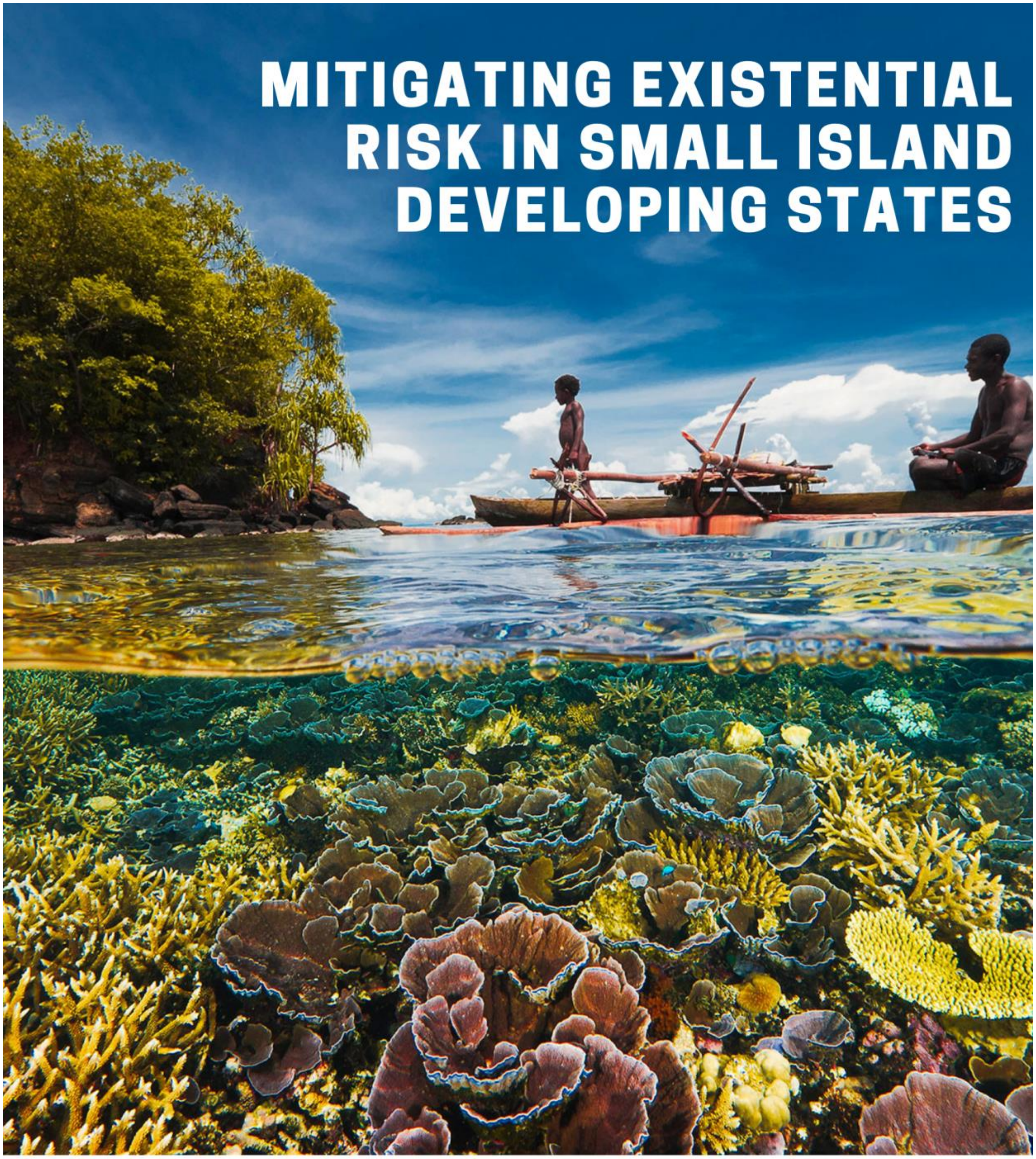

TEAM MEMBERS: KATIE BLANN, KELSEY HARTFELDER, ANNA JOHNSON, KENISHA JOHNSON, PWINTPHYU NANDAR, GRANT SUGIMURA, SAMANTHA WU

ADVISORS: PETER KAREIVA, JENNIE DEAN, TOMAS OLIVIER

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UCLA IoES WAITT FOUNDATION

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Introduction: Heightened Natural Disasters Pose an Existential Risk for Small Islands

The climate crisis falls unevenly across people and nations. Small Island Developing States (or SIDS henceforth) are among the most vulnerable of all nations in the world when it comes to climate change – so much so that the climate crisis poses an existential threat to many small islands. This extreme risk stems from a combination of geographical isolation, vulnerable infrastructure, low-lying geography, and exposure to tropical storms, typhoons, cyclones, and hurricanes.

On the other hand, oceans surrounding SIDS provide opportunities for enormous economic growth. Currently the global blue economy is estimated to be $1.5 trillion per year (The Commonwealth, n.d.). SIDS have access to this economic potential through their Exclusive Economic Zone (EEZ), which in many SIDS represents an area several times larger than their land area.

These two goals – protecting the environment and growing the economy – are the goals of the “Blue Prosperity Project“ led by the Waitt Institute and Waitt Foundation, in collaboration with over 20 partner institutions.

In this report we focus on risk, especially from natural disasters, and take the first steps towards developing an approach that could be turned into a tool kit for SIDS. The four facets of risk we examined were: sea level rise, general adaptation strategies, disaster risk response, and lifeline planning. We collected risk-relevant information for 4 of the 57 SIDS that exist worldwide, our goal was to make suggestions for how each of these 4 SIDS might reduce their risk and to test a framework for investigating and managing risk in small islands around the world. While many of these risks have been examined separately in many islands, ours is the first research project to consider all four risk dimensions at once and to apply a lifeline analysis to SIDS.

In our initial case study we focused on four SIDS: Bermuda, Curaçao, the Republic of the Marshall Islands (RMI), and the Kingdom of Tonga. These were selected because they both spanned a wide geographical range and were islands of interest to the Waitt Foundation.

Five Case Study Island State Profiles

	Bermuda	Curaçao	Republic of Marshall Islands	Tonga
Island Isolation Index*	91	22	88	103
Political Organization	British Overseas Territory	Autonomy within the Kingdom of the Netherlands	Sovereign state in free association with the United States	Sovereign nation under the United Kingdom with retention of their own Monarchy
Land Area	53.2 sq km (20.5 sq mi)	444 sq km (171 sq mi)	181.43 sq km (70.05 sq mi)	748 sq km (289 sq mi)
Population	70,864	149,648	74,539	106,479
Population Density	1,332/sq km (3,449.9/sq mi)	337 sq km (872.8 sq mi)	411/sq km (1,064/ sq mi)	142/sq km (367/sq mi)
Gross Domestic Product (GDP) overall	$5.853B USD	$2.977B USD	$199.4M USD	$493M USD
Human Development Index (HDI)**	0.981 Very high	0.811 Very high	0.708 High	0.726 High

Table a: Summary of Country Profiles of the Five Case Study Island States.

*Island Isolation Index (Dahl, 2010) is an indicator of an island's distance from the closest source of colonization. The higher the number, the higher the distance from main landmasses. For nations with multiple islands, we recorded the isolation index for the most populated island.

**Human Development Index is used to rank countries into four tiers of human development (low, medium, high, very high), based on the indicators of life expectancy, education, and per capita income. The higher the HDI, the higher the life expectancy, education, and per capita income.

Population sources: see Lifeline Analysis section

GDP sources: see Lifeline Analysis section

Land area source: Integrated Island Database (Dahl, 2010)

This table is an overview of our SIDS (Bermuda, Curaçao, Republic of the Marshall Islands, and Tonga) in comparison to each other. The purpose of the table is to provide an easy means of comparing and contrasting these islands with regards to the following categories: Island Isolation Index, political organization, land area, population, overall GDP, and Human Development Index.

Bermuda

Bermuda is a British Overseas Territory located in the North Atlantic Ocean, approximately 1050 kilometers off the coast of North Carolina. It is self-governing and formulates its laws independently of the United Kingdom, which is mainly responsible for defense and foreign relations. As a colony, the islands and their people have faced the environmental and cultural struggles of imperialism and colonialism.

Bermuda consists of 181 islands, which have a cumulative area of roughly 53 square kilometers and over 64 miles of coastline. With a population of approximately 70,864 people; Bermuda is Britain's most populated overseas territory. The population is dispersed relatively evenly throughout the territory. Bermuda's leading industries are insurance and tourism. Tourism brings in roughly 600,000 people per year, with cruise ships accounting for the largest number of visitors.

Bermuda lies at the edge of the hurricane belt and therefore experiences less hurricane damage than many other SIDS. It is also afforded protection by its surrounding coral reefs.

Curaçao

Curaçao is a single, 62 kilometer long Dutch Caribbean island in the South Caribbean Sea. It lies approximately 70 kilometers off the coast of Venezuela. Curaçao has a maximum elevation of 372 meters, which means sea level rise is not necessarily an existential threat. The island has a population of 149,648 people and a total land area of 443.9 square kilometers, which translates to a population density of approximately 337 persons per square kilometer.

Curaçao is generally sheltered from tropical storms and hurricanes due to its location on the edge of the hurricane belt. However it can experience storm surges, heavy rain, and strong winds. Curaçao has a semi-arid climate with rainy and dry seasons, and is prone to long dry periods and droughts. Similar to other SIDS, the island originated as a result of volcanic activity, has coral reef fringes off of the coast, and is home to high levels of biodiversity.

While the land mass itself may not be as vulnerable to sea level rise, warming oceans threaten Curaçao's natural resources, especially vital coral reef systems which host a variety of fish. These fish are important food sources. Land based natural resources are also at risk, due to elongated dry spells and heavy rain. There is already some evidence that heavy rains are exacerbating the flooding and mudslides experienced in Curaçao (Ministry of Public Health and Environment, 2016).

Republic of the Marshall Islands

The Republic of the Marshall Islands (RMI) is an island nation in Micronesia. It is also a member of the Compact of Free Association with the United States which grants RMI economic assistance, defense, and other benefits. This association also allows most citizens of both countries to live and work in the other country.

Geographically, RMI is composed of more than 1,000 islands scattered throughout the central Pacific. These islands are part of two massive coral atoll systems that run parallel to each other.

RMI has a population of 74,539 people, with approximately three-quarters of the population located in urban centers. Nearly half of the population lives on the capital atoll of Majuro, which has a high point of less than 10 feet above sea level and is particularly vulnerable to sea level rise and storms. The nation encompasses about 181.43 square kilometers and thus has a population density of approximately 411 persons per square kilometer.

RMI has little in terms of natural resources. The nation's main industries revolve around tuna fishing, transshipments, and processing.

An issue unique to RMI is the long-lasting repercussions of American nuclear testing. The Marshallese have experienced health issues stemming from the nuclear fallout of these tests and nuclear waste from these tests is still stored in the islands (Greenpeace, n.d.). The structure that holds this waste has not been upgraded in decades, which means that any storm or rise in sea level could jeopardize its integrity (Greenpeace, n.d.).

Tonga

The Kingdom of Tonga, known as "The Friendly Islands" in Tongan, is an archipelago in the South Pacific. Its geographical location makes it vulnerable to tropical cyclones, while its geology makes it vulnerable to volcanic eruptions.

The nation has a population of about 106,479 and a total land area of about 748.507 square kilometers, although about half of the population lives on the main island of Tongatapu.

There is a significant amount of subsistence farming in Tonga, but urbanization on Tongatapu has decreased available agricultural land (Vaioliti, 2014). Farming is also declining because young Tongans are abandoning the land and moving to cities and other countries in search of better opportunities (MAFFF, 2015). While this farming is important to local food security, it is not an important economic engine for the nation. The greatest contributor to Tonga's economy is money that comes to the island through remittances - in other words, from Tongans who have left Tonga. Within the island, the largest economic contributor is tourism.

Historically many Tongans have lived at higher elevations, removed from the risk of storm surge or sea level rise. But Tongan migration patterns, whereby large numbers have moved to the main island of Tongatapu, have profoundly changed this. The resulting settlement pattern has placed many people in low-lying and flood-prone areas, including coastal areas, where vegetation damage has increased erosion (Government of Tonga, 2018).

Climate change poses many threats to Tonga. The weather is becoming less predictable which makes farming more difficult. Tropical cyclones are projected to become less frequent, but more intense (Tu'uholoaki and Vea, 2013). Sea level rise is causing saltwater intrusion and increased salinity in freshwater, as well as the inundation of previously dry land during storm surges. In some areas, land has been permanently claimed by the sea.

Tropical cyclones pose a significant challenge for Tonga. Many homes and community buildings cannot withstand the strong winds because materials to build to the necessary standards are too expensive.

Transportation infrastructure is also vulnerable to damage during tropical storms. Roads are frequently flooded and port infrastructure has broken down in the past (Government of Tonga, 2018).

Mapping Sea Level Rise and its Risk to Critical Infrastructure

Figure 1: Aerial view of Majuro Atoll, the capital of the Marshall Islands. Photograph by Giff Johnson RNZ news, New Zealand (Johnson, 2019).

Introduction

In this section, we focused on creating maps to demonstrate the threat of sea level rise to our four SIDS. To do this we mapped four different sea level rise scenarios. We improved upon past efforts to evaluate the threat of sea level rise by using newer, more accurate sea level rise estimates, which predict faster rates of rise and therefore greater threat. Each of the scenarios we mapped represents projections for the year 2100.

To produce sea level rise maps, we acquired digital elevation models (DEMs) for each of the four SIDS. DEM data was collected from various sources - we always used the source with the highest resolution data. The full list of DEM sources are available in Appendix I.

After conducting a literature review, we identified four different sea level rise scenarios for the year 2100. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change predicted sea level rise in the year 2100 to be between 0.52m and 0.98m for the "business as usual" scenario (RCP8.5) (Mayer, 2015). Nerem et al. (2018) predicted a more extreme value of 1.3m for the year 2100. Our last and most extreme value of 2.0m of sea level rise, was taken from Pfeffer et al. (2008). Using ArcGIS we reclassified the DEM layers to represent the sea level rise land loss predicted by these four current, peer reviewed scientific sea level rise estimates. For two of the four islands (Curaçao and Tonga), we mapped 1m and 2m sea level rise scenarios and did not include 0.52m, 0.98m, and 1.3m scenarios due to restrictions of the quality of the individual DEMs.

The mapping was done with elevation as the sole input, and not taking into account flow patterns or geographic features that would impact distribution of water, as a result you may see inland areas 'under water' without a clear connection to the ocean (for example Figure 1a-1d for Bermuda).

Sea level rise poses a threat to critical infrastructure on these islands. To this effect, we collected geographic coordinates for hotels, schools, hospitals, government buildings, grocery stores, airports, ports, and desalination plants. All of these constitute critical infrastructure for our SIDS because of their role in the local economy (i.e., hotels, airports, and ports), and in providing access to vital goods and services (i.e., schools, hospitals, grocery stores, and desalination plans).

We used Google Maps to determine the coordinates of critical infrastructure. We searched the SIDS of interest, and used the “nearby” feature in Google Maps to search for the terms “Hotels,” “Schools,” “Hospitals,” “Government,” “Ports,” “Desalination Plants,” and “Grocery Stores.” In the case of desalination plants, Google Maps information was insufficient or outdated. Thus, we conducted a regular Google search of “Desalination Plants (SIDS)” to find websites on water providers and scientific papers to find the remaining plants (Kim-Hak et al., 2015; WaterWorld, 2017; Water & Wastes Digest, 2014). Hotels included both large hotels and smaller informal bed and breakfasts, but we focused on the largest hotels in the area. Sea level rise would cause severe damage to large hotels, making them undesirable or unoperational. The loss of hotels generally lead to the loss of tourists, which would be devastating for the economies of most of these SIDS. Large hotels are typically located on the beaches of these islands, making them one of the first pieces of infrastructure to be affected by sea level rise.

We geocoded the coordinates into points that we could input into ArcGIS. For each SIDS we created a map containing these major points of infrastructure (Figure 1e, Figure 1h, Figure 1m, and Figure 1p). We also created more detailed maps for the capital cities of each SIDS because they are some of the most populous and important cities for each nation. For more detailed methods on mapping infrastructure, see Appendix I.

A critical constraint to our analysis was mapping very low lying areas. We encountered problems while mapping the sea level rise over beach areas because the DEM layers only accounted for pure elevation, a lot of times excluding low lying areas like beaches which are tidally submerged. For this reason some beach front infrastructure may not appear underwater when they actually would be.

Sea Level Rise and Critical Infrastructure Analysis

Bermuda

Bermuda: 0.52 meters of Sea Level Rise

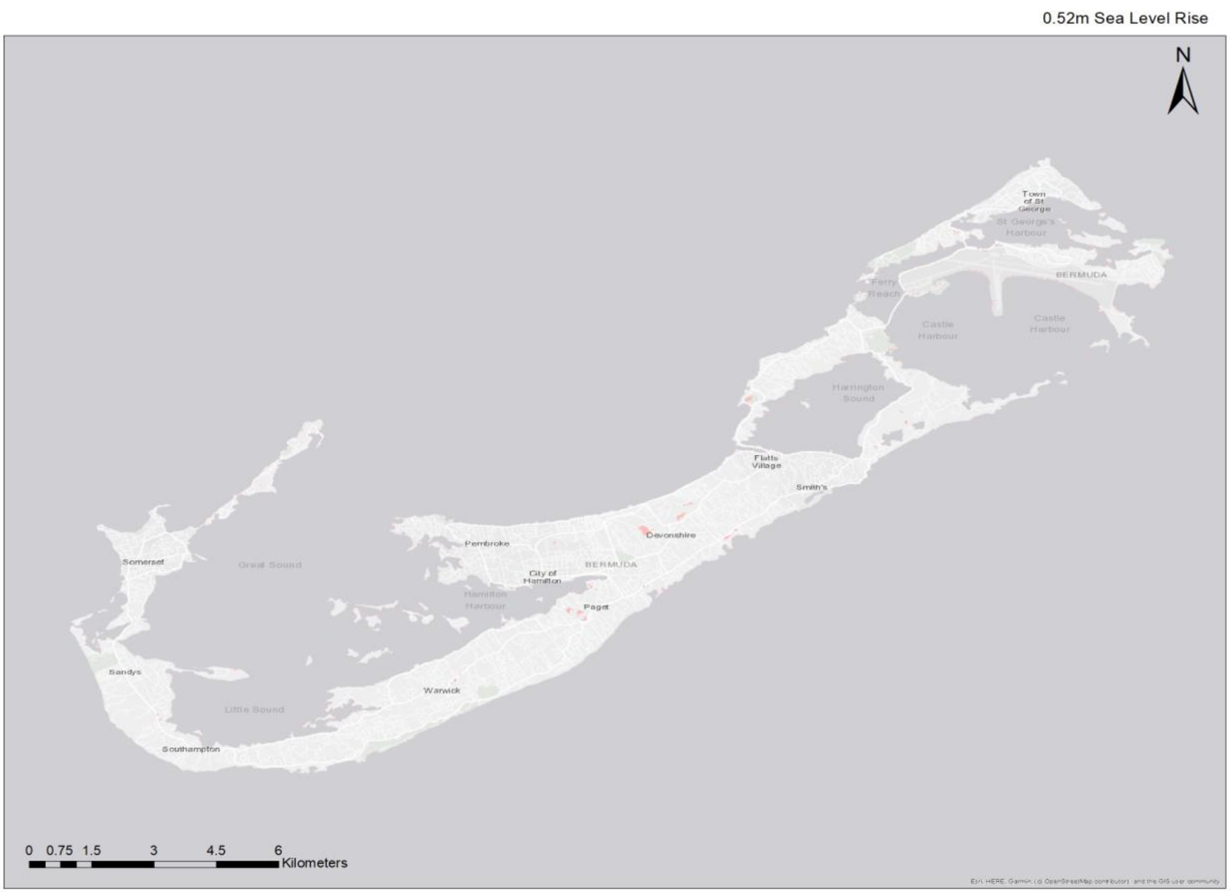

Figure 1a: Map of Bermuda. The light pink represents 0.52 meters of sea level.

Bermuda: 0.98 meters of Sea Level Rise

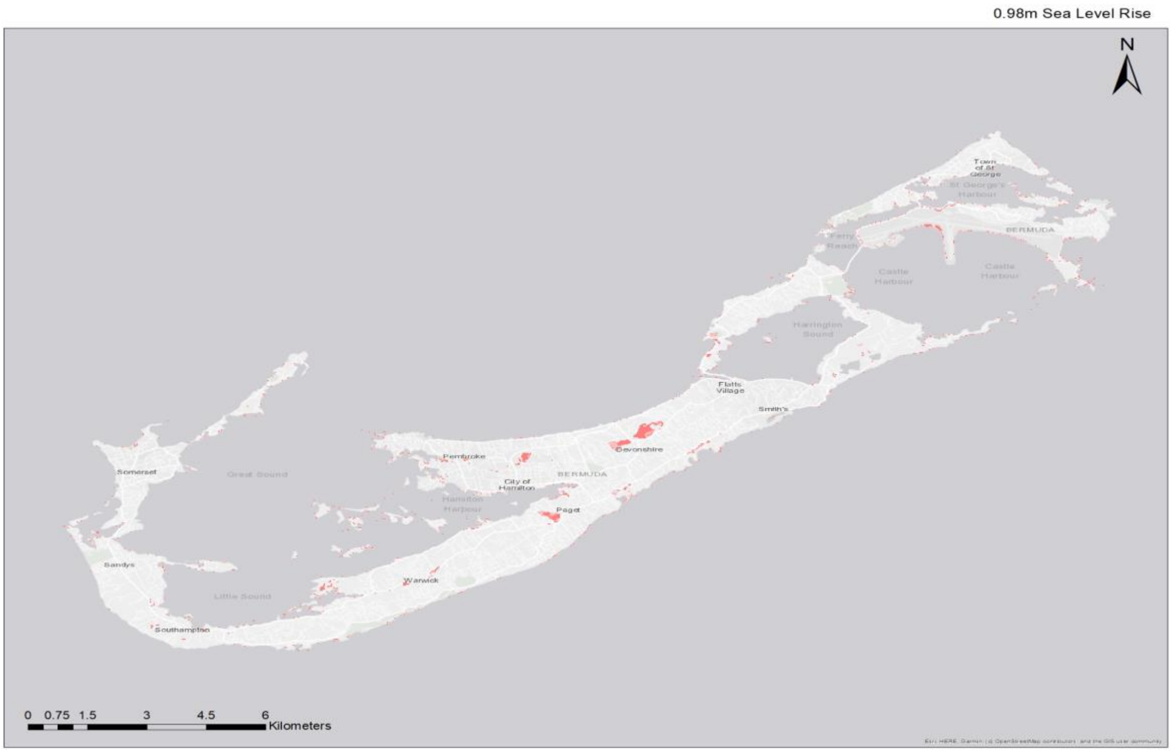

Figure 1b: Map of Bermuda. The red represents 0.98 meters of sea level rise.

Bermuda: 1.3 meters of Sea Level Rise

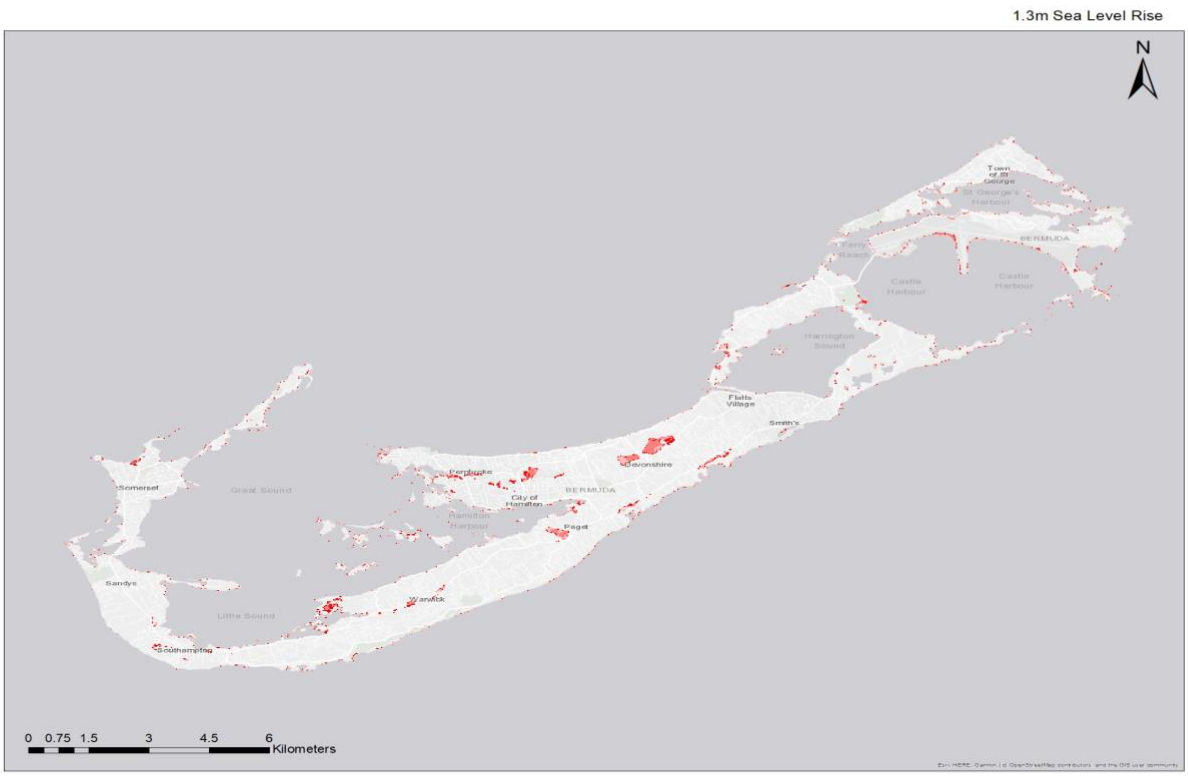

Figure 1c: Map of Bermuda. The red represents 1.3 meters of sea level rise.

Bermuda: 2 meters of Sea Level Rise

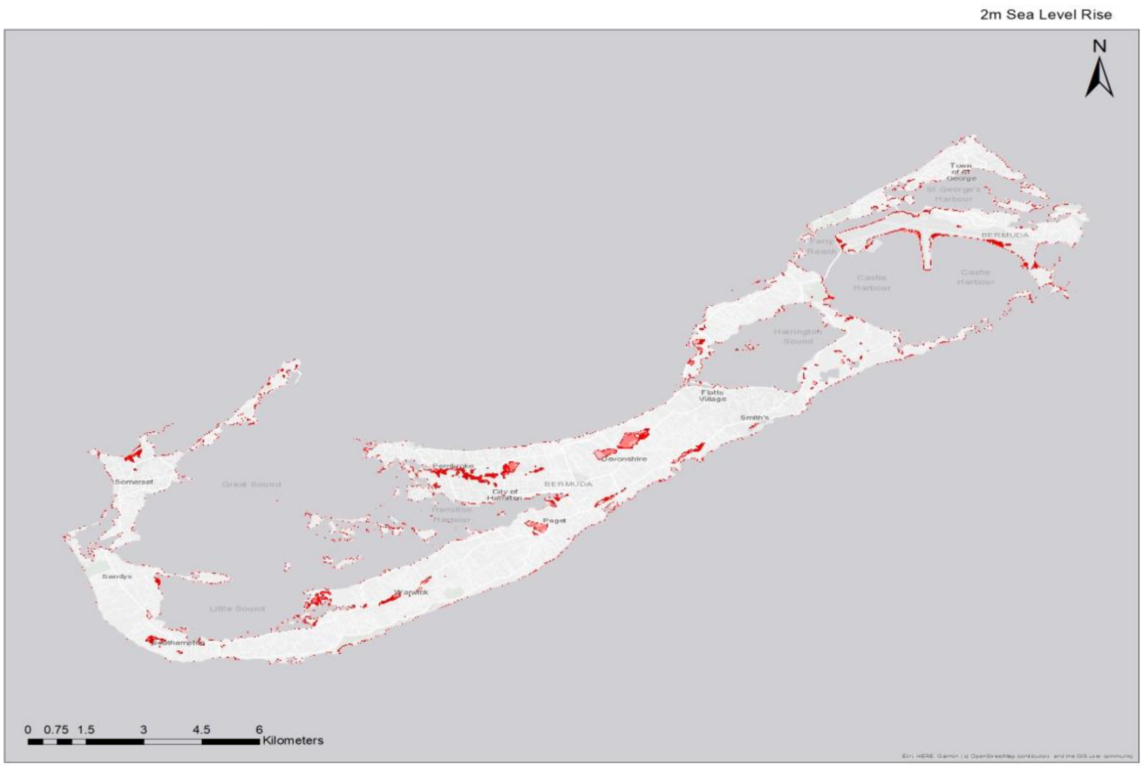

Figure 1d: Map of Bermuda. The red represents 2 meters of sea level rise.

Important Infrastructure and Sea Level Rise Scenarios

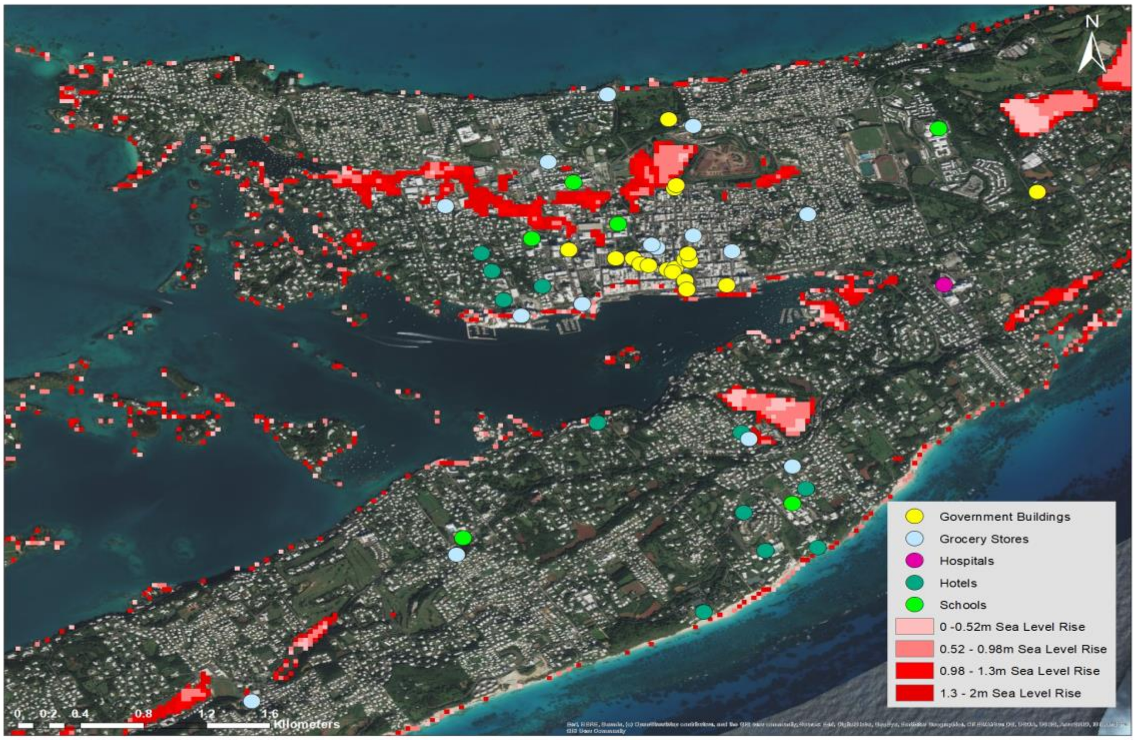

Figure 1e: Zoomed in map of Hamilton in Bermuda. The various points represent important infrastructure on the island.

Sea level rise does not appear to be a significant problem in Bermuda until it reaches the 1.3m level. At the 1.3 meter mark, we begin to see coastline all around the island moving inland. Although these inland areas not immediately connected to the ocean they would still be affected by sea level rise due to storm surge, tidal forcing, and flooding. However, even then critical infrastructure and buildings are largely safe. For example, in the capital city, only 6 of the 51 mapped points appear to be directly affected by sea level rise in the 1.3m to 2m range (Figure 1e).

Schools, most of the government buildings, and the hospital are all situated inland and remain mostly unaffected by sea level rise. This shows that while there are some serious implications regarding sea level rise in Bermuda, most of its critical infrastructure will not be impacted.

Curaçao

Curaçao: 1 meter of Sea Level Rise

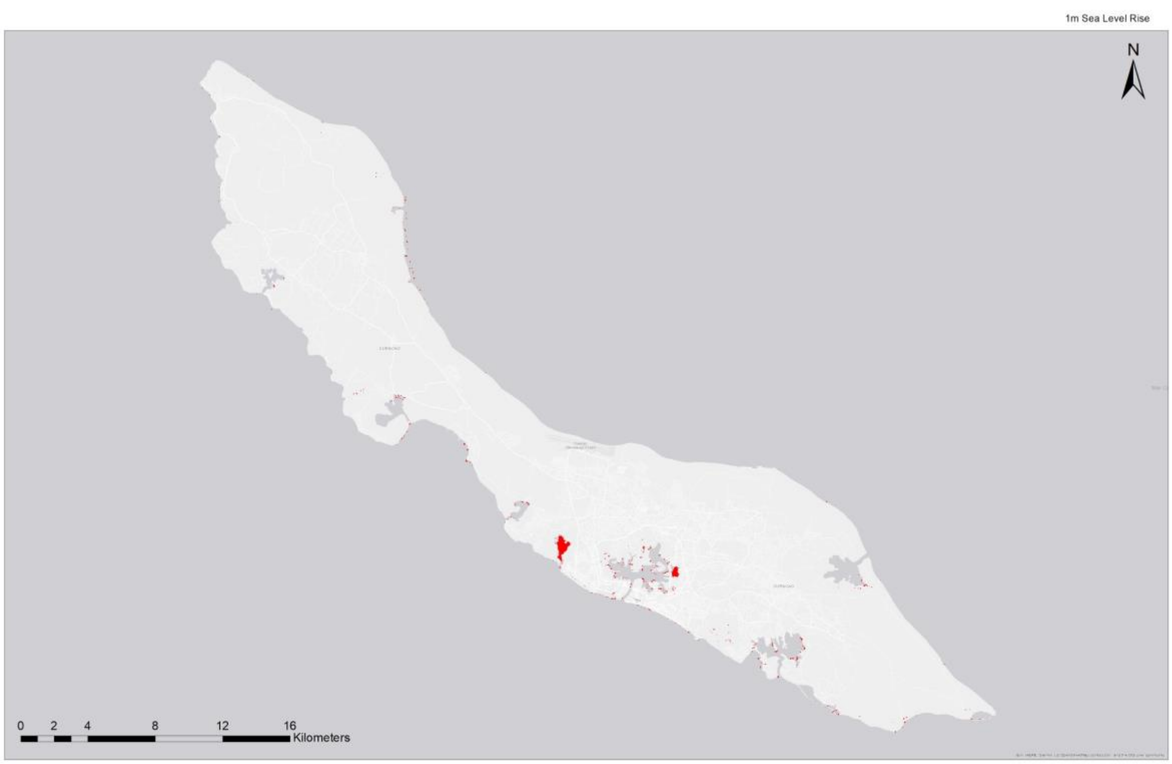

Figure 1f: Map of Curaçao. The red representing 1 meter of sea level rise.

Curaçao: 2 meters of Sea Level Rise

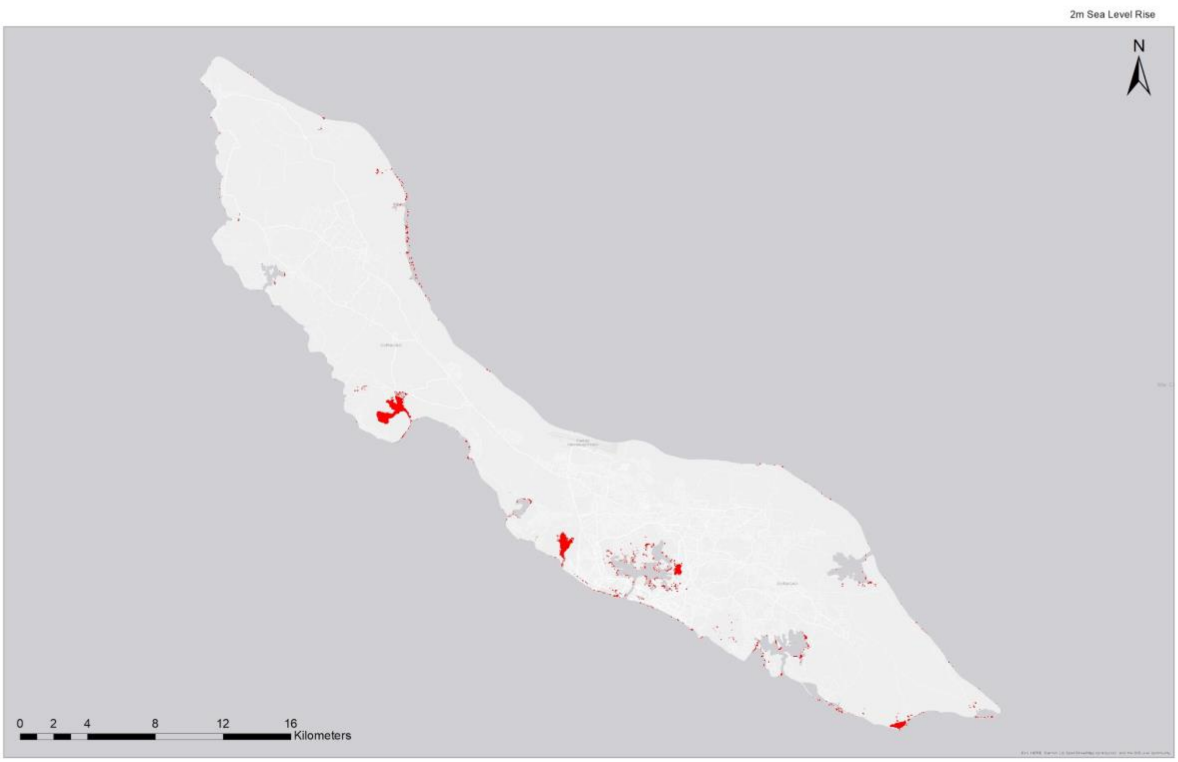

Figure 1g: Map of Curaçao. The red represents 2 meters of sea level rise.

Important Infrastructure and Sea Level Rise Scenarios

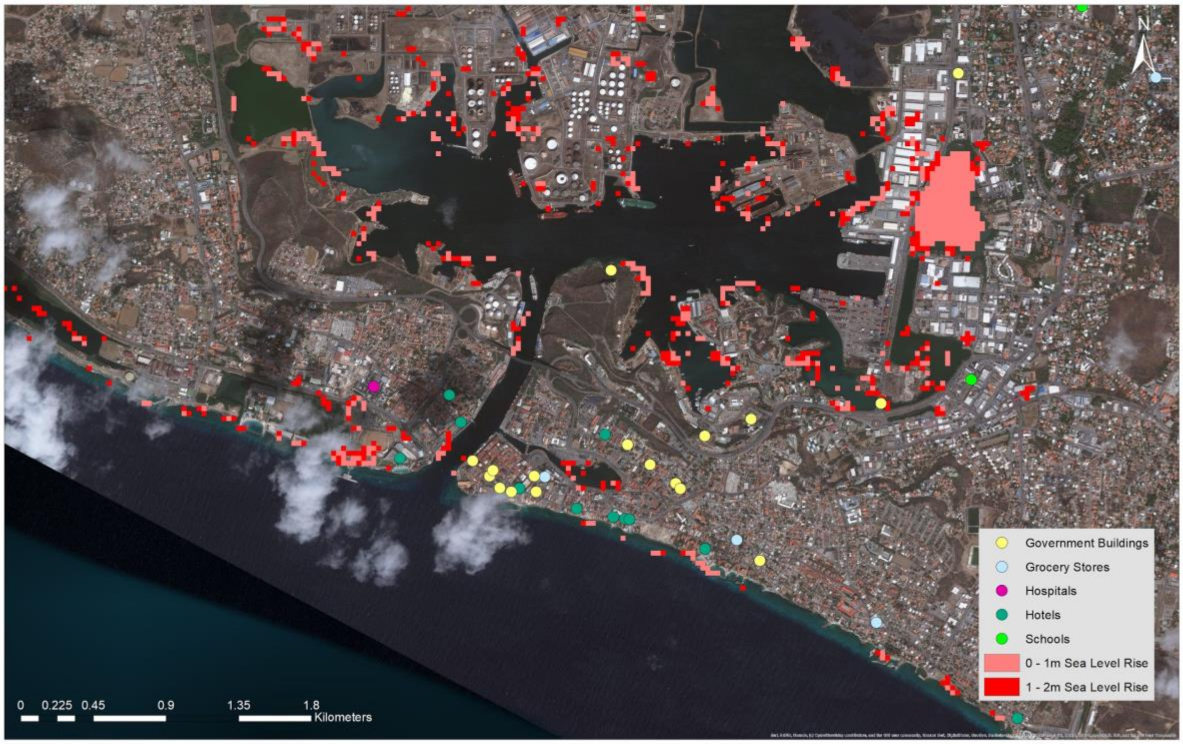

Figure 1h: Zoomed in map of a heavily populated area in Willemstad, the capital city of Curaçao.

In Figure 1h, we can see that only 2 of the 35 critical buildings are affected by sea level rise, and only at the most extreme two meter rise scenario. While only two critical buildings are directly impacted by these sea level rise scenarios, there are numerous others located close to affected areas that would likely be threatened in the case of storm surge. Most of the buildings that are affected by sea level rise, or are close to being affected by sea level rise, are either government buildings or hotels.

A one meter rise in sea level appears to affect only a relatively small percentage of the total land area in Curaçao. However, the inundated areas include ports and docks meaning sea level rise could still disrupt trade and tourism. At two meters, the damage becomes more widespread - flooding occurs all over the coastal parts of the island, as well as over some low-lying areas inland.

Republic of the Marshall Islands

The Marshall Islands: 0.52 meters of Sea Level Rise

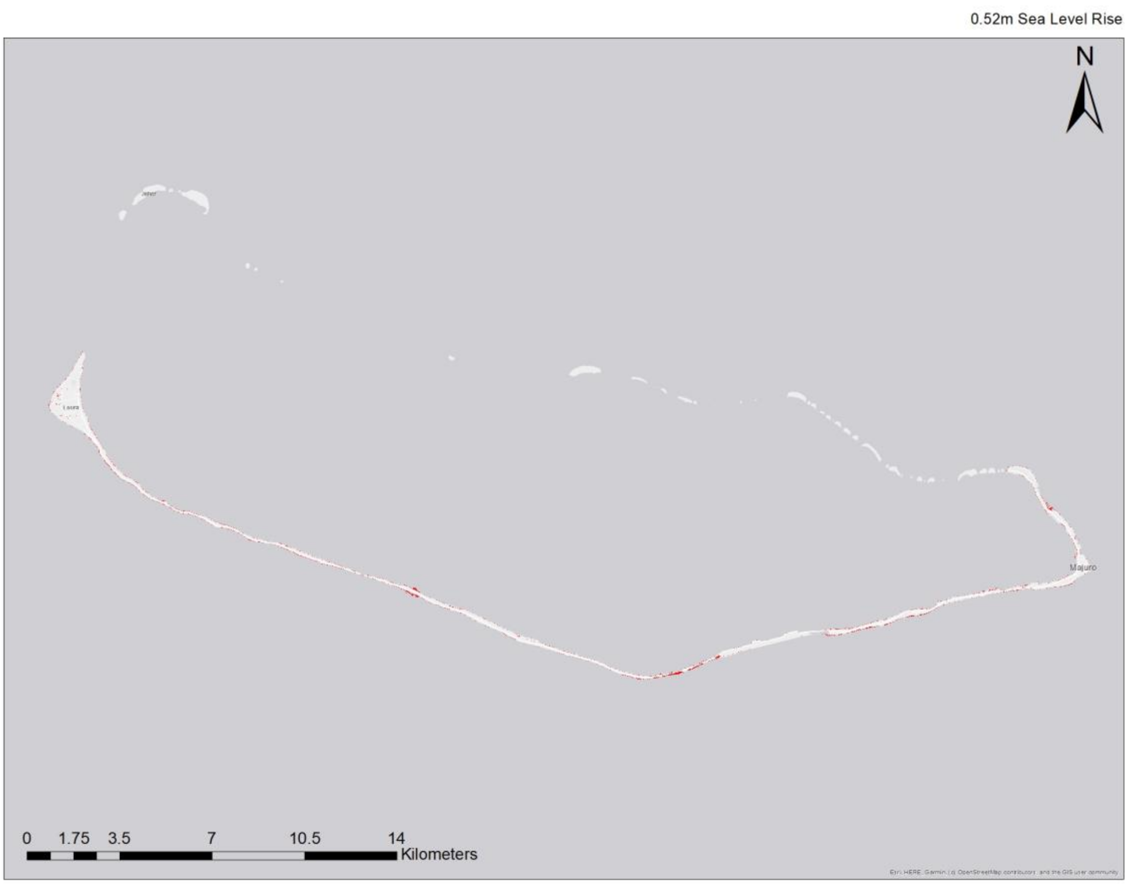

Figure 1i: Map of Majuro, the capital atoll in the Marshall Islands. The red represents 0.52 meters of sea level rise.

The Marshall Islands: 0.98 meters of Sea Level Rise

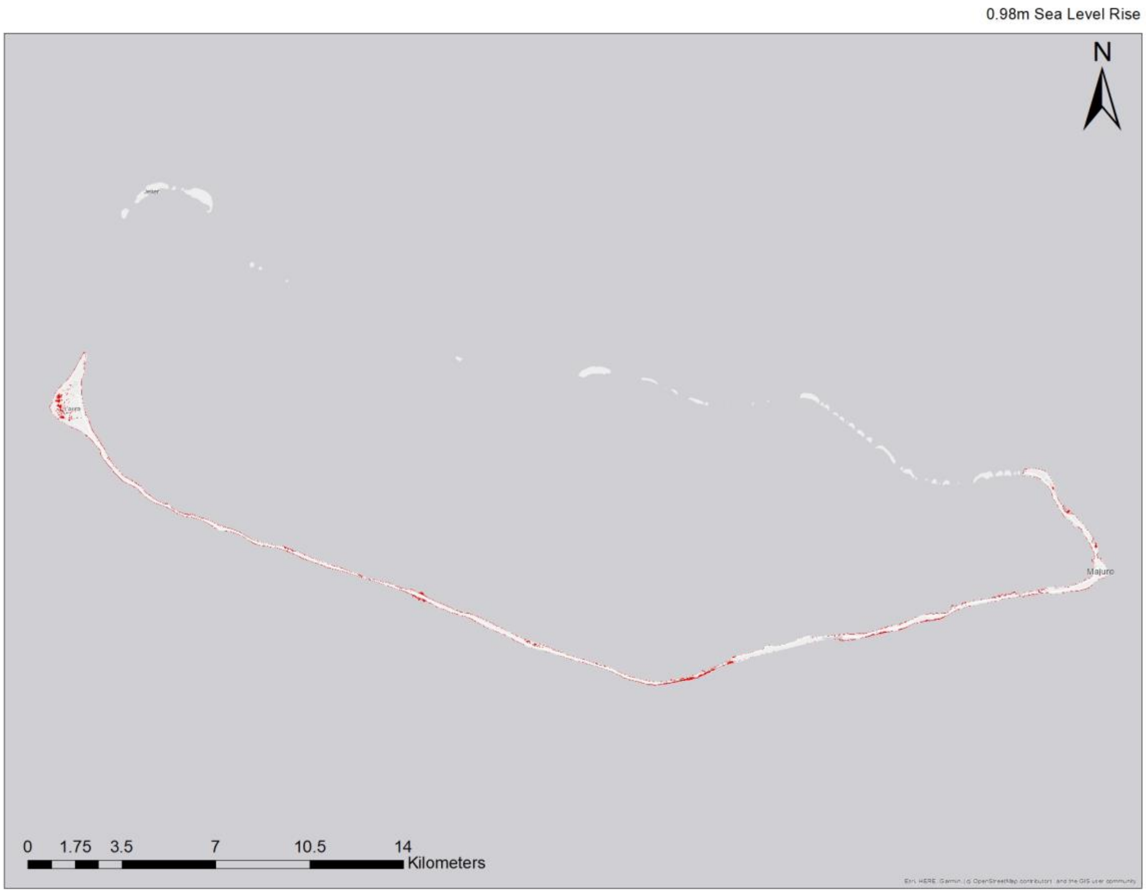

Figure 1j: Map of Majuro, the capital atoll in the Marshall Islands. The red represents 0.98 meters of sea level rise.

The Marshall Islands: 1.3 meters of Sea Level Rise

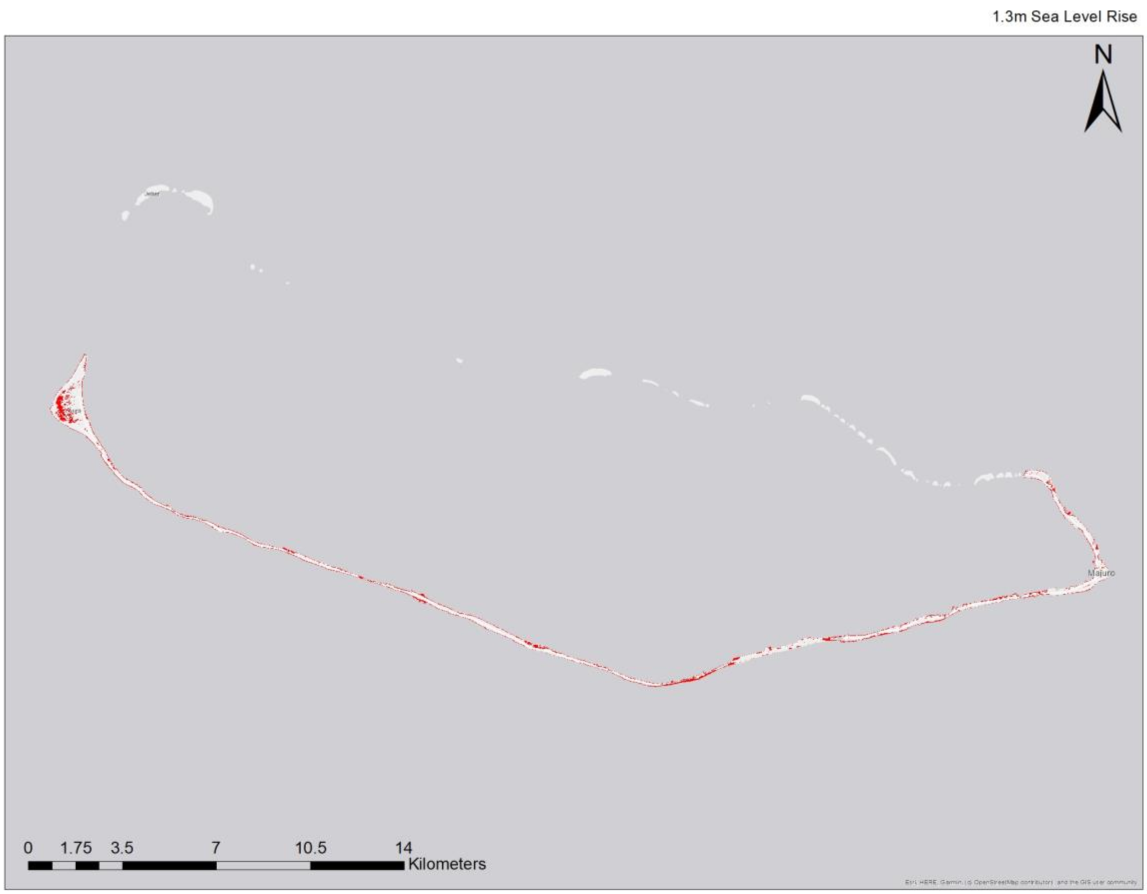

Figure 1k: Map of Majuro, the capital atoll in the Marshall Islands. The red represents 1.3 meters of sea level rise.

The Marshall Islands: 2 meters of Sea Level Rise

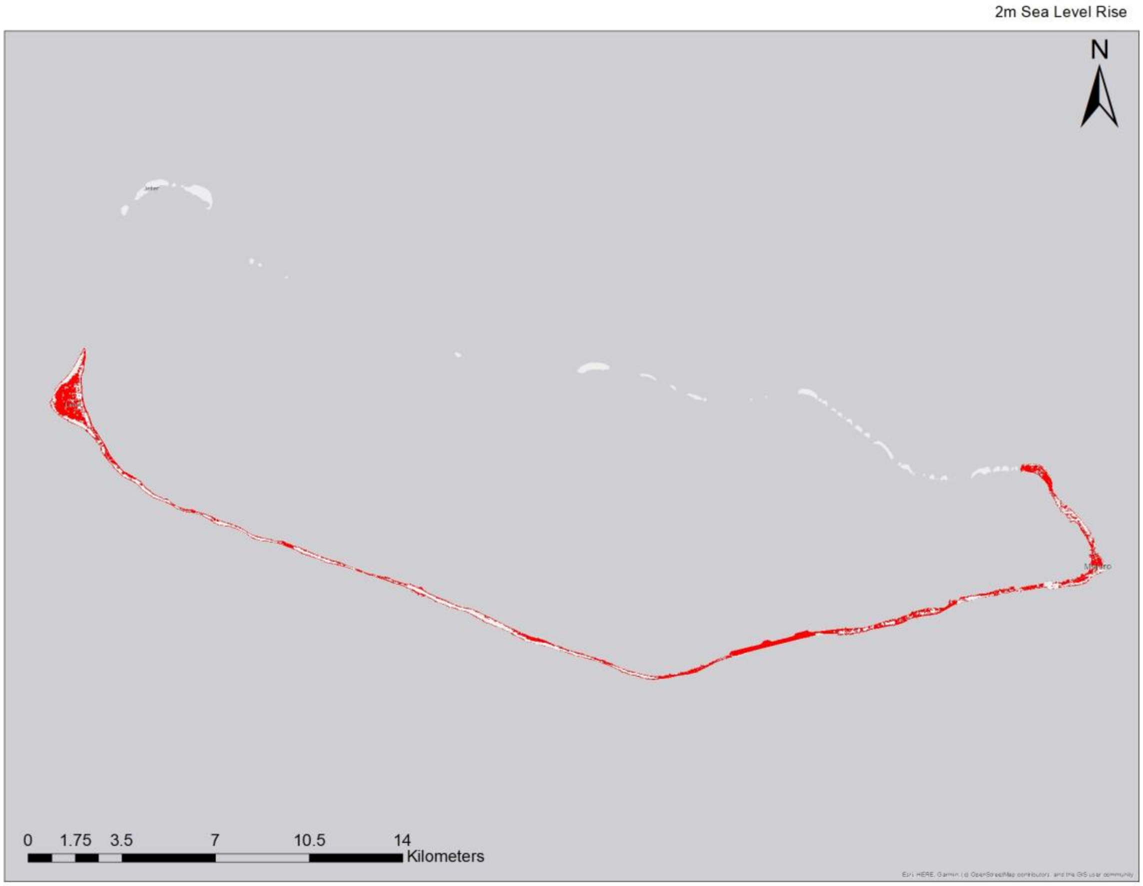

Figure 1l: Map of Majuro, the capital atoll in the Marshall Islands. The red represents 2 meters of sea level rise.

Important Infrastructure and Sea Level Rise Scenarios

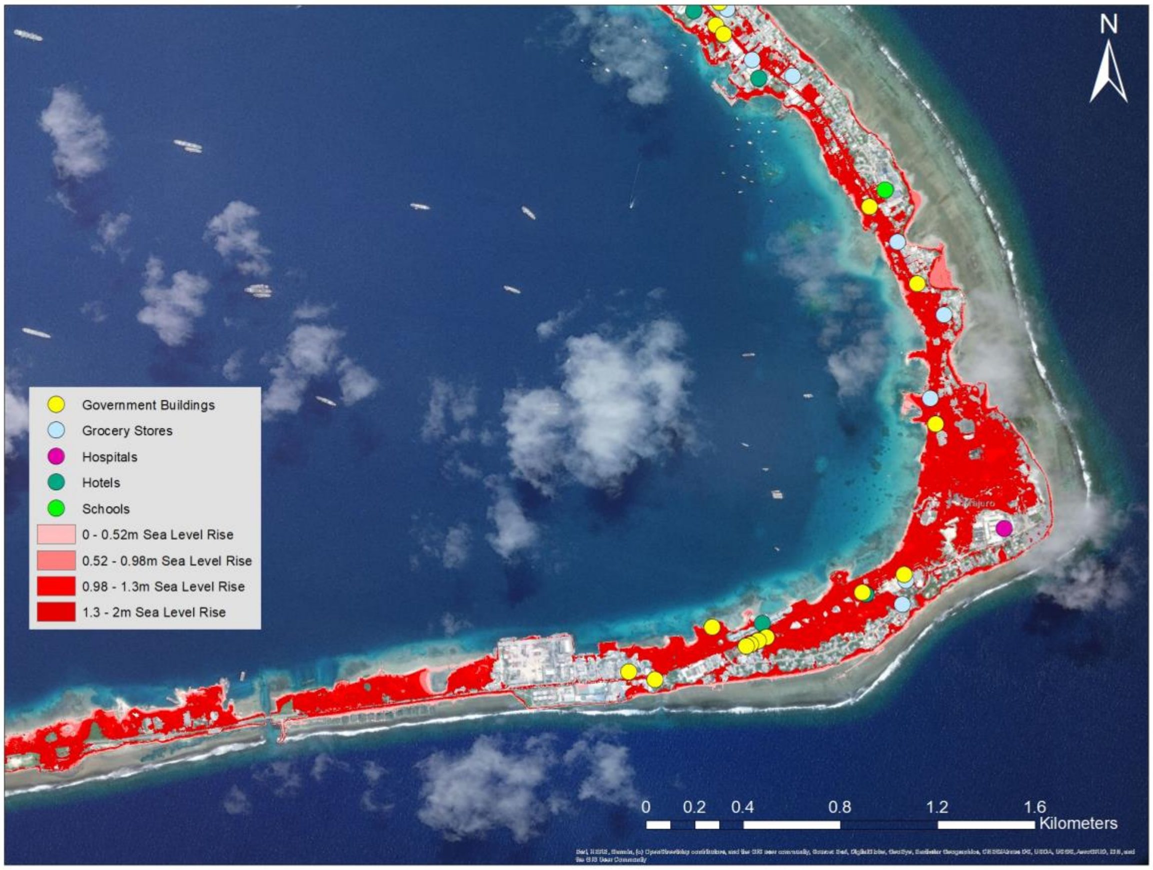

Figure 1m: Zoomed in map of Majuro, the capital atoll in the Marshall Islands. The red represents 2.0 meters of sea level rise.

First, it is necessary to note that in the maps depicting the whole island, we are missing data for the upper north portion of the island, due to the lack of publicly-available data.

Majuro, the capital of the Marshall Islands, experiences the most extreme sea level rise consequences when compared to our other SIDS. In our zoomed-in map of Majuro's city center, 29 critical buildings are identified: 15 government buildings, 8 grocery stores, 4 hotels, 1 hospital, and 1 school. In the 0.52m and 0.98m sea level rise scenarios, 2 of the 29 critical buildings are affected, one government building and one hotel. In the 1.3m sea level rise scenario, this doubles, with 4 of the 29 critical buildings affected, including one government building, one hotel, and two grocery stores. However, in the most extreme scenario of 2m sea level rise, all 29 of the critical buildings identified will be impacted by sea level rise.

The Marshall Islands are the most at risk to sea level rise compared to the other three SIDS due to the narrow widths across the atolls. The capital island Majuro that we mapped above (Figure 1i, 1j, 1k, 1l, 1m) is the second largest atoll in the Marshall Islands, however, it is only 0.5km at its widest point, making all of this atoll coastal and very vulnerable to sea level rise.

Tonga

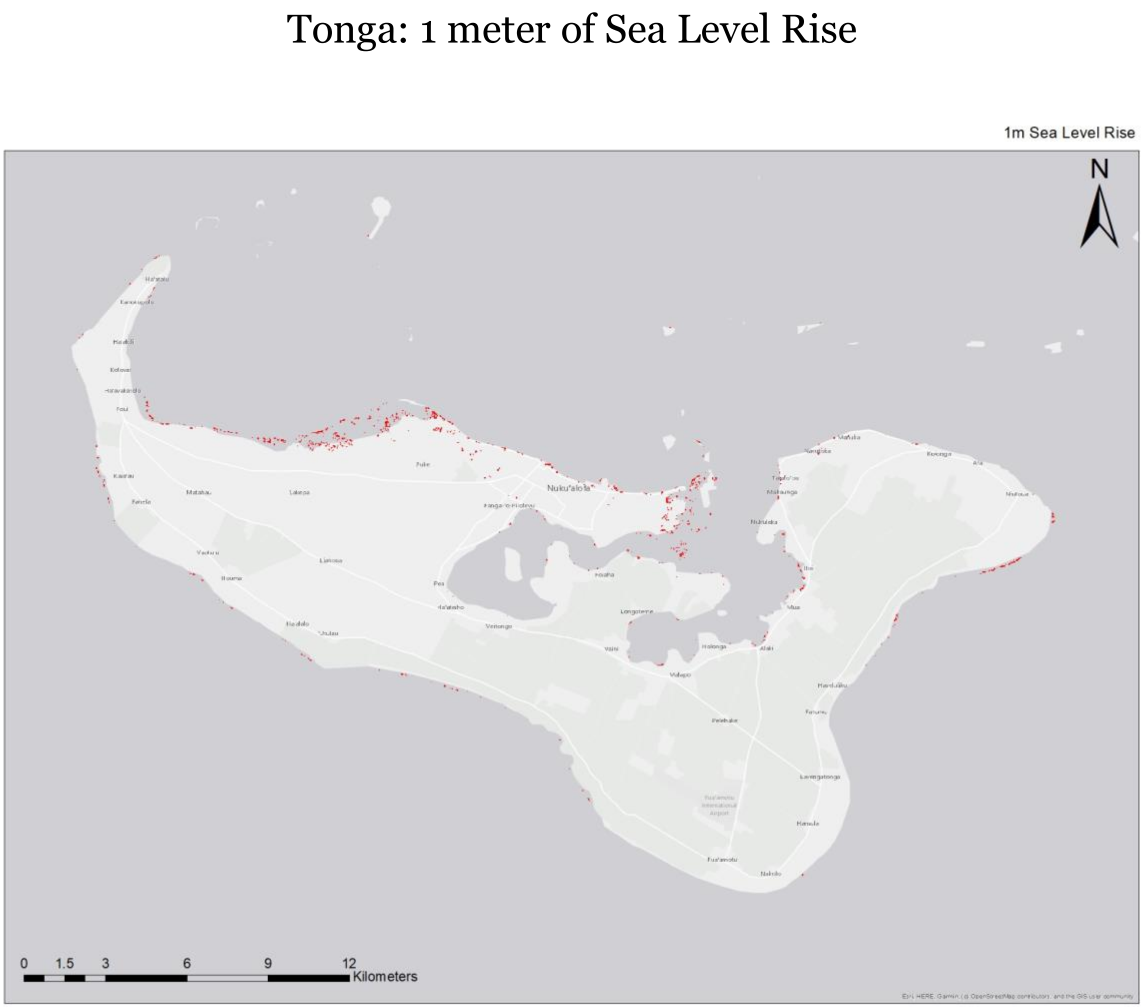

Figure 1n: Map of the capital of Tonga, Nuku'alofa. The red represents 1 meter of sea level rise.

Tonga: 2 meters of Sea Level Rise

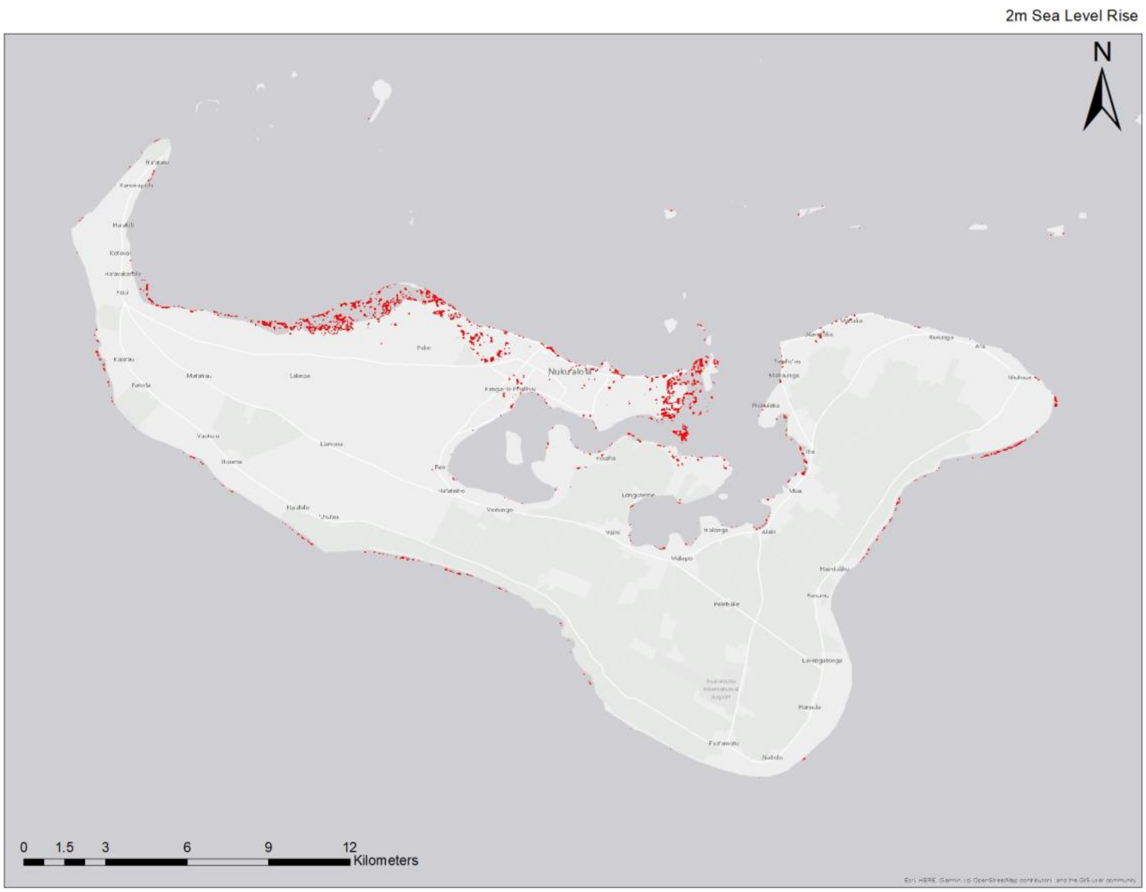

Figure 10: Map of the capital of Tonga, Nuku'alofa. The red represents 2 meters of sea level rise.

Important Infrastructure and Sea Level Rise Scenarios

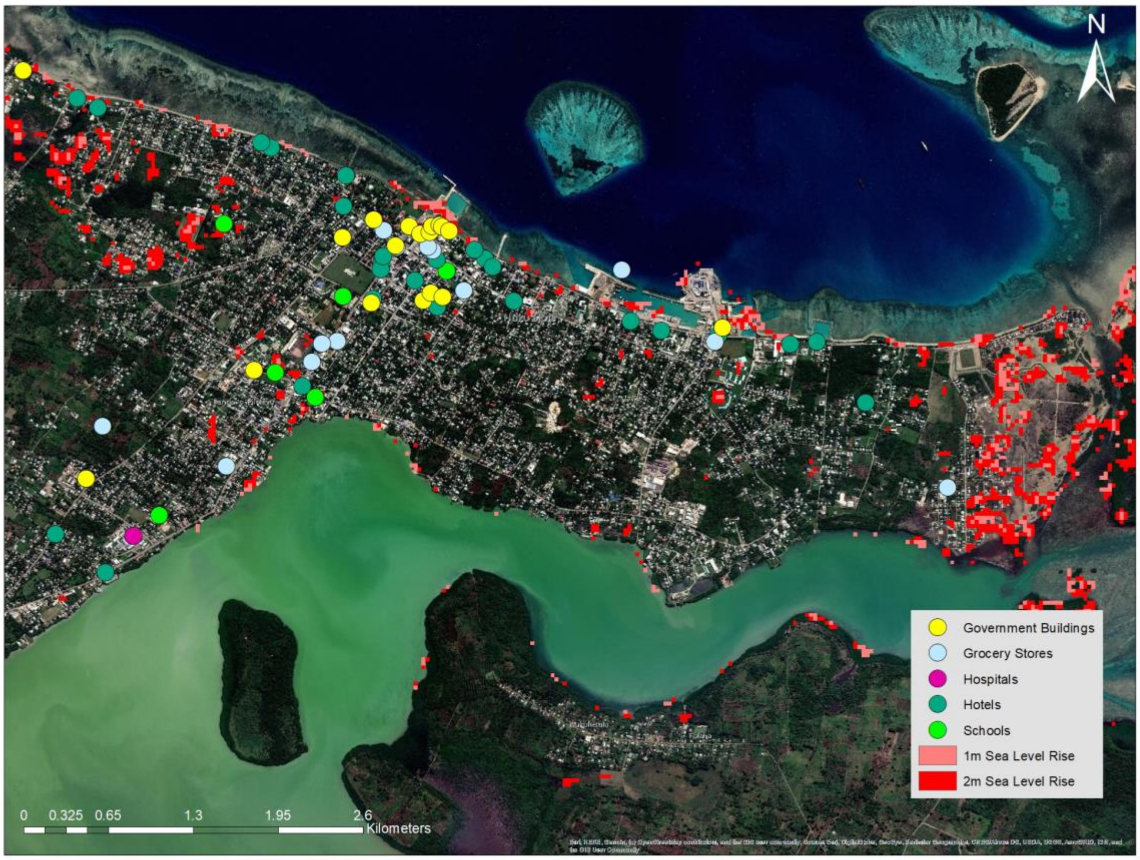

Figure 1p: Zoomed in map of the capital of Tonga, Nuku'alofa, depicting one and two meter sea level rise scenarios.

In this zoomed-in snapshot of the island (Figure 1p), 12 out of 60 points of major infrastructure were affected by the most extreme sea level rise scenario; five of the afflicted buildings are beachfront hotels, five are government buildings, and two are schools. All of the affected buildings are damaged only at the most extreme two-meter scenario except one - a single grocery store is damaged in the one-meter scenario.

The Ministries of Fisheries, the Environment, and Agriculture and Food are some of the government buildings that would be overtaken by sea level rise. Additionally, the headquarters of Tonga's armed forces is close to the inundation zone.

Sea level rise in Tonga would predominantly affect the less-populated islands of Tonga (not depicted), but the capital city of Nuku'alofa is at risk of serious damage. While most buildings escape direct, or near direct damage, many are close enough to be affected by storm surge.

Summary

Important Infrastructure Affected by 2m Sea Level Rise Scenario

	Bermuda (Hamilton)	Curaçao (Willemstad)	Republic of Marshall Islands (Majuro)	Tonga (Nuku'alofa)
Affected Points of Infrastructure (Most Severe Scenario)	6/51	2/35	29/29	6/51
Percentage Affected	12%	6%	100%	12%

Figure 1q: Percent of important infrastructure affected in the zoomed in maps for each island (Figure 1c, Figure 1h, Figure 1m, and Figure 1p).

Each of these SIDS will be negatively impacted by our projected sea level rise scenarios. Some of the islands are impacted by earlier sea level rise scenarios (less rise), where others are not impacted until the more extreme rise scenarios. The Marshall Islands are the most at risk and Curaçao is the least at risk out of the four nations.

Estimates of sea level rise continually increase as the rate of sea level rise itself is accelerating. So, while our estimates are based on the most recent research, these scenarios are likely still underestimates. The scenarios selected for the maps in this section are based on current predictions for 2100, but they may become a reality much sooner. All four of these island nations will have significant beach loss and erosion that is not reflected in Figure 1q. Beach loss and erosion will also affect each island and the people living there due to decreased tourism, cliff erosion-leading to landslides, and other impacts. Additionally, our analysis does not take into account storm surge, which will exacerbate sea level rise effects. As a result our depictions represent a lower threshold instead of an upper, and we anticipate the impacts of sea level rise will be more pronounced in many of the locations than our maps suggest.

Ideas for Improved Adaptation Strategies on a Limited Budget

Small island residents live on low-lying islands with limited land and must contend with the daily realities of climate change, which include threats such as rising sea levels, increased frequency and severity of storms, and water and food insecurity. In order to survive, they will have to adapt. Adaptation requires innovation both technologically and behaviorally. Critical to this innovation is learning about other adaptations in similar geographical and cultural settings. We conducted a literature review of the adaptation strategies implemented in Bermuda, Curaçao, the Marshall Islands, and Tonga in order to gain an understanding of the adaptation priorities for each island and to learn about adaptations already in place.

We then researched successful climate change adaptations in other parts of the world and evaluated their suitability for application in our SIDS. We have found multiple promising climate change adaptations and have described them further in the section: "What Can We Learn from Other Vulnerable Nations?"

In our examination of currently used adaptations, we looked into three main categories: hard, green, and soft infrastructure. Hard infrastructure refers to the physical built environment and includes elements such as roads and buildings. In our review, we focused on building strategies, transportation infrastructure, and agriculture. Green infrastructure refers to alterations to the natural environment, such as replanting of mangroves or beach restoration. Examples include marine restoration, coastal restoration, and agricultural adaptations. The final category, soft infrastructure, refers to laws and policies. For this category, we focused on laws regulating an individual's environmental impact, protected areas and environmental protection laws, and agricultural and water practices and policies.

Identifying Current Adaptation Strategies in SIDS

The purpose of this review was to gain an understanding of what the SIDS have already done to combat climate change and what strategies have been successful. With this context, we were able to make more informed and useful recommendations. We found our sources by looking at the government websites of each SIDS and checking any department related to climate change or the environment. We also conducted Google searches with the following phrases: "[SIDS] + "Cyclone resistant building," "[SIDS] + Transportation infrastructure," "Climate resilient [SIDS]," "Food sources [SIDS]," "Food security [SIDS]," "Marine Management [SIDS]," "Fishery Management [SIDS]," "Coastal Restoration [SIDS]," "Beach/coastal restoration [SIDS]," "Mangroves [SIDS]," "Coral reefs [SIDS]," "Agriculture [SIDS]," "FAO [SIDS]," "Reforestation [SIDS]," "Environment laws [SIDS]," "Environmental policy [SIDS]." This allowed us to identify climate adaptation measures and plans already in place in our SIDS.

When looking through official adaptation plans and news articles, we focused on: the purpose of the adaptation plan, the climate change effects addressed, the strategies suggested and their impact, how old the plan was, and who was involved. In addition to all of this, the news articles provided valuable context.

Identifying Successful Adaptation Strategies in Other Countries

In addition to analyzing current adaptations in our SIDS, we examined examples of successful adaptation in other places facing the same threats, such as sea level rise and storms. These included Hawaii, the Netherlands, New Zealand, Florida, Papua New Guinea, Haiti, the Philippines, and Vanuatu, as well as other SIDS. We selected twelve adaptations that were effective, interesting, new, or a combination of the three. We found these adaptations by reviewing scientific literature and news articles related to resilient building, sea level rise adaptations, climate change adaptations, and indigenous adaptations in SIDS.

Once we decided to include an adaptation, we researched its implementation and effectiveness. We used Google and Google Scholar to search for information about the success of the adaptations. We also reached out to experts involved in adaptation projects when their contact information was available and additional information would be helpful.

We researched what factors made the adaptations a success and used this information to determine whether or not the adaptation would be successful in each of our SIDS.

Country Context & Existing Adaptations

In this section, we provide a summary of the adaptations each of these SIDS have already implemented or are planning to implement. This has helped us determine the priorities of each nation. This section will include information on official government adaptation and management plans, as well as community and NGO projects. These adaptations were categorized by "hard," for physical adaptation strategies, "green," for natural adaptation strategies, and "soft," for legislative and planning strategies (See Table 2A).

Hard	Building Strategies	Transportation Infrastructure	Agriculture and Water	Energy
Bermuda	- Short streetlights to withstand category 5 storms - Road width at least 16 feet, sidewalks at least 3 feet	- Electric car infrastructure being developed to reduce emissions	- Rainwater collection tanks required for every building - Traditional roof designed for optimal rainwater capture	- All transmission cables underground - 50% of distribution cables undergound - Fuel generators raised 4.5 meters above ground
Curaçao			- Water desalination - Rainwater control and capture management	- Renewable energy projects to reduce dependence on oil
RMI		- Marshall Islands Maritime Investment Project to improve quays, ports, docks - Integration of sea level rise and flooding in port management - Seawalls protect roads and airport	- Increased capacity of Majuro airport reservoir - Solar powered water purifiers distributed to outer islands	
Tonga	- Working with World Bank to build cyclone resilient housing - Tonga National Infrastructure Investment Plan discusses community infrastructure upgrades	- Improved road drainage and adding footpaths - Airport built to survive cyclones - Port Authority Tonga building new infrastructure to survive category 5 cyclones	- Tonga Food Road Map 2014-2064	- Expanding renewable energy and reducing dependence on petroleum

Green	Marine Restoration	Coastal Restoration	Agriculture and Water
Bermuda	- Coral restoration projects	- Mangrove and coastal vegetation restoration	- Grassy or planted verges at least 3 feet wide required next to roads for rainwater collection
Curaçao	- Deep reef observation - Working to reduce overfishing	- Coral reef restoration	
RMI	- Biorock technology for coral reef restoration	- Sea walls - Mangrove restoration - Replanting of native species on the coast	
Tonga	- Tonga Deepwater Fishery Management Plan 17-19 - Special Management Areas run by local communities	- Mangrove and coastal vegetation restoration - Fences to keep livestock away from fragile coastal vegetation	- Tonga Agriculture Sector Plan 2016-2020

Soft	Laws and Policies Targeting Individual Impact	Protected Areas and Protection Laws	Agriculture and Water
Bermuda	- Bermuda Biodiversity Action Plan - Environmental Impact Statement Requirements	- Bermuda Conservation Management Plan - National Parks Act - 218 ha of terrestrial nature reserves - 3/4 of coastline designated a Park, Nature, or Coastal Reserve	
Curaçao	- Banned use of gill nets - Laws to prevent invasive species	- No fishing zones	- Government program to protect drainage areas
RMI	- National Climate Change Policy Framework - Vision 2018	- Reimaanlok National Conservation Area Plan pledges to conserve 30% of marine resources by 2020 - No take zones	
Tonga		- 7 protected areas and 2 territorial parks - National Forest Policy for Tonga plans to designate additional national parks and reserves - Forestry Act of 2009	- Tonga Food Road Map 2014-2064 - reducing reliance on imports - Tonga National Agriculture Census Report

Table 2a: Existing adaptations in Bermuda, Curaçao, Republic of the Marshall Islands, and Tonga. *Boxes are empty where we did not find any information during our literature review.

Bermuda

To counter the effects of climate change, the Bermudian government, along with NGOs, has begun to implement adaptations to mitigate future harm. Several written works have been published to help guide these actions, including the *Bermuda Biodiversity Action Plan*, *Bermuda State of the Environment Report*, *Conservation Management Plan*, *National Parks Act*, *Bermuda Climate Change Impact Analysis*, *Sustainable Development Strategy and Implementation Plan*, and the *Bermuda Plan*. These detail different adaptation strategies to be implemented in all aspects of society, including adjustments to the building code and construction standards, rainwater collection methods, resilience in the energy sector, and investments in cleaner technologies.

In terms of building adaptations, roads must be at least 16 feet wide, sidewalks at least 3 feet wide, and grassy or planted verges at least 3 feet wide. These requirements reduce the chance that the entire road will be blocked in a disaster and prevent passage (Gischler, 2018). Groundwater is not a good source of drinking water for Bermuda. Building codes have been adapted to require rainwater collectors and water tanks 8 times the size of the roof underneath each house. These can be used to provide drinking water in the case of a drought. Streetlights in Bermuda are also shorter than traditional ones to ensure that they can withstand even Category 5 hurricanes.

For public infrastructure adaptations, Bermuda has taken significant steps to become more resilient in the face of climate change. 100% of transmission cables and 50% of distribution cables are underground to increase the chance that they work in extreme conditions. BELCO, Bermuda's electric utility company, plans to move the rest of the distribution cables underground in the next few years. In addition, fuel oil generators must be at least 4.5 meters above the ground on concrete blocks to ensure that they work in floods or when sea level rises (Gischler, 2018).

Bermuda also requires Environmental Impact Statements for new development projects in order to monitor the environmental harm of industries and establish responsibility for any disasters. The statements must be completed before the projects start.

Bermuda has taken steps to protect and conserve natural habitats. With over 218 ha of terrestrial acres protected as nature reserves, Bermuda has done well in the ecological adaptation field. In addition, roughly three-fourths of Bermuda's coastline has been designated as a Nature Reserve, Park, or Coastal Reserve (Needs Assessment: Bermuda, 2012).

Finally, agricultural adaptations have not been as prioritized by the Bermudian people. With less than 50% of land zoned for agriculture actually in use and fewer than 50 professional farmers left in Bermuda, the domestic agricultural industry has plummeted (McKittrick, 2010). The government passed the *Agriculture Act of 1930* to set standards and protective regulations for the industry as well as embargoes to prioritize local production over imports. In 2002, the Department of Agriculture was merged with Fisheries and Parks to form the Department of Conservation Services, Environmental Protection, and Parks. However, farmers throughout Bermuda have expressed concern over the industry and a need for the government to do more to protect the local agricultural industry.

Curaçao

Curaçao recently developed two reports: the *National Report of Curaçao (2014)* and the *Strategies for Sustainable Long Term Economic Development of Curaçao (2013)*, which we will reference for this section. The *National Report of Curaçao (2014)* assesses the state of implementation of the *Barbados Plan of Action* (BPoA) and the *Mauritius Strategy for the Further Implementation of the BPoA* (MSI), which are regional policy agreements. *Strategies for Sustainable Long Term Economic Development of Curaçao (2013)* focuses on plans for a more sustainable future for Curaçao.

Curaçao has also enacted laws to protect its environmental resources. This includes laws to reduce overfishing, ban the use of gill nets, and prevent invasive species from reaching the island (The Ministry of Health, Environment, and Nature of Curaçao, 2014). In the future, Curaçao is aiming to implement more programs to end overfishing, improve marine water quality, and manage marine pollution from its waste systems (The Ministry of Health, Environment, and Nature of Curaçao, 2014).

For hard infrastructure, Curaçao has focused its efforts on water supply - given that the country is located in an area where hurricanes and earthquakes are not a priority concern. Curaçao's groundwater is not safe for drinking, even after reverse osmosis processing since it is very high in silicates (Buurt, 2018). Instead, the nation relies on desalination plants to produce its drinking water. Currently, the Ministry of Health, Environment, and Nature and the Meteorological Department are working towards a better system for groundwater and surface water management (The Ministry of Health, Environment, and Nature of Curaçao, 2014). This will consist of rainwater runoff control, capture, and flow management (The Ministry of Health, Environment, and Nature of Curaçao, 2014). A government program to protect drainage areas on Curaçao is also soon to be implemented. Water security is important to Curaçao due to its dry climate and susceptibility to long periods of drought or dry seasons. With changing climate and rising temperatures, Curaçao must become water secure in order to survive an increase in dry periods and unpredictable weather patterns affecting their water supply (Taylor et al., 2018).

Energy supply is another emphasis within the hard adaptation category. Curaçao's energy adaptations are guided by the recognition that their oil refinement processes have led to the deterioration of fellow island nations. Since the 1990's, private energy providers of Curaçao, such as Aqualectra, have been investing in renewable energy projects (The Ministry of Health, Environment, and Nature of Curaçao, 2014). Caribbean Research and Management of Biodiversity (CARMABI) has installed solar panels (The Ministry of Health, Environment, and Nature of Curaçao, 2014) and renewable energy now meets 22% of energy demand of the nation. For Curaçao, energy independence is an important means of climate change adaptation. By meeting the energy demands of their citizens using renewable sources, Curaçao is able to lessen their carbon emission contributions.

Curaçao has made strides in coral reef, mangrove, and seagrass restoration. Coastal and marine ecosystems not only contribute to Curaçao's economy by attracting tourists and providing food, but also mitigate climate change effects such as coastal erosion (Roberts et al., 2017). The preservation of natural resources and ecosystems is generally achieved through laws and policies.

Coral reef restoration is one of many priorities for climate change adaptation in Curaçao. The *National Report of Curaçao*, published in 2014, has fourteen areas of concern. While none of them explicitly state coral restoration, it is addressed in the following areas of concern: 1) climate change and sea level rise, 2) natural and environmental disasters, 3) management of wastes, and 4) coastal and marine resources. The nation has approached coral reef restoration through coral nurseries and outplanting (Coral Restoration Foundation Curaçao, n.d.). Similarly Curaçao has advanced other coastal and marine resource preservation. In 2012 an agreement was made between Substation Curaçao, a submarine diving service for tourists and deep sea research, and the U.S. Smithsonian Institute of Deep Reef Observation Program (DROP) (The Ministry of Health, Environment, and Nature of Curaçao, 2014) to document local biodiversity, monitor changes in the deep reef ecosystem, and conduct comparative biodiversity assessments (Coral Restoration Foundation Curaçao, n.d.).

Republic of Marshall Islands

The Marshallese government has integrated climate change adaptation considerations throughout national policies and strategies. The *National Climate Change Policy Framework* (NCCPF) lays out government commitments to addressing climate change, and the *Vision 2018*, outlines sustainable development goals. In addition, the government is considering climate change in the energy and disaster sectors, as shown in the *RMI Energy Policy and Action Plan* and the *Joint National Action Plan for Climate Change and Disaster Risk Management*.

One of the largest priorities for the Marshall Islands is the development of preemptive adaptation strategies to address long-term threats. In order to accomplish this, the government is developing a *National Adaptation Plan* which will list concrete adaptation actions and deadlines for their completion.

The main adaptation strategy for sea level rise in the Marshall Islands is the construction of sea walls, by citizens and the government (Huang and Rapp, n.d.). Government-constructed sea walls are made of cement and line the roads to Majuro airport, the runway of Majuro airport, and the Lagoon of Majuro. In contrast, citizen-built sea walls are often made of old cars and trash (Huang and Rapp, n.d.). The fact that citizens are constructing seawalls from junk material highlights the fact that sea level rise is threatening homes and communities despite building adaptations.

The transportation infrastructure in the Marshall Islands is incredibly vulnerable to the effects of climate change due to the island's low-lying geography and limited transportation providers. Efforts to address vulnerabilities in marine transportation were recently launched - the Marshall Islands Maritime Investment Project aims to improve port infrastructure by integrating sea level rise and flooding considerations in port management and planning (World Bank, 2019). This is a good start to addressing the vulnerability in the nation's transportation infrastructure, but the Marshallese will need to address road and airport infrastructure as well

The Marshall Islands' marine restoration efforts are guided by a national conservation plan and bolstered by specialized projects and programs. In the *Reimaanlok National Conservation Area Plan (2008)*, the Marshallese government pledged to conserve 30% of marine resources by 2020. A program on the Namdrik Atoll transforms this pledge into action by implementing fish aggregation devices and seasonal no-take zones to reduce overfishing (UNDP, 2013). Another project tested the feasibility of Biorock technology, which uses electrified wires as a foundation for coral reef restoration (Jormeu, Hagberg, & Goreau, 2010). The initial results were promising - the Biorock structures induced rapid coral growth. However, at one of the project sites, power to the Biorock structures was cut for roughly a year due to storm damage (Goreau & Trench, 2013), which calls into question the long-term feasibility of Biorock technology for the Marshall Islands.

Coastal restoration projects include replanting mangrove seedlings in Namdrik and Jaulit Atoll (SPREP, 2013), while overall mangrove restoration efforts are augmented by a project that studies mangrove enhancement specifically for the Marshall Islands. Replanting native vegetation projects include the Jannor Windward Forest Project, in which high school students replant native tree species protected by coconut frond wind breaks (jalitak), and the Bikirin Island Conservation and Restoration Project, in which coconut and pandanus trees were planted along the shoreline (Rudiak-Gould, 2013).

The Marshall Islands has numerous projects focused on combating climate change; however, they are somewhat disconnected. A centralized plan, as promised by the publication of the *National Adaptation Plan*, would consolidate the resources and technical expertise needed to counter climate change on a larger scale.

Tonga

Tonga is working to adapt to climate change and has made significant progress in incorporating climate change issues into government plans and in making real strides towards physical resilience. The government has released numerous adaptation plans including *The Tonga National Infrastructure Investment Plan*, the *Tonga Food Road Map 2014-2064*, the *Tonga Deepwater Fishery Management Plan 2017-2019*, among many others. From these publications and ensuing governmental actions, it is clear that one of Tonga's priorities is mainstreaming climate change adaptations (D'Este et al, 2013). All plans for future growth, development, and infrastructure improvement take into account the present and future risks due to climate change.

In terms of building adaptations, Tonga faces various roadblocks. There are a number of building techniques that minimize damage and flood danger and, if properly enforced, Tonga's building codes would prevent a substantial amount of cyclone damage. But, because of the nation's remoteness, the required construction materials all are imported across long distances. This results in high cost of materials meaning that many locals can't afford to utilize these better construction materials. Because of the nation's remoteness, the required construction materials would need to be imported across long distances. In some places, nonprofits have built resilient housing and schools, but more work is needed in this area.

Tonga's transportation industry has endured well in the face of storms, after Cyclone Gita there was only minimal damage. According to the *Post Disaster Rapid Assessment* (Government of Tonga, 2018) the only damage to roads was to road signs, and the only damage to the airport was a passenger terminal roof. However, in the area of marine transportation, port infrastructure had been degraded by saltwater exposure and did not fair well in the cyclone. Currently, the Port Authority of Tonga is striving to make all transportation infrastructure capable of standing up to Category 5 cyclones (Government of Tonga, 2018).

Tonga has made significant strides in ensuring agriculture and food security. The *Tonga Food Road Map 2014-2064* (Vaioleti, 2014) identifies the weaknesses in Tonga's agriculture and proposes solutions such as using new technology. The Tonga National Agricultural Census Main Report (MAFFF, 2015) found that Tonga has surprisingly strong long term food security due to subsistence farming. We will examine Tonga's food security in the specific context of disasters in the lifeline section of this report.

Tonga has also taken restorative measures - there are efforts to restore and protect mangroves and other coastal vegetation to prevent erosion. In addition, the government is working to ensure the sustainability of the fishing industry. This has included the creation of Special Management Areas by the Ministry of

Fisheries (Gillett, 2017) and a *Fishery Management Plan* (Ministry of Fisheries, 2017). These are recent changes and so it is difficult to analyze their effectiveness, but local communities have responded positively because they have more power over their resources under this new system (Ministry of Fisheries, 2017). There are also plans to restore Tonga's beaches, forests, and mangroves (Pacific Scoop, 2014; Government of Tonga, 2009; Loop Pacific, 2017).

What Can We Learn From Other Vulnerable Countries?

We looked to other vulnerable nations to find examples of successful adaptations to climate change. We then researched each adaptation and determined what physical characteristics made it successful. We used this information to assess whether or not the conditions in each of the SIDS were suitable for the implementation of these adaptations. This section includes this information organized into nearshore, shoreline, agriculture, built environment, and disaster resistance adaptations. These recommendations are based only on publicly-accessible information and thus the next step would be to consult local experts about specific local conditions and the adaptations' potential usefulness.

Community Adaptations

Long Lasting Beach Replenishment	Disaster Resistant Buildings
Artificial sand peninsulas allow currents to move sand to beaches and offer long term beach replenishment that is less harmful to the ecosystem than frequent dredging.	Building structures that can survive disasters reduces future economic losses and can prevent casualties.
Salt Tolerant Crops	**Natural Landscape Restoration**
Crops with high salt tolerance can grow in areas that experience salt water intrusion and frequent storms, making them important for food security and independence.	Natural ecosystems protect coastal areas from threats such as erosion caused by wave impact, storm surge, and sea level rise.
Dune Construction and Strengthening	**Planting Seagrass**
Sand dunes act as barriers between coastal settlements and the ocean, protecting from storm surge, flooding, and sea level rise.	Seagrass restoration is a natural remedy against coastal erosion and can even counter sea level rise by encouraging sedimentation.

Individual Adaptations

Elevating Houses with Stilts	Subsistence Farming
The elevation of traditional houses using stilts protects structures from sea level rise and storm surge wave impacts.	Subsistence farming for individuals and families promotes food independence, especially following storms and other disasters.
Stormwater Management with Rain Gardens and Green Roofs	**Energy Independence via Mini-Grids**
These stormwater management techniques help protect communities from flooding in extreme precipitation events.	Mini-grids scale down renewable energy sources to provide enough energy for a single household, allowing for energy independence as well as energy availability following disasters that could take out powerlines.

Table 2b: Summary of adaptations discussed in this section.

Long Lasting Beach Replenishment

Long Lasting Beach Replenishment	Recommended?	Key Opportunities/ Constraints
Bermuda	X	Economic dependence on tourism makes consistency of beach appearance important; located in hurricane belt, causing frequent storms; high cost of dredging and importing sand
Curaçao	✓	Slim to no chance of hurricanes, causing this to be effective long term; access to funding as part of the Netherlands
RMI	X	Cyclones wash away sand deposits; high cost of dredging and importing sand
Tonga	X	Cyclones wash away sand deposits

Table 2c: Long Lasting Beach Replenishment in Bermuda, Curaçao, Republic of the Marshall Islands, and Tonga.

*check mark indicates that our team believes this adaptation is suitable here, x indicates that we felt constraints or obstacles were too large for the adaptation to be successful.

Beaches provide numerous benefits for SIDS. They protect coastal development from waves and storm surges and bring in tourist revenue. Unfortunately, the beaches of SIDS face erosion and must be frequently replenished if the SIDS want to continue to reap their benefits.

Beach replenishment usually involves dredging the seafloor which is expensive and also harmful to the benthic ecosystem. In the Netherlands, they have minimized the disruption and expense by dredging once and creating a sand motor. The sand motor or sand engine is an artificial peninsula of sand created along the coast. The idea is that over time, the sand will be moved by waves to the beaches which need replenishing.

The project in the Netherlands has been successful thus far and the Dutch expect that it will end the need for dredging and direct beach replenishment for at least 20 years from its creation. The sand motor has moved the erosion point away from the coast and towards the sea (Brière et al, 2017) and improved the beaches in the area. As of 2015, only 5% of the sand had disappeared from the sand motor, which means its lifespan is likely longer than the originally anticipated 20 years (Brière et al, 2017).

In order for the sand motor to be successful in the SIDS, the sand needs to be the same type as the present sand because retaining the quality of beaches is important for sustaining the tourism industry. There also needs to be reasonable belief that the motor will last for a sufficient time before any major storms arrive that could either destroy the motor or cut its lifetime short. This is possible in some SIDS that are not regularly hit by extreme storms. Finally SIDS face additional challenges that the Netherlands does not; they are generally in deeper water so peninsula creation may be more difficult, and an island is a more difficult target to hit than the coast of a continent.

Dune Construction to Reduce Flooding

Dune Construction & Strengthening	Recommended?	Key Opportunities/ Constraints
Bermuda	Uncertain	Dependence on tourism as a barrier; unique pink hued sand constrains the sand type necessary for dune construction
Curaçao	X	Tourism is a substantial industry, beach appearance is important; located outside of the hurricane belt, therefore, Curaçao experiences less flooding than other SIDS
RMI	✓	High flood risk, therefore, high need for shoreline protection; long history of dredging reduces availability of sand
Tonga	✓	Sand resources depleted

Table 2d: Dune Construction and Strengthening in Bermuda, Curaçao, Republic of the Marshall Islands, and Tonga.

Sand dunes can fortify the beaches and coastlines of island nations against erosion, flooding, and sea level rise. Dune construction involves the creation of artificial dunes from dredged sand. These dunes can then be strengthened by vegetation planting, dune thatching, and dune fencing - all of which aim to further consolidate the constructed dune as a barrier and anchor it within the existing beach landscape. Dune planting consists of planting vegetation on the face of the dune; dune thatching involves adding plant matter and branches on top of the dune; and dune fencing refers to constructing fences on the dune (APAN, 2015). Dune strengthening used in conjunction with dune construction can be a powerful barrier against the inundation threats of climate change.

New Zealand's dunes are one of the primary ways New Zealanders combat coastal erosion. New Zealand has been funding dune restoration (mainly planting native dune grass) for years (de Lange, 2006). New Zealand's dunes may not necessarily be attractive, but they are effective and 3 million people still make their way to visit New Zealand every year.

The primary economic cost of this adaptation technique comes from the initial creation of the dune - specifically the process of dredging sand from another location, transporting the sand, and then sculpting the dredged material. However, given the shorter implementation time of 1-5 years for dune construction (Climate ADAPT, 2015), this adaptation stands as one of the faster methods to address the time-sensitive threats of flooding, saltwater intrusion, and sea level rise the islands face.

In order for dune construction to be successfully implemented, a wide swath of beach area is required. In addition, the impact of artificial dunes and strengthening techniques on beach access, touristic value, and recreational scenery must be taken into account - especially considering the fact that dunes are not a natural feature of SIDS.

Restoring Seagrass, Mangroves, and other Natural Coastal Landscapes to Reduce Storm Surge and Wave Impacts

Restoring Seagrass, Mangroves, and Other Coastal Landscapes to Reduce Storm Surge and Wave Impacts	Recommended?	Key Opportunities/ Constraints
Bermuda	✓	Gulf Stream provides warm water ideal for mangrove growth; formerly had vast corals, mangroves, and seagrass ecosystems
Curaçao	✓	Necessary habitat for Juvenile Reef Fish; many inland bays good for seagrass and mangrove growth
RMI	✓	Fringing coral reefs are the main natural shoreline protection
Tonga	✓	Active protection laws enforced; awareness programs

Table 2f: Restoring Seagrass, Mangroves, and Other Natural Coastal Landscapes to Reduce Storm Surge and Wave Impacts in Bermuda, Curaçao, Republic of the Marshall Islands, and Tonga

Natural coastal ecosystems — such as seagrass, mangroves, and coral reefs — can protect coastal areas during disasters and under normal conditions. Functioning as a barrier between land and sea, these ecosystems dissipate wave energy, storm surge, and sea level rise (Spalding, 2014). The dissipation of wave energy before the wave reaches the shore means coastal erosion is drastically reduced which is good for coastal communities. Lower storm surge reduces damage to the natural environment and to built infrastructure. Where possible, it is beneficial to restore multiple ecosystems because the combination of seagrass, mangroves, and coral reefs can provide more benefits than anyone can alone (Guannel et al., 2016).

Historically SIDS have benefited from these ecosystems, but human development and activity have damaged them and left islands at an elevated risk. Coastal regions around the world have begun restoring mangroves, seagrass, and coral reefs to restore natural landscapes and the ecosystem services they provide. Some examples of areas that have found great success in reducing erosion and inundation levels using this practice include Belize, New Zealand, and Florida (Guannel et al., 2016). Guannel et al. found that mangroves reduce non-storm waves by 70 percent (2016). They also found that mangroves reduce inundation levels during hurricanes (Guannel et al., 2016). The State of Florida has had success with restoring mangroves simply by restoring hydrological conditions in areas that have historically been suitable for mangroves, without planting any seedlings (Waters, 2016).

Compared to other adaptations for dealing with erosion, storm surge, and sea level rise this is a low cost option that causes only minimal disruption in citizens lives while providing huge benefits.

Stormwater Management with Rain Gardens and Green Roofs

Stormwater Management with Rain Gardens and Green Roofs	Recommended?	Key Opportunities/ Constraints
Bermuda	✓	Currently implements roof rainwater collection, could look at directing stormwater for freshwater lens recharge
Curaçao	X	Does not get large amounts of rain to make this effective
RMI	✓	Currently catches rainwater, however this could be more effective and efficient, there likely no space for rain gardens
Tonga	✓	Predicted to have increasing rainfall in the future, does not currently implement any of these strategies

Table 2g: Stormwater Management with Rain Gardens and Green Roofs in Bermuda, Curaçao, Republic of the Marshall Islands, and Tonga.

Due to their limited land area, SIDS are more vulnerable to flooding in extreme precipitation events than landlocked nations. As a result, experts and activists are recommending landowners develop rain gardens and green roofs as stormwater management techniques. Concrete has minimal permeability - water stays on the surface of concrete roads and buildings, unable to seep into the earth, which can lead to flooding (Dussaillant et al., 2005). Green roofs and rain gardens increase the area available for water collection and absorption. This will help prevent flooding, especially in SIDS, where development has reduced the already minimal land available for absorption.

This technique will be most applicable in areas with the greatest development and reduction in natural landscape, rather than across entire islands or states (Laukkonen et al., 2008). In areas that are uninhabited and have not been developed with concrete to a large degree, the ground is already permeable and there would be little to no benefit from rain gardens or green roofs. It is also important to note that in some SIDS, such as Bermuda, the biggest problem is that groundwater is not a good source of drinking water and a better technique is to capture and store rainwater. Bermuda has had great success in storing large amounts of rainwater. The water flows down white stepped roofs, where it is purified by sunlight and is then stored in large tanks.

Increasing surface permeability in cities could also be important, because in many SIDS freshwater lenses are thin and additional replenishment could be very helpful to maintain them. This is especially true for SIDS such as Tonga, which get large amounts of rain. Within each SIDS, there are both natural areas and cities with heavy development. Rain gardens and green roofs should be implemented in areas with a high density of impervious surface, generally urban centers, in order to achieve maximum impact.

Planting Seagrass for Coastal Erosion

Planting Seagrass for Coastal Erosion	Recommended?	Key Opportunities/ Constraints
Bermuda	✓	Has experienced extensive coastal erosion; lower disaster risk relative to other SIDS examined
Curaçao	✓	Dependence on tourism, seagrass is unattractive and could deter tourists from visiting; less frequent disasters relative to other SIDS examined
RMI	✓	Has experienced extensive coastal erosion; extremely vulnerable to cyclones and floods; plentiful lagoons provide sheltered areas for restoration
Tonga	✓	Has experienced extensive coastal erosion; extremely vulnerable to cyclones and tsunamis; plentiful lagoons provide sheltered areas for restoration

Table 2h: Planting Seagrass for Coastal Erosion in Bermuda, Curaçao, Republic of the Marshall Islands, and Tonga.

Beaches are critical barriers for island nations against seas and storms - and seagrasses are a critical barrier for beaches. Seagrass restoration can reduce coastal erosion and even counter sea level rise. Seagrass beds dampen the force of waves crashing on the shoreline, which reduces coastal erosion. As sea levels rise, seagrass spreads into shallower waters, where the sediment it collects helps slow the rate at which land is claimed by the sea (Reynolds, 2018).

There are three methods of seagrass restoration: natural recolonization, transplantation, and seeding. Natural recolonization focuses on improving water quality and restoring natural aquatic conditions to induce recolonization of seagrass rather than actually planting seagrass. Transplantation consists of relocating seedlings or mature plants to the restoration site. Seeding simply involves propagating seagrass seeds directly into the water (Rhode Island Habitat Restoration Portal, n.d.).

All four of our SIDS have historically had native seagrass populations, but a number of factors need to be considered for the successful restoration of seagrass. These include plot size, species of seagrass, and season of planting. In a 2017 study on open coast seagrass restoration, 6-square-meters was found to be the minimum plot size to have successful restoration (Glynn, 2019). In addition, the study concluded that the best results came from planting the species *Zostera marina* during spring and summer (Bovida et al., 2019). Successful seagrass restoration hinges on a clear understanding of the threats to seagrass survivability. It is also important to consider the risk of invasive seagrass, which can be problematic for local ecosystems. Seagrass restoration efforts would need to be carefully executed to ensure that the ecosystem isn't damaged by the introduction of new types of seagrass. Currently the Living Shorelines Project in the San Francisco Bay area, California is experimenting with new technology to plant seagrass successfully. Planting seagrass aids in reinforcing the area's shoreline without degrading the wildlife habitat (Ikaraski, 2014).

The chief threat to successful seagrass restoration is storms, which can uproot newly planted seagrass beds and agitate sediments to block light. Strong wave energy also poses a threat to seagrass restoration efforts (Glynn, 2019).

Elevating Houses with Stilts for Sea Level Rise

Elevating Houses with Stilts for Sea Level Rise	Recommended?	Key Opportunities/ Constraints
Bermuda	Uncertain	Common housing construction material is concrete, which would too heavy for stilts
Curaçao	Uncertain	Limited application because sea level rise is only a moderate threat relative to other SIDS examined due to hilly topography
RMI	✓	Government has announced elevating the islands as a centerpiece of their climate change initiative
Tonga	✓	Limited forest resources, therefore wooden stilts not recommended; however, concrete posts have been used in the past

Table 2J: Elevating Houses with Stilts for Sea Level Rise in Bermuda, Curaçao, Republic of the Marshall Islands, and Tonga

Elevating houses with stilts can allow island nations to continue living on islands as sea levels rise. To elevate structures, utility and line connections need to be disconnected and the structure needs to be separated from its pre-existing foundation (FEMA, 2013).

The structure is then lifted by hydraulic jacks and an elevated foundation is constructed underneath (Hill, 2014).

Stilt houses have a long history in Southeast Asia and Central America where they feature prominently in areas vulnerable to flooding. They are made from local, natural materials such as wood, bamboo, or cane. The stilt houses of Buenavista and Nueva Venecia, both in Colombia, are a potentially replicable case study for small island nations, given their similar issues with water inundation. In Buenavista and Nueva Venecia, all the houses are supported by wood stilts and the houses are connected by canoes. Specifically, the houses are elevated with mangrove wooden stilts that are driven into the ground (UNESCO, 2013).

It is important to consider the threats that are specific to each potential location. Some SIDS may have limited resources and be unable to use wood, while others might face frequent high wind in addition to flooding and may need to consider stronger materials.

Salt Tolerant Crops

Salt Tolerant Crops	Recommended?	Key Opportunities/ Constraints
Bermuda	✓	Limited freshwater resources; declining value of domestic agriculture production - less than 50 individual farmers left
Curaçao	✓	Rely mainly on imports, however would be beneficial and more sustainable
RMI	✓	Preference for imported food; younger population uneducated in growing crops; lack of space for agriculture
Tonga	✓	Conducting research on salt tolerant sweet potatoes; weak household food security

Table 2K: Salt Tolerant Crops in Bermuda, Curaçao, Republic of the Marshall Islands, and Tonga.

SIDS have limited freshwater resources and even these are at risk due to saltwater intrusion into freshwater lenses and changing precipitation patterns. This can pose a challenge for farming because many crops do not tolerate highly-saline water. Many SIDS practice subsistence agriculture to some extent - and given their isolation, it is important that this practice continues in case the islands are cut off from outside sources.

There are two ways to address salinity tolerance in agriculture - one, making traditional crops more salt tolerant, and two, introducing naturally salt-tolerant crops. Crops can be made to be more salt tolerant through breeding and selection (Bergkamp et al, 2018). This is an important option because it allows people to continue to grow and eat crops of cultural importance.

Some crops are naturally more saltwater tolerant, but they must meet other criteria in order to be viable options for agricultural introduction. They need to have good yield potential, irrigation needs that won't interfere with existing crops, and act as substitutes for conventional crops (Bergkamp et al, 2018). In this area, there is the potential to introduce more salt-tolerant varieties of traditional or widely-grown crops and minimize the impact on island residents' diets. One example of this is the use of a strain of rice in Cuba which is naturally more tolerant to salty water (Bergkamp et al, 2018). The Maldives have seen success with coconuts (Bergkamp et al, 2018). Others include beets, sweet potatoes, and barley.

Food can have an important cultural value and we know that many SIDS have experienced food imperialism in the past which has caused persistent health problems. For these reasons, we believe that agriculture should remain as is wherever possible and that research is focused on how to breed current widely-grown crops to be more salt tolerant.

Subsistence Farming

Subsistence Farming	Recommended?	Key Opportunities/ Constraints
Bermuda	Uncertain	Declining value of domestic agriculture production - less than 50 individual farmers left; younger generation showing interest in culture revival and preventing foreign investors
Curaçao	✓	Imports the majority of food; history of African wild rice production by descendants of enslaved Africans
RMI	X	Lack of land and space; preference for imported food
Tonga	✓	Small scale subsistence farming already occurring; a lot of fallow land; may allow growth to a community level

Table 2L: Subsistence Farming in Bermuda, Curaçao, Republic of the Marshall Islands, and Tonga.

Subsistence farming is a practice where food is produced to feed a family, as opposed to producing large quantities of food to sell for profit. Subsistence farming is a form of climate change resilience when applied well (Sima et al., 2015). Subsistence farming at an individual or a neighborhood level can supplement imported food with local sources. This decreases a SIDS' reliance on costly imports.

Before colonization and modernity, many indigenous and local communities depended on subsistence farming. In times of surplus, each island culture had their own way storing food so they could save the food for times of need (Mercer et al., 2007). Root crops were the staple crop for many island communities, as the root portion of the plant remained safe from disaster (Mercer et al., 2007). Due to the diverse nature of SIDS, each island often had a staple specific to their land, soil, and location (Mercer et al., 2007).

Currently, land on some SIDS is used for cash cropping and commercialized farms. Individuals and families are unable to rely on what is grown for their own use. It is important for islands to develop or improve their local subsistence farming as the climate changes.

Energy Independence via Mini-Grids

Energy Independence via Mini-Grids	Recommended?	Key Opportunities/ Constraints
Bermuda	✓	Access to space on land and water for mini-grids
Curaçao	✓	Access to space on water for mini-grids; trying to reduce oil dependence, so population would be receptive
RMI	✓	Access to space on water for mini-grids
Tonga	✓	Access to space on land and water for mini-grids

Table 2M: Energy Independence via Mini-Grids in Bermuda, Curaçao, Republic of the Marshall Islands, and Tonga.

SIDS current energy systems rely on imported, non-renewable sources such as oil and gas. Energy independence is an important climate change adaptation. The concept of energy independence for the home is based off of Subhes C. Bhattacharyya's (2016) proposal for mini-grids for rural electrification of developing countries. Mini-grids consist of small-scale renewable energy generators with batteries that are attached to homes and can make them energy independent. The islanders would have access to power and electricity even after storms and disasters, which frequently knock out power lines.

Earthship, an architecture firm, is already applying this to homes. Each Earthship home is built with the goal of self-sufficiency for energy, water, and food (Reynolds, n.d.), which makes them unique among NGOs and other organizations installing renewable energy sources. Each Earthship home is unique to the local environmental and cultural needs. Additionally, this has already been done on an island - Earthship founder Michael Reynolds helped rebuild Haiti after the 2010 earthquake by teaching 40 Haitians to build their own Earthship homes (Aleph, 2014).

There are also other technologies that can be implemented for SIDS to become energy independent, one of which is SwimSol GmbH. This project consists of floating solar systems on the sea, called SolarSea. The SolarSea panels have been already implemented in the Maldives and there is the potential for expansion to other SIDS (United Nations, 2018). Floating solar panels are a useful adaptation for SIDS where land is limited, but for this particular adaptation we advise extra considerations because the project is fairly new and it is unclear how long the panels will last. SIDS would also need to consider the impacts the solar panels could have on tourism and the local ecosystem.

Lastly, the international governmental organization International Renewable Energy Agency (IRENA) has started a framework to support small island nations in transitioning to renewable energy systems (IRENA, n.d.). This framework is known as SIDS Lighthouses Initiative and also provides further support on grid stability.

Disaster-Resistant Buildings

Disaster Resilient Buildings	Recommended?	Key Opportunities/ Constraints
Bermuda	✓	Older structures are generally one story and more resilient to storms; newer structures use cheaper materials and need to be retrofitted
Curaçao	✓	Dutch architecture not suited for the climate; need to improve heat resistance and stormproof roofing
RMI	✓	Local resources available to wind-proof structures
Tonga	✓	Local resources available to wind-proof structures

Table 2N: Disaster-Resistant Buildings in Bermuda, Curaçao, Republic of the Marshall Islands, and Tonga.

Disaster resistant buildings are able to withstand powerful storms and earthquakes with minimal damage and to protect the people inside. They are increasingly important as climate change causes more extreme weather in SIDS. Round buildings are especially popular due to their flexibility and strength (Econation, 2016). A round home requires a solid foundation and a limber frame, which makes the overall structure more resistant against earthquakes. A rounded roof is less affected by wind planning, which can occur during storms when a strong wind lifts up the roof structure (Econation, 2016). Deltec homes is an American architectural company that specializes in round homes. Their main selling point is the hurricane-resistant nature of their buildings, which were able to withstand Hurricane Katrina's winds and tidal surges (Deltec Homes, 2019).

In addition to round homes, there are other disaster-resistant structures that are less costly. Build Change is an organization specializing in rebuilding after disasters and working towards disaster-resistant buildings. The organization emphasizes learning from the local culture to help improve building techniques. Build change has worked with various cities and countries after disasters, including the Philippines (Build Change, 2019).

Conclusion

This section consists of an overview of current adaptations in Bermuda, Curaçao, RMI, and Tonga, as well as reviews of potential climate change adaptations to apply to SIDS that can be further discussed with local experts. The review of current adaptations served as a springboard for making informed recommendations for novel adaptations. These current adaptations were examined through the lens of three major categories - green, hard, or soft infrastructure - in order to standardize the review across all SIDS. In addition, relevant plans, policies, and projects were covered to provide a comprehensive overview. In the latter half of the section, a total of ten potential climate change adaptations were reviewed. The recommendations were made on the basis of key opportunities and constraints for each SIDS.

We found that in all SIDS building techniques could be modified to better resist the effects of climate change, such as sea level rise and increasingly severe storms. Some adaptations cannot be applied in all SIDS, for example stormwater capture and rain gardens are useful in Tonga and Bermuda, but are not practical in Curacao and the Marshall Islands which get very little rain. Additionally, the Marshall Islands faces more space limitations than the other SIDS we studied, which makes dealing with rising sea level more difficult. It is important for SIDS to use a variety of climate change adaptations tailored to their specific situations in order to combat the threat of climate change.

Reducing the Devastation of Natural Disasters by Proactive Planning

Figure 3A: Four Fiji children play on a bilibili, a traditional raft, in a small river outside of Lami (Hobgood 2005).

As a result of the increasing effects of climate change, SIDS have begun to see more extreme and more frequent disasters. These disasters not only cause hundreds of millions of dollars worth of damage, but also death, the spread of disease, and decreased quality of life. Governments of SIDS must develop and refine disaster management plans to facilitate coordination between government agencies, NGOs, stakeholders, and the affected communities following a disaster. Here, we used two avenues to evaluate disaster planning in our four SIDS:

1. Research current disaster management plan documents to provide a context for existing goals and actions regarding disaster management, and
2. Evaluation of in-practice disaster management through case studies of disasters in recent years.

Through this research, we hope to understand the disaster management operations in each SIDS and identify strengths and weaknesses of applied disaster management. This will allow us to identify areas of disaster management with potential for future improvement.

Identifying and Analyzing Disaster Plans

To find disaster management plans to read and evaluate, we conducted a Google search and used the most recent disaster plans released by the SIDS' governments. In order to evaluate these plans, we selected several elements to specifically find and highlight. The elements include:

- The nation's risk context (physical, geographical, and socioeconomic factors that contribute to elevated risk),
- Actors and stakeholders involved in disaster management (NGOs, government agencies, community groups, external contributors, and corporations that are responsible for implementation of the plans),
- Funding sources, and
- Prioritized goals to be identified by disaster planning document.

Methods for Disaster Case Studies

To determine the two disasters for each of our SIDS, we started with a Google search of "State" + "Natural Disasters". From the results, we selected the first link available that had a comprehensive list of disasters from 1990-2019. We then read through the list of disasters and selected two based on the following criteria, in the order they are listed: disasters that fall within the 1990-2019 time frame, disasters that are responsible for the most deaths, and then if there were not two disasters with deaths in that time period, or there were more than two, we looked to those disasters that had the highest financial cost.

Summary of Disaster Risk in Four SIDS

Disaster Type	Bermuda	Curaçao	RMI	Tonga
Storm Surge	High	Medium	High	High
Hurricanes	High	Low	High	High
Sea Level Rise	Medium	Medium	High	Medium
Earthquakes	Low	Low	Low	High
Drought	Medium	High	High	Medium

Table 3a: Common Disasters and Risk Level Associated for Bermuda, Curaçao, Republic of the Marshall Islands, and Tonga.

The figure above is a table summarizing key findings about the relative risk of five types of common disasters in the four SIDS. We found the common disasters, as well as their associated risk, on each of the four islands through literature reviews of government documents, as well as peer-reviewed papers. We ranked the level of risk low, medium, or high, based on a comparative analysis of the frequency of disasters and the potential of said disaster occurring on each of the four islands.

All the islands are either currently experiencing rising sea levels or are facing a strong potential for sea level rise in the future, but RMI is at higher risk than the others because of its low-lying geography. In contrast, earthquakes are of low risk of occurring in all our study islands, with the exception of Tonga.

While hurricane risk is of varying level across the four countries, it was the type of natural disaster that was most impactful using our case study selection methodology. Only the Republic of the Marshall Islands had a different disaster: drought.

A deeper analysis for each country is provided next, along with a conclusion that identifies compares across the countries.

Bermuda

Figure 3b: Aerial view of the island of Bermuda (Skinner 2017).

The major document utilized for this section is the *Royal Bermuda Regiment Disaster Management Plan V6.6 (2016)*. This disaster response document was selected based on its time-relevance and production by Bermudian government agencies with the aid of external stakeholders. It is also important to note that the Government of Bermuda has several plans, policies, and reports dealing with disaster management and planning in addition to the one selected for this report. There are also other strategies implemented to prepare for disaster and mitigate potential harms besides those listed.

Risk Context:

The *Disaster Management Plan* is the Royal Bermuda Regiment's plan to protect the island in the event of a significant disaster, either natural or manmade. While the island is vulnerable to many threats, major hurricanes are described as the most likely and result in the most damage. Historically, the most casualties have resulted from flooding due to storm surges. Due to its location, Bermuda is vulnerable to El Niño and La Niña conditions, which impact the magnitude, frequency, and duration of hurricanes. La Niña years have more suitable atmospheric conditions for hurricane formation and so have a greater risk.

Tsunamis are also seriously considered in the plan, and oil spills are another potential threat.

Actors and Stakeholders:

There are a vast number of groups and individuals involved with disaster planning in Bermuda. They include local Bermudian Agencies such as the Bermuda Police Service, the Ministry for Public Works, The Department of Public Transportation, and the Bermuda Weather Service. These agencies were identified in the *Disaster Management Plan* which also lists their specific roles in disaster management. Since Bermuda is a part of the British Commonwealth, there are also agencies from the United Kingdom involved in disaster management, as well as international NGOs that provide disaster relief.

Funding:

The Royal Bermuda Regiment functions as the state's military branch and is the lead agency for disaster management and response. They are funded through taxation and support from the United Kingdom, due to their status within the Commonwealth. In the event of a disaster, they also have emergency funds available.

Officers in the Bermudian Government recently attended an emergency financial assistance workshop in the British Virgin Islands with a host of international representatives from organizations such as the Red Cross and the World Food Program (Government of Bermuda, 2019).

There are also international organizations and NGOs that provide support for communities in the face of disasters. Some examples of these organizations include the European Union, the World Bank's Global Facility for Disaster Reduction and Recovery, the Global

Environment Facility (GEF), and the Red Cross.

Goals:

The Royal Bermuda Regiment lists their mission as, " to support the Civil Authority with the security of Bermuda, its peoples, property, and livelihood and interests in order to maintain normality." To accomplish this, they list goals which include:

- Coordination of work
- Unity of effort
- Maintain normalcy
- Timely, prompt, and effective communication between all departments

Their *Disaster Management Plan* provides instructions for actions to implement in order to achieve each goal. For the goal 'Coordination of Work,' these actions include pre-positioning supplies and equipment to prepare for the impacts of an emergency event. The regiment will also form into five Immediate Response Teams (IRT). Another strategy utilized is the Pairing of Key Personnel. This means that during the hurricane season, from June to November, key government agencies coordinate with each other to ensure that any leaves or absences will not coincide and leave the island vulnerable. Coordinating Instructions are included at the bottom of the *Disaster Management Plan* in the Template Operations Order.

Case Studies:

Hurricane Fabian

Figure 3c (left) & 3d (right). *Destruction of Hurricane Fabian on the Causeway (Royal Gazette 2012). Aftermath of Hurricane Fabian on Bermuda's roads (Bernews 2003).*

Hurricane Fabian lasted from August 27th through September 10th, 2003 and made landfall in Bermuda on September 5th, 2003. It reached peak winds of 145 miles per hour, with winds of 120 miles per hour (MPH) after making landfall. It was considered, at its highest, a Category 4 hurricane on the Saffir-Simpson Scale and it was a Category 3 when it made landfall in Bermuda (Pasch, 2003). Hurricane Fabian caused four deaths in Bermuda when two vehicles were swept off the island's main causeway. As a result of strict orders to stay inside, there were no other deaths in Bermuda resulting from the hurricane and only nine people were hospitalized for injuries. Had the four people who died followed the official instructions to stay inside, Bermuda would've had no deaths from Hurricane Fabian.

Five shelters were opened across the island for those who did not choose to evacuate. These shelters were noted to be overcrowded and short on resources. The airport was closed for several days after part of a wall was destroyed. Widespread flooding affected the island and winds knocked over countless trees and tore off roofs. The storm surge was estimated at 10 feet and there were reports of swells up to 20 feet (Pasch, 2003). Vegetation was significantly damaged, particularly affecting the agriculture industry. This hampered recovery efforts in the coming months, as many resources normally relied upon were diminished or destroyed in the storm (Pasch, 2003).

Insured damages from the storm were estimated at $300 million and over 78% of customers were without power at one time (Johnston-Barnes, 2012). During the hurricane, buildings and equipment were damaged, partly due to their old age. Many buildings that reported damages experienced roof damage. While 78% of customers were without power, sections of the capital city, Hamilton, retained power due to many of their power lines being underground. This allowed the lines to remain unaffected in the face of the strong winds and heavy storm conditions that plunged the rest of the island into darkness. Since the storm, Bermuda has moved 100% of its transmission cables and 50% of distribution cables underground (Johnston-Barnes, 2012).

Hurricane Gonzalo

Figure 3e: Yachts crashed into trees as they broke free from their moorings (Associated Press 2014).

Hurricane Gonzalo lasted from October 12th through 20th, 2014 and made landfall in Bermuda on October 18th, 2014. It reached peak winds of 144 miles per hour and was considered a Category 4 hurricane (Brown, 2014). It came soon after Hurricane Fay, which made landfall in Bermuda on October 12th, 2014, a mere four days beforehand. At Gonzalo's time of impact, 4% of customers in Bermuda were still without power. Once Hurricane Gonzalo made landfall, over 86% of customers lost power.

Estimated insured losses from the storm were between $200-400 million, making it one of the most fiscally damaging storms in recent Bermudian history. On the day it hit, emergency services received 123 calls related to the storm, with incidents including fire, roof, and structural damage, medical necessities, and minor incidents. The airport was closed for roughly two days, due to roof damage, but repair efforts were swift (BBC, 2014).

Following new building codes in Bermuda requiring construction specifics to withstand sustained winds of 110 MPH and gusts of 150 MPH, many more buildings survived and experienced less damage than previous storms of similar strength. Specifically in the tourism industry, most resorts reported only minimal roof damage (Liston, 2014).

Unfortunately, most of the island was without power after the disaster, as they hadn't yet moved the majority of power lines underground. Bermuda did manage to avoid any fatalities caused by Hurricane Gonzalo thanks to improvements in disaster coordination and preparation between industry and government officials since Hurricane Fabian eleven years prior.

Figure 3f: A car struggles to drive through Hurricane Gonzalo as it hit Bermuda (Reblop 2014).

Conclusions:

The goals listed in the *Disaster Management Plan* are: maintain normality, coordination of work, and unity of work. Bermuda has been most successful with coordination and unity of work. Supplies are pre-positioned following hurricanes and work crews are coordinated so that maintenance is able to clear roads for emergency workers.

Bermuda improved between Hurricane Fabian and Hurricane Gonzalo, and was more successful at maintaining normality. After Hurricane Gonzalo the airport was only closed for two days and many buildings survived the storm. There is still work to be done on this goal however, as significant power outages affected the majority of the population in both storm examples. Bermuda has worked to address this by moving power lines underground. Furthermore, buildings experienced notable weaknesses in the strength of their roofs in both storms, highlighting a gap in building standards and construction. Bermuda should take steps to improve resilience and decrease roof damage in the face of strong winds and high levels of precipitation. Additionally, Bermuda should consider investing in crops and resources that can withstand hurricanes to minimize economic losses. This would allow the government to maintain normality long term after disasters.

Curaçao

Figure 3g: The port of Curaçao as seen from the perspective of a cruise ship (Costa Cruises 2019).

For the purposes of this section, we will be referring to the *National Report of Curaçao 2014*, a comprehensive document detailing progress towards national priorities, which include disaster response.

Risk Context:

This Dutch Caribbean island is relatively safe from hurricanes. Curaçao is part of the 'ABC' or Leeward Islands which include Aruba, Bonaire, and Curaçao. According to the Meteorological Department of Curaçao, there is a common misconception that the island is located outside the hurricane belt, while in fact Curaçao is located on the southern edge of the hurricane belt (Meteorological Department of Curaço, 2018). Curaçao is situated such that many hurricanes are formed and move near the island, but may not necessarily pass over the island directly. The Meteorological Department of Curaçao states that a tropical storm will occur within 150 kilometers of the ABC islands every four years on average while a considerably damaging hurricane may hit the islands every hundred years (Meteorological Department of Curaço, 2018). However, the risk of hurricanes may increase with climate change (Meteorological Department of Curaçao, 2018).

The primary hazards in Curaçao include: flash flooding from tropical storms, heavy rainfall, breaching of dams, and other risks associated with severe thunderstorms (Meteorological Department of Curaçao, 2018). These periods of irregular and heavy rainfall are both the most common and the most damaging (Meteorological Department of Curaçao, 2018). Normally Curaçao's arid climate yields dry seasons which can become prolonged into droughts (Burt, 2018).

Less frequent hazards are tsunamis and oil spills (Meteorological Department of Curaçao, 2018).

Actors & Stakeholders:

For the island nation of Curaçao, a single department can fill multiple roles in the categories of management, distribution of relief resources, medical relief, rescue operations, finance and foreign aid, and warning and communications. A total of 27 actors and stakeholders have been identified for Curaçao, including international partners and non-governmental organizations. Some of the most notable are the Caribbean Disaster Emergency Management Agency (CDEMA), Curacao's Operational Team, the Caribbean Coast Guard, the United Nations, and the International Conference for Small Island Developing States. These actors and stakeholders were identified via the *National Report of Curaçao (2014)* and *Maritime Emergency Response Plan for the Dutch Caribbean (2013)*, which lists organizations and their responsibility relating to disaster preparedness and response.

Funding:

Curaçao is part of the Kingdom of the Netherlands and has association status within the European Union. This means Curaçao is eligible for EU funds when disaster strikes. Curaçao is hit by disasters less often than other SIDS and they are generally less severe. This means that there is less historical information available about disaster relief funding in Curaçao than for the other nations we discuss in this report. However another Dutch Caribbean nation, St. Maarten, has recently been affected by natural disasters. As St. Maarten and Curaçao have the same status in the Kingdom of the Netherlands, it is reasonable to assume they have access to the same sources of funding. After Hurricane Irma in 2017, St. Maarten received financial assistance from the Netherlands and from the World Bank (The Daily Herald, 2019). Therefore, we believe the Netherlands and the World Bank are potential sources of funding for disaster recovery in Curaçao.

Goals:

Curaçao is planning to prepare for disasters with large consequences to the environment, society, and economy, such as hurricanes, tsunamis, and storm surges. The *National Report of Curacçao* has reported on Curaçao's developmental progress in 14 different areas. The areas which are relevant to disaster risk management and disaster response are: 1) climate change and sea level rise, 2) natural and environmental disasters, and 7) energy resources.

The first area, climate change and sea level rise, is especially important for Curaçao as climate change adaptation and mitigation are considered a national priority. Achievements in this area include: 1) dissemination of information by the Meteorological Department to increase public awareness on climate change, 2) sea level monitoring at the Mega Pier and Bullenbaai, and 3) climate studies conducted by the Meteorological Department to establish the level and impact of climate change in Curaçao.

Natural and environmental disasters are the second area relevant to this section. The island is already very vulnerable to natural disasters, which will likely worsen with sea level rise and changing weather patterns. Storm surges can be powerful enough to damage coastal zones and underwater ecosystems. The Regional Risk Reduction Initiative (R3I) project has completed an assessment of preliminary risks and hazards, identifying both natural and environmental hazards, and creating a document repository for archiving disaster management documents. This project is continuing to focus on hazard mapping and working with GIS. At the time the report was published (2014), the current Disaster Management Structure was being revised.

Energy resources, area number seven, are important for sustainable development, climate change adaptation, and disaster response. An over-reliance on oil makes Curaçao vulnerable during and after disasters. To minimize the risk of blackouts, the government has drafted policy on electricity regulations as part of the overall Energy Plan. This policy's aim is to provide sustainable electricity for corporate markets and private households. After regulations for small-scale and renewable productions were stipulated, households and companies were able to produce their own renewable electricity, solar panels were installed, and oil imports decreased.

Disasters Case Studies:

Hurricane Lenny, 1999

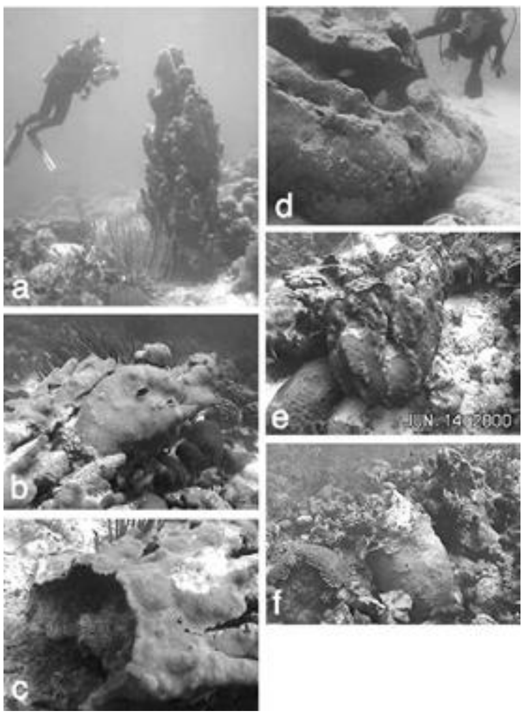

Figure 3h: Left - Aftermath of Hurricane Lenny leading to the destruction of large coral reefs (Bries et al. 2004).

Hurricane Lenny was the fifth Category 4 hurricane to hit the Caribbean in the 1999 season (Guiney, 1999). Lenny was unusual due to its eastward track, as most hurricanes swerve northward. Lenny formed south of Jamaica and headed east towards the Dutch Caribbean. Most of the damage was felt by the Windward Islands of Saba, Sint Eustatius, and Sint Maarten. Hurricane Lenny passed 200 miles north of the ABC islands but still caused unprecedented levels of environmental damage (Bries et al., 2004).

Curaçao, along with the other ABC islands, experienced heavy rainfall for 36 hours (Guiney, 1999). Additionally, strong surf conditions wrecked the southern coast. These coastlines were hit with 24 hours of waves that were 3 to 6 meters high (Bries et al., 2004). There were also swells, which caused severe beach erosion and damage to small vessels and beach structures (Bries et al., 2004). The coral reefs around Curaçao, however, felt the most damage (Bries et al., 2004). Massive coral colonies older than 100 years and 2-3 meters high were toppled over and overturned (Bries et al., 2004). A combination of the rainfall and heavy surf conditions led to coral fragmentation, tissue damage, bleaching, and smothering (Bries et al., 2004).

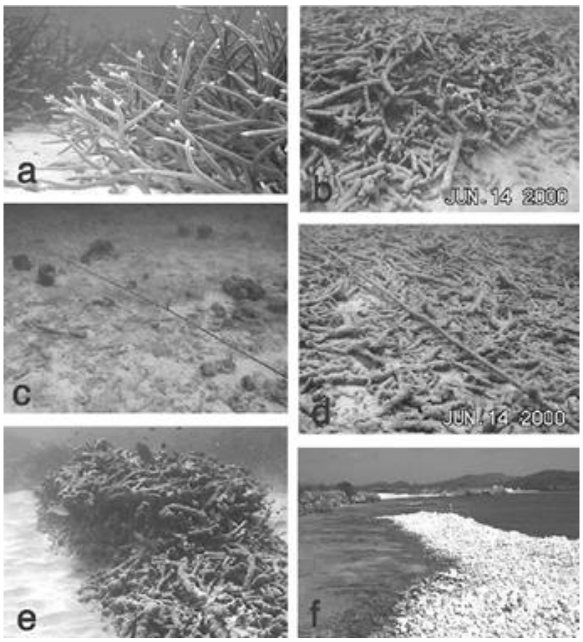

Figure 3i: Aftermath of Hurricane Lenny leading to the destruction of smaller corals (Bries et al. 2004).

This damage took Curaçao by surprise. Curaçao's coral reefs are culturally, environmentally, and economically significant. They are home to many fish species, which were a food source for the people of Curaçao. They are also a highly-visited tourist site and attract many visitors to Curaçao each year. As such, the reefs are important to Curaçao's economy. The unprecedented damage caused by Hurricane Lenny drew the concern of many scientists which led to a wave of scientific studies in the Curaçao region to survey the damage and search for ways to restore the reefs.

The worst outcome of Hurricane Lenny for Curaçao was the destruction of the reefs. As stated above, the island is rarely directly hit or even impacted by hurricanes. Although the Meteorological Department of Curaçao is well aware of the likelihood of hurricanes and the damage they may cause, no one on Curaçao was prepared for: 1) the strength of Hurricane Lenny, 2) the unusual direction taken by the Hurricane, or 3) the impact the storm had on the coral reefs (Guiney, 1999). Furthermore, there were only 36 hours lead, or warning, time for the Leeward Islands (Guiney, 1999). These facts highlight the need for better hurricane prediction and preparedness in Curaçao. Although the island is relatively safe from hurricanes, there is still a very real possibility that it will suffer from being in proximity to a storm. Additionally, it's possible that climate change could mean hurricanes get closer to the island in the future.

Following Lenny, Curaçao aided the Dutch islands of Saba, Sint Eustatius, and Sint Maarten as well as other areas that had faced more severe damage, especially deaths and bodily harm. Curaçao transported relief commodities at the request of the Netherlands and with the help of the United

States Department of Defense (US Agency for International Development, 1999). The relative safety of Curaçao means the island is able to assist other islands and countries in the vicinity following tropical storms.

Figure 3j: Hurricane Matthew hits the coast of Curaçao (CL 2017).

Like Lenny, Hurricane Matthew passed 125 miles north of the ABC islands during late September and early October 2016. Hurricane Matthew did not pass directly over the island but Curaçao still felt its impacts (Associated Press, 2016b).

Curaçao was better prepared for Hurricane Matthew than for Lenny, as the people were warned ahead of time that the storm had the potential to hit the island directly (Associated Press, 2016a). Authorities on the ABC islands told citizens to stock up on supplies and reinforce their homes (Associated Press, 2016a). Curaçao was under storm watch for many days, as the direction of the hurricane was still unknown (International Federation of Red Cross And Red Crescent Societies, 2016). The warning resulted in long lines at gas stations and supermarkets (Associated Press, 2016b).

During the storm, flooding damaged cars and heavy rain damaged outdoor bars and restaurants (Associated Press, 2016a). The winds in the area strengthened to tropical-storm force winds (Associated Press, 2016a). Matthew also caused swells which hit Curaçao and resulted in life-threatening surf conditions and rip currents (International Federation of Red Cross and Red Crescent Societies, 2016). Locals and tourists were warned of these conditions and told to avoid the coast. Since Curaçao is a popular tourist destination year round, the amount of damage suffered by beaches and beachfront properties was documented by tourists and uploaded to YouTube.

Figure 3k: The severity of storm surge due to Hurricane Matthew on beachfront properties (CL 2017).

Curaçao learned from Hurricane Lenny, which occurred almost 20 years before Hurricane Matthew. The island was better prepared because warnings were issued ahead of time and people took them seriously, as indicated by the long lines at gas stations and supermarkets. With better early warning systems, Curaçao's authorities should focus on communicating the level of threat to their people, ensuring there are enough resources for everyone, and working towards guaranteeing safety for vulnerable populations.

Conclusions:

The *National Plan of Curaçao 2014* makes it clear that Curaçao is very aware of the potential increase in disasters caused by climate change. Of the 14 development areas discussed in the National Plan, climate change and sea level rise, natural and environmental disasters, and energy resources all specifically address ways Curaçao is currently preparing and will prepare for a future with increased disaster risks. As the National Plan states, there is more action to be taken and the island nation is seeking to partner with other countries and organizations to strengthen their preparedness.

Curaçao rarely experiences hurricanes directly passing through; however, the island is still vulnerable to the indirect impacts of hurricanes. Hurricane Lenny provides a great example of unprecedented damage to Curaçao's coral reefs. As Lenny demonstrates the need to better predict hurricane paths and implement early warning systems, Hurricane Matthew shows the negative consequences of issuing warnings without enough information. Both hurricanes reveal the need for an overall improvement in the prediction of hurricane paths. Fortunately, both hurricanes did not result in any human harm for Curaçao.

Republic of the Marshall Islands

Figure 3l: An aerial view of Majuro, the capital atoll of the Marshall Islands (Naydenova 2018).

The major document utilized for this section is the *National Action Plan for Disaster Risk Management (2008 – 2018)*. This disaster response document was selected based on its time-relevance and production by RMI governmental agencies, with some aid from external stakeholders.

Risk Context:

Given its climate, location, and physical characteristics, the Republic of the Marshall Islands (RMI) is especially vulnerable to numerous climate-related natural disasters. Floods and droughts are the principal natural disasters that put the nation at risk. Flooding is the result of intense precipitation during a short span of time and in RMI can be exacerbated by storm surge and King Tides. Drought is exacerbated by increasing seasonal precipitation variability due to climate change, as well as saltwater intrusion into freshwater reserves. Both floods and droughts increase in intensity and prevalence during El Niño years. During an El Niño year, RMI experiences increased precipitation early in the year and decreased precipitation in the dry season (NOAA, n.d.).

The Republic of the Marshall Islands is also especially vulnerable to these natural disasters due to compounding geographic and socioeconomic factors. The nation of 29 atolls has a very low average elevation of about two meters, wide dispersal over a large area of the Pacific Ocean, ecosystems that are vulnerable to climatic and environmental changes, and limited freshwater resources. Some of the islands do not even have a water table (Mellgard, 2017). Socioeconomic risk factors include the large variation in population density across the twenty-nine atolls, high rates of poverty in some regions, and a weakly developed economy heavily reliant on the public sector. These risk factors are fundamental to understanding disaster risk in RMI and appropriately developing response mechanisms.

Actors and Stakeholders:

There are a vast number of agencies, groups, and individuals involved with disaster planning in RMI. They have a wide array of functions including high-level management, distribution of relief resources, medical relief, rescue operations, finance & foreign aid, and warnings & communications. RMI has a few governmental agencies that are very active in disaster planning, including the Environmental Protection Authority (EPA) and National Disaster Management Office (NDMO). Local corporations, like Majuro Water and Sewage Company and Kwajalein Atoll Joint Utility Resources, and local non-governmental organizations also play a role. All of these entities work together under the National Action Plan Implementation Unit, appointed by the government of RMI, to enact the disaster recovery plan.

Funding:

RMI receives financial support from the United States, under the Compact of Free Association (COFA). Prior to 2008, the country received aid for disaster response through Federal Emergency Management Agency (FEMA). According to the disaster response plan document, aid is currently being re-negotiated under USAID. RMI's own budget mainly relies upon public sector revenue. In disaster situations, RMI is to first use their National Disaster Assistance

Emergency Fund. Additionally, there are a number of potential sources for funding for disaster response that are available to all SIDS, including the European Union, the World Bank, and the Global Environmental Facility.

Goals:

In the most recent disaster management plan, the nation identified ten overarching disaster planning goals. These goals are concerned with creating a governmental infrastructure that streamlines disaster response roles, actions, and budgeting. Many of the goals show a motivation to implement preemptive disaster management mechanisms, such as sustainable coastal development, economic stability, effective warning communication, and disaster management awareness. The ten goals according to the plan are as follows:

- Goal 1: Establish an enabling environment for improved Disaster Response Management (DRM) in Marshall Islands.
- Goal 2: Mainstream DRM in planning, decision making and budgetary processes at national and local levels.
- Goal 3: Improve capacity for emergency preparedness and response at all levels.
- Goal 4: Build a strong and resilient DRM early warning and emergency communication system.
- Goal 5: Access to safe and adequate clean water at all times.
- Goal 6: Sustainable development of the coastal area.
- Goal 7: Reduce economic dependency of the Outer Islands.
- Goal 8: Improve understanding of the linkages between zoning, building codes and vulnerability to disasters.
- Goal 9: Raise the awareness of DRM amongst the public.
- Goal 10: DRM NAP implementation and impact is monitored and reviewed on a regular basis.

Case Studies:

2013 Drought

Figure 3m: The 2013 Drought leads to intense drying of vegetation (UNDP 2019).

The 2013 drought actually began near the end of 2012. Conditions worsened until the Government of the Marshall Islands declared a state of emergency on April 9, 2013, stating that 5,756 Marshallese were living in drought-affected atolls and 11,000 residents were experiencing drought conditions (USAID 2013). The northerly atolls experienced the most extreme drought conditions.

These drought conditions resulted in extreme water shortages; many Marshallese were limited to less than one litre of water each day (Muller, 2013). The drought also damaged crops across the atolls and harmed human health. As freshwater reservoirs in densely populated regions were depleted, the concentration of salts and bacteria in the water increased. As a result, illnesses such as pink eye and diarrhea were more frequent (Muller, 2013).

Fortunately, as this drought took hold of RMI, the government, community organizations, and external donors worked together to bring freshwater and emergency supplies to the affected Marshallese. The nation received $166,655 in disaster response funding from USAID, 40% of which was allocated for water, sanitation, and hygiene (USAID, 2013). The New Zealand Red Cross assisted the effort with financial aid, water filtration units, and other emergency supplies. The United Nations brought in experts to help assess need in the nation. The Government of the Marshall Islands, with help from UNDP, both increased the capacity of Majuro's freshwater reservoir by 14% and installed a new lining and cover in the freshwater reservoir, which reduced evaporation. As a result, the freshwater reserves which previously provided freshwater for 3-4 weeks can now hold freshwater for 3-4 months (UNDP Asia and The Pacific, 2014). This is an essential adaptation and will hopefully prevent water emergencies in future droughts, or at least minimize them. Another approach to ensuring freshwater access included sending solar water pumps and purifiers to outlying atolls (UNDP Asia and the Pacific, 2014). This is a better option for the more remote atolls that do not have access to freshwater reservoirs. Thanks to the coordination of local and international efforts, many post-disaster improvements were made that will hopefully improve disaster management for years to come.

2015-2016 Drought

Figure 3l: Dried vegetation due to the 2015 - 2016 drought on the Marshall Islands. (Fellenius 2016) .

RMI experienced a severe drought that spanned from 2015 to 2016 and was attributed in part to an intense El Niño Southern Oscillation. Some atolls received no precipitation at all for an extended period of time (Hopewell, 2016). The Government of the Marshall Islands declared a state of emergency on February 3, 2016 and a state of disaster on March 4, 2016 ('Post Disaster Needs Assessment', 2017). The drought affected 21,000 people and resulted in $4.9 million of total damages (EM-DAT).

The drought impacted all sectors of RMI and especially threatened the nation's agriculture and freshwater resources. Municipal water sources in heavily populated areas were depleted despite the improvements that had been made and government officials continually "[received] complaints from the public that [they were] out of water" (Majuro Mayor Ladie Jack, cited in Milman, 2016). According to a Marshallese Diplomat "water [was] being meted out in the city only once per week for a four-hour period, forcing each family to allocate their water reserves carefully to last them into the following week" (Hopewell, 2016).

In response to the drought, The National Disaster Management Office arranged for additional solar powered water purifiers to be delivered to outer atolls (Leenders, Holland, & Taylor, 2017). RMI also received $2.5 million in USAID in funding for the purchasing and distribution of emergency supplies (USAID, 2019).

The Marshall Islands will certainly face more droughts in the future and the nation must plan for them. In order to better understand the disaster and response to the disaster the government of the Republic of the Marshall Islands - with support from the European Union, the Pacific Community, the United Nations Development Programme, the United Nations, and the World Bank - produced the *Post Disaster Needs Assessment (PDNA) of the 2015-2016Drought*. This post-disaster needs assessment is the first of its kind in RMI, as well as in the entire North Pacific (UNDP Pacific Office in Fiji, 2016). The assessment helps to quantify and qualify the drought's impacts, as well as identify opportunities for improvement. According to the Marshallese Minister of Finance, "This PDNA is critical in informing the national budgetary process" (Brenson Wase, Cited in UNDP Pacific Office in Fiji, 2016).

According to the assessment, opportunities for improvement include increasing public awareness during times of disaster, improving communication before and after disaster events, and collecting GIS data layers that help indicate regions of heightened hazard vulnerability. These GIS layers could assist government officials with identifying regions of heightened risk that may need more emergency resources. Additionally, GIS can be essential as a component of communication systems, increasing public awareness and emergency preparedness during times of disaster (Holser, 2016). Thus, it would be beneficial to undertake the development of an RMI geospatial database.

Conclusions:

Given the low elevation and wide dispersal of atolls of the Republic of the Marshall Islands, it is essential that emergency supplies are distributed efficiently and disaster risk awareness is communicated effectively. Recent disaster plans have addressed this, but there is room for further improvement. Using internal funding and external aid to maximize the capacity of freshwater reserves and distribute solar-powered water purifiers was a key step towards ensuring public access to clean water during times of disaster. In order to improve disaster management in the future, it will be essential to begin collecting and developing a platform to publicly disseminate GIS data.

Tonga

Figure 3m: A few islands which are part of the Kingdom of Tonga (Getty Images 2019)

The main plan referenced in this section is the *Tonga National Emergency Plan (2009),* designated by the Tongan government as the guiding document in the case of disasters. The *Tropical Cyclone Gita Immediate Response Plan (2018),* as well as various online sources, were used as supplemental resources when information was found lacking in the primary plan.

Risk Context:

Tonga is vulnerable to a wide range of natural disasters. The most common include earthquakes, volcanic activity, tsunamis, cyclones, and floods. Tonga's extreme vulnerability arises from a convergence of geographical and geological factors. Tonga is not only situated atop a subduction zone, but also located within the Pacific Ring of Fire - both of which bring earthquakes and volcanic activity. Unfortunately, earthquakes and volcanoes are not isolated disasters, as they often trigger tsunamis in their aftermath. Additionally, the nearby Tonga Trench is another source of tsunamis. Tonga's vulnerability to disasters is further compounded by socioeconomic factors. One particular area of concern is Tonga's reliance on agriculture - agriculture is a substantial industry for Tonga, and nearly 60% of all economically active Tongans rely on farming for direct sustenance. This means that both the overall economy and individual livelihoods can be severely impacted by disasters.

Actors & Stakeholders:

The central government agency in Tonga for emergency management and response is the National Emergency Management Office (NEMO). However, the highest authority for disaster management is the National Disaster Council, which oversees five committees. The highest-tiered three are national committees, which cover all aspects of the disaster preparation and response process. Namely, these committees oversee management, operations, and recovery. One level below are the district committees, and at the bottom, the village committees. The three national committees provide an end-to-end comprehensive coverage of disaster management, and the hierarchical structure ensures that disaster information and provisions can disseminate down to Tongan citizens.

On the island, there are a total of 21 agencies that are involved in disaster response. Tonga also receives frequent aid and financial support from developed countries and international relief agencies in the aftermath of disasters.

Funding:

Tonga has its own Emergency Fund which is stocked by donor contributions and insurance payouts (Post Disaster Rapid Assessment, 2018). In addition, Tonga receives funding from numerous international sources which include governments, development banks, regional programs, and insurance programs. After Cyclone Gita in 2018, Tonga received $20 million from the World Bank IDA Crisis Response Window. Tonga is also part of the Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) pooled insurance program, which provided the islands with $1.27 million after Cyclone Ian (GFDRR, n.d.). This reliance on international funders for disaster response can be problematic if international relationships become strained.

Goals:

The *National Emergency Management Plan* currently lacks a set of prioritized goals for disaster planning. This is a potential area of concern, as a universal list of prioritized goals can reduce the decision-making lag time that can accompany formulating a new set of goals for each disaster.

In order to examine the disaster management goals Tonga typically uses, we looked at the response plan for Cyclone Gita. In this plan, the strategic objectives are laid out in the beginning of the report. They are focused on the provision of basic services, restoration of livelihoods, and the safety of citizens. The three main strategic objectives are as follows:

- Objective 1: Provide life-saving assistance to people affected by the Cyclone and re-establish basic services.
- Objective 2: Support the restoration of livelihoods and self-reliance.
- Objective 3: Provide safety and protection for vulnerable people, including women, girls, boys and men, including provision of transitional shelter.

The main objectives are each supported by sub-objectives which delve into specific actions that will be taken in the aftermath of a disaster. These actions are focused primarily on the distribution of essential relief resources, such as water, food, shelter, and medical services; rebuilding damaged infrastructure and utilities; and providing protection to citizens, especially the more vulnerable groups.

Case Studies:

Cyclone Winston

Figure 3n: The devastation after Cyclone Gita in Nuku'alofa, Tonga's capital (Pulu 2018).

Cyclone Winston passed over Tonga from February 16 - February 19 of 2016. The cyclone system actually went over Vava'u island twice - first as a Category 2 storm (Caritas, 2016), and later a Category 4 storm bringing winds over 120 km per hour (NEMC, 2016). As a result, damage was spread across numerous sectors, with crops damaged, downed power lines leading to power outages, and school buildings damaged. In terms of human impact, an estimated 2,700 people (roughly 20% of the Vava'u population) were directly affected (NEMC, 2016). The economic cost of Cyclone Winston totalled at $1.4 billion for all affected areas.

The local response to Cyclone Winston was characterized by early and sustained alerts to the public and swift coordination of local agencies. Advisories were issued, awareness programs were broadcast on TV and radio, and live radio interviews were held to warn the public about the imminent storm. The National Emergency Management Office was in operation the night before Winston made landfall, and the National Emergency Coordination Centre and the District Emergency Management Committees were activated swiftly afterward (Government of Tonga, 2016). On the international front, New Zealand, Australia, the Red Cross, and Oxfam deployed relief supplies and aid (NEMC, 2016).

The best measure identified in Tonga's response to Cyclone Winston was preemptively training Vava'u citizens in disaster response - to have these citizens become first-responders of their own communities. This measure was boosted by the prepositioning of emergency supplies before Winston made landfall, which the trained volunteers distributed after the disaster (Caritas, 2016). Equipping those directly impacted by the disaster with knowledge and supplies not only minimizes the time for aid distribution, but also maximizes the effectiveness of on-the-ground disaster response.

A weakness in Tonga's response to Cyclone Winston was the insufficient number of shelter supplies distributed. In the aftermath of Winston, 44 homes were destroyed and 275 homes were severely damaged, resulting in a total of 319 homes that were unusable. This translates into 319 families in need of shelter. However, in Tonga's Tropical Cyclone Winston Response Plan, the recorded number of distributed shelter provisions capped at 231, with 199 tarps and 32 tents distributed (NEMC, 2016). There is a sizable mismatch between the shelter provided and the number of families in need of shelter.

Figure 30: Power Lines were pulled down by the storm, as seen on Vava'u island (Just 2016).

Cyclone Gita made landfall in Tonga on February 12 - February 13 of 2018. It was a Category 4 cyclone and inundated Tonga with a deluge of rain, winds of 230 km/h, and storm surge. The cyclone's passage over Tonga was brief, but it damaged homes, public buildings, water and food security, and transport and communication infrastructure (ACAPS, 2018). The impact on human lives was similarly vast - an estimated 80,000 (roughly 80% of the population) were directly affected by the cyclone (Reliefweb, 2018). On top of the physical devastation to the islands and the human life impacted, the economic cost of Cyclone Gita was $164 million U.S. dollars, equivalent to nearly 40% of the country's GDP (Australian Government Department of Foreign Affairs and Trade, 2018).

In the aftermath of the cyclone, the National Emergency Management Office coordinated local agencies for response. This included assessments conducted by Red Cross volunteers, debris clearing on the roads by the Armed Forces, and the drafting of an Immediate Response Plan by the National Emergency Management Committee. In addition, there was a strong response from the international community led by Australia and New Zealand. This international aid primarily consisted of the shipment of emergency supplies and teams to assist with local assessment of the damage (ACAPS, 2018).

The local and international response efforts to Cyclone Gita highlight both the strengths and weaknesses of disaster management in Tonga. The best measure identified in the response for Gita was the distribution and storage of emergency relief supplies *before* the cyclone season. These supplies included tarpaulins, water containers, and hygiene kits - vital for meeting immediate shelter and water needs (Mitchell, 2018). By distributing relief supplies before the disaster season, the time, manpower, and resource consumption that would normally be invested in distribution is dramatically reduced, freeing up resources to direct to other disaster-response efforts that cannot be preemptively prepared, such as search and rescue. To further maximize the benefit of this response action, emergency food packs and crop seeds could be added to the relief supplies, as Cyclone Gita had a devastating impact on Tonga's subsistence crops.

A pronounced weakness in Cyclone Gita's response lay in the damage to Tonga's electricity network, and the subsequent time required for restoration. 80% of Tonga's electricity network was damaged in the storm, and at the time of initial assessment, 5 weeks was the estimated time frame before the power could be fully restored (ACAPS, 2018). Electricity is necessary for three critical aspects of disaster recovery in Tonga - water supply (as the water pumps require power), hospitals, and communication between coordinating agencies (ACAPS, 2018). Damage to the electrical network severely impeded successful response and recovery efforts in the aftermath of a disaster. To reduce vulnerability to this weakness, moving power lines underground should be considered.

Conclusions:

As the nation is vulnerable to so many disasters, Tonga needs a robust disaster management system in place, one that is supported by comprehensive plans and coordinating actors. In this area, Tonga seems to be doing reasonably well. The disaster response structure appears well-established and comprehensive, with national, district, and village branches. The *National Emergency Management Plan*, the central guiding document in the case of disasters, clearly lays out the structure of the emergency management system, its correct operational forms, and the responsibilities of various agencies. This allows for easy comparative analysis between the actual response to a disaster against the established, theoretical response, which can clearly reveal weaknesses in real-time response. However, despite these strengths, there is one potential weakness in Tonga's disaster management system - the lack of a newer version of the *National Emergency Management Plan*. This plan's creation dates to 2009. Given Tonga's pronounced vulnerability to disasters, revisions to their central disaster plan that take into account lessons learned from disasters accrued over a decade seem quite necessary.

But even with a strong disaster management architecture in place, implementation is just as vital. The examination of the disasters cases of Cyclone Gita and Cyclone Winston reveals that there are both improvements still to be made, but also worthwhile actions that should be replicated or scaled up. The strengths of the response to Cyclone Gita and Cyclone Winston are strikingly similar - they involved distributing relief resources before the crisis even hit. This offloading maximizes the timeliness and effectiveness of disaster response in the aftermath, while freeing up resources for other essential disaster response actions. However, the response to Cyclone Winston also highlighted that perhaps one way to improve the effectiveness of this preemptive distribution would be to increase the inventory of shelters in stock. And in the case of Cyclone Gita, vulnerabilities of Tonga's electrical infrastructure were exposed. Thus, it seems that efforts to disaster-proof the electrical infrastructure should take priority in the improvement of Tonga's disaster planning

Conclusion for Reducing Natural Disasters Impacts by Proactive Planning

This chapter provides an overview and analysis of the most current disaster management plans, supplemented by case studies of two disasters for Bermuda, Curaçao, the Republic of the Marshall Islands, and Tonga. All four SIDS have learned from past disasters and improved their management strategies over time. However, there is still significant room for improvement in all of them. After analyzing official documents and each case study, it is our conclusion that each SIDS is well aware of the challenges they face. All four SIDS are limited by money and resources. Our wealthier SIDS, Bermuda and Curaçao, have made significant progress and experience relatively small amounts of damage in more recent disasters. The Marshall Islands and Tonga on the other hand, have enacted regulatory policies that would reduce damage if implemented, but still experience large amounts of damage because citizens cannot afford to build to code.

Using a Lifeline Analysis to Estimate the Peril of Being Cut Off After a Natural Catastrophe

Figure 4a: Mona Jetnil, carrying her son, stands on the lagoon side of her home in the Marshall Islands (Hinzel, 2014).

Introduction

All islands are by definition isolated. That being said, when a natural disaster occurs on an island, the delivery of food or medical aid can be challenging. Many SIDS only have one major port and one major airport. It is easy to imagine a tropical storm or a tsunami wiping out this critical infrastructure and damaging local agriculture. Many islands are aware of this vulnerability, Hawaii for example reports on how much food the state imports and the available supply of this food at any given time. They claim that 85-90% of Hawaii's food is imported, and that the State could only last two weeks based on what is stored or grown locally (Office of Planning, 2012). Inspired by this, we developed a "lifeline analysis" tailored to an extreme case of natural disaster and isolation for Bermuda, Curaçao, Marshall Islands, and Tonga. Specifically we asked: what if a disaster hit a small island and eliminated their ports and airports temporarily, and also destroyed most of their local agriculture? Given the population's dietary needs and the amount of imported food that is available, how long could the amount of food on-hand support the island population?

Despite extensive searching, we were not able to find the source of Hawaii's statistics, so we developed our own methodology to calculate similar statistics for our SIDS. To quantify each islands' food supply during and following disasters, we looked at how much food each SIDS imports and calculated how long their supplies would last in a worst case disaster scenario.

Because many SIDS have a large tourism industry, we did calculations based on both the busy season and off-season populations. For the sake of this project, we assumed there were no incoming supplies in the aftermath of the disaster, and that local food sources on the islands were damaged either damaged and inedible, or inaccessible. We believe this scenario is realistic because a powerful storm or tsunami could damage ports, which would prevent supplies from arriving, destroy crops, and ruin fishing boats and supplies.

We did these calculations with the hope that our work could quantify how perilous a situation these islands are in and inspire further research and better disaster preparedness. To our knowledge, this type of project has not been done before.

Methodology

For this analysis, we focused on Bermuda, Curaçao, the Marshall Islands, and Tonga. This first step is to calculate the daily food needs of each island's population.

Population Data

We used indexmundi.com for population data to maintain consistency across SIDS. For annual visitor numbers to each SIDS, we used data obtained from the government websites of each SIDS, with the exception of the Marshall Islands. The data from the Marshall Islands came from WorldData.info because the Marshall Islands' government site only included data through 2011.

In Bermuda, we calculated the busy season population to be 108,307 in July and the off-season population to be 80,189 in January using local population data (Bermuda Demographics Profile, 2018) and seasonal tourism data (Matthew Howe, n.d.).

Curaçao has tourism year-round and we found the off-season population to be 179,728 in June and the busy season population to be 196,706 in December using local population data ("Curaçao Population - Demographics," n.d.) and tourism data (Curaçao.com, n.d.).

The Marshall Islands does not have a large amount of tourism, so there is nominal difference between the off-season and tourist season populations. We used the local population of 74,539 (Marshall Islands Demographic Profile, n.d.) for the off-season and used tourism data to get a busy season population of 75,539 ("Tourism on the Marshall Islands," n.d.),

We estimated the busy season population of Tonga to be 119,917 and the off-season population to be 106,479 based on tourism data ("Migration Statistics - Tonga Stats," n.d.) and local population data (Tonga Population - Demographics," 2018).

Detailed methods for our population numbers can be found in Appendix II.

How much food is needed per person in our SIDS?

Average Dietary Requirements per Day

	Latin America and Caribbean (Curaçao and Bermuda)	Oceania (Marshall Islands and Tonga)
Average weight (kg)	67.76	73.94
Minimum amount of protein per day (g per kg of body weight)	0.8	0.8
Average necessary amount of protein per day (g)	54.213	59.148

Figure 4b: Calculations of average protein requirements per person for Bermuda, Curaçao, the Marshall Islands, and Tonga.

Our next step was to determine how much food is needed per person per day. We calculated the necessary food by finding the daily required protein and calories per person. To meet basic nutritional requirements, a person must eat 0.8 grams of protein per kilogram of body weight a day (Pendick, 2018). We then found the average weight for men and women combined for the Caribbean, Latin America, and Oceania. We multiplied 0.8 grams times the average weight of the people in these regions and produced an approximation of how much protein the people in these areas would need to eat.

Calories vary depending on age and lifestyle. We assumed an average sedentary lifestyle because food would be limited in a disaster, and found the requirement to be 2,200 calories per person per day (Center for Nutrition Policy and Promotion, n.d.).

How much food is imported in our SIDS?

Our team used MIT's Observatory of Economic Complexity (OEC) database to find information on food imports to our four SIDS. The OEC database breaks down all imports into categories and gives the percentage of an imported good compared to total imports for each category, where the good comes from, and the total value of that import. We decided to look at the top four sources of foodstuffs as calorie sources and the top four sources of meats as protein sources because they represented a majority of substantive imported food for each of our SIDS.

Calculations Methodology

The OEC database gives the financial value of imports, but not the weight. For each food product we analyzed, we first determined the amount of money each SIDS spent on importing it. We then looked at which nations the food was being imported from, and based our calculations on whichever nation was the largest provider to the island State we were analyzing,

We found U.S. export data in pounds to the SIDS for poultry, bovine meat, and pork using the USDA ERS website, and so for those items we were able to skip this step. Export pricing on some products and imports from other countries was less readily available. When we were unable to find data on export pricing, we took the total market value of the product in the origin country and divided it by the total volume sold and used this value for our calculations.

We then divided the total amount of money spent on importing food X for the nation we were analyzing by the price per unit of the product in the country it had been exported from. This gave us the total weight of the food that the SIDS of interest had imported. For more detailed information on each calculation, please see Appendix III: Food Calculations.

After we found the annual amount of food imported to each SIDS, we divided the total calories and protein by 12 to get an estimate of how much was available each month, because we used monthly tourism data and wanted the time scale to be consistent. Furthermore, many island residents live in fairly remote areas and would likely buy food infrequently.

We also used population data as well as nutritional guidelines to calculate the total amount of calories and protein each SIDS needs per day. Finally, we divided the total number of calories and protein by the amount needed per day to get the lifeline numbers for each SIDS.

Discussion of Results

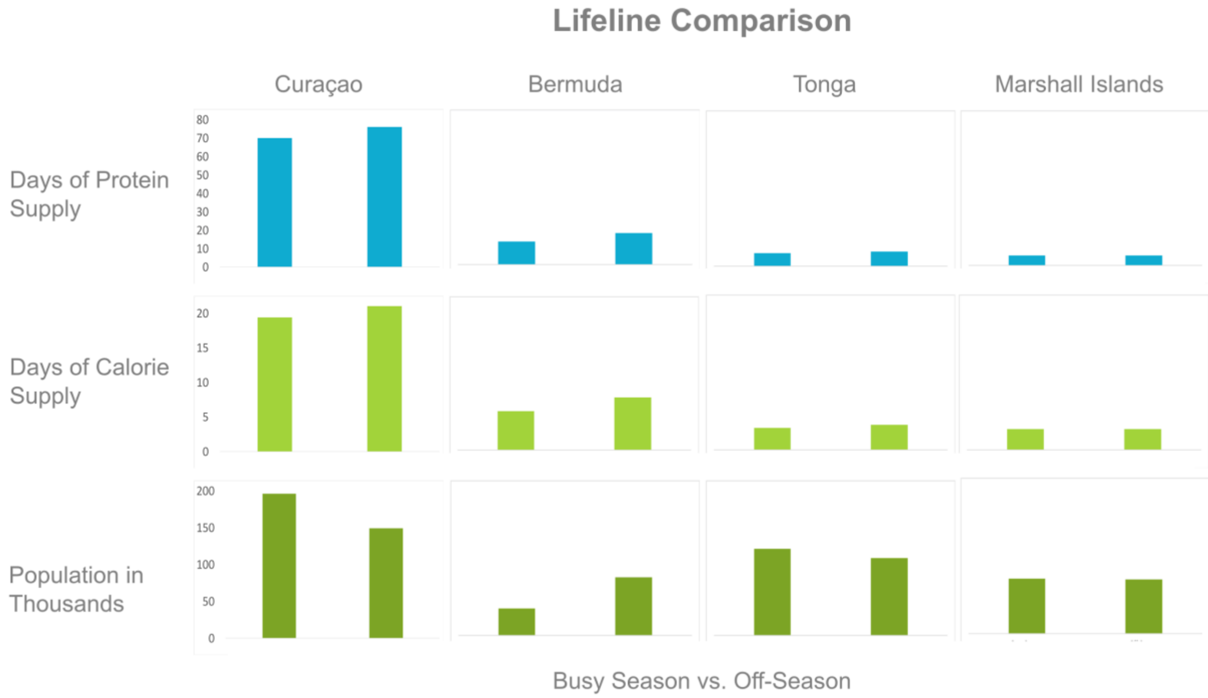

Figure 4c: Protein requirements per day were calculated using the average weight of the general population for each country. We extrapolated average weight from an article published in BMC Public Health titled "The weight of nations: an estimation of adult human biomass" (Edwards, 2018).

Our results showed a significant disparity between Curaçao's lifeline numbers and those of the other SIDS (Figure 4c). During the off season, Curaçao would have 92 days of protein and 26 days of calories, followed by Bermuda at 17 and 8 days respectively. During the tourist season, Curaçao's numbers are reduced to 70 and 19, still significantly higher than Bermuda which would have 11 days of protein and 5 days of calories. Our lifeline calculations are based on the imported supplies that are on the island at the time shipments are disrupted. We are assuming they are packaged well enough to survive a worst case scenario tropical storm or other disaster that results in flooding, where crops would be damaged or destroyed. Therefore, we believe Curaçao's high lifeline numbers can be attributed to the island's relatively high imports and lack of agriculture compared to the other SIDS. Agriculture is only 0.7% of Curaçao's GDP and accounts for 1.2% of the labor force ("The World Factbook — Central Intelligence Agency," n.d.).

In contrast to Curaçao, 30% of Tonga's GDP comes from agriculture and fishing ("The World Factbook — Central Intelligence Agency," n.d.) and 20% of the population's livelihood comes from subsistence work (Lora Vaioleti, 2014). This results in Tonga having lower lifeline numbers, with 7 days of protein and 3.4 days of calories in the off season and only 6 and 3 days respectively in the busy season.

The Marshall Islands has a GDP that is 4.4% agriculture and fishing. The Marshall Islands and Curaçao have agricultural GDP percentages that are much closer than we would expect for such drastically different lifeline numbers. We believe this is because of the difference in magnitude of their GDPs and because of the difference in their GDPs per capita. The Marshall Islands has a GDP of $199.4M and GDP per capita of $3,454.30 ("Marshall Islands GDP Per Capita," n.d.) while Curaçao's overall GDP is $2.977B and the GDP per capita is $18,487.38.

Some SIDS have a larger difference between off-season and busy-season lifeline numbers than others. Curaçao and Bermuda both experience noticeable differences because they have a population change of 16,978 and 28,118 respectively. Tonga and the Marshall Islands both have sub one day differences between busy season and off season because their populations only change by 13,438 and 1,000 respectively. The reason Tonga and Curaçao have similar population changes but noticeable differences in supply days is that this change represents a 12.6% population change for Tonga and only a 9% population change for Curaçao.

Nations with more agriculture and higher food self-sufficiency show low lifeline numbers. It is important to remember that these numbers are only indicative of emergency supply in disasters and assume a worst case scenario such as a tropical storm where crops are damaged or destroyed. Food self-sufficiency is something SIDS should strive for to increase their security, especially because of their isolation. Our recommendation to improve these numbers is to store more food for disaster preparedness, but not to increase the proportion of their diets based on imports. According to our analysis, Curaçao and Bermuda would last longer after an acute disaster but are more dependent on outside sources of food, especially Curaçao. This means that any long term conflict such as a blockade would have a worse effect on Curaçao and Bermuda than it would on Tonga and the Marshall Islands. They are also more vulnerable to market volatility. The transport of large amount of food long distances across oceans contributes heavily to fossil fuel consumption and is expensive. We recommend that Curaçao and Bermuda increase their local food production where possible in order to protect themselves against outside influences.

There were a lot of obstacles and limitations in this study and future research is needed to determine exactly how much available supply SIDS have after a disaster. We were limited by time and did not include every food imported by the SIDS in our calculations. Some crops, such as root crops, might survive a worst case scenario disaster but we were unable to include them because the data on agricultural production is not consistent across SIDS and is difficult to find. More research and data collection would need to be done on what food sources exist and how much of it is being grown.

We were also limited by tourist data. We made our calculations using monthly visitors; however, not all those visitors would be present on the day of the disaster. In order to have more precise calculations, we would need to know the average length of stay for visitors for each SIDS. The import data was supplied by the OEC in terms of monetary value and not volume. This means there is likely error because we had to convert value to volume. There are many data gaps and constraints that have impacted our analysis. They include having to calculate import volumes for food supply, the possibility of food rationing, the possible existence of undamaged crops, and monthly fluctuations in food imports among others.

Conclusion

Small island developing states are at the frontlines of climate change and are already affected by warming ocean temperatures and sea level rise. These nations are the first to feel the impacts of climate change and are experiencing the most severe changes - disappearing land and dangerous storms - despite the fact that they contribute very little to global carbon emissions.

In this report we review the risk of climate change to four SIDS and possible options for SIDS to mitigate and protect themselves from these effects. Sea level rise projections for each of our four islands based on the most recent projections would cause damage in each case by the year 2100. The visual representation of these various sea level rise scenarios show just how drastic the problem is.

Adapting to climate change in SIDS' is going to be very important for the people living there. Although the effects of climate change are similar in most SIDS, implementing certain adaptations may not be reasonable for some islands. Adaptation strategies vary from saltwater tolerant crops to dune construction and strengthening to elevating houses.

The third section of our report addressed disaster preparedness and planning. Each of the four SIDS we worked with had some disaster plan and were aware of issues that posed a threat to their islands. All the islands would benefit from more extensive disaster planning and coordination as climate change threats continue to escalate.

Lastly, our final section assesses the "lifeline" of an island in a disaster scenario. The lifeline scenario calculates the amount of food necessary for the population to survive; as well as how long the amount of food would sustain the islands population. This information has the ability to show our SIDS where they have room to improve and become more prepared.

Small Island Developing States are facing severe challenges as a result of global climate change, but we see a lot of potential for adaptation and believe there is hope. Ultimately, SIDS can take steps to mitigate the impacts of climate change while still growing their economies.

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Appendices

Appendix I Mapping Sea Level Rise Scenarios Methods and Resources

DEM Data:

For the Curaçao and Tonga, we downloaded Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global images from USGS's Earth Explorer to use as DEMs ("EarthExplorer - Home," n.d.). For Bermuda, we found a data layer from the National Oceanic and Atmospheric Administration (NOAA) Coastal Elevation Models (National Geophysical Data Center, n.d.). This DEM is a 1 arc second WGS84 projection layer created in 2013 that has higher vertical accuracy than the SRTM data. For the Republic of the Marshall Islands, we found a DEM from a USGS paper "One Meter Topobathymetric Digital Elevation Model for Majuro Atoll, Republic of the Marshall Islands" (Monica Palaseanu_Lovejoy et al., 2018). This layer has the highest vertical accuracy, but there is data missing along the Northwest region of Majuro.

Important Buildings:

We used a google maps search, inputted the check-in and check-out dates as September 17/September 18 and said we had four guests. Using a date far in advance, it would imply that the hotels have the least amount of reservations and thus the most hotels would appear in our searches. By searching for four guests (the maximum that Google would allow), we filtered smaller bed and breakfasts that might be renting out one of their rooms. If there were more than 75 results listed on google maps, for practicality sake, we did not map all of them. To further narrow down the search, we then used the price filter to exclude hotels without listed prices. We assumed that the larger, more prominent, hotels would list their prices online. Then, to find hotels' latitude and longitude coordinates, we used Google Maps "What's here?" feature.

- Hotels
    - Used google maps - compiles a lot of travel website data.
        - Term "Hotels"

- Searched for 1 room, for one night in the latest month that google would allow (September 18-19). This was to maximize the vacancy options/hotels.
    - Mapped all listed hotels
- Schools
    - Used google maps.
        - Term used "Schools"
    - Mapped all listed schools
- Hospitals
    - Used google maps
        - Term used "Hospitals"
    - Mapped all listed hospitals
- Big Government Buildings
    - Used google maps
        - Term used "Government"
    - Mapped all listed government buildings
- Airports/ports
    - Used google maps
    - Looked up SIDS
        - Used nearby feature
        - Term used "Ports"
    - Mapped all listed ports
- Desalination plants
    - Searched in google for "Desalination Plants"
    - Did not use google maps as results were not accurate
    - Mapped all desalination plants that were found
- Grocery Store
    - Used google maps
    - Looked up SIDS
        - Used nearby feature
        - Term used "Grocery Store"

- Mapped all listed grocery stores

Appendix II Full Population Calculation Methodology

The government website for Bermuda provided a breakdown of visitor numbers by month. The visitors were broken down by reason for visit and we added up the values for leisure, business, visiting friends or relatives, and other. January had the least visitors at 9,325 (Matthew Howe, n.d.) which we added to the local population of 70,864 to get a total off season month population of 80,189. Bermuda had the most visitors in July with 37,443 (Matthew Howe, n.d.) which gave a total busy season month population of 108,307.

Curaçao has a large number of tourists year round. For the off season we took the local population of 149,648 ("Curaçao Population - Demographics," n.d.) and added June's 30,080 ("Curaçao Population - Demographics," n.d.) tourists to get a total population of 179,728. For the busy season we added December's 47,058 (Curacao.com, n.d.) tourists to the local population for a total of 196,706 people on the island.

The Marshall Islands did not give tourist breakdown by month, only annually. The tourist authority recommends May to October ("Best Time To Visit Marshall Islands," n.d.) so we divided the total 6000 ("Tourism on the Marshall Islands," n.d.) annual tourists by 6 to get 1000 tourists per month for the busy season. For the off season we assumed zero tourists and used the local population of 74,539 ("Marshall Islands Population - Demographics," n.d.). Adding 1000 gave us a busy season population of 75,539.

Tonga also only had the annual number of tourists, and the latest year with information was 2015, when 53,752 people visited Tonga ("Migration Statistics - Tonga Stats," n.d.). We did our analysis in terms of monthly numbers, so we needed to convert this to a monthly number of visitors in Tonga. The vast majority of visitors to Tonga go during the tourist season which is from June to September, so we divided 53,752 by those four months and found that for each month of the busy season Tonga has 13,438 tourists per month.We added this to the local population of 106,479 ("Tonga Population - Demographics," 2018) which put the population for a busy season month at 119,917.

Appendix III Food Imports to Each Small Island Developing State

I. Bermuda

A. Meats/Protein

1. Poultry Meat

The OEC database said that 97% of Bermuda's poultry meat imports came from the United States ("OEC - Bermuda (BMU) Exports, Imports, and Trade Partners," 2017). Since this is a majority, we used the value from the United States. The USDA ERS data said that the United States exported 787,000 pounds to Bermuda in 2018 ("USDA ERS - Livestock and Meat International Trade Data," 2019). For simplicity's sake we assumed that the cost of all imported poultry in Bermuda was the same and found that Bermuda imported 810,610 pounds of poultry in 2018.

2. Bovine Meat

The OEC database said that 100% of Bermuda's bovine meat imports came from the United States for $5.46M and that 81% of Bermuda's frozen bovine meat imports came from the United States for $4.88M ("OEC - Bermuda (BMU) Exports, Imports, and Trade Partners," 2017). We assumed that the percentage of value and the percentage of volume would be equivalent and found that 91.033% of Bermuda's bovine meat imports came from the United States ("OEC - Bermuda (BMU) Exports, Imports, and Trade Partners," 2017). The USDA ERS data said that the United States exported 3.108M pounds of bovine meat to Bermuda in 2018 ("USDA ERS - Livestock and Meat International Trade Data," 2019). Using the 91.033% and assuming that the cost of all imported bovine meat in Bermuda is the same we found that Bermuda imported 3,386,694.36 pounds of bovine meat in 2018.

3. Fish Fillet and Other Processed Fish

For this section we combined Fish Fillet and Other Processed Fish because we were only able to find pricing data for the United States in a category called "edible fish".

The OEC database said that 79% of Bermuda's fish fillet imports come from the United States for $5.2M and that 83% of Bermuda's processed fish imports come from the United States for $1.13M ("OEC - Bermuda (BMU) Exports, Imports, and Trade Partners," 2017). This means Bermuda spent $6.33M on fish imports, mostly from the United States. For the sake of these calculations we are assuming that all of Bermuda's fish imports had the same price per unit. The USDA ERS data did not include data on fish exports so we used statista. According to NOAA, in 2016 the total market value of "edible fish" in the United States was $5.0b and included 1,281,534 metric tons of fish (National Oceanic and Atmospheric Administration, 2016). For this calculation we decided to use an average value for all fish. We found that the price of fish in the United States in 2016 was $1.769 per pound. Using this we found that Bermuda imported 3,578,292,82 pounds of fish.

4. Sausages

   The OEC database said that Bermuda gets 88% of its $2.67M in sausage imports from the United States ("OEC - Bermuda (BMU) Exports, Imports, and Trade Partners," 2017). Because this is the majority we used sausage pricing from the United States. We found that in the United States sausages cost an average of $3.64 per pound ("USDA ERS - Livestock and Meat International Trade Data," 2019). This means Bermuda imported 733,516.484 pounds of sausage.

B. Calories

1. Pasta

   The OEC database said that 78% of Bermuda's $1.57M in pasta imports come from the United States ("OEC - Bermuda (BMU) Exports, Imports, and Trade Partners," 2017). Since this is the majority, we used the price per unit of pasta in the United States for this calculation. Statista said that spaghetti costs $1.24 per pound in the United States and we used this to find that Bermuda imported 1,266,129.03 pounds of pasta ("U.S. retail price of spaghetti," 2018).

2. Baked Goods

The OEC database said that 89% of Bermuda's $12.8M in baked goods imports came from the United States ("OEC - Bermuda (BMU) Exports, Imports, and Trade Partners," 2017). Since this is the majority, we used price data from the United States. Using statista data, we averaged the price per weight of cakes, pies, muffins, pastry, Danishes, coffee cakes, and doughnuts to find that baked goods cost $4.056 per pound in the United States ("Baked goods and dessert category average price per unit United States," 2016). Using this, we found that Bermuda imported 3,155,818.54 pounds of baked goods.

II. Curaçao

A. Protein

1. Poultry Meat

The OEC database states that 68% of Curaçao's 21.7M in Poultry Meat imports came from Brazil ("OEC - Curaçao (CUW) Exports, Imports, and Trade Partners," 2017). Since this is the majority, we used price data from Brazil. Using data from the Food and Agriculture Organization of the United Nations, we found that poultry meat cost $.08265 per pound (Food and Agriculture Organization of the United Nations, 2004). Using this we found that Curaçao imports 17,935,050 pounds of poultry meat.

2. Frozen Bovine Meat

The OEC database states that 32% of Curaçao's 9.09 million in frozen bovine meat comes from Brazil ("OEC - Curaçao (CUW) Exports, Imports, and Trade Partners," 2017). As this is their number one importer, we decided to use import data from there. And using data from the Food and Agriculture Organization of the United Nations, we found that frozen bovine meat cost $2.02 per pound (Food and Agriculture Organization of the United Nations, 2004). Using this, we found that Curaçao imports 45,000,000 pounds of frozen bovine meat.

3. Bovine Meat

   The OEC database said that 48% of Curaçao's bovine meat imports came from the United States ("OEC - Curaçao (CUW) Exports, Imports, and Trade Partners," 2017). The USDA ERS data said that the United States exported 2,445,000 pounds of bovine meat to Curaçao in 2018 ("USDA ERS - Livestock and Meat International Trade Data," 2019). Using the 48% and assuming that the cost of all imported bovine meat in Curaçao is the same, we found that Curaçao imported 3,716,400 pounds of bovine meat.

4. Pig Meat

   The OEC database states that 25% of Curaçao's $7.62M of pig meat comes from the Netherlands ("OEC - Curaçao (CUW) Exports, Imports, and Trade Partners," 2017). As they are the number one import partner, we decided to use data from the Netherlands. Furthermore, we used data from AHDB to find that pork is $0.51 per pound (Colby, 2017). Using this data, we found that Curaçao imports 14,941,176.47 pounds of pig meat.

5. Sausages

   The OEC database states that 52% of Curaçao's $3.12M in sausages comes from the United States ("OEC - Curaçao (CUW) Exports, Imports, and Trade Partners," 2017). As the majority of sausages come from the United States, we used data from there. Furthermore, we used data from the USDA to find that the average price of sausages is $3.64 per pound ("USDA ERS - Livestock and Meat International Trade Data," 2019). And then through this, we found that Curaçao imports approximately 857,142.857 pounds of sausages.

B. Calories

1. Pasta

   The OEC database states that 38% of Curaçao's $817K of pasta comes from Spain ("OEC - Curaçao (CUW) Exports, Imports, and Trade

Partners," 2017). As they are the number one import partner, we decided to use data from Spain. Furthermore, we used data from Statista to find that pasta cost $0.70 per pound ("Pasta & Noodles - Spain | Statista Market Forecast," 2019). Using this data, we found that Curaçao imports 1,167,142.86 pounds of pasta.

2. Baked Goods

   The OEC database states that 43% of Curaçao's $6.96M of baked goods comes from the United States ("OEC - Curaçao (CUW) Exports, Imports, and Trade Partners," 2017). As they are the number one import partner, we decided to use data from the United States. Furthermore, we used data from the USDA to find that baked goods are averaged to cost $4.056 per pound ("USDA ERS - International Baseline Data," n.d.). Using this data, we found that Curaçao imports approximately 1,715,976.33 pounds of baked goods.

III. Marshall Islands

A. Protein

1. Poultry Meat

   The OEC database states that 99.2% of the $2.53M in poultry meat coming from the United States ("OEC - Marshall Islands (MHL) Exports, Imports, and Trade Partners," 2017). Since the United States is, by far, the number one importer, we used data from the USDA and found that approximately 363,000 pounds of poultry meat are imported to the Marshall Islands ("USDA ERS - Livestock and Meat International Trade Data," 2019). Using this to extrapolate the total imported poultry meat, there is approximately 365,904 pounds being imported in total.

2. Non-fillet Frozen Fish

   The OEC database states that 99.1% of the $1.78M in non-filet frozen fish came from China ("OEC - Marshall Islands (MHL) Exports, Imports, and Trade Partners," 2017). Since China is, by far, the number one importer we use Chinese sales numbers. Using a USDA dataset, we found that the average price is $2.02 per pound, and then we could extrapolate that approximately 881,188.12 pounds of frozen fish are imported to the Marshall Islands ("USDA ERS - International Baseline Data," n.d.).

3. Frozen Bovine Meat

   The OEC database states that 88% of the $549K in frozen bovine meat comes from the United States. Since the United States is, by far, the number one importer, we used data from there ("OEC - Marshall Islands (MHL) Exports, Imports, and Trade Partners," 2017). Through the USDA, we found that there is 441,000 pounds of it being imported from the United States ("USDA ERS - Livestock and Meat International Trade Data," 2019).Then extrapolating the total from that, we found that there is 493,920 pounds being imported in total.

4. Pig Meat

   The OEC database states that 91% of the $548K in pig mean being imported to the Marshall Islands comes from the United States ("OEC - Marshall Islands (MHL) Exports, Imports, and Trade Partners," 2017). Thus, we used the USDA to find that 1,065,000 pounds of it were imported to the Marshall Islands from the United States ("USDA ERS - Livestock and Meat International Trade Data," 2019). Then again, we could extrapolate that there is approximately 1,160,850 pounds being imported in total.

5. Sausages

   The OEC database states that the top exporter is the United States with 98% of the $668K market share ("OEC - Marshall Islands (MHL) Exports, Imports, and Trade Partners," 2017). We used USDA data to find that the average price is $3.64 per pound ("USDA ERS - Livestock and Meat International Trade Data," 2019). And from there, our total assumed is 183,516.484 pounds.

6. Processed Fish

   The OEC database states that the top exporter is the Philippines with 69% of the $731K total value ("OEC - Marshall Islands (MHL) Exports, Imports, and Trade Partners," 2017). We used data from Statista to find that the average price, from the Philippines, is $3.35 per pound ("Processed Fish & Seafood - Philippines | Statista Market Forecast," n.d.). And then from there, our total assumed is 218,208.955 pounds

B. Calories

1. Pasta

The OEC database states that the top exporter is the United States being 80% of the total $1.33M imported ("OEC - Marshall Islands (MHL) Exports, Imports, and Trade Partners," 2017). We used data from the statista to find the average price of pasta, in the United States, is $1.24 per pound ("U.S. retail price of spaghetti," 2018). And then from there, our total assumed imported is 1,072,580.65 pounds.

2. Baked goods

The OEC database states that the top exporter is the United States with 75% of the total $4.36M being imported to the Marshall Islands ("OEC - Marshall Islands (MHL) Exports, Imports, and Trade Partners," 2017). We then used data from the statista to find the average price of baked goods coming from the United States is $4.056 per pound ("Baked goods and dessert category average price per unit United States," 2016). Then the total assumed imported is approximately 1,074,950.69 pounds.

IV. Tonga

A. Protein

1. Poultry meat

The OEC database said that 89% of Tonga's $8.34 million poultry meat imports came from the United States ("OEC - Tonga (TON) Exports, Imports, and Trade Partners," 2017). Since this is a majority, we used the value from the United States. The USDA ERS data said that the United States exported 26,576 pounds to Tonga in 2018 ("USDA ERS - Livestock and Meat International Trade Data," 2019). For simplicity's sake we assumed that the cost of all imported poultry in Tonga was the same and found that Tonga imported 41,000 pounds of poultry in 2017.

2. Sheep and Goat Meat

The OEC database said that 89% of Tonga's $4.37 million dollars worth of sheep and goat meat imports came from Australia ("OEC - Tonga (TON) Exports, Imports, and Trade Partners," 2017). Since this is the majority, we used the value from Australia to do our calculations. Using the website Meat & Livestock Australia we were able to find the prices of both sheep and goat meat. We averaged these prices to get $2.90 per pound of sheep and goat meat combined ("Get in the know: Goat prices and exports | Meat & Livestock Australia," n.d.). This lead us to calculate that Tonga received approximately 1,506,896 pounds of meat in 2017.

3. Frozen Bovine Meat

   The OEC database said that 77% of Tonga's $3.14 million dollars worth of frozen bovine meat imports came from New Zealand ("OEC - Tonga (TON) Exports, Imports, and Trade Partners," 2017). Since this is the majority we used the value from New Zealand to calculate the pounds of frozen bovine meat per year imported. We found that New Zealand bovine meat cost $2.24 USD per pound in 2017, which is the same year our import data was collected for ("Australia/New Zealand Beef Price," n.d.). This lead us to calculate that Tonga received approximately 1404293.38 pounds of frozen bovine meat in 2017.

4. Bovine Meat

   The OEC database said that 99.1% of Tonga's $554,000 dollars worth of bovine meat imports came from Australia ("OEC - Tonga (TON) Exports, Imports, and Trade Partners," 2017). Since this is a clear majority, we used the value from Australia to calculate the pounds of bovine bovine meat per year imported. We found New Zealand and Australia to have the same price for bovine meat, $2.24 USD per pound in 2017 ("Australia/New Zealand Beef Price," n.d.). This lead us to calculate that Tonga received approximately 20646.99 pounds of bovine meat in 2017.

5. Processed Fish

   The OEC database said that 86% of Tonga's $2.92 million dollars worth of processed fish came from China ("OEC - Tonga (TON) Exports, Imports, and Trade Partners," 2017). Since this is the majority we used the value from China to calculate the pounds of fish per year imported. We found that China's processed fish cost $2.02 USD per pound (USDA Foreign Agricultural Service, 2017). This lead us to calculate that Tonga received approximately 1445544.55 pounds of processed fish in 2017.

6. Sausages

   The OEC database said that 86% of Tonga's $1.1 million dollars worth of sausage imports came from Brazil ("OEC - Tonga (TON) Exports, Imports, and Trade Partners," 2017). Since this is the majority we used the value from Brazil to calculate the pounds of sausages per year imported. We found that Brazil's sausages cost $2.41 USD per pound (Food and Agriculture Organization of the United Nations, 2004). This lead us to calculate that Tonga received approximately 456431.54 pounds of sausages in 2017.

B. Calories

1. Pasta

   The OEC database said that 50% of Tonga's $1.22 million dollars worth of pasta imports came from Indonesia ("OEC - Tonga (TON) Exports, Imports, and Trade Partners," 2017). Since half of Tonga's pasta imports came from Indonesia, we decided to use Indonesia's value to calculate the pounds of pasta per year imported. We found that Indonesia's pasta cost $0.73 USD per pound (Statista Market Forecast, 2019).This lead us to calculate that Tonga received approximately 1742857.14 pounds of pasta in 2017.

2. Baked Goods

   The OEC database said that 49% of Tonga's $1.53 million dollars worth of baked goods imports came from Indonesia ("OEC - Tonga (TON) Exports, Imports, and Trade Partners," 2017). Since this is almost half of all the baked goods imports we decided to use the value from Indonesia to calculate the pounds of baked goods per year imported. Assuming that the rest of the 51% was similarly priced. We found that Indonesia's baked goods cost $0.67 USD per pound (Statista Market Forecast, 2019). This lead us to calculate that Tonga received approximately 2283582.09 pounds of baked goods in 2017.