrating the three beaches surveyed. Left to right: Stone Town Forodhani Site, Stone Town Tembo Site, and Pange Sandbar Site. Photographs taken by CJ O'Brien.

5.0 Discussion

This is the first study to quantify plastic in the Stone Town Harbor area. It is clear that current waste management practices are insufficient. In support of hypotheses, data show a consistent presence of plastic pollution in both marine and coastal environments. Micro-plastic

was found in 94% of sea surface samples and plastic was found in 64.76% of coastal beach survey quadrats. There are many explanations for why an overwhelming amount of plastic pollution concentrates in this area.

5.1 Micro-plastic Sampling in the Aquatic Space of the Harbor

It is calculated that there are 172,061 floating plastic particles at the sea surface in the Stone Town Harbor area. However, this may be an underestimate due to many geophysical factors, to wit: "Wind-driven mixing of the surface layer will drive particles downward, which causes underestimations of plastic in the ocean if relying on surface sampling only." (Erikson, Marcus, et al. 2014). While it is only an estimation, the data show the magnitude of micro-plastic presence and impact in this marine ecosystem. This many particles in the water column could have serious health impacts on marine species in the area. Micro-plastic will only proliferate if the population continues to increase without a change in disposal practices. In general, the projected population in the municipality is 2.9 million by 2025 with municipal solid waste generation per capita of 0.55kg/capita/day (World Bank, 2012 cited in Achankeng, 2003).

Micro-plastic has been thoroughly studied in recent years and the repercussions of its effects are coming to the attention of states and citizens. It is known that plastic never fully degrades. In fact, it only increases in influence due to "UV radiation, chemical degradation, wave mechanics, and grazing marine life" (Sebille et al. 2015). The size class data in this study suggest that most of the plastic within the harbor has been degraded. The size class that ranges from 2mm-5.1mm was in highest abundance (35%) followed by nearly microscopic plastic that ranges from <0mm-0.5mm (27%). If the majority of plastic in the harbor is nearly microscopic, then marine creatures are susceptible to ingesting plastics. Marine birds, mammals, invertebrates, and

fish species are all vulnerable to this pollutant. Plastic causes negative socioeconomic impacts as well. If the marine animals consume plastic, so will humans that consume these resources. This will in turn effect the livelihoods of artisanal fisherman and limit food resources for people who rely on the harbor. Micro-plastic has become a "silent killer" due to its poorly known presence (lack of visibility) and lethal effects.

Observations show that the most heavily populated sites had the highest micro-plastic concentrations. Stone Town, with a population of about 100,000 people and about 300,000 foreign visitors a year, is the primary contributor to pollutants in the harbor area. Pange Sandbar is the site with third highest concentration of plastics. Tourist vendors frequent the sandbar daily providing guests with meals that use plastic utensils. Subsequently, Changuu Island, the site with fourth highest concentration has a hotel, restaurant, and a tortoise exhibit that bring an influx of visitors. The sites with lower plastic concentrations included Bawe Island and the middle of the harbor. Bawe Island is a small island with few permanent residents. The data support the hypothesis that human impacts are the leading causes of micro-plastic accumulation. Population size in this coastal environment is proportional to the micro-plastic abundance in a localized area.

While plastics are known to travel across the world's oceans eventually aggregating in ocean gyres, the plastic in the harbor area congregates near landmasses. It is believed that plastic traveled using the SE monsoon winds and eventually stopped at a landmass. This projection is supported by consistent high concentrations of plastics at landmasses. This is apparent in transect 1 at both Pange and Stone Town 1 sites, which contain 10 and 12 plastic particles, respectively. Additionally, comparative analysis shows a difference between plastic abundance samples near landmasses and those samples far from landmasses. Even though small sample size and lack of a

normal curve prevented a t-test, the bar graph (Figure 10) indicates a meaningful variance: 46.38% of plastics accumulated close to land, 30.43% accumulated mid-distance from land, and 23.19% accumulated far from land.

A previous SIT student studied water quality in Stone Town, "the fact that all of the samples' ENT means greatly exceeded 104 cfu/100 mL clearly demonstrates that Stone Town's waters are highly polluted and should not be used for recreational purposes." While this predominantly tested a sewage contamination, the results could have been influenced by high plastic pollution that emitted toxins.

In addition, tide influxes could contribute to plastic movement within the harbor. Low tide could cause plastic to accumulate toward the middle of the harbor, while high tide produces plastic spread out along landmass edges. Since all of the samples were taken at high tide, this could pose an important future study question.

An alternative conclusion, is that micro-plastic travels to the Stone Town harbor area from other highly populated areas, such as Dar es Salaam especially during SE Monsoon winds that flow south to north. It is more likely; however, that plastic would flow from Dar es Salaam to southern Pemba. However, with a population of 4,364,541 it is likely that plastic waste from Dar es Salaam also impacts Stone Town harbor. Plastic movement is determined by many geophysical factors and it is not accurate to assume that no plastic in the harbor area is arriving via alternative areas.

5.2 Plastic Sampling in the Terrestrial Space of the Harbor

Coastal terrestrial surveys showed a total of 390 plastic pieces. Plastic was found at 100% of sites, but found in 64.76% of the 210 quadrats surveyed. These surveys were taken as supplementary data to further prove micro-plastic hypotheses. Data show that highly populated

areas contain high plastic pollution. Pange Sandbar produced 134 pieces, Stone Town Tembo site 133 pieces, and Stone Town Forodhani 123 pieces.

Although Pange Sandbar is not an island with permanent residents, data show that the human impact is great at this location. Tides and weather conditions greatly impact plastic presence on the sandbar. On days with high wind, plastic was scarce and during high tide, the sandbar nearly vanished. This supports the hypotheses that pollution directly enters the ocean due to poor plastic disposal. If citizens leave waste on the sandbar without returning it to Stone Town, the waste will enter the ocean. This further explains why Pange Sandbar had such high micro-plastic concentrations.

It is apparent from the coastal terrestrial surveys that Stone Town is plagued with plastic pollution. Stone Town is the most heavily polluted area within the harbor. From observations, it is theorized that there is a lack of awareness and lack of proper practices to prevent plastic pollution. This supports the hypotheses that pollution is directly entering the ocean due to lack of appropriate plastic disposal. If citizens and tourists litter or improperly dumb waste, it directly enters the ocean or accumulates in urban areas.

The size class data taken on coastal beaches suggests that most of the plastics within the harbor have been degraded. In agreement with micro-plastic data, the small size classes produced the highest plastic concentrations. The micro-plastic and small macro-plastic size classes (<0mm-10mm and 1.1cm-30cm) were in highest abundance: 42% and 48%, respectively. Similarly, plastic fragments (unidentified pieces) were the most frequent category found on coastal beaches. Fragments accounted for 48.07% of the total plastic types. Data show that large plastic pollution is not being recycled but instead broken down into smaller plastic pieces.

Coastal terrestrial beach surveys were unique in that they illustrated the abundance of specific plastic types. The known plastic usage was recorded for each plastic piece found. There were 26 specific categories, broken down into six classes. Plastic fragments were omitted from this statistic due to the lack of specific use identification. Styrofoam accounted for 33.19% of plastic data. It is known that Styrofoam products never biodegrade and that the production creates the largest carbon footprint among plastics. The high quantity of Styrofoam will increase toxicity of coastal waters in the harbor area. Subsequently, food/drink packaging was the second most common plastic type. If citizens and tourists reduced their use of packaged foods, it would greatly mitigate plastic pollution, by up to 27% (based on findings). Similarly, eliminating plastic utensils would reduce plastic waste by 5%. There are many steps that citizens and visitors could implement to alleviate plastic abundance in Stone Town.

Single-use plastics are plastics that are only used once before being thrown away. These items include plastic bags, straws, water bottles and most food packaging. The total amount of plastic within the three sites included 388 plastic pieces and out of that total, 170 single-use items were found. Single-use items in this study included plastic forks, plastic plates, plastic bags, wrappers, bottle caps, plastic bottles, Styrofoam, plastic lollipop sticks, cap seals, and plastic cups. Single-use items included 43.81% of plastics found while non single-use items included 56.19% of plastics found. Based on data, if the population increased reusable items in their everyday lives, it would eliminate plastic by 43.81%.

5.3 Zanrec Plastics Ltd. Interview

An interview with Zanrec Plastics Ltd was conducted on April 23. This interview was set up by appointment with Justin Mado, an employee for the organization. Zanrec Plastics Ltd is a private company that aims to introduce recycling education in Zanzibar and to reduce pollution

on the island. When asked about the source of the plastic pollution problem, Justin Mado explained that it lies in weak infrastructure. The Zanzibar Municipality only works within Stone Town and is overwhelmed by the amount of waste produced. He explained that most of the plastic pollution comes from the tourism industry since local communities typically cannot afford items such as filtered water in plastic water bottles.

Zanrec is doing the best it can to mitigate plastic waste, and claims to be the only recycling center on the island. Zanrec trains hotels that become "Zanrec certified" on waste separation techniques and in return acquires income through these contracts. Zanrec also reaches out to local communities and villages. They visit schools to explain the importance of throwing trash away properly and avoiding the use of plastic. They teach how to separate plastic, glass, and organic waste so that there is no contamination. Once the waste is separated, it is brought to a collection point where Zanrec gathers the trash to bring back to their facilities. However, Zanrec faces many challenges. Their collection trucks are too expensive to reach Stone Town and no formal landfills exist that are in close proximity. Zanrec works with 60 out of approximately 400 hotels and 3 districts out of 11 total. At the moment, the transfer site does not have electricity so the waste is bought by an agent who shreds the waste, and then sends the recyclable materials to Dar es Salaam. This company feels as though its work has been successful. Zanrec has noticed that informal dump sites in participating villages have decreased. They plan to get electricity in the future so shredding can occur on site.

When asked about possible recommendations to reduce plastic waste, Justin Mado explained that education as well as improved infrastructure is needed. He said that since most people do not know about the longevity of plastic or how to separate waste, education programs

are needed so more people do their part. He explained that there should be more formal landfills, different bins for separation, taxes on plastic products, and a fine for littering.

5.4 Study Limitations

Due to a short time period, methodology limitations, and weather there were many influence that could have skewed results. Most microplastic studies state to tow the plankton net on the side of the boat to avoid down welling debris. However, the type of boat used for this study did not have an outrigger or pole to attach the rope to the side of the boat. Samples were thus collected behind the boat. Although the net was positioned to the side of the wake while being towed in the back, the results might have been improved if tows were done on the side. The net used was picked due to accessibility. Some microplastic studies use mesh sizes as small as 300µm. This study used a mesh size of 150µm, meaning that smaller particles could have escaped the net while sampling. Additionally, GPS waypoints taken at micro-plastic sites could have errors. Occasionally, waypoints were taken prematurely during times when the plankton net was being set-up. This could produce transect lengths longer than estimated, impacting average transect length data. This study was done using a standard microscope with no measuring scale to measure microplastics less than 0mm. Instead, a size class was created for those objects too small to measure. In addition, some microplastics could have been missed due to their extremely small size which could have been seen with more advanced microscope equipment. Additionally, this study was done during the rainy season which could contribute to the water logging floating plastic, causing sinking to occur.

6.0 Conclusion

It is vital for the government and communities of Zanzibar that the coastal ecosystem within the Stone Town harbor area is healthy for socioeconomic and ecological reasons. Consequently, in a developing coastal city, such as Stone Town, where population, consumerism, and urbanization continue to increase, so too will plastic pollution increase. An absence of plastic waste awareness and proper mitigation strategies will cause mismanaged plastic to directly enter the ocean in vast quantities. Once plastic enters the environment, it never fully degrades, only decreasing in size. These small plastic particles or micro-plastics are a major problem. If awareness about visible plastic is deficient, the dangers of pollutants that are unseen is an environmental crisis. Micro-plastic could have negative implications for all marine life due to involuntary ingestion. However, not only marine biota is unwillingly ingesting plastic. If humans consume resources subjected to plastic, they become subjected as well. Nearly microscopic contaminants could create a cascading relationship that damages fisheries, food resources, eco-tourism and the livelihoods of people in the Stone Town Harbor area.

Based on quantitative data, there are approximately 172,061 floating micro-plastic particles in the Stone Town Harbor area. Data shows a consistent presence of plastic pollution in both marine and coastal environments. Micro-plastic was found in 94% of sea surface samples and plastic was found in 64.76% of coastal beach survey quadrats. Furthermore, micro-plastic was consistently found to accumulate in higher concentrations near landmasses. These data indicate that plastic traveled via Southeast monsoon winds and eventually stopped when a landmass was reached. However, there are many geophysical factors that govern how micro-plastic travels in the ocean that were not assessed in detail in this study. Additionally, commonly found plastic categories were analyzed, illustrating that eliminating single-use plastic would

decrease plastic in Stone Town by 43%. If proper waste separating strategies, recycling practices and infrastructure development were implemented, plastic waste would diminish in the Stone Town harbor area substantially. Nothing can be done without appropriate education. By quantifying plastic amounts in the Stone Town harbor area this study provided crucial baseline knowledge that will contribute to the conservation of natural resources and plastic waste awareness.

7.0 Recommendations

The current plastic waste situation in the Stone Town Harbor area is deficient. In order for plastic to be reduced, changes must be made. From observations, quantitative data, and interviews with possible mitigation organizations, recommendations have been made. These include future studies, recommendations for Stone Town Municipality, and recommendations for individuals.

7.1 Future studies:

Since this study was a preliminary analysis, more baseline knowledge needs to be completed in order to gain a more accurate depiction of plastic pollution in the harbor. Repeating these methods during all tides, at more locations, and more transects may give a better understanding of how plastic moves in the harbor and at what abundance. It would also be crucial to perform this study during the dry season, in case water logged plastic caused underestimations to be made. For more broad implications, this study could be performed on the coast of Dar Es Salaam or southern Pemba to see how plastic is moving throughout the entirety of the Zanzibar archipelago. Additionally, a holistic approach to marine debris is needed by looking at microplastic effects of the physiology of marine life. This would include dissection of fish species that are being consumed by the community, mussels used for aquaculture farms,

sponges used in sponge farms, and sea birds to analyze microplastic within their digestive tract or tissues. For the future, these study recommendations would increase knowledge and raise awareness of the negative impacts plastics have on marine life, thus causing negative impacts on human health, economy, and resources.

7.2 Recommendations for Stone Town Harbor Area:

From my observations, plastic waste could be mitigated in Zanzibar by prioritizing, educating, raising awareness, and getting started on proper infrastructure. Adding more waste bins around Stone Town would be helpful. Sometimes waste bins are not seen for many kilometers which in turn, promotes littering. Proper infrastructure requires money, which can be collected by putting taxes on water bottles or other single-use plastic products. An example of this would be to give 5% of water bottle revenue to create proper landfills, provide separation bins, and hire waste management staff in the municipality. There could also be a fine for those who litter in the streets instead of properly throwing trash away.

Education on proper separation techniques is crucial in the step towards recycling plastic products. Bins given to communities labeled “plastic”, “organics”, and “glass” would help waste collectors and recycling centers such as “Zanrec Plastics limited” dispose of plastics properly.

Since recycling centers are not easily accessible, using plastic to make alternative resources is another way to mitigate plastic pollution. Organizations such as “Creative Solutions” located in Mangapwani create art pieces and drinking cups from discard, while also providing educational services about recycling. A fundi named Laurian Mchau, with “Windmill Enterprises” in Dar Es Salaam, uses plastic buckets as pots to grow food resource crops in an urban setting, plastic bottles to create water purification systems, and scrap metal to construct windmills. A group at Mnarani Marine Turtle Conservation Pond uses plastic to create bricks for

building homes. Ideas like these implemented in Stone Town would help alleviate plastic pollution. This problem can be addresses with innovation and approaches to sustainability. Waste management as a whole must be thought of as an integrated problem that impacts the health of natural systems as well as the people of Zanzibar. One overall initiative of importance would be to "add waste management to the Integrated Coastal Area Management (ICAM) to provide the best long-term plan and sustainable use of coastal resources without threatening its natural environment through such adverse impacts as those posed by pollution" (Mohammed, 2002: 38).

It is known that while tourism adds to the economy in Stone Town, it also increases the amount of plastic waste produced. Eco-tourism can be a successful business in the Stone Town harbor area. If tourism companies were to capitalize on no-waste strategies, it could potentially bring in more clients, thus increasing revenue. An example of this is Chumbe Island, which successfully makes income from tourists who prioritize eco-friendly lodging. If hotels worked hard to recycle plastic waste or become "Zanrec certified," they could advertise this to tourists who prefer sustainability. In regards to Pange Sandbar, tourism companies should not be allowed to use plastic utensils to serve food on the island and instead should use reusable items. This would show tourists the town's commitment to sustainability while also decreasing plastic on the sandbar. Education tents for tourists, explaining proper waste disposal could also be implemented on beaches or sandbars throughout Stone Town.

7.3 Recommendations for Individuals:

Plastic waste can often times seem overwhelming. You may ask yourself, what can I do individually to reduce plastic waste around the world? The main culprit of plastic waste is single-use items such as straws, coffee cups, water bottles, and plastic bags. There are many steps that you can take to reduce plastic waste. Politely refusing to use straws at restaurants is one strategy.

Using reusable water bottles, reusable mugs at coffee shops, or bringing reusable bags to the grocery store reduces waste. You can also boycott micro-beads in beauty products by not using them or educate your friends and family on the harm plastic has to the environment. Lastly, you can recycle and participate in beach cleanups.

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