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Local Scale Assessments on Mangrove Ecosystems Status and their Role *in* COASTAL RESILIENCE

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nepa National Environment and Planning Agency
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Glossary

Anemometer	An anemometer is a device used for measuring wind speed and is also a common weather station instrument.
ASTM	refers to standards, ASTM International, formerly known as American Society for Testing and Materials, is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services.
Auger	An auger is a drilling device, that usually includes a rotating helical screw blade called a "flighting" to act as a screw conveyor to remove the drilled-out material, in this study soil or substrate.
Bathymetry	is the study of underwater depth of lake or ocean floors. In other words, bathymetry is the underwater equivalent to hypsometry or topography.
Benchmark	something that serves as a standard for measurements by the installer or other, in this study it is a steel pole, fixed by cement.
Buffer	A buffer in GIS is a zone around a map feature measured in units of distance or time.
Conductivity	Conductivity is the measure of the ease at which an electric charge or heat can pass through a material.
Depth sounder	a device for determining the depth of the seabed or detecting objects in water by measuring the time taken for sound echoes to return to the listener.
Gas flux	flow of volatile gas emissions from a specific location.
Geochemistry	the study of the chemical composition of the earth and its rocks and minerals
GPS	Global Positioning System.
Horizon marker	a layer of powder, dust, glitter, feldspar powder, kaolinite which is laid down on the surface of a soil to later act as a marker, in this study we use white lime.
In situ	in the original place.
Lateral accretion	deposit Inclined layers of sediment, deposited laterally rather than in horizontal strata, particularly by the lateral outbuilding sediment on the surface for example a river point par or in a coastal zone.

LOI	Loss on ignition is a test used in inorganic analytical chemistry, particularly in the analysis of minerals. It consists of strongly heating ("igniting") a sample of the material at a specified temperature, allowing volatile substances to escape, until its mass ceases to change.
pH	a Figure expressing the acidity or alkalinity of a solution on a logarithmic scale on which 7 is neutral, lower values are more acid and higher values more alkaline. The pH is equal to $-\log_{10} c$, where c is the hydrogen ion concentration in moles per liter.
Plot	Area of a known size.
Pneumatophores	Breathing roots protruding from the soil around the base of a mangrove.
Polyethylene	a tough, light flexible synthetic resin made by polymerizing ethylene, chiefly used for plastic bags, food containers, and other packaging.
Prop roots	Roots that extend from the main tree stem into the ground providing support to the tree.
PVC	Polyvinyl chloride is a common, strong but lightweight plastic used in construction. It is made softer and more flexible by the addition of plasticizers.
Rset	Rod Set Elevation Table.
Salinity	Salinity is the measure of all the salts dissolved in water.
Sapling	Plant greater than 0.5m but less than 1.5 m high.
Sedimentologist	a person who studies modern and ancient sediments such as gravel, sand, silt, and clay, and the processes that result in their formation (erosion and weathering), transport, deposition and diagenesis.
Seedling	Young plant less than 0.5 m high.
Site	Area of interest.
SPSS	Statistical Platform for The Social Sciences.
Statistics	Statistics is a branch of mathematics dealing with data collection, organization, analysis, interpretation and presentation.
Substrate	an underlying substance or layer, the layer from which organisms thrive, it may be soil, peat, sand or a combination in this study.

Taphonomy	the branch of palaeontology that deals with the processes of fossilization and useful evidence about the organism life and behaviour up to fossilization.
Ternary Diagram	A ternary plot, ternary graph, triangle plot, simplex plot, Gibbs triangle or de Finetti diagram is a barycentric plot on three variables which sum to a constant.
TDS	Total Dissolved Solids. Total dissolved solids are a measure of the dissolved combined content of all inorganic and organic substances present in a liquid in molecular, ionized or micro-granular suspended form.
Transect	A line or narrow area within area site along or within which points are established for collecting data.
Tree	Plant greater than 1.5 m high.
Vertical accretion	vertical accretion deposits, which accumulate when deposits from rivers or coastal activity result in a higher sediment level.
Wave attenuation	reduction in the strength of wave.
YSI 566	a device that measures multiple water parameters.
Zooplanktologist	a person who studies zooplankton taxa.

Acronyms

ASA	Analytics and Advisory Services
CMS	Centre for Marine Sciences
DOGG	Department of Geography & Geology
DVRP	Disaster Vulnerability Reduction Project
EM-DAT	Emergency Events Database
ECLAC	European Commission on Latin America and the Caribbean
HRRACC	Hazard Risk Reduction and Adaptation to Climate Change
ICENS	International Centre for Environment and Nuclear Sciences
IPCC	Intergovernmental Panel on Climate Change
NRCA	Natural Resources Conservation Authority
NEPA	National Environmental Planning Agency
ODPEM	Office of Disaster Preparedness and Emergency Management
PIOJ	Planning Institute of Jamaica
PROFOR	Program on Forests
SIDS	Small Island Developing States
UNFCCC	United Nations Framework Convention on Climate Change
UWI	The University of the West Indies
WB	World Bank
WRA	Water Resources Authority

Executive Summary

Mangroves provide a suite of ecosystem services which make them one of the most valuable coastal areas globally. Despite this they are being lost at a rate of 1 – 2% globally. Concurrent with mangrove loss is the rise of climate change effects (increased storminess and sea-level rise). The protecting services of mangroves can mitigate the effects of these on coastal communities and infrastructure. There has been little done in the Caribbean and virtually nothing in Jamaica to investigate the protective services of mangrove systems. This study aims to promote cost-effective coastal protection measures through mangrove ecosystem enhancement.

The study was carried out in three sites which were in Bogue Lagoon, St James, Salt Marsh Trelawny and Portland Cottage in Portland Bight, Clarendon. Mangrove ecology and physical assessments and socio-economic assessment of households in areas adjacent to the mangroves were conducted. Mangroves were assessed at each of the three sites while the socio-economic study dealt with the assessments of households, livelihood, demography and response to past flooding as well as damage assessments for the above sites.

The ecological component of the field work comprised of measuring the structural attributes of mangroves such as species composition, biomass indicated by Diameter at Breast Height (DBH), tree height, prop roots and their aerial network along a 50 m belt transect in replicate 10 x 10 m plots. The field data was used to identify tree species diversity and abundance, vegetation density and structure. Fish larvae abundance and species composition and the ratio of commercial to non- commercial fish families determined from light-trap fish samplers placed in lagoons adjacent to each forest.

The overall findings of the ecological studies indicate that *Rhizophora mangle* (Red mangrove) was the dominant species at all locations with infrequent occurrences of *Avicenna germinans* (Black mangrove) and *Laguncularia racemosa* (White mangrove). As expected the forests were found to have low diversities as mangroves tend to grow in relative monospecific stands. Mangrove forest on the north coast at Bogue Lagoon and Salt Marsh were found to have intermediate structural development while the forest on the south coast (Portland bight) was found to have low structural development which may be due to damage caused by frequent hurricanes.

Assessments of the mangrove aerial root structure indicated general Red mangrove prop root densities decreased with increasing distance towards land while Black mangrove pneumatophore densities generally increased in the same direction.

Generally, Portland Cottage was identified as the mangrove area, providing the lowest ecosystem service despite recording the highest accretion (at one site), while the other site was

experiencing erosion. The studies determined that subsidence seems to be playing an important role within the study sites and coupled with sea-level rise will increase the vulnerability of communities and infrastructure associated with these systems if proper management and protection is not enforced. Bogue Lagoon was identified as the most stable and resilient forest system. Due to the sedimentation patterns at Salt Marsh this forest fringe is considered suspect to increased risk from over sedimentation however is not as vulnerable as the south coast site. The forests areas can therefore be ranked from low to high vulnerability as Bogue> Salt Marsh> Portland Bight based on the protective services they provide to communities and infrastructure. Another way to put it is that Bogue is offering the most ecosystem service in protection of the coastline as it protects critical road infrastructure with linkages within the Parish of St. James and also to neighbouring Parishes Trelawny and Hanover. Salt Marsh would be second protecting infrastructure and livelihood

Understanding the social and economic context presents an important pivot in assessing the role of ecological communities which shape, and are in turn shaped, by socio-economic conditions of those who interact with the resource. Mangrove ecosystems arguably have significant value in the social and economic systems of the communities in relatively close proximity and this can be viewed both from the role that it plays in shoreline protection and also in relation to their value in socio-cultural and economic systems which are directly and indirectly influenced by their presence.

Based on the results of socio-economic surveys of selected residential and commercial coastal communities, this report examines the social and economic value of the mangrove – based ecosystem services and uses the perceptions and experiences of residents to understand nature-society intersections which exist in these communities. The results revealed that while a significant portion of the sample recognized the value of mangroves, there was variation in the extent and nature of the interactions with mangroves. Fewer individuals were directly dependent on the mangrove community as an economic resource but were aware of their value in shoreline protection, hazard vulnerability reduction and their role in maintaining viable fish populations. Respondents at all three sites were cognizant of the issues facing the mangrove community and commonly cited habitat loss and pollution as primary challenges. While these threats were identified across all sites, residents of Portland Cottage recognised the success of restorative efforts which contributed to an increase in the extent of the mangrove community.

Despite the pervasive acknowledgement of the existence of threats to the mangrove community and awareness of its value, there was very limited involvement of locals in restoration activities, indicating glaring gaps in knowledge, attitude and practices. Such observations may suggest a critical need for intervention initiatives which encourage community members to contribute to restoration and protection activities in direct and indirect ways. In this regard, the willingness of businesses to get involved in these activities indicates the potential for private capital to be harnessed for public good. Accordingly, this should be considered as a potential pathway for protection and preservation of a highly valuable system.

The physical section comprised of an understanding and review of the geology of the three sites as well as physical measurements for each. Geological study of the three sites (Montego Bay, Falmouth and Portland Cottage), particularly focusing on the distribution of the Lower Coastal group and Falmouth Formation, indicates that tectonically (fault) driven subsidence has occurred recently or is still occurring. Two physical transects were undertaken at each site (Bogue Site 1, Bogue Site 2; Portland Cottage Site 1, Portland Cottage Site 2; Salt Marsh Site 1, Salt Marsh Site 2). Elevations on five of these transects showed the transects ranging between just below to just above MSL, but Bogue Site 1 was below MSL. Neither vertical accretion nor vertical erosion was measured at Bogue, while vertical erosion was recorded at Portland Cottage Site 1 and Bogue Site 1, and Vertical accretion at Portland Cottage Site 2 and Salt Marsh Site 2. Interpretations form the 1961 aerial photographs indicate that all sites experience lengths of coastline undergoing both lateral erosion and accretion. Lateral (horizontal) accretion was greater at Bogue and Salt Marsh, but lateral erosion was more predominant at Portland Cottage, possibly as a result of recent hurricanes. Shallow, offshore bathymetry varied at different sites. In general, it was shallow, typically in less than 2 m at Salt Marsh Site 1 and Portland Cottage Sites 1 and 2, however, Salt Marsh Site 2 and Bogue Site 1 have depths of 3.8 and 3.4 m respectively, whereas Bogue Site 2 was up to 6.5 m. The latter may be due to the scouring of sediment caused by the passing of marine craft or the signature of the physiography of the terrain possibly a drowned river system. Leaf litter from mangroves accumulated at Bogue, Portland Cottage 2, Salt Marsh, but no accumulation occurred at the RSET plot within the Portland Cottage Site 1. Soil organic matter was very variable and dependent on the proportion of carbonate sediment present. This is particularly true of Bogue Site 1 and both sites of Salt Marsh, where high proportions of carbonate sediments resulted in low proportions of soil organic matter. The non-organic component of the soil consisted of silty sand and carbonate sediments. The carbonate sediments (Salt Marsh and Bogue 1) consisted of marine organisms (molluscs, foraminifers, *Halimeda*), with the molluscs represent mangrove dwellers, and the foraminifers and *Halimeda* transported into the mangrove forests from sea grass beds/reefs by storms. Wind velocities showed significant reductions from the coastal edge of the mangrove forests (4.5-7.5 m/s) to the interior (2.4 – 4.1 m/s) indicating wind attenuation of 34 to 57%. Wave height and energies saw significant reductions passing from open marine conditions (8-34% reductions as they move landward) into the mangrove forests (58-80% within *R. mangle* roots). The physical root and plant component removed from the substrate typically has a mean of between 31 and 43%, but is lower at Bogue Site 1 (14.9%) and Salt Marsh Site 2 (10.53%) due to the presence of areas with carbonate sediments. The physical root and plant component in percentage weight shows the influence and contribution of the mangrove ecosystem on the development and existence of the wetland's substrate as a trapping for sediment and a critical component itself. Soil pH values ranged from 6.45 to 11.90, with the greatest variability at Bogue Lagoon. Water temperature ranged from 25 to 33°C and salinity varied greatly with values of 2.5 and 8 g/Kg for Bogue, 40 g/Kg for Portland Cottage and 35 g/Kg for Salt Marsh. Conductivity had values of 12 (Site 1) and 47 MS/cm (Site 2) at Bogue, 40 (Site 1) and 72 MS/cm (Site 2) at Portland Cottage and 49 (Site 1) and 56 MS/cm (Site 2) at Salt Marsh. Trace elements (macronutrients: K, Ca, Mg; and micronutrients: Na) did not show any significant patterns. Mean CO_2 flux ranged from 1.86 to 3.13 $\mu molm^{-2}s^{-1}$. Furthermore, above ground and below ground biomass was highest at Bogue Lagoon, followed by Salt Marsh and lowest at Portland Cottage. The risk of flooding was assessed using merged buffers of 250 and 500 m based on historical reported floods and reports of experienced floods in relation to the projected 1 m, 5 m and 10 m coastal inundation events and based on experienced and reported flooding the risks were highest at Portland Cottage. Both sites at Bogue Lagoon and Salt Marsh are considered to be in moderate health, (even though sandy sediment and higher water pH at Salt Marsh is cause for concern) and offer significantly more ecosystem services than the sites at Portland Cottage which both seem at risk, but Site 1 has more risk than Site 2.

Overview of Report

Purpose of Document

Flooding and coastal erosion has been one of the major effects of natural disasters on coastal towns and communities in Jamaica, the third largest island in the Caribbean. The Planning Institute of Jamaica (PIOJ) (2002, 2004, 2005a, 2005b, 2007, 2008, 2009, 2010 and 2012) reports six severe hydro-meteorological events in Jamaica during the period 2002-2007 which have resulted in massive flooding and damage to infrastructure resulting in loss of US$ 1.02 billion. Much of the coastal flooding and erosion could be concurrent with the decrease in percentage of mangroves along major coastal areas of the island. The major reason for the reduction in the mangroves is coastal and urban development, poor solid waste disposal practices, extraction of fuel-wood, as well as conversion for aquaculture and agriculture (Polidoro et al., 2010). The mangrove depletion results in reduction of natural filters, biodiversity loss, and carbon sinks loss, all of which are important for climate change adaptation mitigation, and disaster risk reduction.

This document details the work done as a part of ongoing effort to address disaster risk reduction and protection of coastlines by the Government of Jamaica (GoJ). This project has been facilitated through funding from the World Bank (WB) Programme on Forests (PROFOR) aimed at implementing the Analytics and Advisory Services (ASA) titled "Assessment and Economic Valuation of Coastal Protection Services Provided by Mangroves in Jamaica". The Grant is linked to the ongoing Jamaica Disaster Vulnerability Reduction Project (DVRP), which focuses on enhancing the climate and disaster resilience of key infrastructure and the country's disaster response capacity. The document is prepared by the University of the West Indies Mona (Department of Geography and Geology (DOGG), Centre for Marine Sciences (CMS) and International Centre for Environment and Nuclear Science (ICENS)) as the final technical report for WB and stakeholder agencies to aid in decision making and planning for coastal risk reduction and mitigation for vulnerable communities. This is also the first time a multicomponent study was carried out in Jamaica which can act as a tool for such studies in other parts of the Caribbean with similar topography, physiography and incidents of coastal flooding and erosion. The project commenced in November 2017 and continued for 18 months.

Brief Project Background

The concept of using mangroves as natural barriers to coastal erosion came into scientific knowledge and developed into policies following the 2004 Indian Ocean Tsunami and the storm surge from Hurricane Katrina in 2005 in New Orleans. Extensive work has been done in the Asia-Pacific region (Indonesia, Thailand), Bangladesh, USA (Florida coast) on mangrove ecosystem and coastal protection. However, in the Caribbean, very limited work has been done on this and thus this project is a detailed study on the role of mangroves in coastal protection, their current status, density, vulnerability of the coastal areas of Jamaica to storm surge using three study sites on a pilot scale.

The overall objective of this project is to support the GoJ (Government of Jamaica) in promoting cost-effective coastal protection measures through mangrove ecosystem enhancement. This activity was carried out through a combination of three different tasks (physical, socio economic and ecological data collection) for each of the three selected study areas in the island thus targeting the **four research areas** (Habitat Status Assessment, Coastal Protection Ecosystem services, Habitat Risk and Cost-effective assessment) which were identified as current knowledge gaps.

The project was supervised by the World Bank, and led at the local level by the National Environment and Planning Agency (NEPA) of Jamaica and implemented by the Local Firm i.e. The University of the West Indies, Mona Campus, Jamaica (UWI). The UWI Mona comprised of staff and students from the Department of Geography and Geology (DOGG), Centre for Marine Sciences (CMS) under the Department of Life Sciences and the International Centre for Nuclear Sciences (ICENS). The physical and socio-economic data collection and analysis was carried out by the DOGG and ICENS while the ecological component was carried out by the team from CMS. The team from CMS comprised of Prof. Mona Webber, Ms. Patrice Francis and Mr. Camilo Trench. The team from DOGG comprised of Drs. Rose Ann Jasmine Smith, Robert Kinlocke, Arpita Mandal and Taneisha Edwards and Prof. Simon Mitchell. ICENS was represented by Dr. Adrian Spence. In addition, there was active involvement of students at both Undergraduate and Post-Graduate level at different stages of data collection and analysis for all the components.

The multidisciplinary group from the UWI, carried out studies of three mangrove areas in Jamaica spread across the north and south coast of the island (Figure 1). Two study sites were demarcated in each mangrove area for the physical and ecological team and the socio-economic survey was executed in the adjacent communities. The sites selected were **Bogue, Salt Marsh and Portland Cottage** which were deemed to cover a range and be representative of mangrove forest areas across the island. The UWI's role in the project included the identification of suitable study sites within each mangrove area, which are representative of the mangroves and their functionality and then conducting physical, ecological and socio-economic assessments in each. Having selected the mangrove area and representative sites, the UWI has collected data on mangrove forest extent, tree density, root density, height and other associated forest parameters as well as data related to wave height, coastal erosion and extent of inundation. Data on demographics, livelihoods of communities in each location have been collected using structured questionnaires developed by UWI and guided by WB and NEPA. UWI has also conducted onsite and pre-field work training of stakeholders (NEPA, ODPEM) in data collection methods.

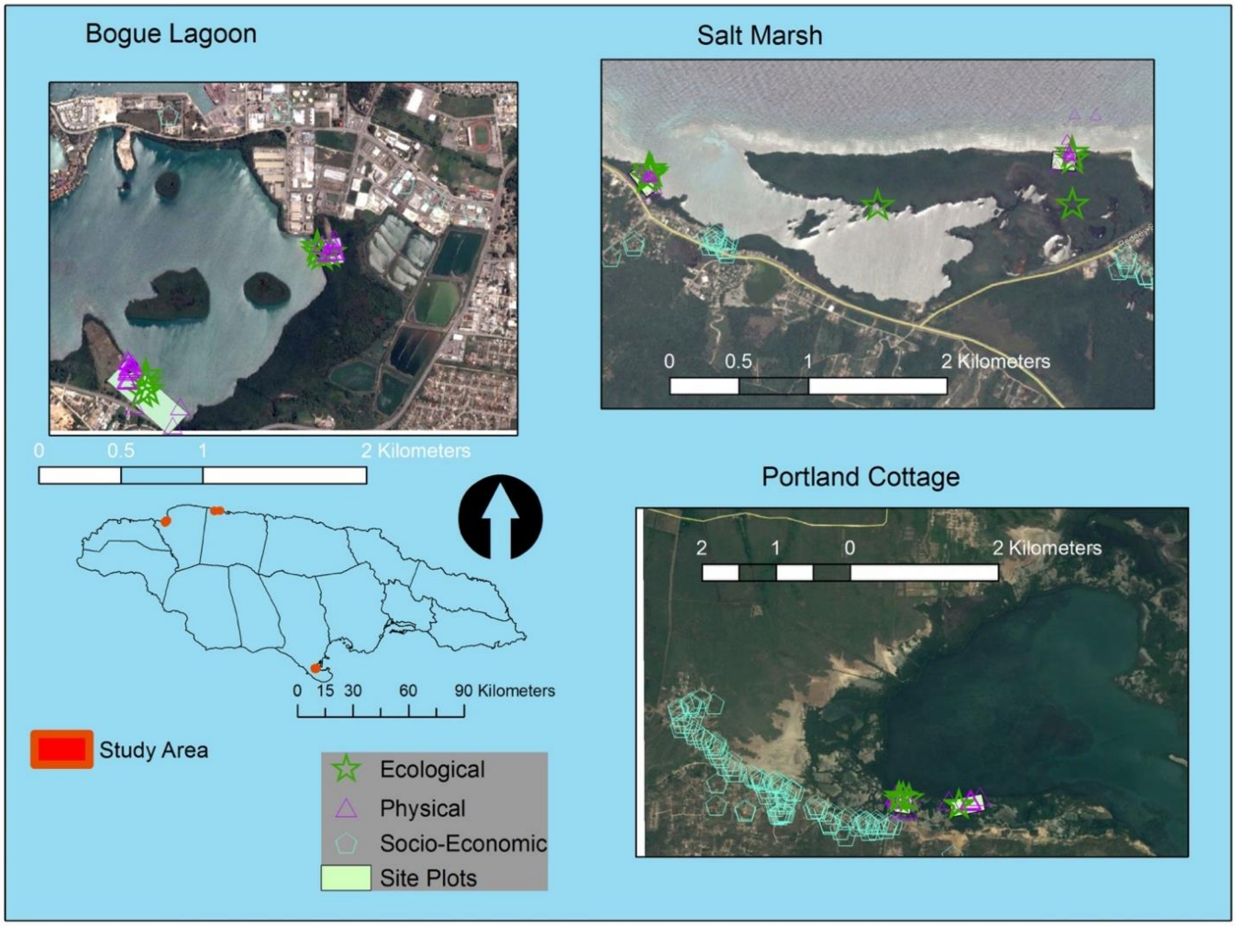


Figure 1: The location of the study areas in Jamaica (red marker), and the extent of the activities at each site (insets), white circles highlight some of the area that the ecological team studied, blue pentagon highlight some respondents of the socio-economic survey and the pink triangles indicated where data was collected by the physical team. The ecological and physical team mostly worked the same study sites within the areas marked by the green rectangles. Maps were created in ArcGIS, by T. Edwards (2019) using GPS Coordinates shared from the socio-economic, the ecological and physical team along with geo-referenced Google Earth imagery, WGS84.

Introduction

Mangroves are defined as trees, shrubs, ferns and palms (> 0.5 m) that grow and live in coastal intertidal zones (Hogarth, 2015). They are primarily found in low-oxygen, slow moving waters which are also sites of sediment accumulation. Areas dominated by these trees are called mangrove forests and they occur in tropical and sub-tropical latitudes. Mangrove forests and associated aquatic environment provide a range of regulating and supporting, provisioning and cultural ecosystem services (Webber et al., 2016).

Supporting and regulating services include:

1. habitat for juvenile fish that are important both as essential components of coral reef and other ecosystems and are important commercial species;
2. carbon sequestration
3. climate regulation
4. shoreline stabilization water filtration and pollution regulation.

Mangrove provisioning ecosystem services include:

1. fisheries production;
2. aquaculture production
3. pharmaceutical generation;
4. coastal protection.

Finally, mangroves provide cultural services that include

1. recreation and tourism;
2. educational opportunities;
3. aesthetic and cultural values (Webber et al., 2016)

Climate Change and Coastal Vulnerability in Caribbean

The Small Island Developing States (SIDS) of the Caribbean lying directly in the path of the Atlantic Hurricane belt are at risk from storm surge and flooding associated with tropical cyclones and hurricanes affecting life and livelihood. Collymore, 2011 in his work on disaster risk reduction in the Caribbean shows that amongst the different types of natural hazards in the Caribbean, floods and windstorms account for more than three-fourths. The EM-DAT (2015) database that records flood events associated deaths and damages for the Caribbean, showed that in the period 1900–2015 there was an occurrence of 138 floods which were responsible for 4983 deaths and a total damage of USD 980,484,000 (EM-DAT 2015). The risk is higher for the Caribbean, South Asia, and East Asia where the flood plains and coastal areas are the sites of major urban developments and infrastructures (cities, towns, airports and seaports). Some of the recent examples of flooding in the Caribbean were in the years of 2016 and 2017 with 2017 recording the high impact ones. The year 2017 saw the passage of 2 Category 5 hurricanes, Irma and Maria in the Caribbean which caused devastating impact in Puerto Rico, Dominica, US Virgin Islands, St Thomas and Croix, St Martin. The year 2016 saw the passage of Hurricane Mathew which resulted in flooding and wind damages to Haiti. Cavallo and Noy (2009) in their study on hazards and risks in the Caribbean reported that hydrometeorological events in the Latin America and the Caribbean accounted for USD31.8 billion or 54 % of the total losses from natural hazards for the period 1970 to 1999 (using the year 1998's exchange rate for Jamaican to US dollars).

The vulnerability of coastal communities to flooding in the Caribbean are expected to rise with impacts of climate change such as increase in sea level, temperature increase, increases in intensity and frequency of hurricanes. This will thus impact the high density of human settlement and infrastructures around the coastline in the Caribbean (Lincoln, 2017). The impacts of increasing sea surface temperatures and storm surge will directly affect the marine ecosystem which will thus accelerate the degradation of marine and coastal habitats and impact on commercial fisheries, as well as contribute to the spread of harmful pathogens (Lincoln, 2017).

Although there is low confidence in the projections for increase in tropical cyclones and hurricanes in terms of their intensity and frequency (IPCC 2012), the projections still show that an average increase in tropical cyclone maximum wind speed is likely to increase in the decades ahead, while the global frequency of tropical cyclones is likely to remain essentially unchanged (IPCC, 2012). Increased mean sea level rise (SLR) coupled with the likely increase in tropical cyclone maximum wind speed, would be a particularly salient issue for tropical small island states.

Increase in sea level rise will result in an increase in coastal erosion thus leading to receding shorelines and loss of beaches which are potential sites for tourism, the main economic drivers for the Caribbean. IPCC's fifth assessment report AR5 reports an average increase in sea level from 0.5-0.6 m for a 1.4 deg C rise in temperature (the RCP scenario 4.5 for the main SIDS regions) (CDKN, 2014). CARIBSAVE risk atlas for the islands of Jamaica, Antigua and Barbuda, Dominica, St Lucia and the Grenadines as well as Belize shows that a projected sea level rise of 1-2 m will cause erosion of coastlines by 50-100 m thus affecting coastal habitats and tourism sector ranging from 6 to 100 percent (CARIBSAVE, 2011a, b, c, d, f, g) (Lincoln, 2017). Study conducted by Scott et al., 2012 on the vulnerability of Caribbean coastal tourism to climate change and sea level rise shows that countries which will be affected most by the projected 1-2m rise and the induced erosion will be Belize and Turks and Caicos Islands, with over 80% of resort properties at risk in the 50 m erosion scenario. Further, eight countries will have over 50% of resort properties at risk in the 100 m erosion scenario (such as Anguilla, Barbados, Haiti, St. Kitts and Nevis, The Bahamas and Trinidad and Tobago) (Scott, 2012). As the beaches are the main drivers of the economy, damage to them will thus significantly affect the country's economy. This can thus be prevented by adopting soft solutions along with hard engineering and adaptation plans such as restoration of mangroves, sea grass and coral reefs. The present work is such a case study from Jamaica which is discussed in detail in sections below.

The Jamaican Context

Framework

Jamaica, the third largest island in the Caribbean, has been impacted by tropical storms and hurricanes due to its location in the Atlantic hurricane belt which has resulted in loss to life and livelihood. The island is centred on latitude 18o15' N and longitude 77o20' W and has a total landmass of 10,991 square kilometres and approximately 1,022 kilometers of coastline. A compilation of hurricanes and tropical storms from 1900-2012 by Taylor et al., 2014 and Nandi et al., 2016 in their study on flood risk in Jamaica shows an increase in the number of hurricanes and tropical storms which have hit or pass Jamaica in the time span 2000-2012 as compared to the 1900-2000. Burgess et al. (2013) in their compilation of flood records from the Water Resources Authority of Jamaica (WRA), the Office of Disaster Preparedness and Emergency Management (ODPEM) and the Meteorological Service of Jamaica shows that Hurricane Ivan in 2004 accounts for the highest damage and loss amounting to 8% of the GDP in the decade 2000-2009. Other significant flooding events which have affected the island are from hurricane Michelle (2001), where most damage were caused by the rainfall and not by the passage of the cyclone itself (European Commission on Latin America and the Caribbean, ECLAC 2001), resulting in damages worth USD 53 million island-wide.

About 56% of the island's economic assets and ~70% of the population are located along coastal areas which range from tourism to major towns and cities as well as infrastructures (airports, seaports, power plants). The last 10-15 years has shown an increase in the demand for coastal space thus showing continued growth regardless of the vulnerability of Jamaica's coastline to natural hazards such as hurricanes and storm surges (Richards, 2008).

Flooding (coastal and riverine) in Jamaica from tropical storms and hurricanes have caused extensive damages to infrastructures both inland and coastal. Some notable examples include collapse of bridges in Yallahs (St Thomas), Kintyre (Kingston and St Andrew), Port Maria (St Mary), flooding from riverine and storm surge in coastal towns such as Port Maria and Annotto Bay (St Mary), Montego Bay (St. James), Negril (Westmoreland), coastline of St Thomas and sections of the island's south coast. Research conducted by Robinson and Khan (2011) on the physical damage assessments caused by hurricanes Ivan (2004), Dean and Felix (2007), Allen (1980) and Emily and Wilma (2005) on the coastlines of Jamaica showed a maximum surge height of 3-6 m for the Palisadoes in the south coast of Kingston and St Thomas for Hurricane Dean with a run up of 50-170 m. A maximum run up of 1000 m was also reported for the same event for Portland Cottage, a coastal community in southern Jamaica, which has been prioritized for the implementation of this project. A run up distance of 573 m was also observed for Hurricane Ivan (2004) for Old Harbour Bay located in the parish of St Catherine (Robinson and Khan 2011). Further work done by Robinson and Khan (2011) on the Negril, Annotto Bay and Mammee Bay coastline of Jamaica showed that for the period from 1971-2003 the coastline of Negril showed a 16 cm retreat as compared to the 7 cm shoreline retreat proposed by Intergovernmental Panel on Climate Change (IPCC) (2007).

According to Dasgupta et al., 2009, the impact of sea level rise and intensified storm surges in Latin America and the Caribbean will be highest in Jamaica – noting an increase of 56.8% - with 28.49% of the coastal population exposed and potential losses of coastal GDP projected to exceed 26.62%. Furthermore, the study also reveals that the inundation risk in Jamaica from storm surges will cover 36.55% of the coastal wetlands, which are already squeezed between the sea and the urban constructions. Continued increase in extreme events will result in degradation of coastal ecosystem thus increasing the vulnerability of communities in these areas.

Jamaica, like other SIDS is also affected by the impacts of climate change which will affect its water supply, biodiversity and coastal environments (CSGM, 2017), (Third National Communication of Jamaica to UNFCCC, 2018). The State of the Jamaican Climate 2017 shows a warming trend with the months of June to August showing the maximum high temperatures (CSGM, 2017). Other projections show an increase in the frequency of very hot days and nights with a decrease in the cold days and nights. Sea level rise was predicted to be in the range from 0.18-0.59 m by 2100 relative to 1980-1999 levels, according to the IPCC's AR4 report but other studies give projections up to 1.4 meter. The IPCC's AR5 report shows projected SLR over all Representative Concentration Pathways (RCPs), for Jamaica's north coast to be 0.43 to 0.67 meter, by the end of the century with a maximum rise of 1.05 meter for the south coast (CSGM, 2017). The CARIBSAVE Climate Change Risk Atlas – Jamaica (2011) noted that the intensity of hurricanes still increases despite decrease in frequency. CARIBSAVE, 2011 study showed the percentage of possible loss of beach area from projections of SLR for Port Antonio and surrounding areas (Orange Bay, Buff Bay, Hope Bay, Boundbrook to Drapers and Snow Hill) which were then extrapolated to the rest of Jamaica; and to project sea level rise and storm surge impacts on the coast of Portland Parish. Results showed that a 0.5 to 3 m projected SLR would lead to a 30-100% loss in beach area with the maximum being at Hope Bay in Portland. All of these will have a direct impact on infrastructure, homes, and livelihoods including the loss of beaches, mangroves, and breeding grounds for fish and other marine life. This has resounding economic implications that are likely to be observed at the local and national scale, affecting local communities, fisheries, tourism, and other sectors. (Coastal Management and Beach Restoration Guideline for Jamaica, 2017)

There has been significant impact of climate change to Jamaica's ecosystems that are most vulnerable which includes coral reefs, highland forest and coastal wetlands (mangroves). Over the years Jamaica's biodiversity has been already under human-induced stress such as land use change, pollution, invasive fish species such the Lionfish, which infested Caribbean waters and over harvesting commercially valuable fish species. Hurricane intensity has resulted in the loss of valuable island species, changes in the species competitive interactions and species community composition. The altered intensity of the hurricanes has also caused significant changes to the range of invasive species, mostly due to migration from the Pacific to the Caribbean. Further damage has been associated with an increase in damage to nests and nesting sites. Over the years there has been increased destruction to sensitive habitats like coral reefs, mangrove ecosystems and terrestrial (especially forest) ecosystems (Coastal Management and Beach Restoration Guideline for Jamaica, 2017).

Thus, there is a need for preservation of the coastal ecosystems considering that majority of the country's economy and business is from these areas.

In lieu of the above the Government of Jamaica has proposed several guidelines for coastal management and beach restoration. Currently in Jamaica there are two core guidelines which are used for coastal management interventions and beach restoration.

These are:

- Natural Resources Conservation Authority (NRCA) Guidelines for the Planning, Construction and Maintenance of Facilities for Enhancement and Protection of Shorelines (Circa 1995); and
- Draft Guidelines for the Relocation and Restoration of Jamaica's Coastal Resources: Corals,
- Seagrasses & Mangroves, A Guide for Developers (2010).

Aside from these there is the Government of Jamaica (2017) National Coastal Management and Beach Restoration Guideline which was developed by World Bank Group. The above documents provide certain guidelines on the preservation of beaches, wetlands and suggests a combination of soft and hard engineering for the restoration of beaches and coastal areas of which mangroves are one of the primary ones. These guidelines are to be used by technical persons from stakeholder organisations as well as developers and planners who are responsible for technical interventions and building climate resilience at both national and community level. Preservation of wetlands and mangroves are also important as Jamaica is a signatory to the Ramsar convention as discussed below.

Ramsar Convention: The Convention of Wetlands (Ramsar Convention) is an intergovernmental treaty that provides the framework for the conservation and wise use of the wetlands and their resources. The Ramsar Convention was adopted in the Iranian city of Ramsar in 1971 and was imitated in 1975. Since its implementation, almost 90% of the UN member states, from all the world's geographic regions, have agreed to become "Contracting Parties" including Jamaica.

Jamaica became a signatory to the Ramsar convention on February 7, 1998. Jamaica currently has four (4) sites designated as wetlands of international importance (Ramsar sites), with a total surface area of 37,847 hectares. The four Ramsar sites are Black River Lower Morass, Mason River Protected Area, Palisadoes – Port Royal and Portland Bight Wetlands and Cays (Table 1).

The description below (Table 1) is from the Ramsar website (https://www.ramsar.org/) which describes each of the four sites. The geographical and ecological aspects of each site is described.

The Black River Lower Morass (Site 919) is in the southwestern region of the island with an area of 5700 ha (Table 1). This area is the largest freshwater wetland ecosystem in Jamaica and the Caribbean. Natural attributes include mangrove swamps, permanent rivers and streams, freshwater swamp forest and peatlands. It is a biologically diverse and extremely complex natural wetland ecosystem that supports diverse plant and animals' communities which include rare, endangered and endemic species. This site supports human habitation, livestock grazing, fishing, tourism and cultivation.

The Mason River Protected Area (Site 1,550) is a flat area with several surface depressions, ponds, and sinkholes that seasonally store surface water, located in the hilly regions in the parishes of Clarendon and St. Ann (Table 1). The wetland types in this area have a vital ecological function in preventing downstream flooding by absorbing precipitation. Upland peat bog and scrub savannah are representative and rare examples of organic material and vegetation at this site. It currently acts as an educational resource for students within the area and throughout Jamaica. Threats to this site include invasive species, illegal bird shooting, fires, illegal removal of trees and encroachment.

Palisadoes Port Royal Protected Areas is located on the southeastern coast just offshore pf the of the capital city Kingston. This site comprises of cays, shoals, mangrove lagoons, mangrove islands, coral reefs, seagrass beds and shallow water, thus hosting a variety of underrepresented wetland types. Endangered and vulnerable species such as the American crocodile (*Crocodylus acutus*), green turtle (*Chelonia mydas*), Hawksbill turtle (*Eretmochelys imbricata*), West Indian manatee (*Trichechus manatus*) and bottlenose dolphin (*Tursiops truncatus*) is also found at this site.

Portland Bight Wetlands and Cays is located on the south coast of the island, west of Kingston. Portland Bight (or Bay) comprises of 8,000ha of coastal mangroves, salt marsh, several rivers, offshore cays, coral reefs, seagrass beds, and open water. The site constitutes a critical feeding and breeding location as well as a general habitat for internationally threatened species such as the cave frog (*Eleutherodactylus cavernicola*), the Jamaican boa (*Epicrates subflavus*), the endemic hutia or coney (*Geocapromys brownii*), and the West Indian manatee (*Trichechus manatus manatus*).

*Table 1: Jamaica's wetlands which are Ramsar sites. (Source: **https://www.ramsar.org/** accessed on 20/7/2019)*

Names	Site Number	Administrative Region	Coordinates	Area	Designation Dates
Black River Lower Morass	919	Southwestern region	18°04'N 77°48'W	5,700 ha	October 10, 1997
Mason River Protected Area	1,990	Clarendon and St Ann	18°12'N 77°16'W	82 ha	June 12, 2011
Palisadoes – Port Royal	1,454	Kingston	17°55'N 76°49'W	7,523 ha	April 22, 2005
Portland Bight Wetlands and Cays	1,597	St Catherine and Clarendon	17°49'N 77°04'W	24,542 ha	February 2, 2006

Mangrove Status

Mangroves have a critical role to play in the preservation of biodiversity, therefore, it is imperative that despite the vulnerabilities such as changes in the climate behaviors, depletion of the green cover due to rapid urbanization and overfishing, the mangroves in Jamaica is preserved.

1. Some of the importance of mangroves are as adapted from Webber (2016):
2. Act as a sediment trap
3. Act as natural purifiers of the water (contaminants such as sewage and fertilizers)
4. Natural barriers for the shoreline as they play a critical role in infrastructure protection
5. They support, preserve and balance the ecosystem by releasing key nutrients
6. Nursery ground and habitat for species

7. Refuge ground for aquatic species during hurricanes and storm events
8. They also provide exploitable resources, food and timber

Mangrove forest types have been classified as fringing, riverine, over-wash and basin (Campbell et al., 2008) and all these forest types can be found in Jamaica. Jamaica, being a tropical island has its wetlands largely comprised of mangrove forests which in 2005 covered approximately 2% of the island's land surface occurring along low-lying coastal plains, rivers banks and offshore cays (National Environment and Planning Agency (NEPA, 2014). NEPA in 2014 in a study on the "Status of Jamaican Mangroves" reported that although distributed across all the parishes (Figure 2), most mangrove forests reside in southern parishes with highest distribution in the parish of St Elizabeth. An area of approximately 7,000 hectares located in the Black River Lower Morass, represents the largest mangrove dominated freshwater ecosystem in Jamaica and the Caribbean. Table 2 shows the description of Mangrove areas across the different parishes of Jamaica as sourced from the Status of Jamaican Mangroves (2014) by NEPA.

Table 2: Description of mangrove areas across parishes (Status of Jamaican Mangroves, 2014, NEPA)

Parishes	Description of Mangrove Areas Across Parishes
ST. THOMAS	The major wetlands are located with the Bowden and Great Morass with smaller areas distributed along the Yallahs Salt Ponds.
ST. ELIZABETH	Most mangroves are located within the Black River Lower Morass and is formed by the Black River and its tributaries making a large freshwater swamp, with a complex of shallow brackish lagoons, limestone islands, tidal marshes, mudflats and mangroves near the coast, and extensive freshwater marshes with peat formations. Font Hill represents the second largest area of wetland occurring within the parish.
CLARENDON AND ST. CATHERINE	The Portland Bight Protected Area is found in both Clarendon and St. Catherine. The Protected Area is the largest on the island and includes approximately 187, 515 hectares of coastal lands and marine area to a depth contour of 200 metres. Of that amount, approximately 8,288 hectares is covered by wetlands which are distributed across the coastal areas of the wetland and offshore cays.
KINGSTON & ST.	Most wetlands are found within the Palisadoes-Port Royal Protected Area as well as sections of Hunt's Bay. The variety of wetland types

ANDREW	are found in this area including cays, shoals, mangrove lagoons and islands.
WESTMORELAND	A significant portion of the wetlands are found in the Negril Great Morass which straddles both Westmoreland and Hanover. It covers an area of approximately 2,289 hectares. The remaining portions of wetland are located within the Savanna-la-mar area and coastal sections of Little London.
ST.JAMES	The largest continuous wetlands in St. James are located around the Bogue Lagoons, the Donald Sangster International Airport and Greenwood – Long Bay. Mangroves are also located Half Moon Hotel and at the Wyndham Rose Hall sewage ponds.
ST. ANN	Wetland distribution in the parish are scattered in small clusters along the coastline. These include sections of the Rio Bueno River, Discovery Bay, Green Grotto, Pear Tree Bottom and Priory.
PORTLAND	Portland does not have a vast expanse of mangroves; those areas where mangroves are found have been heavily impacted by development nonetheless a few areas exist with intact forest. mangrove areas include West Harbour, Salt Creek, Turtle Crawl and Manchioneal. The largest distribution with the most significant functionality is located at Turtle Crawl, with Manchioneal being the second largest.
TRELAWNY	Trelawny represents the north coast parish with the largest wetland distribution. The largest wetland area is in Falmouth with smaller areas located in Duncans, Coral Spring and Rio Bueno.
HANOVER	Like Westmorland, a large expanse of the Negril Great Morass is located along the southern boundary of Hanover. Smaller pocket of mangrove is located within coves along the mouths and along the banks or rivers and tributaries throughout the parish. Other mangrove areas in the parish include Green Island, Mosquito Cove, Industry Cove, Copperwood, Lucea and Point.
ST. MARY	St. Mary has the lowest mangrove coverage of all north coast parishes. Mangroves are mainly found in small patches along the

	banks of rivers and tributaries throughout the parish. These include Annotto Bay, Salt Bay, Port Maria and Oraccabessa.

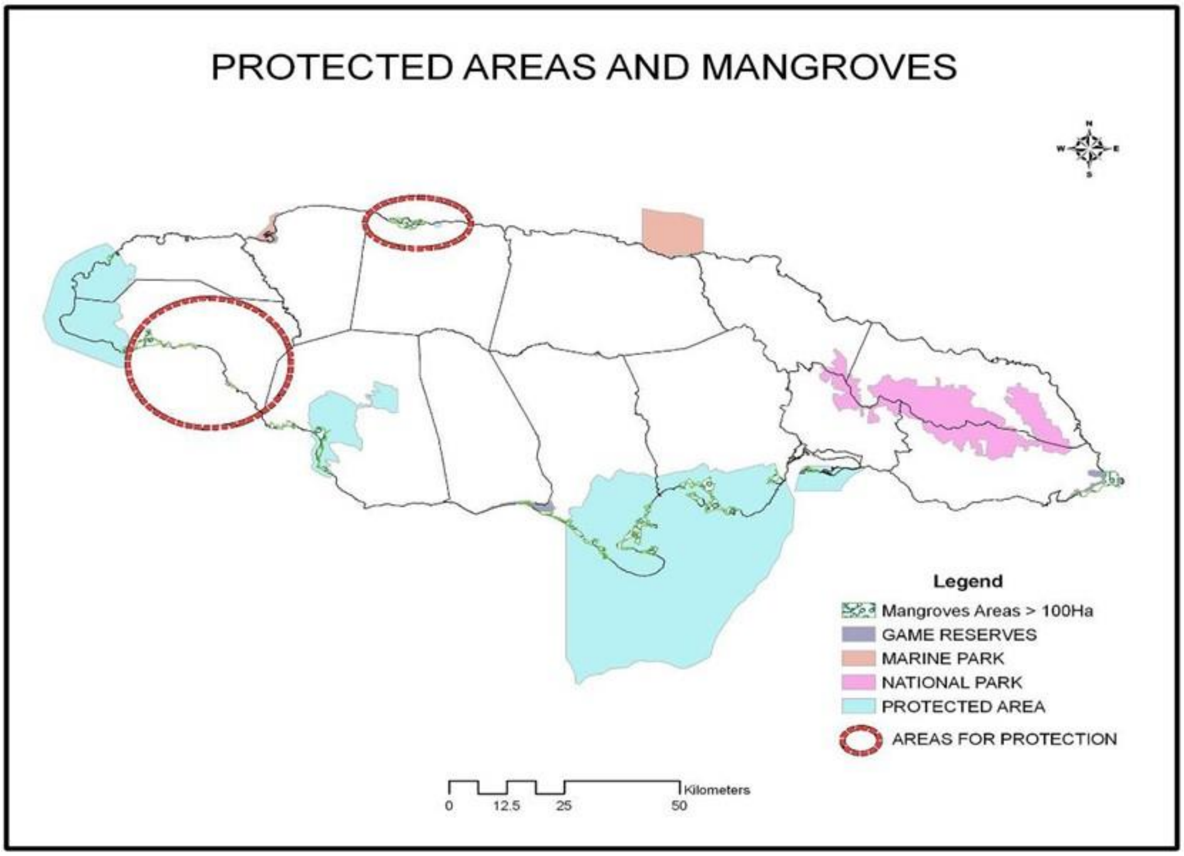


Figure 2: Map showing distribution of mangrove areas within Protected Areas (Source: Status of Jamaican Mangroves, 2014, NEPA).

Estimates from 2010 indicated the main coastal wetland areas of the country where mangroves are found amounted to approximately 11,674 ha. This has increased to 16,735.40 hectares as mentioned in the Status of Jamaican Mangroves, (NEPA, 2012). However much of the mangrove forests have been declining with change in land use pattern which thus results in increase in erosion of coastlines. Although most mangrove forests across the island are showing decrease in area, most of the decline is seen for areas where coastal developments have taken place particularly along the north coast. In 2011, approximately 1584 hectares of land in St. Catherine was classified as wetland. This is a decrease of just over 50% from that classified in 2005, while Clarendon showed a 40% decrease in wetland area, from 3,860 hectares to 2,334 hectares. I In St. Thomas there was a marginal increase of 3% or 66 hectares; the increase was associated with the inclusion of the mangroves surrounding the Yallahs Salt Ponds. Some areas however, showed an increase in wetland coverage with NEPA (2012) indicating that of the seven south coast parishes, five showed an increase in wetland coverage over a six-year period from 2005 to

2011. Furthermore, for the section of the Negril Great Morass located within Westmoreland there was an increase of approximately 42% from 1,815 hectares in 2005 to 2,584 hectares in 2011. In all instances where there was an increase in wetland coverage this was attributed to some areas not being classified in the 2005 survey. Comparisons were made between mangrove areal coverage surveys using remote sensing carried out in 2005 by The Nature Conservancy (TNC) and surveys conducted in 2012 by the National Environment and Planning Agency. Here, the most significant increase in coverage was 300% recorded for Kingston and St. Andrew in 2012; however, this was attributed to areas being excluded in the 2005 survey. The status in 2012 showed that the three parishes along the north coast including Westmorland when verified against the desktop survey in 2011 for mangrove coverage showed an increase in mangrove coverage ranging from 9.3% to 99.7% for St Ann and Hanover. St James on the other hand showed a 6% decrease. Despite these changes between surveys, there is a general trend of alteration and reduction of coastal mangrove area with associated loss of habitat and functionality.

The continued loss of mangroves could have repercussions such as the loss of natural breakers of wave and wind force, reduction in commercial and non-commercial fisheries (essential for livelihoods and food security), reduction of natural filters, biodiversity loss, and carbon sinks loss, which all together represent important points for climate change adaptation mitigation, and disaster risk management.

Socio economic linkages to mangroves

The socioeconomic benefits of mangrove cannot be separated from the ecological benefits of these wetlands. Some of these ecological benefits include shoreline protection and flood protection and wild life habitat and nursery areas including birds, shrimp, crabs and fish (NRCA, 1997). Shoreline protection and flood protection are critical as environmental degradation affects both on the local and national level. Coastal areas, on account of their topography, have been extensively developed as urban centres and for industries, tourist resorts and population, but these are compromised by tropical systems such as hurricanes or coastal flooding, with their vulnerability increasing due to climate change (Richards, 2008). It has been reported that most of the coastal towns in Jamaica have coastal forest origins (Trench, 2018). The removal of these for coastal development would have added to their vulnerability to climate change and climatic variability as they would have lost the ecological benefits of shoreline and flood protection. It was further reported that since 2010, approximately 200,000 m^2 (49 acres) of coastal forests have been lost to informal settlement (reclamation), inclusive of access roads etc. (Trench, 2018) again emphasizing increasing land degradation and vulnerability to coastal flooding. The increasing population and demand for land for housing development may further increase pressure on an already sensitive ecosystem through the removal of mangrove forest and improper waste disposal (Richards, 2008). Richards (2008) reported that the mangrove forest has been declining due to land use demands by humans for coastal developments and charcoal production.

Further, coastal communities are dependent primarily on agriculture and tourism and there are several benefits of mangroves that have been linked to their ecological provisions (Richards, 2008, NRCA 1997). Many of these benefits are important to the Jamaican economy. The faunal biodiversity supported by mangroves are particularly important for the sustainability of the fishing industry. It is reported that these wetlands are habitat for over 220 fish species including commercially important fish such as snapper, grunt, parrot, barracuda and mackerel and economically important crustaceans such as shrimps, lobsters and crab (NRCA, 1997). The Black River Lower Morass has traditionally supported the local shrimp industry (NRCA, 1997). The Black River Lower Morass has traditionally supported an important local shrimp industry.

While traditionally, mangrove forests have been cleared for hotel development promoting mass tourism and continues to contend with this form of tourism, there is much opportunity for ecotourism as it has been reported that these forests host several endemic species of flora and fauna and provide recreational opportunities such as sightseeing, boating, swimming, and sport fishing (NRCA, 1997). Boat excursions into wetlands, for example, is gaining popularity as a tourist attraction (NRCA, 1997). The development of coastal ecosystem-based tourism associated with mangroves could yield huge economic gain for the island (Trench 2018) but would also benefit local communities by making use of their traditional knowledge of the areas and therefore support local livelihoods.

Project Significance

Mangrove and Wetlands as a Nature-based Solution to resilience and disaster risk management

"Climate change is increasing the frequency, intensity and magnitude of natural disasters (like hurricanes), leading to a higher number of deaths and injuries, as well as increased property and economic losses" IUCN 2017. Nature based solutions or Ecosystem-based Disaster Risk Reduction (Eco-DRR) is an "approach where the regulatory functions of ecosystems (forests, wetlands and coral reefs) are systematically harnessed to mitigate, prevent, or buffer against disasters" (Partners for Resilience 2019). Some of the nature-based solutions provided by forests and wetlands include regulating floods, stabilizing slopes and providing protection from storm surge, strong winds and cyclones.

The importance of mangroves as nature-based solutions for coastal damages came into limelight after the 2004 Indian Ocean tsunami as mentioned earlier. EJF, 2006 concluded that of all the countries that were impacted by the tsunami, Indonesia, Sri Lanka, India and Thailand experienced a higher net loss of mangrove cover post the 2004 tsunami. There was a loss of

28% of mangrove cover in these countries from 1980-2000 with Indonesia having the highest rate of loss. All of this attributed to the increase in the vulnerability of the coastlines to the impact of the tsunami waves. Many of the coastal towns and ecosystems that were affected by the tsunami were already at risk from overcrowding thus destruction of mangroves exposed the communities to increased risk.

Studies conducted by Spalding et al., 2014 on the role of mangroves for coastal protection cites examples from Belize, Northern Java where mangroves have been shown to act as buffers for coastal erosion and thus provide protection to ~40% of Belize population who live along coastal areas (http://naturecaptitalproject.org/). Mangroves have been shown to reduce height of incoming waves by 80% thus providing 800% more protection to the coastal areas of Florida at the Kennedy Space Center in Cape Canaveral (http://mangroveactionproject.blogspot.com/2017/06/, accessed on 20th July 2019) (Figure 3)

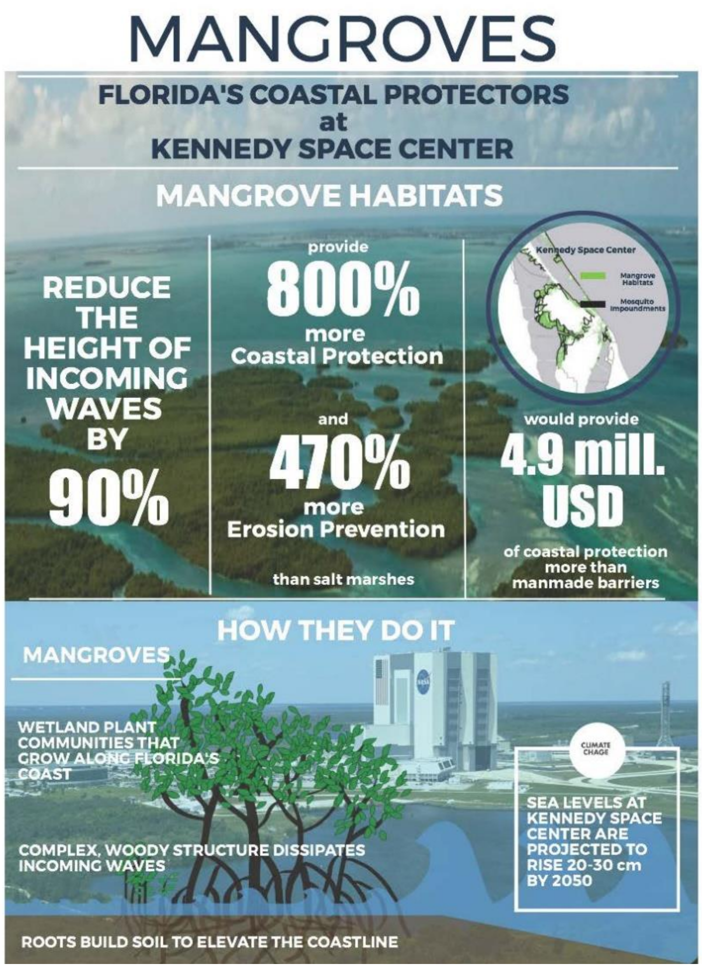


Figure 3: Mangroves act as natural barrier to coastal erosion (http://mangroveactionproject.blogspot.com/2017/06/) sourced on 20.7.2019.

The role of mangroves in coastal risk reduction as summarized by Spalding et al., 2014 is given below:

- Mangroves can reduce wind and swell waves thus reducing the impact of wave damage.
- A wide mangrove belt, ideally thousands of meters across, can be effective in reducing the flooding impacts from storm surges associated with cyclones, typhoons or hurricanes. This is most effective for low lying areas. A narrow mangrove belt will still reduce wind speed, the impact of waves on top of the surge and flooding impact to some degree.
- They act as barriers against tsunami waves thus reducing reduce loss of life and damage to property in areas behind mangroves.
- The dense roots of mangroves help to bind and build soils. The above-ground roots slow down water flows, encourage deposition of sediments and reduce erosion.
- Mangroves are not stand-alone solutions for coastal protection but in combination with hard engineering and other risk reduction measures, they can be effective in reducing damage to coastal towns and cities.
- Mangroves are among the most valuable ecosystems in the world. Policy makers, and the public, need to take full account of the many benefits that mangroves provide, and consider the implications from mangrove loss.

Mangrove coastlines offer a first line of defense as a transition zone from marine to terrestrial environments. Mangrove ecosystems are sensitive and dependent on a balance of sediment supply, appropriate salinity, temperatures, water conditions, appropriate subsidence rates to persist and adapt against sea level rise and climate change. Mangrove systems thus play a vital role in coastline protection, mitigation of wave effects and provide stabilization of soils and mudflats (Boa, 2011). Too much sedimentation (Woodroffe 1992, Woodroffe and Grime, 1999) as a result of natural or anthropogenic processes can disturb the mangrove ecosystem, by choking and can result in the formation of cheniers (sandy plains or lenses) that are often un-vegetated (Woodroffe, 1992) or cause dieback (Sippo et al., 2018). Mass tree mortality in Honduras resulting from Hurricane Mitch in 1998 resulted in a shoreline elevation loss of 11 mm per year, with predictions indicating that elevation loss would last for another 8 years in the absence of re-establishment of the forest (Cahoon et al., 2003).

Figure 4 below shows that there has a been a significant increase in mangrove mortality and diebacks in the Caribbean from natural causes as compared to the rest of the world; albeit the largest die-backs occurred in Australia (Sippo et al., 2018). This highlights the threat to ecosystem services and the sustainability of mangroves. Furthermore, some natural or anthropogenic diebacks (in Clarendon, Jamaica) have not been reported.

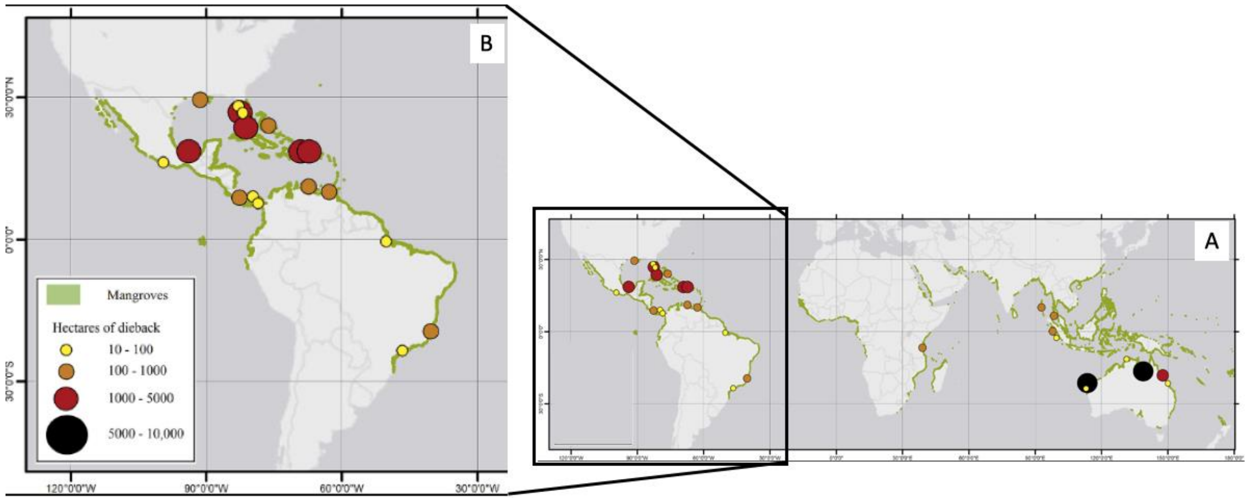


Figure 4: Global mangrove distribution and die-back from natural causes categorised by the magnitude of the area of dieback (A). The western hemisphere in general, and the Caribbean region has significantly more reported die back events (B) (adapted from Sippo et al., 2018 by T. Edwards 2019).

Mangrove forests are also among the most carbon-rich ecosystems due to the gradual accretion of organic matter through an imbalance in the rates of input, degradation, and losses from export. On average, the organic-rich soils of mangrove forests contain carbon stocks that may be two to three times higher than those of most terrestrial forest. Due to their large ecosystem carbon stocks, their vulnerability to land-use changes, and the numerous other ecosystem services they provide, mangrove forests have become increasingly important targets for conservation and mitigation of loss. Furthermore, since the size and changes in the soil organic carbon (SOC) pool are major constraints in global earth system models used for climate predictions, accurate determination of carbon stocks and baseline emissions in natural and managed forests (and other land-use types) is of high priority. In this contribution, we determined the SOM content, SOC content, soil carbon stocks and soil-atmospheric carbon flux (CO_2 emissions) for the surface soils (0–30 cm) of six mangrove sites (two each from the Bogue Lagoon, Portland Cottage and Salt Marsh).

Water quality is a crucial component of ecosystem health and is important in promoting biodiversity, stability and thus enabling human adaptation to climate change. However, human-induced pressures associated with rapid population growth has increased the risks of coastal waters being contaminated by a host of organic and inorganic species, though, for example, wastewater discharge, agricultural runoff, and atmospheric deposition. This report provides a baseline assessment of the water quality (and allied parameters) of selected mangrove forests in Jamaica in order to better understand how the health of the mangrove and associated areas may impact the various ecosystem services they provide.

Understanding mangrove ecosystems, their health and likely future at the national and site-specific scale is very important, and therefore becomes critical for understanding and modelling their response to sea-level rise on the coastlines that they occupy. It is important that effective reconstruction and better protection of coastal ecosystems be undertaken if coastal communities are to fully recover from the disaster, and be protected in the future (EFJ, 2006). This can be achieved by collaborative effort from governments and local communities aiming at restoring mangrove forests as part of the reconstruction process post any natural disaster. This has been taken up by many governments across the world who have now announced such schemes and are proposing better protection for mangroves in the future (EFJ, 2006).

Mangrove restoration and engineered coral reef structures to reduce wave energy are two nature-based solutions used throughout the world. In the Caribbean and in particularly in Jamaica, mangrove restoration/ rehabilitation is the solution used to assist with protection of the coastal roads such as the Palisadoes-Port Royal road.

Contributions to national strategies and capacity building

The overall vision laid out in the GoJ Climate Change Policy Framework and Action Plan (GoJ, 2015) is that: "Jamaica achieves its goals of growth and prosperity for its people while meeting the challenges of climate change as a country with enhanced resilience and capacity to adapt to the impacts and to mitigate the causes in a coordinated, effective and sustainable manner." (World Bank, 2009). The primary aim of this policy framework is to support Vision 2030 by reducing the risks posed by climate change to all of Jamaica's sectors and development goals through the Hazard Risk Reduction and Adaptation to Climate Change (HRRACC) Thematic Working Group 3. One of the primary natural hazards to Jamaica's coastlines and the communities therein is from storm surge and flooding from incoming waves from tropical storms and cyclones. The World Bank report on Coastal Management and Beach Restoration Guidelines: Jamaica (2017) as referred earlier considers that the removal and degradation of mangroves, seagrass beds and coral reefs caused by multiple factors has increased the vulnerability of Jamaica's coastal areas to risk from hurricanes and tropical storms. One of the measures suggested for coastal zone management in the same report was that of soft solutions such as restoration of mangroves, dunes, sea grasses, replanting and beach nourishments. This project is an example of such a study where use of soft measures (mangroves) has been shown and thus fits into the guideline for Coastal Zone Management as referred in the World Bank document.

The project is also well aligned with specific National Development Plan Jamaica Vision 2030 and the World Bank Country Partnership Strategy (CPS FY14-17). This activity will support the GoJ's effort to achieve its National Development Goal of securing a healthy natural environment (Jamaica Vision 2030). The project is aligned to Goal 4 of Vision 2030: Jamaica has a Healthy Natural Environment and initiative will complement Outcome 13- "Sustainable Management and Use of Environmental and Natural Resources" and Outcome 14 - "Hazard Risk Reduction and Adaptation to Climate Change". These Outcomes are well aligned with the United Nations

Sustainable Development Goals 13 and 14 which targets Climate Action and Life on Land (Figure 5).


GOAL 4: Jamaica has a Healthy Natural Environment

National Outcomes -Vision 2030 Jamaica	Sustainable Development Goals (SDG)		
Sustainable management and use of environmental and natural resources	6 CLEAN WATER AND SANITATION	12 RESPONSIBLE CONSUMPTION AND PRODUCTION	14 LIFE BELOW WATER
	15 LIFE ON LAND		
Hazard risk reduction and adaptation to climate change	13 CLIMATE ACTION	15 LIFE ON LAND	
Sustainable urban and rural development	1 NO POVERTY	10 REDUCED INEQUALITIES	11 SUSTAINABLE CITIES AND COMMUNITIES

Source: Vision 2030, 2016

Figure 5: Sustainable Development Goals and Goal 4 of Vision 2030 (Source: Vision 2030, 2016, https://statinja.gov.jm/pdf/AlignmentofVision2030withSDGs.pdf accessed on 20.7.2019).

The project will also contribute to the Country Partnership Strategy (CPS) FY2014-2017 (Report No. 85158-JM), discussed by the Executive Directors on April 29, 2014, supporting Pillar III Social and Climate Resilience, which seeks to increase opportunities for poor and vulnerable communities (Outcome 7) and to improve institutional capacity to plan and respond to climate change events and natural disasters (Outcome 8). It is also aligned with keeping in mind the projections of climate change and its impacts as presented in the Third National Communication to the UNFCCC as well as The State of the Jamaican Climate, 2017. Furthermore, the outcomes of the project will aid in developing policies and plans for disaster risk reduction thus assisting Jamaica in meeting the Sendai Framework as well as feeding into The State of the Jamaican Environment (in progress).

Site Selection and Description

The sites for the study were selected based on consultation with NEPA, World Bank, local on-the-ground organizations, as well as through field visits. The primary considerations were:

1. Proximity to the communities
2. Mix of sheltered site and one that is more open to wave energy
3. Plots where there are no major pools or channels Avoid major pools or channels within the plots if possible
4. Ease of accessibility by land was a consideration but not a priority

The three sites selected were:

- Bogue Lagoon - Montego Bay, St. James
- Salt Marsh - Falmouth, Trelawny
- Portland Cottage - Portland Bight, Clarendon

Figure 1 shown earlier displays the locations of the three sites which were selected for the study area. A brief description of each is given below categorized under the different components.

Socio-Economic

Bogue Lagoon -Montego Bay, St. James

Bogue is in an urban area characterized by a mixture of commercial, industrial and residential land use. Structures associated with these land use types line the mangrove community with the south and south western sections being primarily dominated by residential land use. The eastern and north eastern sections of the mangrove forest transition into industrial and commercial land use. Compared to the Portland Cottage and Salt Marsh, Bogue has the highest land use density.

Respondents from 60 businesses were interviewed within the community between the May 30 to the June 1, 2018. Within this amount, 59% were females in comparison to 41% males. Thirty-six (36%) were managers and only 8% were owners. The majority (56%) fall in other professions within the various businesses. It should however be noted that the intention was to target only managers or owners, but due to their busy schedule, field workers were directed to other employees within the business whom were deemed capable of responding to the questions.

Majority (49%) of the businesses interviewed were described as sole proprietorship, followed by corporations (39%) and partnerships (12%). On average, businesses employed about 11 persons with some businesses employing a maximum of 70 employees. The average years of operation for businesses is 12.3 years with a maximum year of operation at 55 years.

Salt Marsh - Falmouth, Trelawny

The Salt Marsh community is located along the island's northern coastline and is characterized by lower levels of social and economic blight than Portland Cottage. Only 21% of household heads are unemployed while 19% have no formal education (SDC 2017). Primary data was collected from 92 households from the May 4 to 7, 2018. It revealed that the main household income is through self-employment (45%) followed by paid private employee (41%). Majority of the homes within the sample population (72%) are constructed from concrete and blocks. This is in keeping with the secondary data which reported eighty percent (80%) of the homes are constructed from concrete and blocks (SDC 2017). In addition, most (74%) of the sampled households had electricity. There are high levels of access to piped water supply to private homes and only 7% of the homes use pit latrines (SDC 2017). Many of the homes are located along the boundaries of the mangrove forest and settlement densities decrease with further south of the mangrove boundary.

Portland Cottage - Portland Bight, Clarendon

According to the Social Development Commission (SDC (2017), Portland Cottage can be described as a poor community with low levels of education and employment. Approximately 42% of the household heads are unemployed and 56% have no formal education (SDC 2017). Primary data was also collected from a sample of 107 households within the community on the 24th and 25th of February 2018. This data also supports the low levels of education that characterised the community with about 40 % of respondents having less than Secondary High education and only 3.8% attaining university level education. Further, majority of the household income (60%) is through self-employment. Most (69.5%) of the homes are constructed from concrete and blocks, with only 10% of the households within the sample constructed from wood only. This is in keeping with the secondary information which reported about 60% of homes in the community were made from concrete and blocks although the remaining 40% were said to be constructed from wood (SDC 2017). Primary data also revealed that 66.7% owned electricity, but a noteworthy amount (20%) shared electricity. Twenty three percent of the residents receive water from public stand pipe and 52% utilized pit latrines (SDC 2017). Most of the structures in the community are immediately juxtaposed between the mangrove community and in some instances such as in the southern sections of the community, houses have been constructed in mangrove clearings.

Ecological

Bogue Lagoon -Montego Bay, St. James

Bogue Lagoon is in Bogue, Montego Bay, St. James. The area has a shallow lagoon that is protected by fringing coral reefs (located 1.8km from shore). There are two small mangrove islands within the lagoon. The mainland mangrove forest (excluding the islands), covers 66.2 ha

(Figure 6). Of significance is the existence of waste-water stabilization ponds (east of Site 1) from which effluent discharges into the lagoon. The areas sampled had intact fringe forests and there was no evidence of either hurricane damage or timber harvesting.

Figure 6: Bogue lagoon mangroves, St. James showing the sites sampled. (Google Earth, 2018).

Salt Marsh - Falmouth, Trelawny

The Salt Marsh area (Figure 7) is located west of Falmouth, Trelawny. The estimated mangrove coverage in this area is approximately 24.5 ha. Site 1 is located on the north east in proximity to an outer bay called Half Moon Bay. The site is in an intact fringe forest with minimal disturbance.

There was evidence of light to moderate hurricane damage and medium (30-70%) timber harvest. Site 2 is located at the western most point of the main bay, called Salt Marsh Bay. This site, also located in a fringe forest showed moderate hurricane damage, there was no sign of timber harvest but visible signs of human disturbance from plastic and other solid waste accumulation were evident. The associated bay is relatively shallow with poorly defined "islands" of mangrove and is protected by a wide spit of land.

Figure 7: Salt Marsh mangroves, Trelawny. (Google Earth, 2018).

Portland Cottage - Portland Bight, Clarendon

Portland Cottage (Figure 8) is in the western section of West Harbour, Clarendon. The area experienced two intense hurricanes; Ivan and Dean 14 and 11 years ago, respectively as well as tropical storm Sandy (six years ago).

The mangrove in this area covers approximately 63.1 ha, which is a part of the Portland Bight Protected Area (PBPA). The areas sampled have fringe forests which are degraded but still intact (dense mangroves). There was evidence of hurricane damage as well as regeneration of trees; the latter seen especially at Site 2.

Figure 8: Portland Cottage mangroves, Portland Bight, Clarendon showing sites sampled. (Google Earth, 2018)

Physical

Mangrove Geology

The sites studied with mangroves on the north coast of Jamaica lie within the North Coast Belt, as defined by the distribution patterns of deep-water and shallow-water facies in the White Limestone Group (Hose and Versey, 1957; Eva and McFarlane, 1985; Mitchell, 2004, 2013; Figure 9). A key to symbols used on the detailed geological maps is shown in Figure 10.

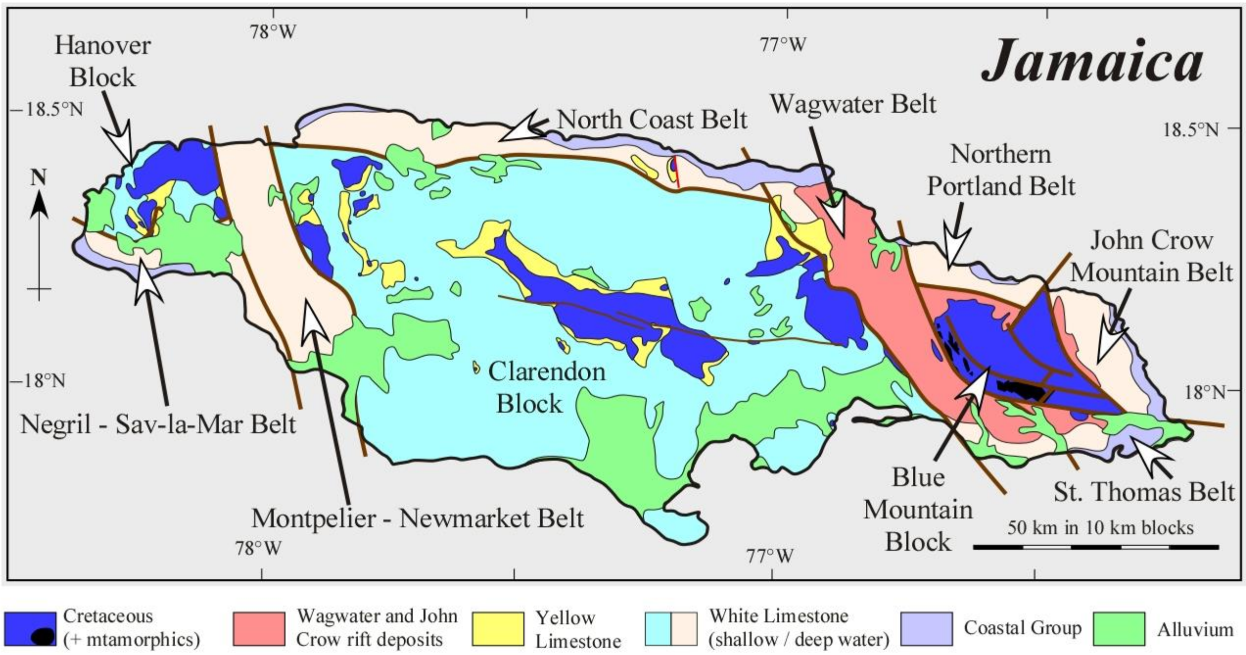


Figure 9: Distribution of blocks and belts in Jamaica based on deep-water and shallow-water facies found in the White Limestone Group. Source: Mitchell 2019.

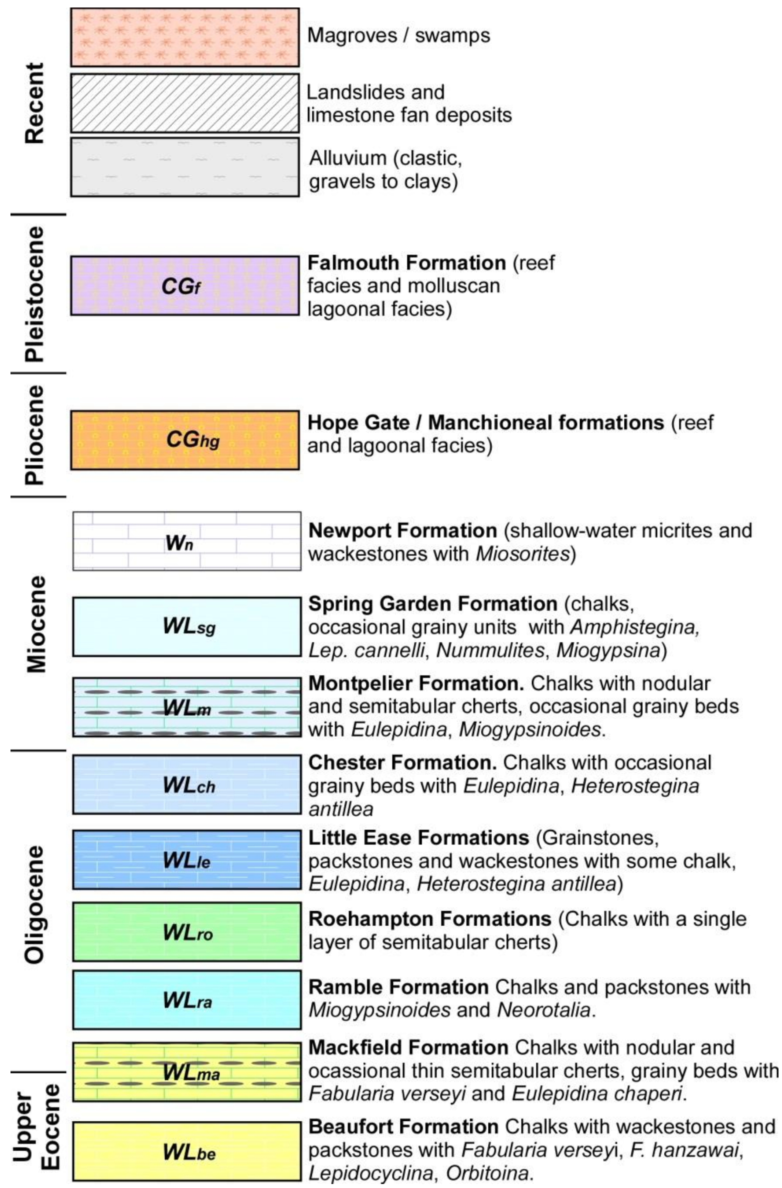


Figure 10: Key to symbols used on geological maps. Many of the names are used informally here as they have not been formally published.

Montego Bay

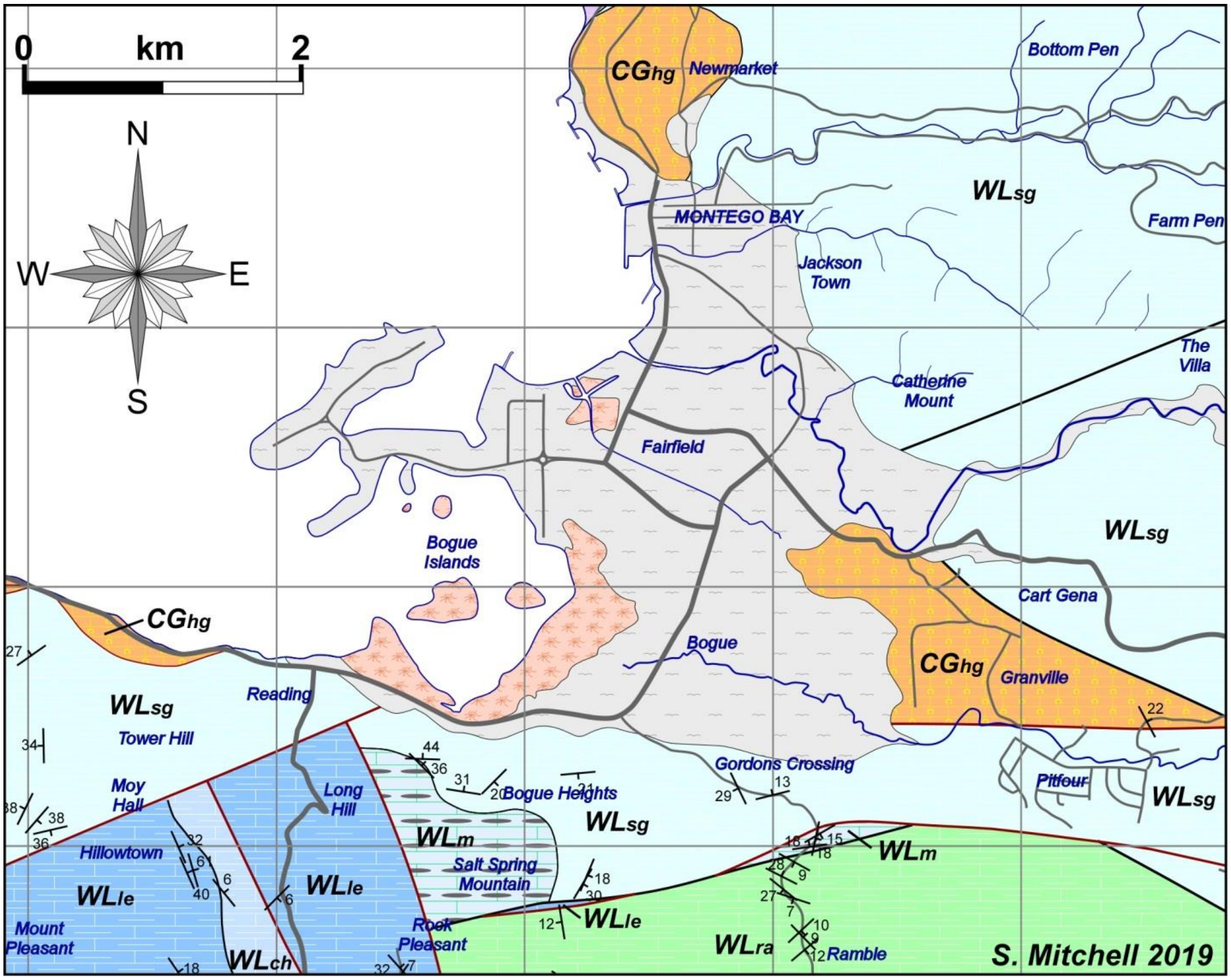


Figure 11: Geology of the area around Montego Bay. Source: Mitchell, in prep. b. See Figure 10 for key to formations; faults in red, boundaries in black, roads in grey, rivers in blue.

The geology of the area around Montego Bay is complex with rocks belonging to the White Limestone and Coastal Group as well as superficial deposits (Figure 11). The most prominent feature is an E-W fault separating the White Limestone in the south of the map from the Coastal Group (between Granville and Pitfour). This fault is a major tectonic feature and forms the coastline from Lucea to Montego Bay and then extends inland to form the northern margin of the Sunderland Inlier (Figure 11). There is significant uplift on the southern side of this fault and progressively older limestones are exposed to the south (Figure 11). The Coastal Group is also separated from the White Limestone to the north of Granville by a NW-SE trending fault; this fault forms the margin of a ramp basin with the Coastal Group faulted down relative to the White Limestone. This has formed a young sedimentary basin where extensive alluvial deposits have formed and is the site of the mangrove swamps around Montego Bay. The apparent lack of Falmouth Formation in this area (it is present as a low terrace to the west and north of the area on the map as a low terrace at +2 m above sea level) probably indicates recent subsidence in the area.

Portland Ridge

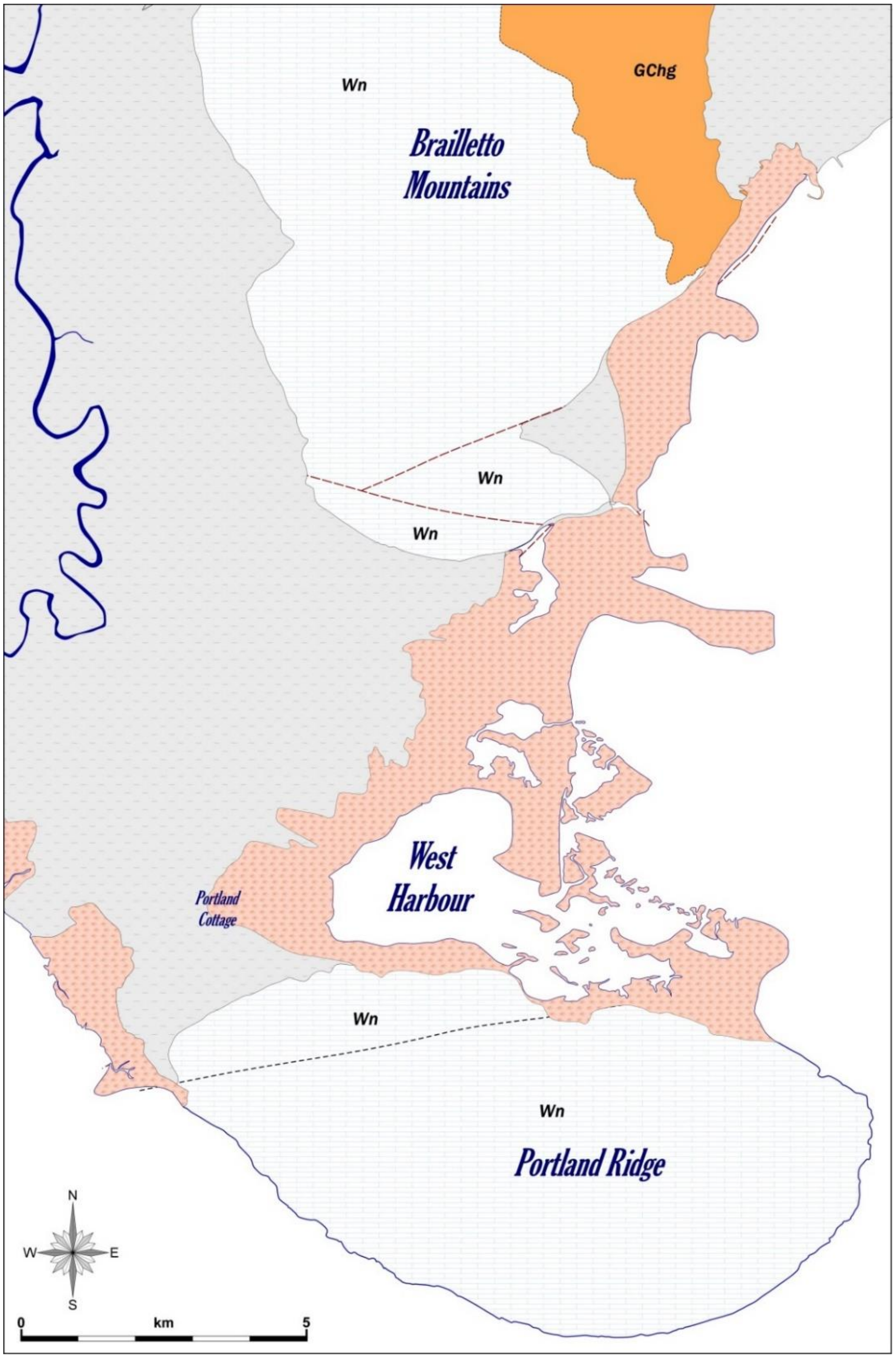


Figure 12: Geology of the area around Portland Cottage. Source: Mitchell, 2015, in prep. c. See Figure 10 for key to formations; faults in red, boundaries in black, roads in grey, rivers in blue.

Geologically, this area is relatively simple when compared to Falmouth and Montego Bay. Portland Ridge forms a hill in the south, whereas the Brazilletto Mountains form an eastwardly tilted block which is faulted against the Vere Plains on its eastern side (Figure 12). Extensive alluvial deposits and mangrove swamps are developed in the area between these two highland areas. There are no deposits of the Falmouth Formation in this area; either it has been eroded or is below sea level and indicates extensive recent subsidence.

Falmouth

The area around Falmouth contains rocks belonging to the White Limestone and Coastal groups, together with superficial deposits (Figure 13). The White Limestone is typical of deep-water White Limestone facies found along the North Coast Belt of Jamaica and includes a range of formations that have not previously been described. The names are used informally here to show the structural relationships and how the distribution of the mangrove areas is controlled by the structural geology. The stratigraphy is summarized in Figure 10).

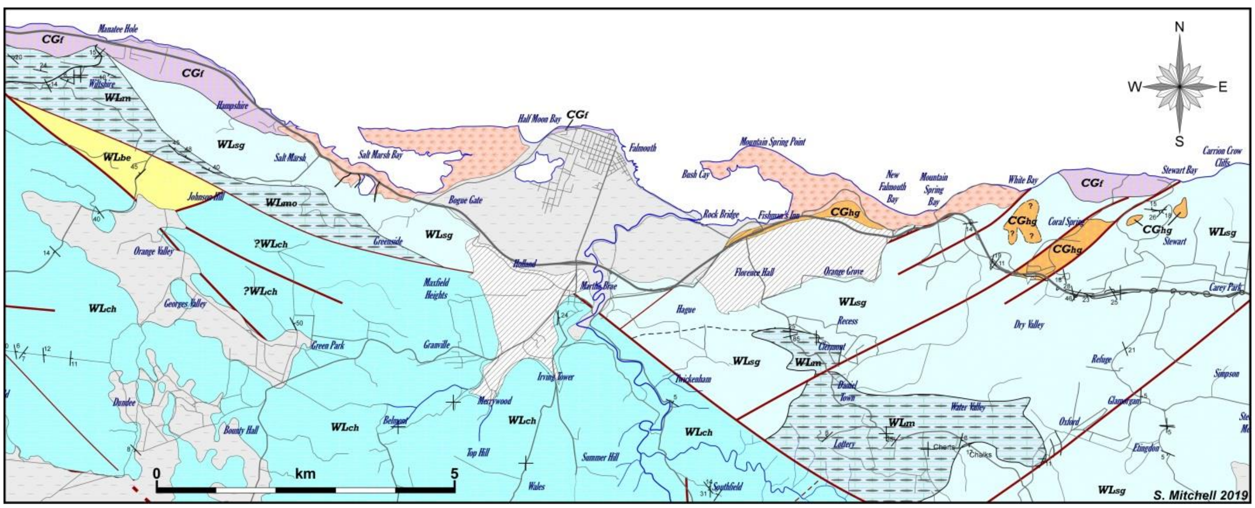


Figure 13: Geology of the area around Falmouth (source: Mitchell, in prep. a). Faults are shown in red, roads are shown in grey, rivers and the coastline are shown in blue. See Figure 10 for the key to stratigraphic units (formations), faults in red, boundaries in black, roads in grey, rivers in blue.

Faults can be mapped, and offsets determined by the different formations seen in the White Limestone Group and the Hopegate Formation. Two sets of faults are readily apparent: a NW-SE trending set, and a NE-SW trending set (Figure 13). The NW-SE trending fault set comprises compressional (reverse or thrust) faults with areas to the SW being uplifted with regard to areas to the NE. This is particularly clear where the Eocene Bleaufort Formation is faulted up in a fault block to the WSW of Falmouth (on the northern upper margin of Figure 13). The NW-SE trending faults are extensional faults that down-step towards the NW; this is particularly well seen in tracing the distribution of the Hopegate Formation, which is only preserved on the highest area above the Carrion Crow Cliffs, but progressively gets lower in each fault block until it disappears to the east of Falmouth. The Hopegate Formation is dated at c. 2.5 million years old (Land, 1991), and indicates extensive tectonic movements in Jamaica after that date. The Falmouth Formation is found as a very low terrace intermittently exposed along the coastline. The Falmouth Formation was deposited during the Sangamonian sea-level highstand at about c. 125,000 years ago. This sea-level highstand was at +6 to +9 m above present sea level (Kopp et al., 2009; Dutton and Lambeck, 2012), yet the Falmouth terrace, where developed, is only at between 1 to 2 m above present sea level. This demonstrates that some 4-8 m of subsidence, caused by continued fault movement, has occurred in the last 125,000 years. Thus, the mangrove swamps around Falmouth are developed in areas of extensive subsidence as indicated by the heights and distribution of geological formations and suggests that tectonics has a strong control on the distribution of Mangroves in this area.

Methodology for Data Collection

Socioeconomic Analysis

Prior to undertaking the fieldwork, a field reconnaissance and pre-data collection exercise from secondary sources was conducted. These are important in determining the sample and sampling technique and understanding spatial layout of the communities. In this study, field reconnaissance was undertaken to understand the spatial layout of the communities and demarcate boundaries within which the assessment will be done. It helped in guiding the development of the questionnaire survey instrument and the identification of the target sample at each site. Pre-data collection was also conducted to understand the characteristics of population of the study areas. The National Census Data (2011) provided by STATIN which provides information at the enumeration district level was referred to and consulted. However, the data provided at the enumeration district presented a challenge as the researchers were interested in only delineated areas close to mangroves. The decision was therefore made to use the population at the enumeration district to compute the sample. The sample size was calculated at the 95% confidence level and a margin of error of $^{\pm}$10%. The sample size was determined according to Equation (1):

Equation 1

$$ss = \frac{Z^2 * (p) * (1-p)}{c^2}$$

Where:

Z = Z value (e.g. 1.96 for 95% confidence level)
p = percentage picking a choice, expressed as decimal
(.5 used for sample size needed as this is a best fit for equal probability across categories)
c = confidence interval/margin of error, expressed as decimal

However, these calculated samples were an overrepresentation of the population as the calculation were done based on the entire Enumeration district (ED).

A questionnaire survey was deemed as the most appropriate to collect data as it allowed for a quantitative assessment of the prescribed indicators. Given the multi-stakeholder nature of this study, the process included the involvement of the stakeholders in the development and design of the survey to ensure all critical components were captured that conformed to the prescribed standards. The instrument was developed with inputs from the World Bank, NEPA and ODPEM. (The full questionnaire can be viewed in Annex 1.)

Field work was started after the survey was completed. Prior to this, the field workers were appraised on the questionnaire and also trained on the use of the Open Data Kit (ODK) – this is a mobile data collection application which is an efficient method in collecting and aggregating the questionnaire data and critical GPS, particularly because this method allowed for the export of data collected into SPSS format, thus reducing manual data entry and in so doing cut cost.

Monitoring data quality standards was a continuous and ongoing process - from determining the sample to collection and entry of data. The following consideration were made for data quality:

- Validity by ensuring that the data meets the objectives of the study and represents the intended result. The multi-stakeholder approach to developing the questionnaire was an important step to achieve this.
- Ensuring integrity of the data by minimizing any human errors that may arise from data entry and manipulation. ODK was employed to ensure minimal errors –the data was automatically uploaded in various format thus reducing any errors that occur in data

entry. The training in the ODK prior to data collection also helps with this. Once data was collecting, efforts were also made to clean the data.

- Reliability–steps were taken to ensure that the data was consistent at all facets – from collection, analysis across time and coherence when it was accessed by the researchers.

For a more comprehensive methodology, please consult the Manual for Monitoring Mangroves in Jamaica (World Bank. 2019).

Ecological Analysis

Mangrove species composition and relative abundance (for diversity)

A 50m transect was established (Figure 14) running from the seaward edge of the forest to the inland areas. A handheld GPS unit was used to record the location of the limits of each transect. Replicate vegetation plots of 10 X 10 m were established along each transect by marking trees with flagging tape. The types and number of tree species were identified, and the results recorded on a data sheet (Appendix 3, Mangroves Monitoring and Evaluation Manual for Jamaica). Simpson's Index was used to determine diversity of each site (n = 2) at each location. The index is a simple measure of diversity accounting for number of species present (richness) and their relative abundance (evenness); e.g. as species richness and/or evenness increase, the Simpsons index value (D) or diversity would also increase. D may range from 0 to 1 for lowest and highest possible diversity, respectively.

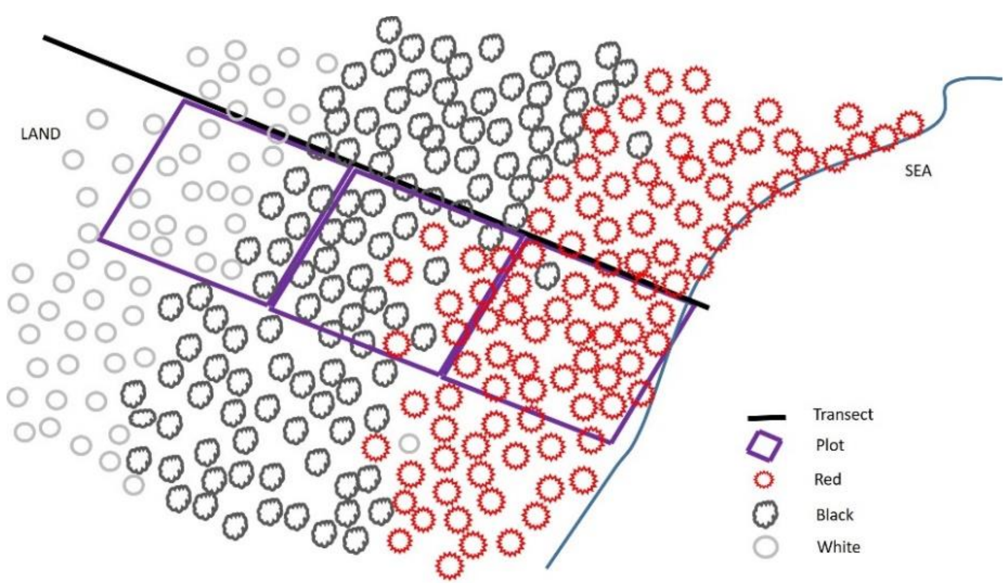


Figure 14: Diagram of monitoring transect and plot setup (Created by Patrice Francis, 2019).

Mangrove Trunk Diameter (DBH)

All trees within each 10 x 10 m plot were sampled for DBH. A 2 m pole was placed upright next to each tree and a calliper or tree diameter tape was then used to determine the diameter at breast height (DBH) at 1.3 m. Details on how to measure 'irregular' tree diameter can be found in the Manual for Monitoring Mangroves in Jamaica (World Bank 2019). Mean diameter at breast height values (with SE) per species, per site and per location were then calculated.

Mangrove height and canopy width

Tree height and canopy width were determined for each tree within each 10 x 10 m plot. A 7 m telescoping pole was placed upright beside the tree to be measured. The pole was adjusted to the highest point of the tree and its height measured. A meter ruler/graduated tape was placed on the ground from edge to edge of the tree crown and the width of the canopy determined. The mean (with SE) height and canopy width per species, per plot was also calculated.

Prop root/aerial root network

Three subplots (1 X 1 m) representing low, medium and high prop root as well as pneumatophore (Figure 15) densities within each 10 X 10 m plot were established before completing tree measurements to prevent damage to pneumatophores or prop roots. The total number of pneumatophores and prop roots within each subplot were then counted and the results recorded on the datasheet.

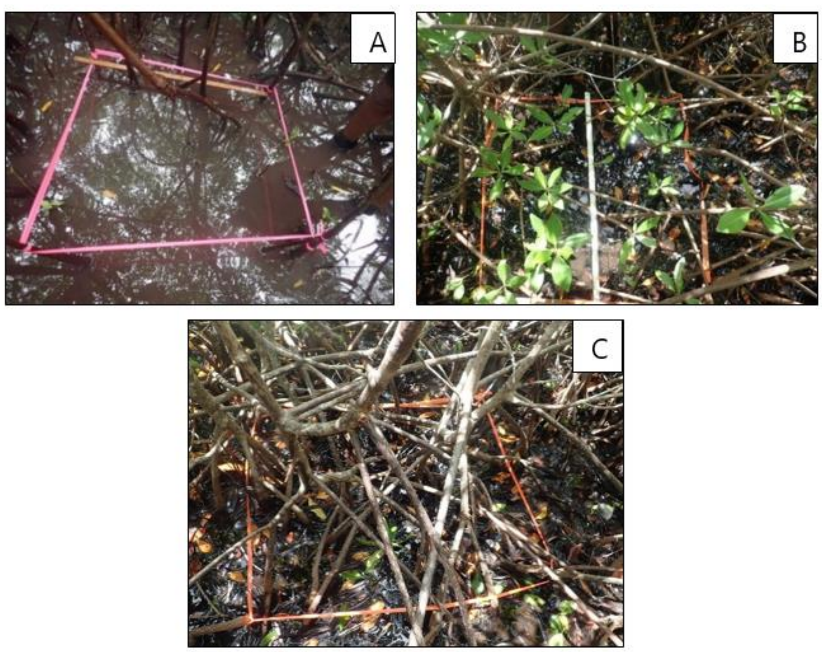


Figure 15: Three 1 X 1 m subplots representing low (A), medium (B) and high (C) prop root densities (Photo credit: Camilo Trench and Patrice Francis, 2018).

Fisheries Ecosystem services

Two light traps (Jones 2006) were secured to red mangrove prop roots (in at least 1 m water depth) using cable ties on new moon night. The light traps were collected early next morning (between dawn and 9 am) to prevent predation of fish larvae by zooplankton. The sample in the collection bucket was poured into pre-labelled bottles containing full strength ethanol. In the lab, the samples were decanted and stored in 200 ml bottles containing 70% ethanol. Fish larvae from these samples were subsequently identified and enumerated using stereo microscope. Richness, presence of commercially important species and their relative abundance were determined.

Physical Analysis

Surface Accretion and Soil Surface Elevation.

A modified rod set elevation Table (RSET) (design adapted from Horstman et al., 2014; Cahoon et al., 1997; Cahoon et al., 2002; Krauss et al., 2003) was employed to set up study plots for elevation change and accretion rates at three study areas in Jamaica. The high precision device called a rod surface elevation table (RSET) which is detachable from the benchmark was used at each benchmark to measure surface elevation of the mangrove substrate to a confidence interval of ± 1.3 mm. The RSET in conjunction with horizon markers and sediment traps allowed vertical accretion to be recorded. Accretion was measured if present with a ruler detected as soil/substrate above the horizon markers and sediment traps. Leaf litter collected at the RSET plots on the sediment traps were weighed.

Sediment Sampling and Assessment

Representative soil samples (0-30 cm depth; n=5) were collected in duplicates along a transect at each study site using an Edelman combination soil hand auger. The soil cores were washed through a set of wet sieves in a closed system to remove roots and plant matter collected in the soils. The retrieved plant matter was collected and weighed to determine the percentage weight. Any biotic sand fraction as were available were point counted for percentage abundance of grain constituents, provenance of grains and comparison using a Leica MZ6 Stereo zoom microscope. Sediment that pass the 170, 90 µm aperture sieve was collected and homogenized and separated in 50 g fractions where possible for hydrometer analysis to determine grain size for textural classification of soils after Shephard (1954).

Elevation profile

Relative elevation was acquired using trigonometric operations of an abney level and profiling staff throughout the study sites in conjunction and control points of known elevations from the National Land Agency website. The same transect was used as a marker to allow the collection of water and soil samples.

Wind Data and Wave Parameters

The wind data was collected with three hand held anemometers, two Skymate wind meter model SM-18 and one Kestrel pocket weather meter model 2500 along a transect seaward and within the shelter of the mangroves at predetermined time intervals of 1.5 h. The anemometers were set to record the average wind speed and they were held for 120 s in the prevailing wind direction as determined by the persons operating the anemometer at the time of data collection.

For the collection of water level, three U20L-02 Water Level pressure and temperature data loggers were deployed at each locality to collect pressure data below the water level, which was then extracted to produce wave parameters to determine wave attenuation along the same transects mentioned.

Soil & Water Quality

Water and soil samples ($n \geq 3$) were collected at varying intervals seaward along each transect. The water samples were analysed by atomic absorption spectroscopy (AAS) and Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). Analyses of quality control solutions, reagent blanks, and duplicate samples were carried out as part of the quality assurance regime. Recoveries were within 15% (or better) of reference values. Dissolved oxygen (DO), pH, salinity, conductivity, total dissolved solids and water temperature, were recorded *in situ* using a YSI 5000 dissolved oxygen meter (YSI Incorporated, OH).

Carbon Flux

A closed chamber system linked to a non-dispersive infrared (NDIR) gas analyser was used to determine GHG (CO_2) emissions from mangrove surface soils.

Soil Biogeochemistry

The elemental concentrations of selected elements of environmental geochemistry interests (e.g. toxic) were determined by instrumental neutron activation analysis. Approximately 0.20 g of (<150-μm fraction) sample was irradiated at varying thermal neutron flux to observe for short-, intermediate-, and long-lived radionuclides (JM-1 SLOWPOKE-2 (Atomic Energy of Canada Limited, ON, Canada) nuclear reactor at ICENS). Data acquisition was performed by an Ortec High-Purity germanium (HPGe) coaxial gamma photon detector system.

Soil organic matter and organic carbon

Soil organic matter (SOM) content was determined by combustion – loss on ignition (LOI; Heiri et al. 2001). Soil carbon stocks (Mg C ha^{-1}) were determined using Equation 2 (Poeplau et al. 2017):

SOC_{STOCK} (Mg C ha^{-1}) = SOC (%) x BD (g cm^{-3}) x depth of soil (cm)
(2)

SOC (%) = the percentage of soil organic carbon measured

BD = bulk density (mass per unit volume of dried soil).

Note, in the absence of measured BD, an average BD value (0.28 g cm^{-3}) determined for tropical coastal wetlands was applied (Adame et al. 2013). Alternatively, pedotransfer functions were used to estimate the BD of the soils studies but values are regionally specific and should therefore be used with caution to avoid an overestimation or underestimation of carbon stocks.

Aboveground biomass and carbon stock

The aboveground (and belowground) biomass (ABG) and carbon stocks were determined using regression allometric models:

$$ABG_{est} = \exp(-2.187 + 0.916) \times \ln(\rho D^2 H)) = 0.112 \times (\rho D^2 H)^{0.916}$$

$(ABG)_{est}$ = estimated ABG (Kg)
exp = exponential
ln = natural log
D = diameter at breast height (cm)
H = height (m)
ρ = wood specific density (g/cm^3)

Note, diameter at breast height and tree height data are determined in the ecological component of this study, while wood density data is obtained from the literature. Tree carbon is calculated from biomass using a factor of 0.47, and belowground carbon stock is assumed to be 20 % of the above ground stock.

Surge Susceptibility Risk

Surge susceptibility risk is determined by the creation of merged buffers in a geographical information system (GIS) software. The merged buffers are created around historical flood points from 1692 to 2009 at 250 m at a lesser radius than the 'coastal flooding experienced point (GPS coordinates) data' collected in this study, 2018 at 500 m radius. The radius difference reflects the interpreted intrinsic data quality. The historical flood data points are a subset of the island wide dataset from the WRA with no differentiation for groundwater, riverine or coastal flooding and therefore, appointed a lesser weight in the GIS operations. The experienced flood data points (collected in this study) is specific to coastal flood experienced at the study areas, is considered more robust and therefore given a higher weight (500 m). The radius for the buffers are chosen based on the scale, and objective of the study but are very conservative as storm surge impacts can extend to greater than 50 km radius proportional to the disturbances impact extent and other physiographic and temporal conditions as seen in the instance of Hurricanes Katrina's and

Sandy's tidal amplified storm surge impact extent on the USA's east coast. The buffers are created around these points, merged and converted to a shaded polygon for easier representation. Coastal inundation extent projection shapefiles (polygon from NSDM) of 1 m, 5 m and 10 m are also presented along with the modified shapefiles of mangrove extent at the sites to show the complex interplay of coastal hazards (particularly surge susceptibility) following the premise that historical events of flooding will most likely be repeated. Susceptible areas with mangroves located on the seaward extent will therefore experience ecosystem benefits from the mangroves in wave and wind attenuation as more roughness (resistive forces) will be experienced by the waves than in the absence of the same.

Assumptions and Limitations

Assumptions

- Several assumptions were made for this study. Firstly, that mangrove forest provides several socio-economic benefits to local communities. Secondly, communities are highly vulnerable to coastal flooding which might be linked to uprooting of the mangrove forest and affects the livelihoods of these local communities.
- In all discussion about subsidence, it is assumed that subsidence is constant. However, instantaneous subsidence can occur due to fault movements. No data exist on previous fault induced subsidence events in this area.
- Storm surge is the most likely relevant coastal inundation threat to all the three study areas and Jamaica. Sea level rise is a long-term threat and tsunamis are more rare and harder to predict.

Limitations

- Budgetary constraints affected comprehensive reconnaissance field work, a smaller number of days for training field workers and the number of workers trained in addition to time allotted for field work. This also limited the extent of data collection especially where respondents were unavailable and repeat visits were required for data collection. Data quality might have also been affected.
- Ecosystem services provision assessment was limited by the single use of one method of data collection. Other methods such as focus groups and semi-structured interviews would have resulted in increased efficacy of data and a more effective analysis.
- The inability to assess fisheries using light traps simultaneously at each study location for a minimum of 12 months due to dependence on new moon every month as well as inability to be in multiple locations at the same time.
- Adult fish biomass is difficult to determine for mangrove areas without destructive sampling (pot/trap fishing). Furthermore, adult fishes use the mangroves seasonally (for spawning) or

diurnally (for feeding) but there are a few 'commercially important' adult species such as grunts, mojarras, sea breams, mullets and tarpons that are found permanently in mangrove areas in Jamaica (Bacon, 1978). So adult fish species were not sampled.

- Measurements of vertical accretion, elevation change, and shallow subsidence will require a longer time period than afforded in this study. Many reports that speak to accretion, elevation change, and shallow subsidence have used long term field collection (multi-year for example Krauss et al. 2003 and McKee et al. 2007) for evaluation in order to correct against fluctuations as a result of hydro-period induced variability and other shallow subsurface activities that can off-set the data.
- Wind speed and water pressure (from which wave parameters were calculated) are taken in fair weather conditions, but the attenuation and reductions offered by mangroves are presented for both fair-weather and extrapolated in qualitative ways to intense weather conditions, it would be therefore useful for future studies to try to obtain intense weather data, furthermore collection of data was limited in space and time and larger data sets can be more informative.

Site Analysis

Bogue Lagoon

Socio-Economic

Socio-Economic Context

Bogue is in an urban area characterized by a mix of commercial, industrial and residential land use. Structures associated with these land use types line the mangrove community with the south and south western sections being primarily dominated by use of land for residential purposes. The eastern and north eastern sections of the mangrove forest transition into industrial and commercial land use. A census of businesses, which fell within the demarcated area for the survey, was conducted as there was a challenge in terms of willingness to participate in the survey exercise given the busy schedule of business owners and managers. Despite the low compliance rate/participation, a total of 60 businesses were interviewed between the 30th May to the 1st June 2018.

Majority of the respondents were females (58.3%) but a noteworthy amount (41.7%) were males. The average range of respondents was 38.9, with modal age of 40. Age range from 20 years to 73 years. Most of the respondents (65.6%) had tertiary education, with 45.9% having university degree, 16.4% with community college degree or certifications and 3.3% regarded as others.

Although a noteworthy percentage of the respondents (35%) were managers and 8.3% were owners, majority of respondents (56.7%) were categorized as others, which included professions such as Clerks, Human Resource Management, Administrative Assistants, Optical Specialists and Supervisors. Although the intention was to only interview owners or managers, these persons were more than often busy, and at times unable to honor appointments due to work exigencies. The alternative was to interview someone who were able to provide information on the business. Some of these respondents were recommended by the managers or owners. There was no statistically significant difference between gender of respondent and their role in the business. Of the 25 males within the sample, 36% were store managers, 8% store owners and 56% fell in the 'Other' category. Of the 36 females, 36.1% were store managers, 8.2% store owners and 55.67% were in the 'Other' category.

Majority of the businesses (49.2%) were sole proprietorship. There were a significant number of corporations (39%), while a small proportion were partnership (11.9%). The length of operation for businesses ranged from less than a year to 55 years with a mean average being 12.36 years. All the businesses, except for one, had employees. On average, businesses had about 11 employees, the maximum number of employees was 70. Three (3) and seven (7) employees was the modal number of employees.

The respondents were reluctant in providing information on income. Just over half (31) of the total respondents provided the net value of their business, while 27 provided the most recent sales turn over. The maximum value of business was close to J$400 million, while the mean value was approximately J$ 2.880 million. Most recent annual sales turnover, which was requested in US dollar was greater than US$3 000 000, but the average was US$2.889 million.

Vulnerability of Coastal Flooding

Exposure

As stated in earlier sections, Bogue Lagoon in a zone of mixed land use which is dominated by commercial and industrial activities. Residential land use is also relatively common in the area but is not generally located immediately juxtapose the mangrove community. Bogue Lagoon has an extensive mangrove community which shelters much of the infrastructure located along the coastline. Exposure is primarily conditioned by the proximity to the coastline and the risk of experiencing storm surge effects which are possible during hurricanes or tropical storms. The island of Jamaica has a long history of hurricanes and tropical storm events. Over a 108-year period, spanning 1900 – 2008, 38 hurricanes passed within 300 km of the island (Jervis et al., 2010). While the risk presented by hurricanes and tropical storms directly influences exposure smaller scale geographical nuances are likely to make some sections more exposed than others, potentially influencing their vulnerability. Figure 16 illustrates the differential risk in relation to possible coastal inundation. Approximately 17 of the 60 establishments surveyed (28.3%) were in areas which would be affected if coastal waters travelled 1m inland and an additional 10 businesses would be affected with 10 m of coastal inundation. Overall, approximately 45% of the sample could considered to have a comparatively high level of exposure to the effects of coastal hazards. In addition to the properties which comprised the sample, it also evident that several highly valued properties including restaurants, hotels, luxury residential real estate, retail and industrial complexes are all located within the 1 m inundation zone rendering these structures as more exposed.

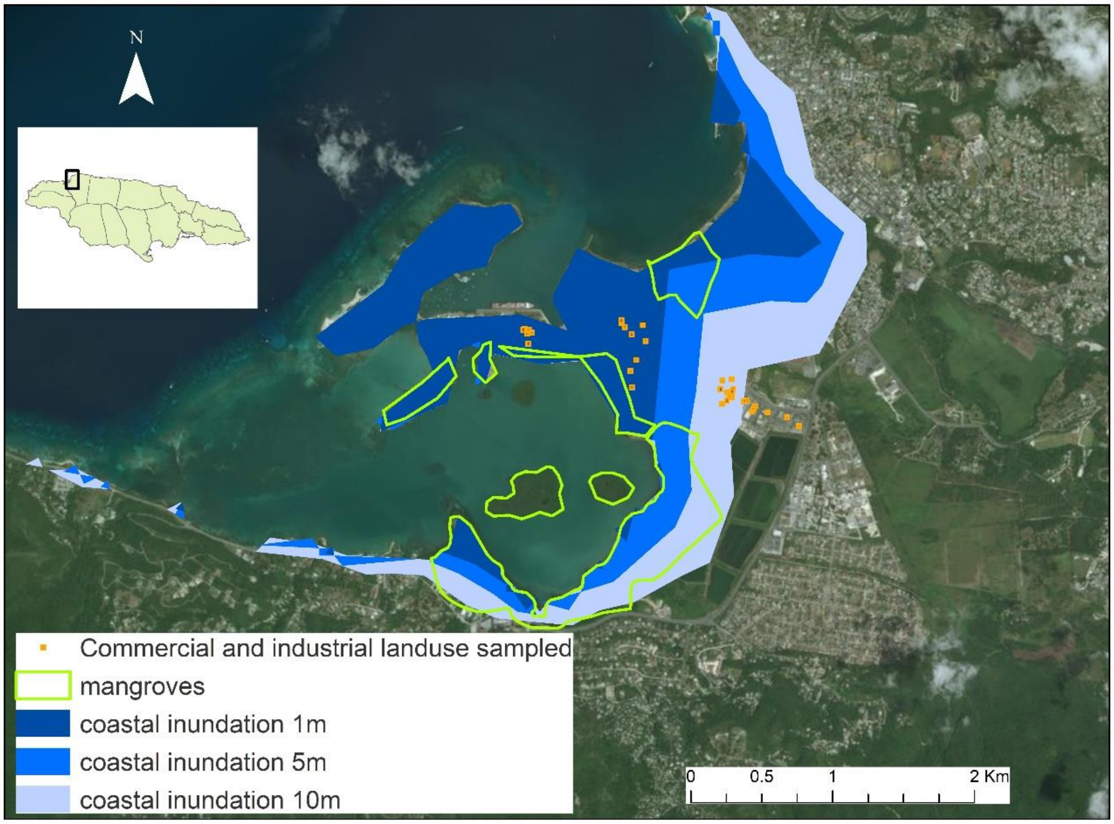


Figure 16: Location of sampled commercial and industrial facilities relative to a distance differentiated coastal inundation model at Bogue, Montego Bay.

Sensitivity

Given the spatial variations in the location of coastal infrastructure, it can be assumed that differential exposure may potentially influence levels of sensitivity. In addition to data derived from inundation models, the experience of flooding in the community was directly assessed through historical accounts from operators and other key personnel in various businesses. Approximately 23% of respondents reported an experience with flooding in the community. In relating the effects of previous episodes, 40% of those who experienced flooding stated that water entered the structure and in some cases was above the level of the wall skirting (20%).

Twenty percent of the respondents also reported that they were prevented from going to work because of flooding.

It must however be noted that while representatives of businesses surveyed made specific reference to significant flood events in 2008, 2017 and 2018, the more recent episodes (2017 and 2018) did not appear to be linked to coastal inundation induced by storm surge activity. Respondents also indicated only minimal levels of displacement due to flood activity. Only one business stated temporary relocation as an effect of the flooding history. Given the challenges associated with the acquisition of economic data, evaluation of sensitivity was based on history and impact of flooding. It generally appears there flooding has not caused severe damage despite its occurrence and this may imply relatively low levels of sensitivity among the businesses in Bogue Lagoon.

Adaptive Capacity

Since commercial and industrial business represent the most dominant land use activities in Bogue Lagoon, socio-demographic factors were not used to assess adaptive capacity. Of more importance is the ways in which these structures navigate their vulnerabilities to coastal inundation through the deployment of strategies to minimize the effects of floods. In this regard only 36% of the businesses that experienced flooding implemented measures to mitigate against future impacts. The most commonly cited measure was the use of sandbags, but this was deployed by only 21% of the businesses that experienced flooding. Additionally, only one business indicated that it secured flood insurance as a means of mitigating future impact.

Ecosystem Services Provisions

The survey focused on commercial establishments. Therefore, it is not clear the extent to which mangroves are important to fishermen in Bogue. In terms of other income or livelihoods, all respondents stated that they did not earn any other income or livelihood from services provided by the mangrove. This area can be investigated through interviews or focus groups with fishermen.

Still, respondents recognized a number of benefits of mangroves. Among the most important mentioned by 50% or more respondents are shoreline protection, providing habitat for wildlife and fishes, and had medicinal value (see Figure 17).

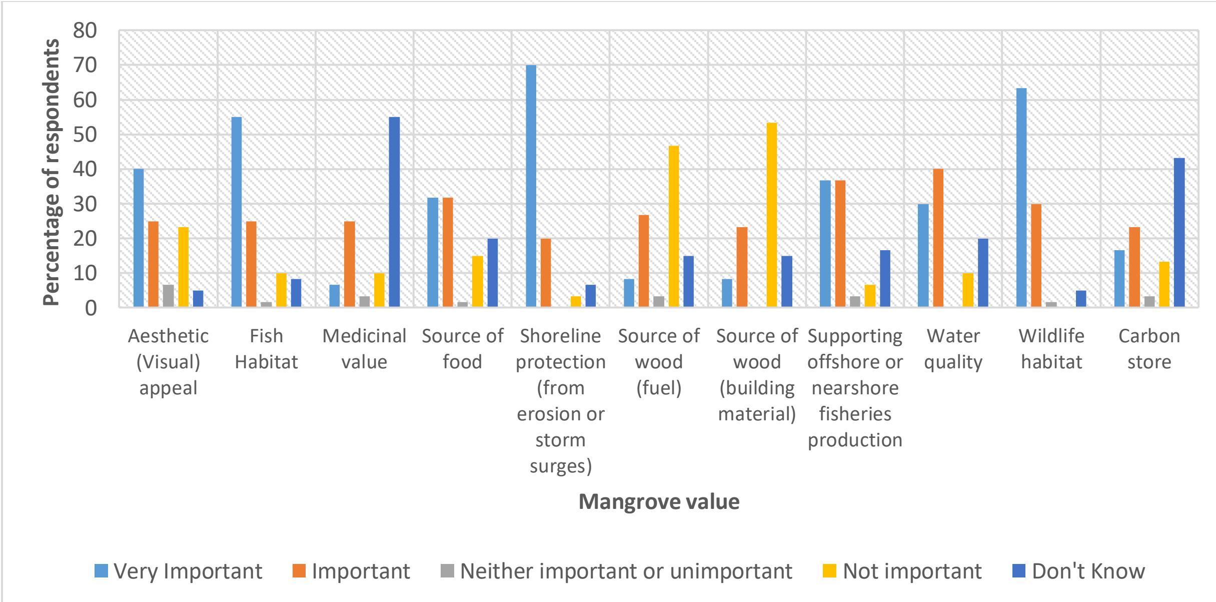


Figure 17: The Value of Mangrove to Community Members of Bogue, Montego Bay

The significance of shoreline protection to respondents could be explained by the proximity of majority of businesses to the shoreline. It is also possible that other benefits are indirectly valuable to respondents. For example, while the survey did not capture fishermen in Bogue, mangrove as fish habitat was reported to be of great value to respondents which may be explained by respondents' knowledge of mangrove services and the importance of fish as protein source to the community.

The mangrove forest is also important for ecotourism activities which may explain the significant number of persons who recognised the value of the forest as a wildlife habitat. The Black River Safari tour, for example, is widely advertised as home to mangrove forests, a variety of birds and American crocodiles. However, attempts to gain data on eco tours within the mangroves in Bogue proved futile as there is no clear database on tour guides or owners of these businesses. Even when contact was made and data was promised, information was not forthcoming. This is a suggested area for future research.

Issues Affecting Mangrove Services

Decrease in the mangrove forest was also a noteworthy observation by most respondents (46%) in Bogue. Most of the respondents who provided reasons for this attributed it to the removal of the mangrove forest for business development, particularly tourism and industrial development. This is in keeping with the socio-economic characteristics of Bogue as a strong commercial area. Shoreline development (land reclamation) and shoreline erosion were reported by 75% and 56.7% of respondents respectively as having a big impact on the mangrove forest (Figure 18).

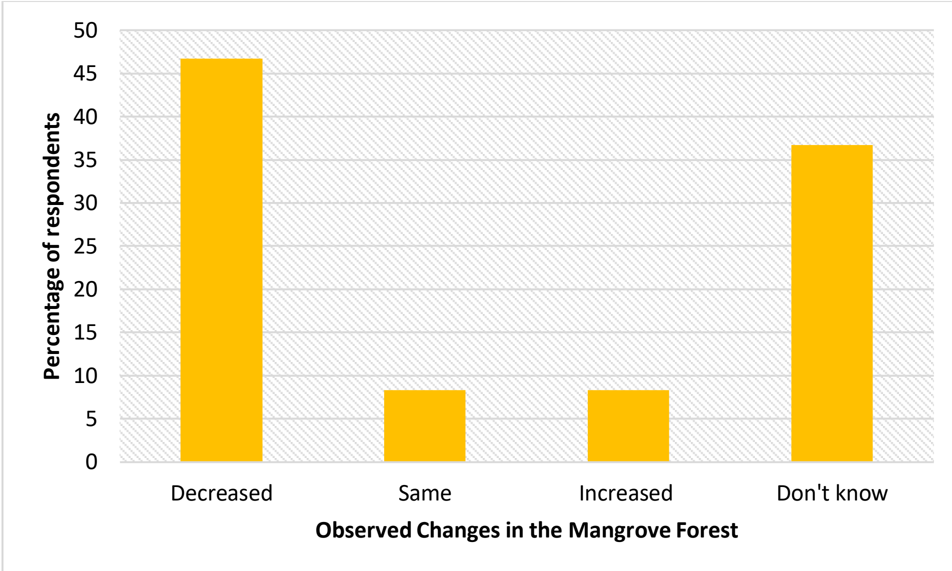


Figure 18: Perceived changes in mangrove forest in Bogue Lagoon for the last 10 years (2008 -2018).

Majority of the respondents (71.7%) were not aware of illegal activities in the mangrove forest. In fact, only five (5) respondents reported that they are aware of illegal activities such as garbage/solid waste disposal and sewage waste. Despite that insignificant number, field observations (see Figure 19) revealed these to be significant issues within the mangrove forest in Bogue. Further, 71.2% said that waste disposal (garbage and sewage) is having an adverse impact on the mangrove forest. It is possible that respondents equate awareness of illegal activities to actual observations of people doing these activities, but their perception of impact is due to the after effects of such activities. For example, the stench from sewage and garbage may have led to such perceived conclusions. Pollutants including garbage, sewage and industrial affluent are the major issues facing mangrove forest (NRCA, 1997). Pollution not only affects mangrove growth, but also restoration activities.

Figure 19: Garbage disposal (top) and effluent dischard (bottom) in mangrove forest (Source: Camilo Trench, 2018)

Another issue that was investigated was whether mangrove was uprooted for construction of buildings to house businesses. Majority (51.7%) of the respondents were not aware of this fact and only 16.7% stated that they were aware of uprooting of the mangroves for the establishment of their business. It should however be noted that not all respondents were owners of the businesses and some of the businesses are subsidiaries of larger companies and as such respondents may not have been privy to certain information. Further, some owners might have been unaware of such information if they acquired an already established business.

It can be assumed that mangrove forests might have been uprooted to clear land for building structures for business. Further, a large percentage of respondents (60%) said that deforestation was having a very big impact on the mangrove forest.

Mangrove Management and Restorative Efforts

Businesses seemed to be disconnected from mangrove restoration activities as majority of respondents (95%) claimed that they were unaware of these activities taking place.

This supports the data shown in Figure 20, where majority of the respondents could not comment on how well the mangrove forest is being managed and others stated that there was no management, or it was not managed very well. However, several respondents felt that the forests were not managed well or could have been better managed, while others described the management as adequate or excellent.

Most of these respondents (32.2%) believed that the forest is managed by the government while others said that the community (6.8%) was responsible for it, while others said that private organisations (8.5%) and NGOs (5.1%) were responsible for the management.

Although some respondents were aware of the organisations that were involved in the forest management, they were not clear if these groups were governmental, private or NGOs. For example, some respondents identified NEPA as a private organisation, while the Montego Bay Marine Park was identified as an NGO by some and as a private organisation by others.

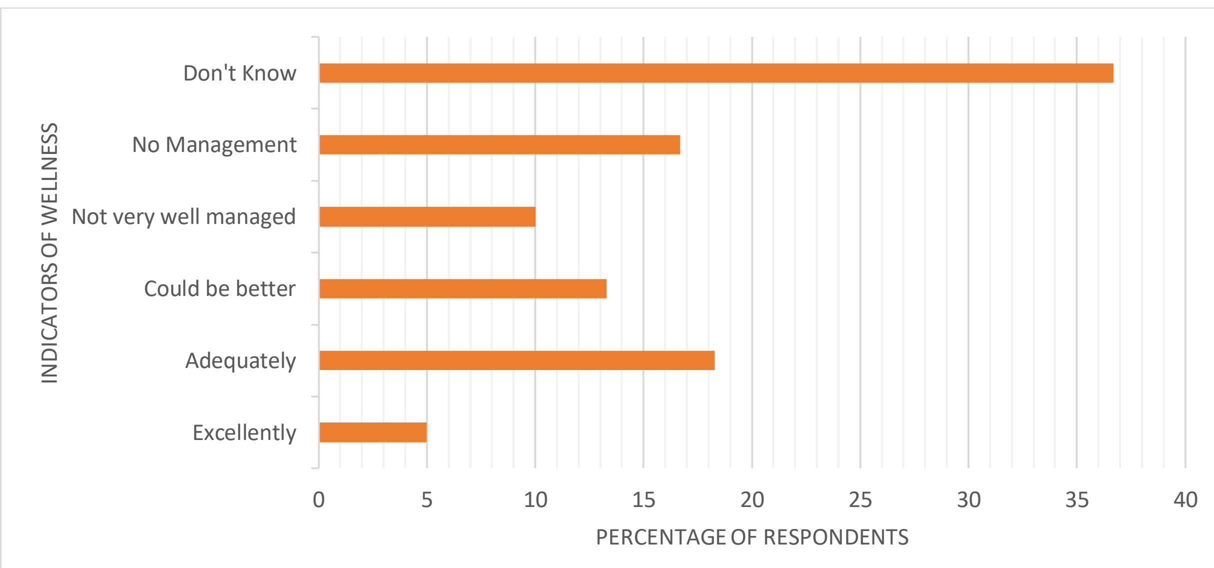


Figure 20: Perception on how well mangrove forest is managed in Bogue Lagoon

Opportunities for Private Public Partnership

Bogue Lagoon provides a great opportunity for private public partnership involving business stakeholders. Although, all the respondents reported that they were not currently involved in mangrove restoration activities, majority (65%) were interested in being engaged in these activities. Only a small percentage (13.3%) stated that they were not interested while 20% were uncertain, but still provide an opportunity to have these conversations. It should be noted that 21 respondents were managers of businesses in Bogue and 76.2% expressed their willingness to become involve in restoration activities. There was no statistically significant difference between male and female respondents.

Ecological

Mangrove Biometrics

Mangrove species composition and relative abundance (for diversity)

Rhizophora mangle (red mangrove) was the dominant species found within the Bogue lagoon study location. *Laguncularia racemosa* (white mangrove) was the other species present but only at Site 2. Mean diversity was therefore low with Site 1 having a diversity of zero while Site 2 had a diversity of 0.24. Mangroves tend to grow in relative monospecific stands within a forest. Low diversity is therefore expected within mangrove ecosystems as "succession and species accumulation are inhabited" (Hogarth 2015).

Site 1 had 37 red mangrove trees while Site 2 had 63 red and 10 white trees. Tree density therefore varied between sites (Figure 21) with Site 1 having a density of 0.07 m^2 red mangroves while Site 2 had 0.13/m^2 red and 0.02/ m^2 white mangroves. These densities are less than those recorded in previous studies by Chin (2014) who obtained 0.5 m^2 tree density at her Bogue study location.

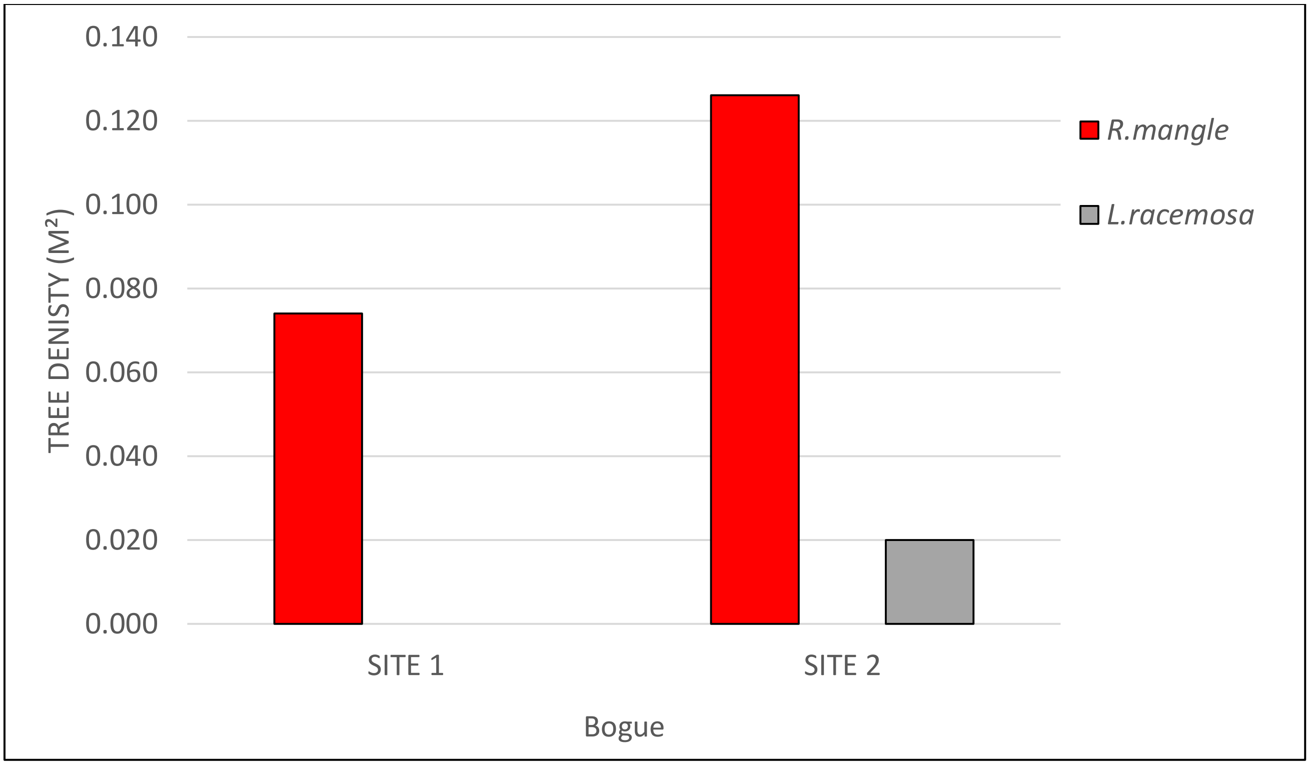


Figure 21: Overall tree densities for both sites at Bogue Lagoon.

Mangrove Trunk Diameter

Diameter at Breast Height (DBH) recorded within the transect ranged from 36 to 332 mm for red mangroves (mean 133.35 ± 10.97 SE, Annex 2). Mean red mangrove DBH valued increased along the transect from 88.55 mm to 198.11 mm (Figure 22). The highest mean DBH was found between 20 and 30 m along the site 1 transect, after which the Red mangrove mean DBH declined landward, towards the end of the transect. There was therefore an optimal distance (20 – 30 m) for Red mangrove DBH at site 1.

Site 2's DBH values ranged between 7 mm to 221 mm (mean 68.94 ± 6.39 SE) for *Rhizophora mangle* and 58-297 mm (mean 147.90 ± 24.97 SE) for *Laguncularia racemosa* (Annex 2). The trend seen (Figure 22) is a decrease in mean DBH for *Rhizophora* from 140.92 mm at the seaward end of the transect (0-10 m) to 33.42 m at the landward end of the transect (40-50 m). *Laguncularia* trees on the other hand increased towards the landward end after declining from 182 mm between 10 and 20 m to 64.3mm between 30 and 40 m. Chin (2014) reported similar mean DBH values (61.75 mm) for white mangroves at Bogue. The combined values for both species indicate greatest DBH between 10 and 30 m of the forest.

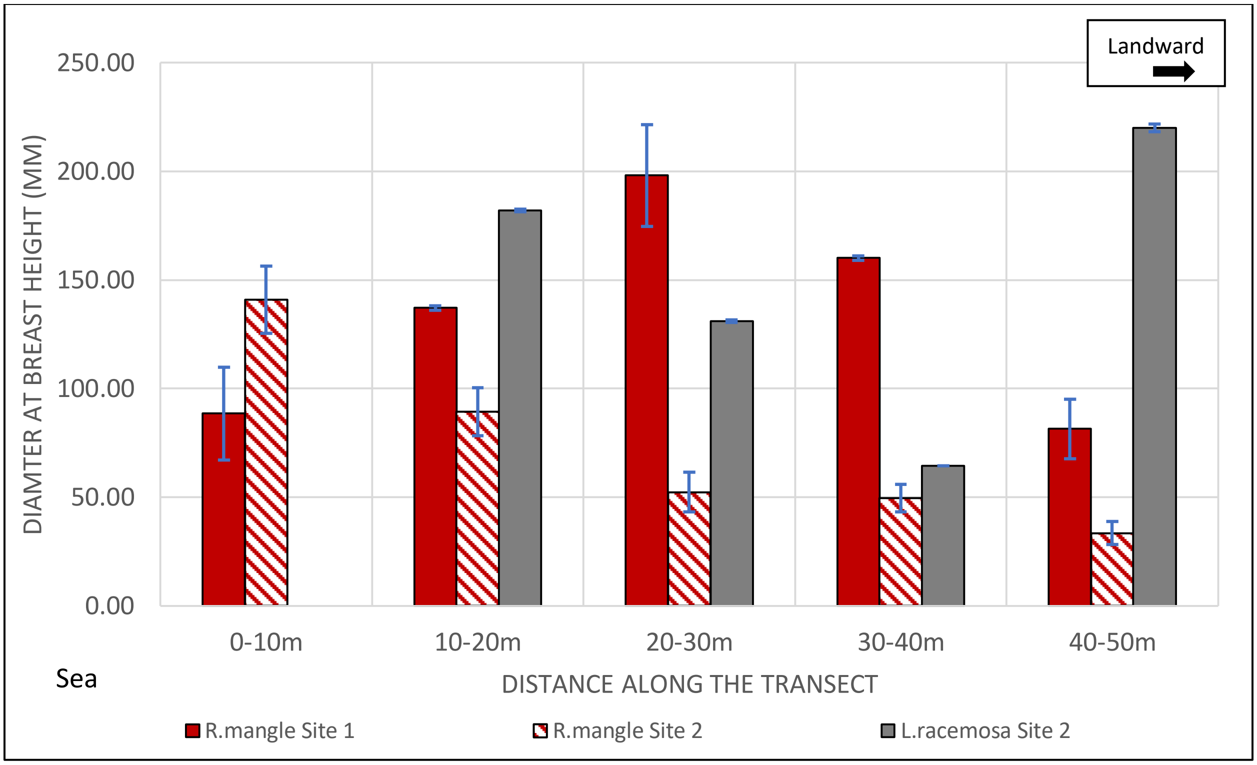


Figure 22: Mean Diameter at Breast Height (with SE) along the transects at Site 1 and 2, Bogue Lagoon

Mangrove Height and canopy width

Tree height ranged between 6m to 16m (mean 10.03 ± 0.43 SE) for *R. mangle* at Site 1 (Annex 2). Height increased from 9.90 m (Figure 23) between 0-10 m distance along the transect to 10.67 m between 20-30 m then declined to 8.51 m between 40-50 m distance along the transect.

Figure 23 also shows the height of *R. mangle* at Site 2 increasing from 10.05 m between 0 and 10m to 10.36 m between 10 and 20m along the transect and then showed a drastic decline to 5.47 m between 40 and 50 m. It has been established (Feller 1995 and McDonald-Senior 2000) that mangrove tree height typically decreases with increasing salinity. Mangrove trees often experience 'normal' salinity or lower at the water's edge, but hypersaline conditions often progress further from the sea. *L. racemosa* mean heights also fluctuated along the transect with values decreasing from 11.85 m between 10 and 20 m to 6.93 m between 30 and 40 m then increasing to 12.23 m. *L. racemosa* has greater ability to regulate internal osmotic conditions and thus do better in hypersaline conditions.

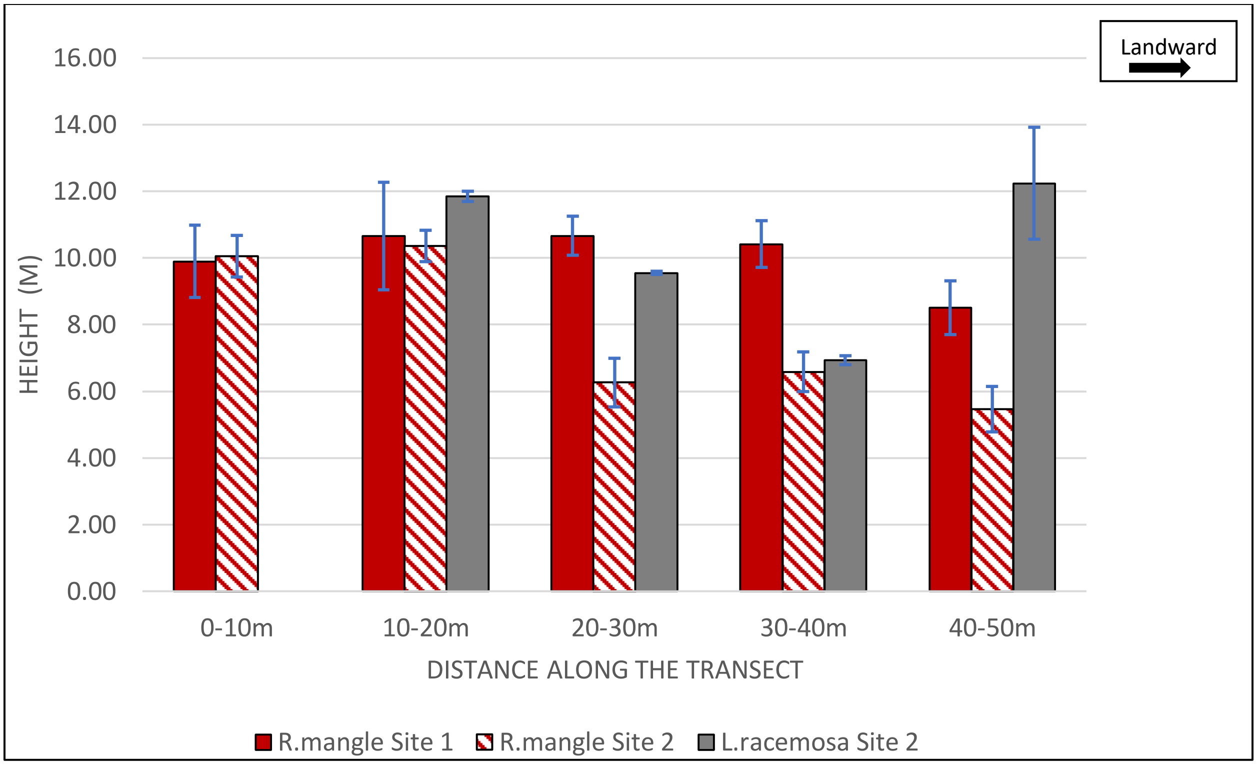


Figure 23: Mean Height (with SE) along the transects at Site 1 and 2, Bogue Lagoon.

Canopy width values ranged between 0.1 m to 13 m (mean 4.93 ± 0.52 SE) for *R. mangle* at Site 1 and 0.1 m and 9 m (mean 2.33 ± 0.24 SE) for *R. mangle* and 0.5m and 8m (mean 2.55 ± 0.71 SE) for *L. racemosa* at Site 2 (Annex 2)

Figure 24 shows *R. mangle* canopy width values at both sites decreasing with increasing distance landward along the transect except between 30 and 40m where R. *mangle* canopy values for Site 1 increased. *L. racemosa* canopy width value remained constant at 2.50 m between 10 and 30 m and then declined drastically to 0.50 m. This was followed by an increase in the canopy values to 4.67 m width at the end of the transect. All *L. racemosa* parameters showed greatest values (indicating optimal conditions) at this distance.

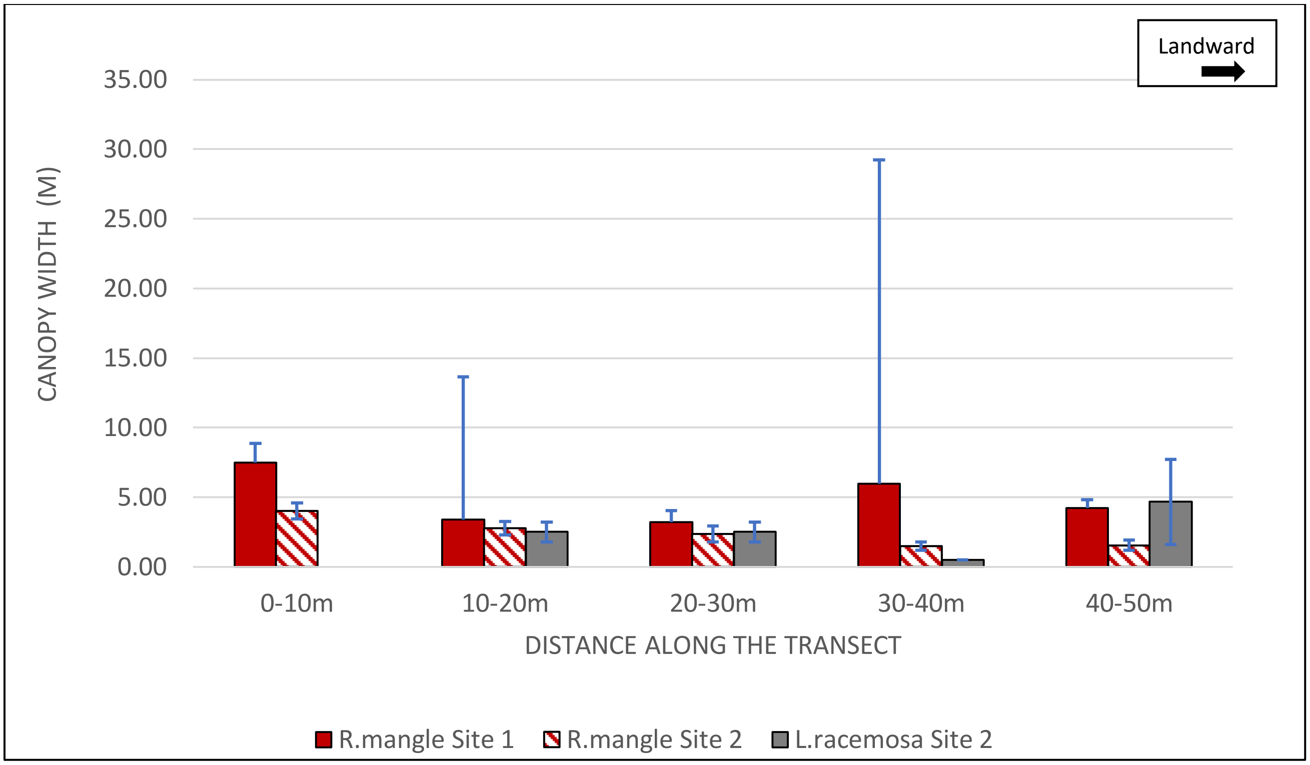


Figure 24: Mean Canopy width (with SE) along the transects at Site 1 and 2, Bogue Lagoon.

Prop root/aerial root network

Prop root density values varied within the categories (low, medium and high). Low prop root density category values fluctuated with values decreasing from 17 roots/m² between 0 and 10 m to 13roots/m² between 10 and 20 m. The values then increased to 28 roots /m² between 20 and 30m and continued to decline to its lowest value of 8 roots /m² between 30 and 40 m. Within the medium prop root density category, values also followed the same trend as the low-density category decreasing between 10 and 20 m and then increasing again to its highest value of 41 roots m² between 20 and 30m along the transect. Values for the high prop root density category ranged between 48-75 roots per/ m², with 75 roots per/ m² obtained between 20 and 30 m. It was expected that the density of the prop roots would decrease with increasing distance from the water's edge towards land.

This was observed by McDonald-Senior (2000) study of Wreck Bay, Jamaica. Ismail et al. (2019) working in Malaysia concluded that Rhizophora sp. "near a water front is denser than the back of the mangroves because the front mangroves occupy lower grounds than inside and as such receive more tidal inundations and nutrients and are therefore much healthier". Ismail et al. (2019) also suggested that the trees at the water's edge would be expected to grow higher due to the longer time spent in tidal inundation and as such would need more roots to breathe and become more stable, thereby resulting in the higher density of roots. Figure 25 and Figure 26 below shows the prop root density along the transects 1 and 2 at Bogue.

However, as obtained for DBH, red mangrove prop-roots showed maximum overall densities between 10 and 30 m from the water's edge which seems to have optimal conditions for the species at this site.

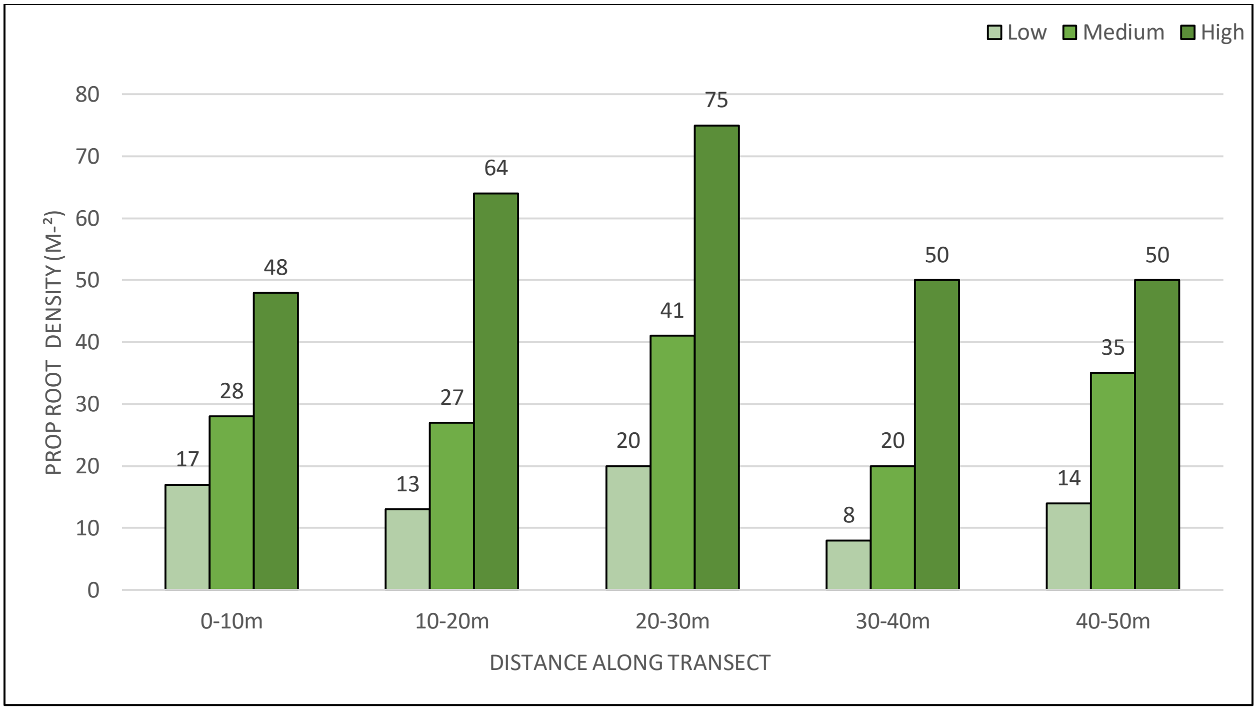


Figure 25: Prop root density along the transect at Site 1, Bogue Lagoon.

Figure 25 shows prop root density decreasing from the water edge towards land. Values ranged from 24 prop roots/ m^2 between 0 and 10 m to 8 prop roots/m^2 between 40 and 50 m along the transect in the low prop root density category. The smallest low prop root density (1 prop root /m^2) was found in the midway along the transect between 20-30m.

Medium prop root density category fluctuated with values ranging between 39 prop roots m^2 at 0-10 m to 23 prop roots/ m^2 at 10-20 m, 17 prop roots/m^2 at 20-30m, 26 prop roots/m^2 at 30-40m then 20 prop roots/m^2 at 40-50 m. Values for the high prop root density category also fluctuate like the medium and low category values. The values were however higher, ranging 76 prop roots/ m^2 at 0-10m to 30 prop roots/ m^2 at 20-30m and then increasing to 64 prop roots/m^2 between 30-50 m. As stated above, a decrease in density towards land was expected due to the *Rhizophora* trees at the water's edge having a better opportunity to grow higher and denser because of tidal inundation.

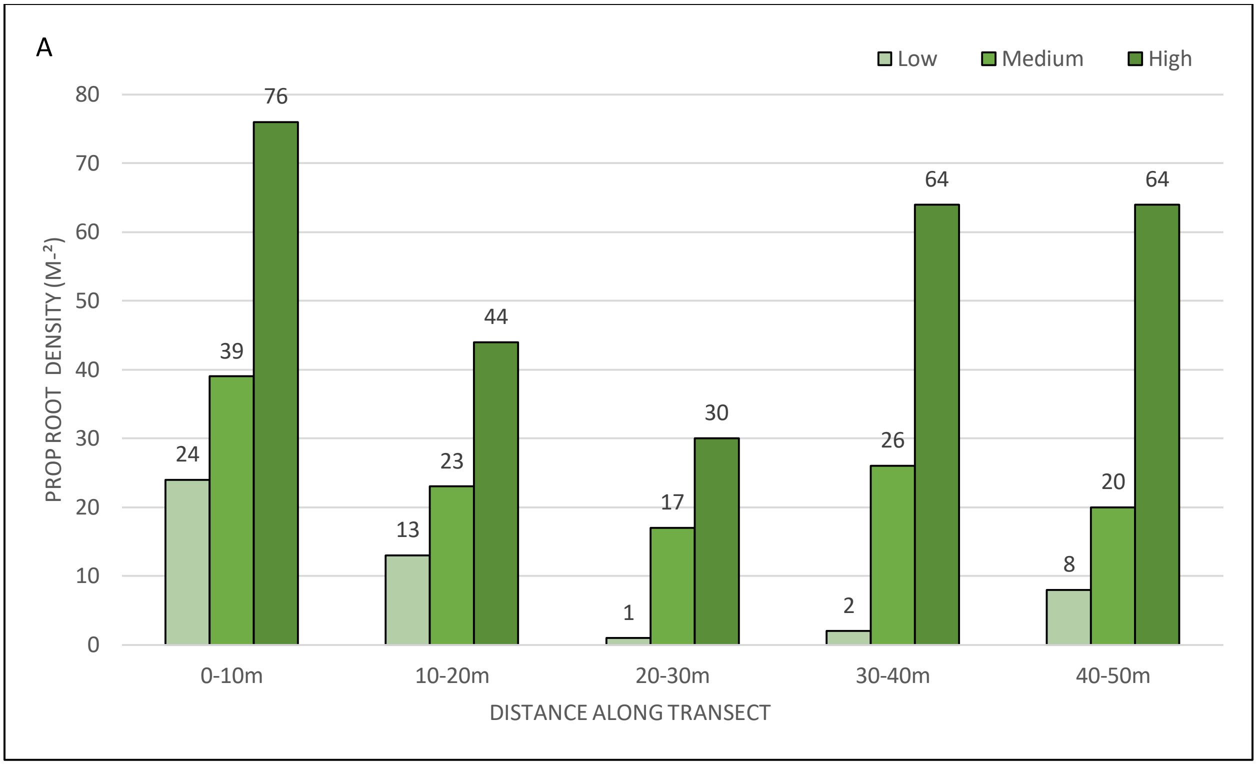


Figure 26: Prop root density along the transect at Site 2, Bogue Lagoon.

Pneumatophore density varied within the various categories (low, medium and high). There were no pneumatophores present at the start of the transect (0-10 m). There was a gradual decrease in pneumatophore density along the transect (between 10 and 40 m), however for the low-density plots, there was an increase from 12 pneumatophores m² to 47 pneumatophores between 40-50 m. For the medium density category, there was an increase between 10 and 20 and 20 and 30m from 39 to 54 pneumatophores/ m², then a decrease at 30-40 m, then finally an increase at the end of the transect (40-50 m) to 70 pneumatophores/ m².

The high-density category had a similar trend with an increase between 10 and 20m and 20 and 30 m, followed by a decrease in 30-40m and finally an increase at the end of the transect to 142 pneumatophores m². Pneumatophore densities varied in a similar manner with *L. racemose* tree height (Figure 27). McDonald–Senior (2000) also saw pneumatophore density varying in similar manner to the tree height and DBH. She concluded that this variation was due to the fact that tree height and DBH reflected the maturity of the trees and the older trees would generate higher densities of pneumatophores.

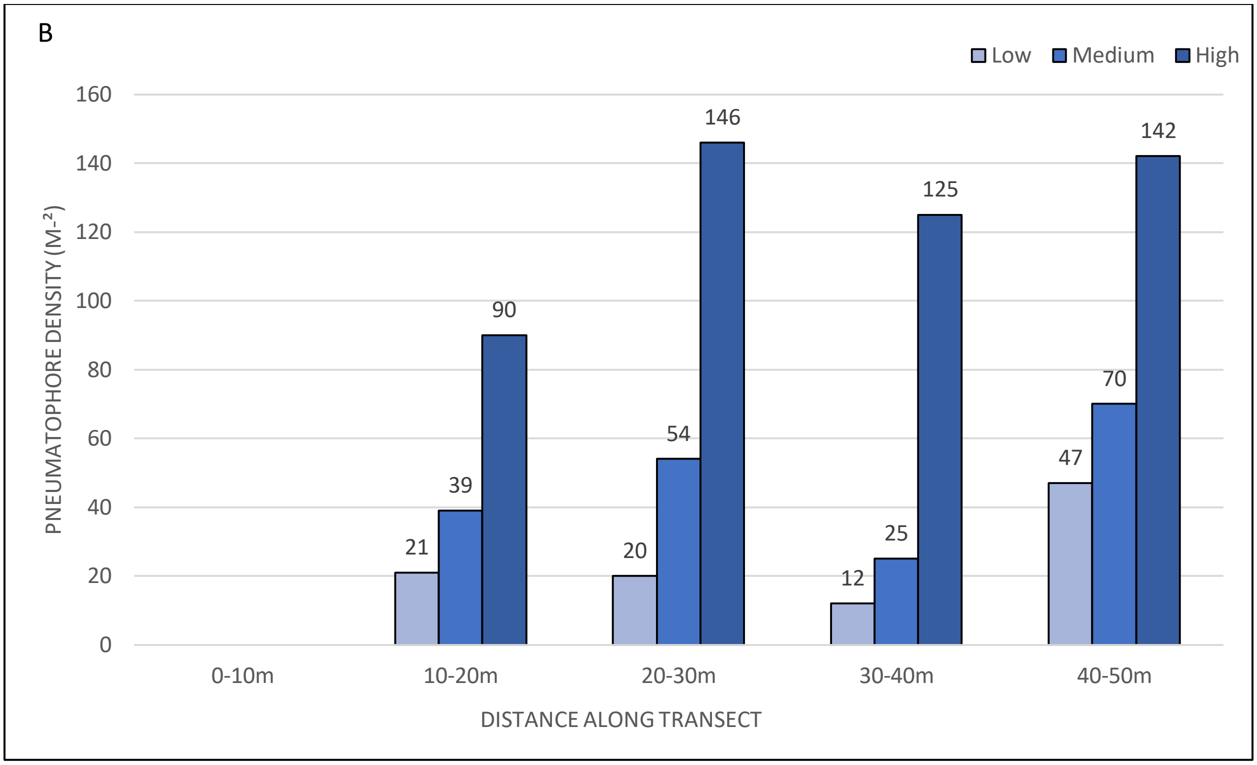


Figure 27: Pneumatophore density along the transect at Site 2, Bogue Lagoon.

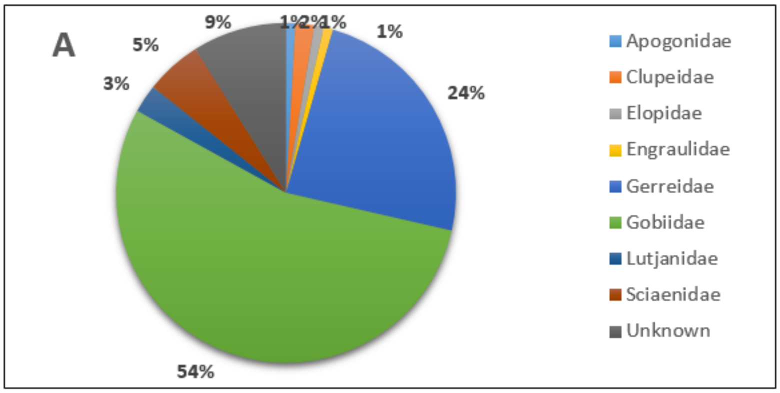
Based on Pellegrini et al. (2009) structural categories, the Bogue Lagoon area is a forest with intermediate structural development- DBH between 4.5 and 14.8 cm and mean height of the most developed trees between 5.7 and 13.7 m.

Of the mangrove parameters assessed at each site only red-mangrove parameters (abundance, mean height, mean DBH, medium prop root density and canopy width) were significantly different and thus facilitated broad comparisons between sites.

Ecosystem Services

Eleven fish families were identified in the Bogue Lagoon study location. Site 1 (Figure 28) had 8 families identified and 1 unknown family. 54% of the species belonged to the Gobiidae family which includes the gobled fish normally found on the floor of the mangrove forest; called mud-skippers in some countries. Site 2 had 7 had the Atherinidae family accounting for 28 % of species. This family include white fry/ silverside which has also been reported from the Port Royal mangroves and as used by fishers as bait (Froese and Pauly 2019).

Other species identified at this site included Gray Snapper and School Master Snapper from the Lutjanidae family and Tetraodontidae (pufferfish family). Photographs of these species can be found with Annex 3. Snapper is a commercially important species.



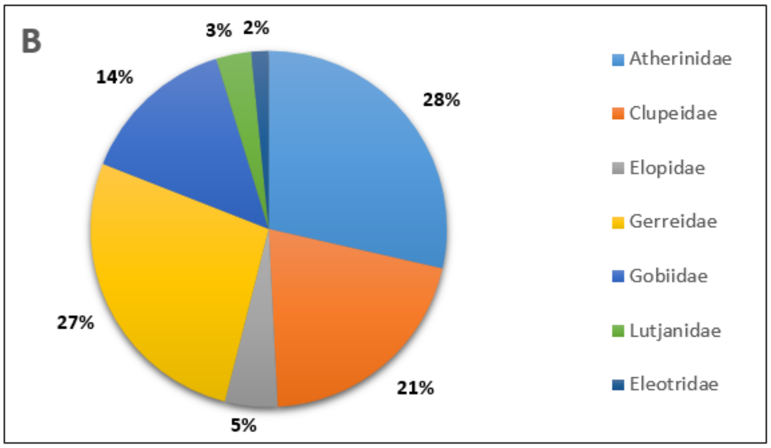


Figure 28: Percentage contribution of each family at Site 1 (A) and Site 2 (B), Bogue Lagoon.

While ichthyoplankton abundance and species richness varied significantly between the three mangrove areas and so could be plotted for comparison (Figure 28 above), the limited time of the assessments could not facilitate conclusions about absolute levels of fish larvae abundance. Data would have to be gathered monthly or at least over different periods of the year to accurately represent the larvae associated with these mangrove areas.

Physical

Elevation and Topography

The study area at Bogue Lagoon (Montego Bay), and in particular the two transects (Figure 29 and Figure 30), has a moderately undulating terrain and the terrain influences the biogeography of the mangrove species with *R. mangle* most seaward and at the lowest elevations and *L. racemosa* more landward or higher elevations (e.g., where one of the RSETs were located at Site 1). Pockets of different or no species of trees can be found in a zone based on the change in elevation. The elevation determined by trigonometry and the use of an Abney level and ranging poles is presented for the two transects studied.

The transect at Site 1 in Bogue Lagoon had an elevation that ranged from 0.4 m below MSL to 0.02 m above Mean Sea Level (MSL) (Figure 29); as a result, the transect is often inundated by water and the species *R. mangle* thrives best here. The lower elevations landward of this transect suggest either erosion as a result of tidal processes and perennial streamflow, or root system death or collapse within the Bogue Lagoon which would lower the elevation. The steep seaward trend is typical and may represent coastal scouring on the edges by boat and ship wakes; this is because the harbour is visited by large cruise ships on a regular basis. However, the lagoon is relatively sheltered, especially by the presence of mangal dominated islands, and this may attenuate some wakes. As a result, ecosystem services are provided in protecting this stretch of coastline which is backed by important road networks, housing developments and commercial activities.

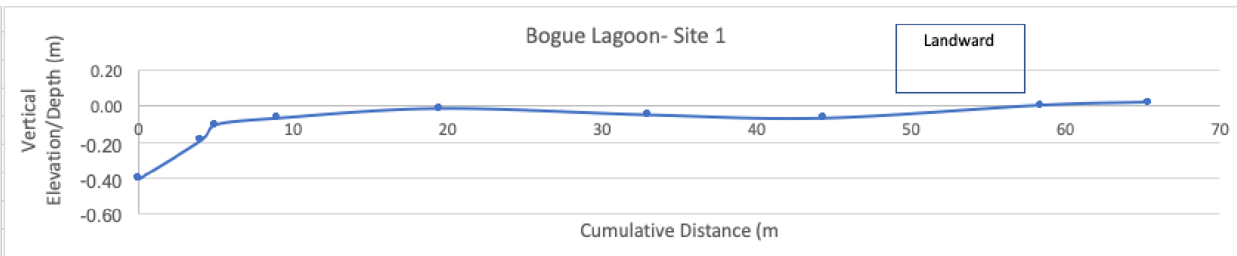


Figure 29: Transect at Site 1 in Bogue lagoon showing Moderate slope variability along the transect (sampled for soil and water) in the physical section. Zero represents MSL (source: T. Edwards 2019).

The transect at Site 2 in Bogue Lagoon is characterised by more undulating terrain, with a higher general elevation ranging from 0.10 m below MSL to 0.10 m above MSL (Figure 30). This area is wet mostly, but is not always inundated by water, and is mostly colonized by *R. mangle* based on the geomorphological suitability of that species to occupy areas with maximum inundation.

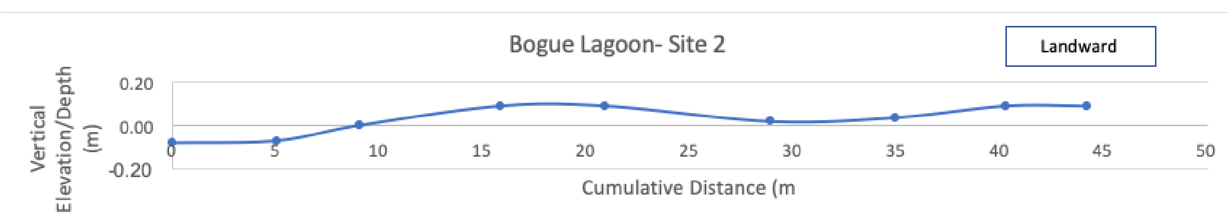


Figure 30: Transect at Site 2 in Bogue lagoon showing moderate slope variability (source: T. Edwards 2019).

Elevation Change

Elevation change was measured at two locations at Site 1, Bogue Lagoon and for 1 location at all other sites in this study. For the RSET experimental site, the benchmark was 3.66 m in depth at station 1 (within the *R. mangle* forest) and 2.7 m at station 2, elevation change (at the Chenier location) at Site 1. Elevation change ranged from -2.8 mm m^{-1} to 1.40 mm m^{-1} with a mean of -0.9 ± 0.9 mm m^{-1} at station 1, whereas elevation change ranged from -1.59 mm m^{-1} to 1.78 mm

m^{-1} with a mean of -0.10 ± 0.1 mm m^{-1} station 2, ^{at} Site 1. At Site 2 the length of the benchmark was 3.35 m and elevation ranged from -1.82 to -0.94 mm m^{-1} with a mean of -1.52 ± 0.2 mm m^{-1}. Variability in elevation change is dependent on many factors, such as shallow or deep subsidence or uplift, sedimentation, hydrological influence (ground and tidal water influence) and bioturbation and root growth. The negative elevation change here is thought to be as a result of shallow subsidence and water withdrawal associated with a change from wet season to dry season and not enough timing to record root contributions, sedimentation or the lack thereof and what that means for future of this mangrove system is discussed next.

Sediment and Litter Retention, and Accretion

Despite having abundant re-emergent stream and influence of the Retirement/Montego River, there was no measurable vertical accretion at Site 1 (n=8) or Site 2 (n=4) over a 6 month and 3-month period respectively. However, the horizon markers were still present at each visit which means there was no erosion and that the sediment supply is very low at Bogue Lagoon and especially for the areas studied. In the absence of accretion, leaf litter was observed above the horizon markers and are expected to contribute to the substrate's vertical accretion in anoxic conditions. Leaf litter for Site 1 was lower ranging from 0.32 to 1.68 g for over a 6-month period than Site 2 which ranged from 1.04 to 2.9 g over a 3-month period. The variation from sites 1 and 2 is as a result of the sample size variation and the variations with tree density and the ability of water currents to mobilize floating litter. Site 1 had more horizon markers that were always inundated, and others located in sparsely vegetated areas to capture potential variations. All the horizon markers in site 2 were in a similar highly dense setting under *R. mangle*, without active currents when inundated. Vertical accretion is normally accessed over many years Rogers et al (2016) to eliminate variability and fluctuations by localised processes in the trends. However, in short time-spans and in threatened mangrove ecosystems such as Honduras, accretion was positive and increased linearly over a 14-month period at 2 mm $year^{-1}$, but all those high accretion rates were associated with algal mats. Additionally, the elevation changes linearly increased in fringe mangrove forests by up to 9.9 mm $year^{-1}$ and decreased by 9.5 mm $year^{-1}$ in basin mangrove systems (Cahoon et al. 2003). Therefore, elevation change values seen at Bogue Lagoon are within the range of reported values for Caribbean mangroves but warrant further study to understand and predict long-term trends specific to this locality.

If there is no vertical accretion or erosion over the period of observation, and the elevation change is negative then shallow subsidence is the dominant process during that period (which spanned the wet and dry season for Site 1 and the dry season for Site 2) occurring at Bogue Lagoon (Cahoon and Lynch, 1997 and Calloway et al. 2013). Questions about the ability of a mangrove system to withstand subsidence and rising sea-level depends on its health, root production, leaf litter and incoming sediments. If there is no incoming sedimentation over a 3 or 6-month period then it makes the system more dependent on the mangrove trees' ability to persist by growing and expanding (especially its roots systems) in the given condition indefinitely to combat local subsidence, compaction and local sea-level rise in order to maintain viability. The lack of sediment supply increases the vulnerability of this mangal system to rising sea-level, climate variability, increased storminess (as expected by Mona Climate change group) and other anthropogenic stressors. Cahoon and Lynch (1997) demonstrated how allochthonous mineral and sediments material, along with algae (both of which are absent from the site over the study period) were important in facilitating vertical accretion and positive elevation change. All of the foregoing is cause for concern and will require further studies to understand the long-term deep and shallow subsidence, the effect of the hydroperiod, as well as root systems, root growth, sediment compaction and peat health in understanding what is causing the elevation to decrease and if it is permanent or operating in pulses which are reversible. Long term lateral trends are discussed next to see how this area has been keeping up with the assumed constant rate of subsidence.

Horizontal Variation (progradation/retreat) of Mangrove Coastline

Bogue Lagoon is bordered by industrial, commercial, residential settings and road networks, and there have been considerable changes in the coastline over the last 5 decades. The area has seen urban reclamation and land use changes, and there are areas where there has been long-term lateral erosion and long-term lateral accretion along the coastline (Figure 31).

The length of the coastline that has accreted is 2.46 km and encompasses the shoreline upon which Site 1 is located. The total area accreted over a 56-year period is 1.2 hectares and if taken over the timespan between the image analysis, accretion would be at a rate of 214 m^2 yr^{-1}. It should be noted that the site of the accretion has a large sewage treatment system behind it (Figure 31) which may enhance its growth and stability. Gillis et al. (2019) demonstrated that nutrients can increase the size and bulk of mangrove roots, but they can also reduce their complexity and therefore their anchorage and resilience; yet no adverse effects of the nutrient supply was observed.

A smaller length of coastline (1.04 km) has undergone long-term erosion and this stretch contains Site 2. The area eroded is 0.9 hectares at a rate of 161 m^2 yr^{-1} and is closer to the main road and other developments. The section of the coastline that has been eroded adjacent to the parcel of land west of, and adjacent to, Site 2 has been interpreted as reclaimed land using field evidence, such as the evidence of dumped limestone rocks, and construction debris to increase the elevation for occupation and is currently fenced off and up for sale by the owner. This means that disturbance in the form of reclamation has had a deleterious effect on adjacent mangrove stands. This domino effect is demonstrated in Sippo et al. (2018) who showed that activities limited to a particular plot of land can cause harm to other areas than the area where the treatment was applied to. This means that reclamation and dumping of material in an area to transform the usage from wetland should be prevented in order to secure the viability of adjacent mangrove stands and their ability to continue to provide ecosystem services. The 1961 aerial photo can be viewed at Annex 8.

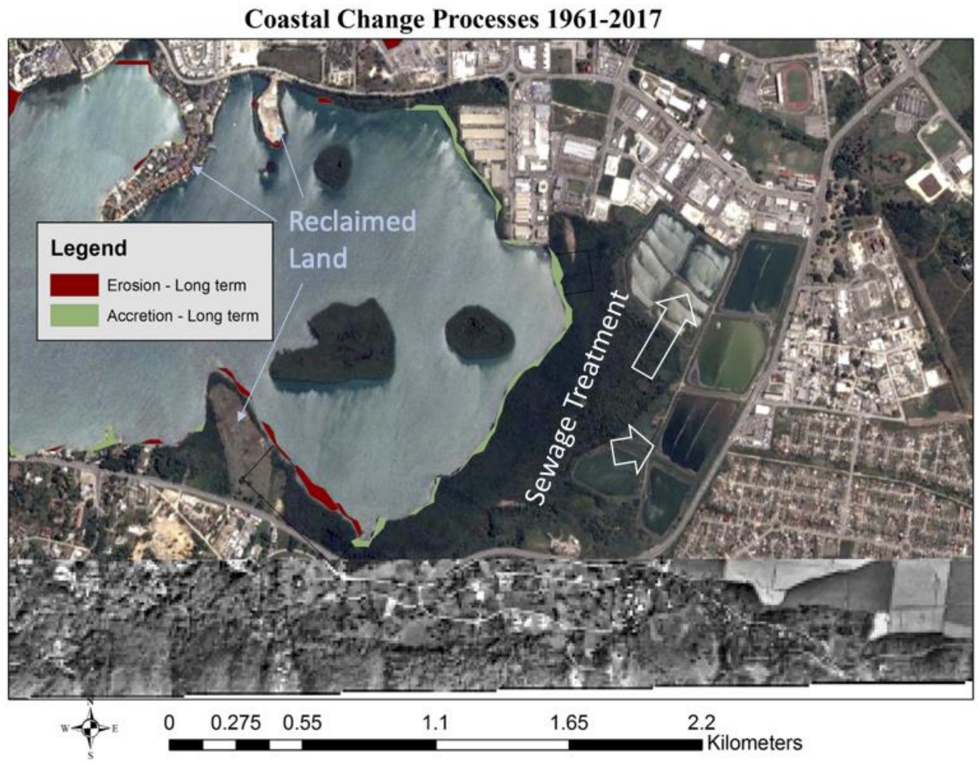


Figure 31: Bogue is relatively sheltered and has more accretion than erosion on the coastal extent of the mangroves, and no change to the landward coverage of trees (created by Taneisha Edwards using Arc-GIS, aerial photo and Google earth imagery, 2019.

Bathymetry

Bathymetry at sites 1 and 2 at Bogue Lagoon is shown in Figure 32. Site 1 is more sheltered and has shallow water depths ranging from 0.4 to 3.4 m; shallow water pockets are present within the centre of the area investigated and most comprise patches of sea-grass and sediment cover. Site 2 displayed water depths ranging from 1.0 to 6.5 m and had less variability within the area surveyed than Site 1 which has a smaller range, shallower, but more variability in depths. Site 2 is more open than the sheltered Site 1 which may be a critical cause of the deeper area of the bay. Site 1 is less sheltered from scouring currents with cruise ships and small marine craft inducing disturbances. Incidentally, the deeper depths here may be associated with the long-term erosion that is occurring at Site 2.

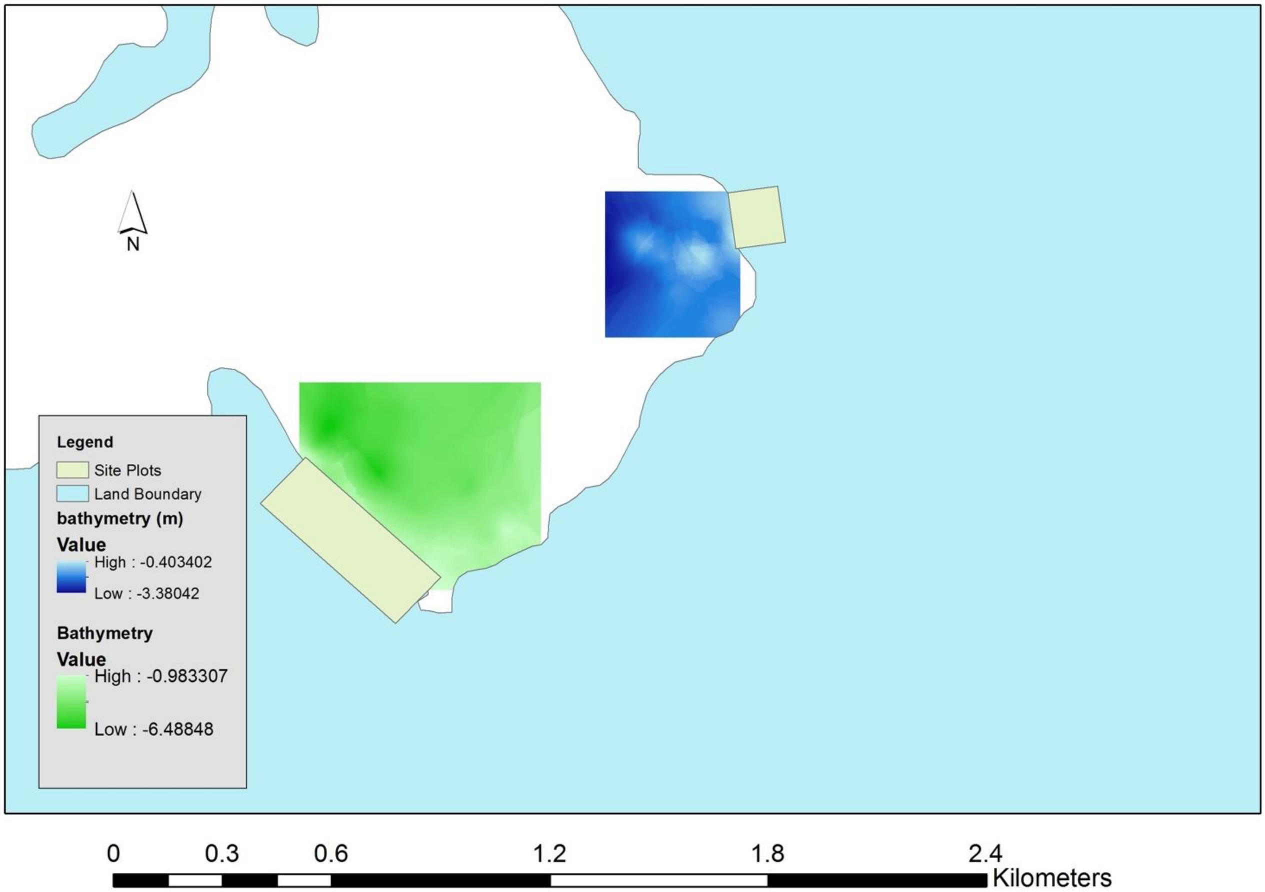


Figure 32: Bathymetry at Sites 1 (east) and 2 (west) Bogue Lagoon (created by T Edwards, 2019 using Arc-GIS).

Wind, Wave Parameters and Wave Attenuation

At the sites at Bogue Lagoon wind and wave speed and therefore energies are attenuated more within the mangrove forest than outside. At Site 1 in Bogue Lagoon wind speeds collected at chest height along a landward transect ranged from 4.5 ms^{-1} (seaward end) to 2.9 ms^{-1} (landward end) indicating the measurements recorded three places along a shore perpendicular transect showed that wind traveling to the shore was reduced by 4% outside the mangrove forest and by 36% within the canopy of *R. mangle* (Figure 33). Reduction of wind speed outside the mangrove forest is as a result of resistive (frictional) forces, however retardation is accelerated within the mangrove structure. Data collected from pressure sensors along the transect over a 6-hour interval indicate wave velocities of 3.08 ms^{-1} on the coast to 1.98 ms^{-1} within the roots of *R. mangle*. Wave heights were reduced by 8% outside of the mangrove forest along a shore perpendicular transect and by 64 % within R. Mangle roots. Mean wave attenuation rates r were 0.001 per m outside the mangrove and 0.008 per m within the mangrove forest. At Site 2, wind speeds collected at chest height along a landward transect ranged from 5.7 m^1 (seaward end) to 3.1 ms^1 (landward end), with wind speed reductions of 7% outside the mangrove and 46% within the mangrove forest (Figure 33). At Site 2 wave height reduction percentages were much higher than at Site 1 and maybe related to higher wave energies. Wave heights were reduced by 33% outside of the mangrove and by 75 % within the mangrove roots, the rate of wave height reduction was considerably higher within the mangroves than outside at 0.002 m^{-1} and 0.008 m^{-1}. For both sites, the rate of attenuation is 0.008 m^{-1}, within R. mangle roots meaning that for every 1 m distance a wave travels within R. Mangle, it is attenuated by 0.8%. Generally, the waves are gentle wind waves in this sheltered setting, but in the event of a storm these attenuation rates will make a significant mitigation, which would be absent where there are no mangrove trees (especially *R. mangle*). *R. mangle* roots serve to reduce the speed, energy and wave height and offer substantial ecosystem services in a micro-tidal regime affected by occasional storms. These values are comparable with values reported by Mazda et al. (1997) for Vietnam because Vietnam has a larger tidal regime and their waves transitioned a longer distance into mangrove forests. Some resistive forces from the sea-floor retarded the waves outside the mangrove's seaward limit including sea-grass.

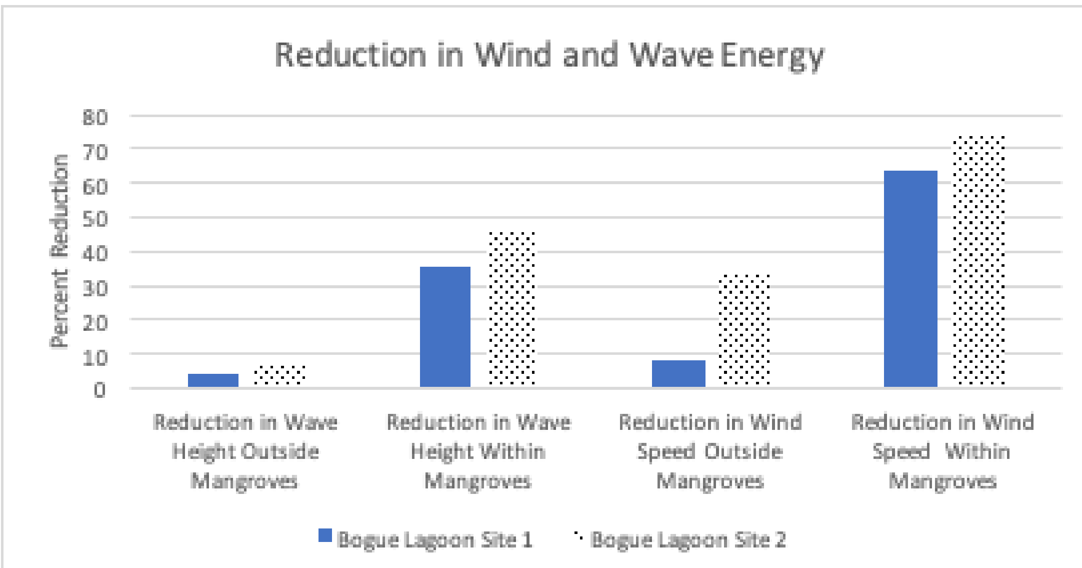


Figure 33: Percentage reduction in wind and wave energies outside and within the mangrove at Bogue Lagoon (Source: T. Edwards).

Substrate Constituents and Properties

Soil Organic content (in the form of % weight visible vegetation + % weight vegetation digested by hydrogen peroxide) is shown in Figure 34. For Site 1 (n=7) percentage weight of plant/animal (washable & digestible component) ranged from 1 to 65 % with a mean of 51% and a standard deviation of 24%. At Site 2, the percentage weight of the plant component ranged from 72-92% (n=5) with a mean of 81% and a standard deviation of 7%. The difference between Sites 1 and 2 is as a result of variability in the substrate due to the geomorphology with a greater amount of carbonate material from the Chenier at Site 1.

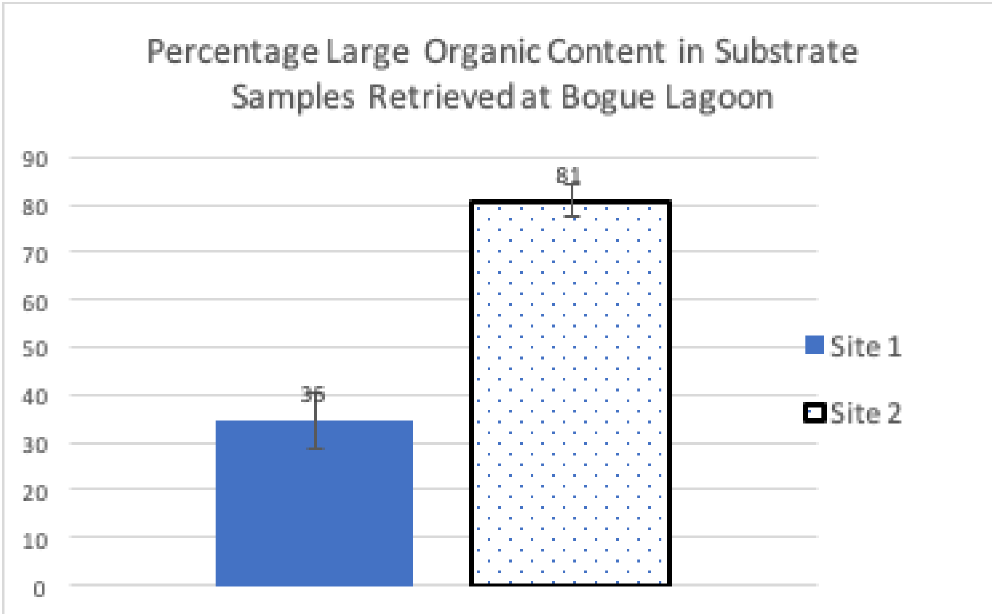


Figure 34: Mean plant percentage removed by handwashing together with percentage loss from hydrogen peroxide digestion of organic matter for each studied at Bogue Lagoon. The error bars represent standard errors of the mean (SEM) and are 9 and 3 percent respectively.

The coarse-grained carbonate component of the sediment at Site 1, consisted of small molluscs, foraminifers, broken plates of *Halimeda* and intraclasts (indistinguishable carbonate grains). The molluscs are interpreted as being autochthonous (derived from within the ecosystem) because of their pristine condition. The foraminifers and *Halimeda* are typically found in reef environments and in sea grass beds and are interpreted to have been transported into the ecosystem by currents; this is supported by their corroded and fragmented appearance. Transport may have occurred during past storm events.

No identifiable older carbonate sediment was identified at the other sample locations, within Site 1 and therefore at the sample depth (0-30 cm) no evidence of fluvial sediment coming in (precipitation events) is recognised. This again points to low sedimentation rates and vulnerability of the mangrove, as it will not be able to trap sediments if sediment is not being provided and redistributed in the system, but the prognosis is not definitive as Cahoon and Lynch (1997) explained that in some mangrove forests in Florida sedimentation occurred in fluxes and was not constant over the time of study. Therefore, it is imperative to evaluate further the sedimentation patterns.

The remaining sediment, after plant matter removal, from both Sites 1 and 2 plots as silty clay (Figure 35) by percentage weight on a texture classification of soils (Shepard, 1954), for the Bogue Lagoon in areas where samples were collected, with one exception from Site 1 that plots as a silty sand. This silty sand was collected in an area that is un-vegetated with contrasting lighter coloured substrate than the surrounding substrate. This silty sand area and substrate is interpreted as a relic chenier (Woodroffe, 1992), which is a sandy system or band found within a mangrove forest or other wetland and most likely formed by a historical storm event; it may have been deposited by a combination of wind and/or storm waves. The material from this chenier or sandy region is thought to be from off-shore and is restricted to a section of Site 1.

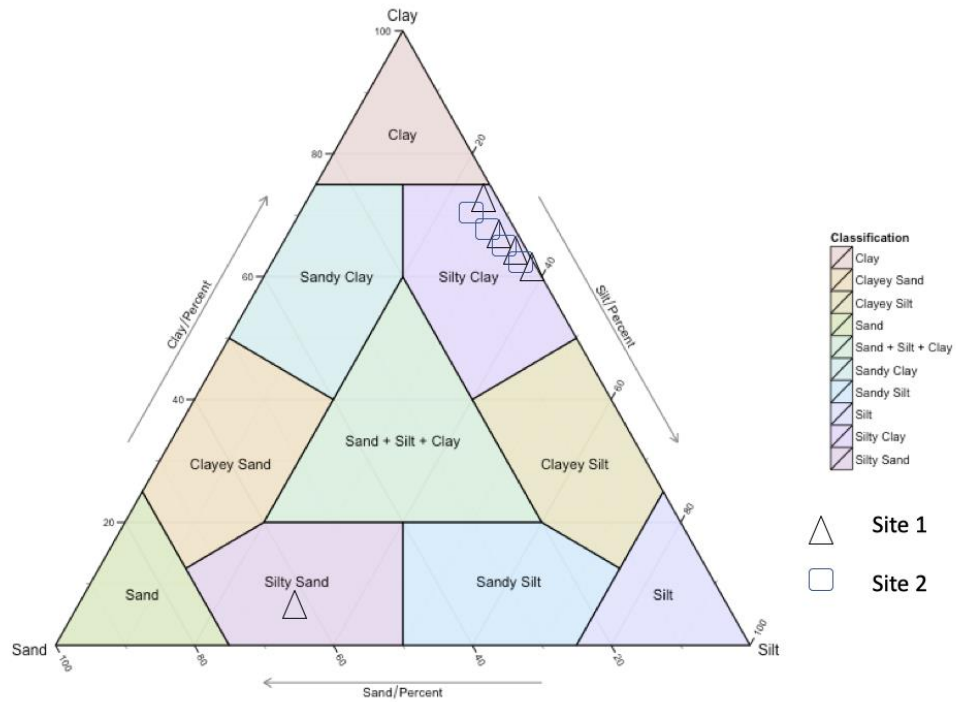


Figure 35: Ternary diagram showing a silty clay textural characteristics of remaining soil fraction at Bogue Lagoon (Sites 1 and 2) normalised after the removal of larger than sand sized particles if any and vegetation, and one silty sand sample from Site 1 (adapted from Shephard, 1954 by T. Edwards 2019).

Soil Quality

Ecosystem Carbon Biogeochemistry

The SOM and SOC contents of the soils varied within and between sites (Annex 4 and 5). Since the SOC content is a function of SOM, it follows that the data distribution patterns are identical. It is also important to note that the inorganic carbon (carbonate) content of the soil is not resolved during dry combustion of the samples (SOM determination) since the oxidation temperature does not exceed 550°C. The SOM content of Bogue Lagoon Site 1 ranges from 3.04% to 30.94% (median 15.56% and mean 14.91%), while that of Bogue Lagoon Site 2 ranged from 8.08% to 72.45% (median 46.06 and mean 43.01%). The SOC concentration pattern is identical to that of the SOM and generally displays considerable spatial variability. The minimum, maximum, median and mean values for Bogue Lagoon Site 1 and Site 2 are: 1.76%, 17.95%, 9.03% and 8.63%; and 4.69%, 42.02%, 26.79% and 25.12%, respectively.

Table 3 provides a summary illustration of the relative concentrations of selected elements from the Bogue Lagoon Sites soil. At Bogue Lagoon the mean concentrations of As, Cd, Co, Cr, Fe, K and Na are similar for Sites 1 and 2. Mean Br, Sr and Zn is significantly more at Site 2 than Site 1. Concentrations of Br and Na fall outside of the global mean.

Table 3: Concentrations of major and trace elements analysed in mangrove surface soils (0–30 cm) from the Bogue Lagoon locality.:

Site		[As] mgKg^{-1}	[Br] mgKg^{-1}	[Cd] mgKg^{-1}	[Co] mgKg^{-1}	[Cr] mgKg^{-1}	[Fe] %	[K] %	[Na] %	[Sr] mgKg^{-1}	[Zn] mgKg^{-1}
Bogue Lagoon Site 1	Min	3.4	20.3	6.6	4.4	17.2	1.0	0.5	1.4	104.0	21.2
	Max	19.2	149.4	11.6	8.2	90.8	4.1	1.3	2.1	799.1	90.1
	Median	10.3	73.3	7.9	6.8	68.5	2.9	1.1	1.6	174.7	54.3
	Mean	10.7	74.6	8.5	6.4	58.9	2.5	1.0	1.7	372.9	57.4
Bogue Lagoon Site 2	Min	1.7	26.1	4.3	1.6	38.8	0.3	0.1	0.3	165.1	35.6
	Max	32.9	580.4	16.7	10.8	109.1	2.8	0.6	4.5	2897.5	179.3
	Median	8.4	228.1	8.3	4.6	61.5	1.1	0.2	1.6	267.5	87.5
	Mean	11.9	304.5	9.1	5.9	69.2	1.2	0.3	2.0	852.0	91.6

*10,000 mg Kg^{-1} = 1%.

The Bogue Lagoon sites (in particular site 1) exhibited the most variable soil pH values. This may be a function of the organic-rich nature of the soils, coupled with contributions from marine carbonates, calcareous parent material, poor drainage and weakly buffered soils (Annex 7).

Water Quality

The temperatures for the Bogue Lagoon Sites averaged approximately 25°C to 28°C and appear to be generally lower that the temperature maxima required to drive most biochemical activities at the molecular level. The salinities for the Bogues Lagoon sites are also relatively low. In the case of Bogue site 1, the maximum salinity is approximately 8 g Kg^{-1}, while Bogue Site 2 appears to have greater spatial variability (2.5 g Kg^{-1} to 28 g Kg^{-1}) (Table 4). These results would suggest that freshwater inflows (ground and surface) are probably an important control on salinity of this ecosystem. Conductivity and salinity are strongly correlated; therefore, the conductivity profile of the water samples mirrored that of the salinity, with a maximum of ~12 MS cm^{-1} for Bogue Lagoon Site 1 and a range of (5 MS cm^{-1} to 47 MS cm^{-1}) for site 2. The concentration of TDS falls below the minimum value (500 mg L^{-1}) for brackish waters. The DO concentrations at the Bogue Sites generally fall below the threshold concentration (5 mg L^{-1}) necessary to sustain healthy aquatic life. These values may be explained by the presence of oxygen depleting source(s) (possibly of an organic nature) at these sites. The pH of the system is predominantly basic (and in the case of Bogue 2 elevated) and is characteristic of bicarbonate species of marine origin, but there may also be contributions from the dissolution of carbonates in the underlying limestone bedrock.

Table 4: Water quality parameters determined in situ at Bogue Lagoon.

Site		Temperature (°C)	Conductivity (MS cm^{-1})	Total Dissolved Solids (mg L^{-1})	Salinity (g Kg^{-1})	Dissolved Oxygen (mg L^{-1})	pH
1	Min	25.06	11.53	7.388	6.45	1.24	6.45
	Max	25.74	13.76	8.930	7.93	2.63	9.25
	Median	25.36	12.03	7.760	6.81	1.42	8.92
	Mean	25.36	12.38	7.992	7.03	1.68	8.38
2	Min	26.56	4.80	3.074	2.52	0.94	8.12
	Max	29.04	46.94	28.320	27.97	4.75	11.90
	Median	28.41	37.82	23.080	22.29	2.50	11.81
	Mean	27.99	28.03	17.039	16.48	2.66	11.05

Elemental water quality

Spectroscopic analysis of surface water samples from Sites 1 and 2 at Bogue reveals variable concentrations for several major elements (Table 5). The mean concentrations of the alkali metals (Na and K) and alkali earth metals (Ca and Mg) vary spatially (Table 5). These elements are essential for plant growth, and can be further divided in macronutrients (K, Ca, Mg) and micronutrients (Na) as a function of the quantity in which they are required for plant growth. While there is no discernible pattern in the data, the mean concentration of Ca appears to be higher at Site 1 (386 mg L^{-1}), while the concentrations of Na, K, and Mg are higher at Site 2. The Ca/Mg ratio is ~2 for Site 1 and 0.5 for Site 2. These values would suggest that there is limited lithological control (contribution from underlying the bedrock) on water chemistry. While the data presented here provide some context for water quality and ecosystem health, it also important to note that for a comprehensive overview of water quality and ecosystem health, indicators such dissolved organic matter, fecal coliform, phosphates and nitrates (beyond the scope of this report) should be considered. Notwithstanding that, these results are consistent with background concentrations of dissolved ionic species in local waters free of contamination from industrial processes and atmospheric deposition.

Table 5: Elemental concentrations of mangrove water samples.

Sites		[Ca] (mg/kg)	[K] (mg/kg)	[Mg] (mg/kg)	[Na] (mg/kg)
Bogue Lagoon Site 1	Min	274.5	20.8	8.1	795.9
	Max	478.6	69.1	288.1	1790.4
	Median	415.8	44.7	215.1	1622.3
	Mean	386.0	46.6	191.2	1429.0
Bogue Lagoon Site 2	Min	28.6	7.4	23.6	193.5
	Max	429.0	340.8	1000.5	5452.7
	Median	248.6	178.3	594.6	368.4
	Mean	225.2	162.4	480.4	2097.7

Soil Atmospheric Carbon Flux, Soil Carbon Stocks and Above Ground Carbon Stocks

Soil carbon flux

The primary losses of carbon form mangrove ecosystems are due to tidal export and mineralization by soil microbiome (autotrophic respiration). The survey mode, and the summary results are presented in Annex 7. Furthermore, the mean and median carbon losses (KgCO_2-C $ha^{-1}d^{-1}$) are presented in Table 6.

Soil CO_2 flux varied spatially and is clearly illustrated in Annex 4. The median and mean flux for Bogue Site 1 is 2.04 $\mu molm^{-2}s^{-1}$ and 3.13 $\mu molm^{-2}s^{-1}$, and for Bogue Site 2, 1.49 $\mu molm^{-2}s^{-1}$ and 1.86 $\mu molm^{-2}s^{-1}$, respectively. These variations may be due in part to the transitions between well aerated sandy soils (of varying OC content) to organic-rich soils inundated by marine waters. Additionally, variation in soil temperature at the local sites, differences in the quantity and quality of DOC, and losses of mangroves due to natural and anthropogenic forcings may play crucial roles. Generally, low soil flux rates would suggest that there is little or no SOM/SOC, or soil microbial activity. However, this may also signify that soil conditions (temperature, aeration, moisture) are constraining biological activity. Note also that respiration from roots and soil fauna (autotrophic respiration) may contribute to these values.

Soil carbon stocks

The mean soil carbon stocks (Mg C ha^{-1}) and potential carbon loss through CO_2 emissions, as well as the aboveground and belowground carbon stocks are summarized in Table 6, Table 7 and Table 8. When considered with net primary productivity, this data set may be used to provide insights into the whole-ecosystem carbon stocks. In general, Bogue site 1 contains higher carbon stocks and exhibit higher carbon losses when compared with site 2. Overall, both sites appear to be significant carbon sinks. Also, see Annex 11 for whole ecosystem carbon stocks (all sights).

Table 6: Soil organic carbon stocks in mangrove ecosystems.

Site	[a]Mg C ha^{-1}	[b]Mg C ha^{-1}
Bogue Lagoon Site 1	72.66	415.09
Bogue Lagoon Site 2	211.01	1205.75

[a] Stock estimates (Mg C ha^{-1}) determined using the mean bulk density value of regional mangrove soils (Adame et al. 2013).

[b] Stock estimates (Mg C ha^{-1}) determined using bulk density value from a pedotransfer function (e.g. Grigal et al. 1989).

Table 7: Carbon losses from mangrove soils through respiration.

Site	$MgCO_2$-C $ha^{-1}y^{-1}$ (Mean)	$MgCO_2$-C $ha^{-1}y^{-1}$ (Median)
Bogue Lagoon Site 1	11.85	7.72
Bogue Lagoon Site 2	7.04	5.64

Table 8: Aboveground biomass, belowground biomass and total C stocks in mangrove vegetation (Mg ha-1).

Site	Biomass (Mg ha^{-1})		C (Mg ha^{-1})
	Aboveground	Belowground	
Bogue Lagoon 1	91.62	18.32	51.67 (12.18)
Bogue Lagoon 2	73.92	14.78	41.69 (9.83)

*Data are mean (standard error). *Five plots (10 m x 10 m each) were sampled for each site.

Flooding

Coastal inundation projections (1 m, 5 m and 10 m of water level above the land surface) from future sea-level (long term) or impact events (storm surge and small tsunamis, with storm surges being the most likely) are presented. The coastal inundation projections reported historical flooding provided by WRA, and reports of recently experienced flooding as primary data collected in this study, see questionnaire in annex 1. Circular Buffers of 250 m and 500 m were created around point reports of historical flooding and points of flooding experienced from the socio-economic survey, they were merged, and then converted to a polygon to demarcate an area of risk for especially surge susceptibility. (Figure 36) and we can see that reported and experienced flooding (along with their merged buffers) occupy a larger area than the maximum 10 m coastal inundation projections. The buffer sizes used here are extremely conservative as it is known that the impact of a hurricane induced storm surge can affect several kilometres squared proportional to the category hurricane and the tidal influence, for example Hurricanes Katrina and Sandy experienced storm surge impacts in an area upwards of 50 km radius. The extent of the surge susceptibility polygon implies that coastal flooding (experienced) is already a big problem for these areas based on the physiography of the terrain, and in the face of climate change, climate change induced variability, more intense hurricanes and storms surges, and flooding will continue to be a problem. Furthermore, some critical infrastructure, such as, health centres and police posts are in the areas at risk and this will significantly affect the resilience of the community.

Intact and healthy mangrove forest will therefore provide some protection against flood severity, and potential storm surge impacts by reducing the energy and damage potential of wind and storm waves through the roughness facilitating heightened resistive forces and attenuation. Furthermore, if the mangrove stands in this area die-off, then the shoreline would be further inland (from substrate collapse) then some of the hazards would be transferred further inland.

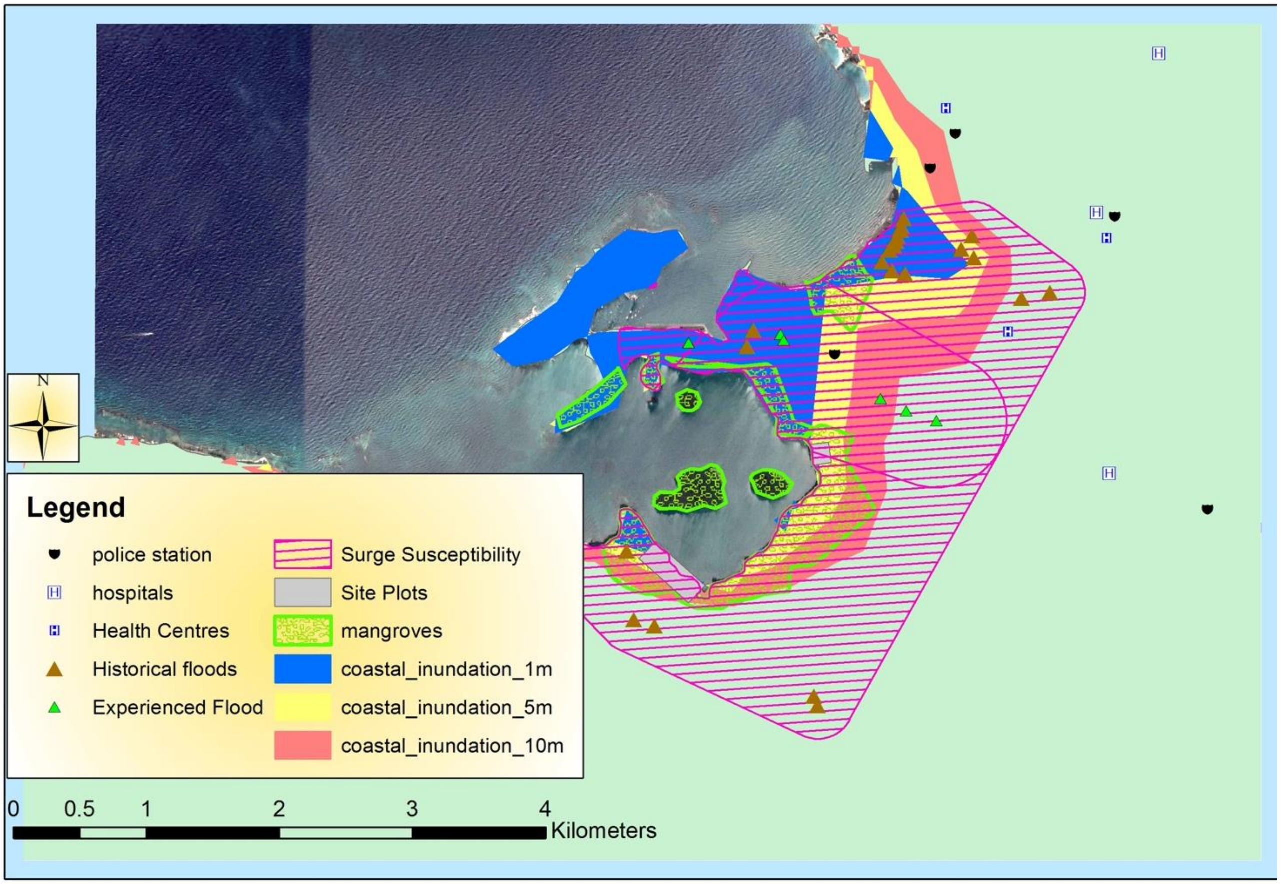


Figure 36: Hazard map for a section of Montego Bay, showing critical infrastructure in relation to experienced floods (this study), and merged buffers of experienced floods and historical floods,the buffers occupy a larger extent than projected areas likely to be affected by 1m, 5 m and 10 m coastal inundation, created by T. Edwards (2019).

Portland Cottage

Socio-Economic

Socio-economic Context

According to the Social Development Commission (SDC) (2019), Portland Cottage can be described as a poor community with low levels of education and employment. Approximately 42% of the household heads are unemployed and 56% have no formal education (SDC 2019). Among the community's issues noted are high levels of adult (25 years and over) and youth (14-24 years) unemployment, high levels of illiteracy and low levels of numeracy (SDC, 2019). Field data conducted with a sample of 107 households supported these low levels of education with about 40% of respondents having less than Secondary to High Secondary education and only 3.8% attaining university level education. There was no statistically significant difference between male and females.

Further, majority of the household income (60%) is obtained through self-employment. Of this amount, 15.2% stated that they had paid employees. Remittances are also a major source of obtaining funds for many households, with 44.8% respondents stating that they obtained remittances in the last 6 months[1].

Of the 97 respondents who reported on savings in the household, 64.9% stated that they were unable to save within the previous month suggesting that there was a possibility of limited income hence little or no savings, or it could also be a result of poor budgeting.

A significant percentage of houses (80%) and the land on which homes are built (74%) are owned by residents. Only 2% of the sample described their lands as squatted. Most (69.5%) of the homes are constructed from concrete and blocks, with only 10% of the households within the sample constructed from wood only. This is in keeping with the secondary information which reported about 60% of homes in the community were made from concrete and blocks although a much higher percentage (40%) were said to be constructed from wood (SDC 2019).

This difference in data relating to percentage of houses constructed from wood might be explained by the timing of data collection. This study, which is more recent, suggests that more houses are now made of brick and concrete. Primary data also revealed that 66.7% households had access to electricity, but a significant amount (20%) shared electricity – further it was revealed that 23.8% households used public stand pipe or private piped water. This is supportive of SDC data which revealed 80% of the community use electricity for lighting, 23% of the residents received water from public stand pipe and 22% receive water from private catchments. While 44.8% of households had toilets in their dwellings, a noteworthy percentage (41%) use pit

[1] Data was collected in the February, 2018

latrines, this data is similar to that obtained from the SDC which revealed that 52% of residents in Portland Cottage utilized pit latrines (SDC 2019).

Vulnerability of Coastal Flooding

Exposure

The location and topography of Portland Cottage positions the community as highly exposed to the effects of coastal inundation from storm surges and other environmental changes which may occur from the impacts of hydrometeorological hazards. Several tropical storms have affected the island and, by extension, the Portland Cottage community. In recent history the most significant of these events was the impact of hurricanes Ivan (2007) and Dean (2007) which resulted in extensive coastal flooding. These events place the population and infrastructure at risk, ultimately influencing their ability to negotiate the adverse effects. The community contains approximately 699 dwellings, many of which are near the coastline. Sections of the mangrove community have been cleared for construction of homes and other infrastructure and this may suggest greater levels of hazard exposure (Figure 37).

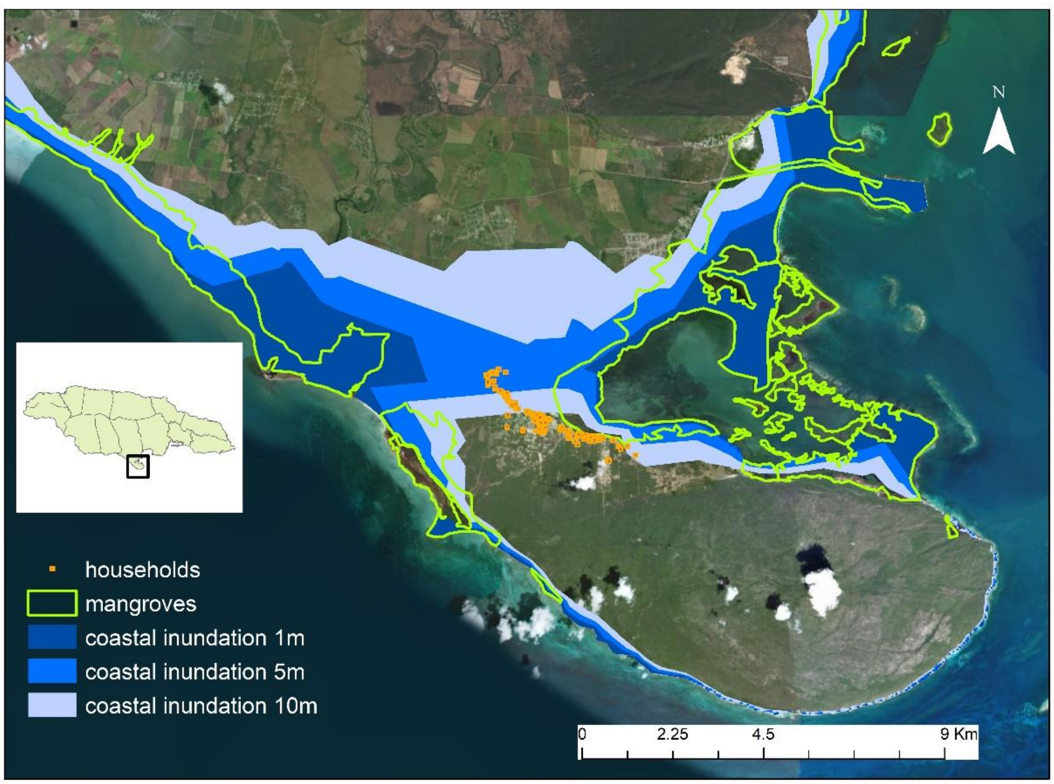


Figure 37: Location of sampled households relative to a distance differentiated coastal inundation model at Portland Cottage, Portland Bight.

Sensitivity

Given the geographical context, coastal inundation and other effects may therefore be seen as highly likely. Sensitivity is primarily conditioned by the differences in the location of structures as well as the prevailing socio-economic characteristics of the community. Damage assessments done by the ODPEM, after the impact of hurricane Ivan in 2004, indicate that buildings closer to the coastline were more severely damaged (Figure 37). This suggests that risk differentiation is essentially expressed in relation to distance from the coastline and elevation. Figure 34 also illustrates the location of households surveyed relative to projections of coastal inundation. The model displayed aligns closely with accounts of damage documented by ODPEM where structures closest to the coastline were most severely damaged.

In addition to data derived from secondary sources, the history and experience of flooding was assessed through surveys of residents in the community. Approximately 89% of respondents reported an experience with flooding while living in the community. Of this portion that asserted direct experience with flooding, 45% reported destruction of livelihood equipment and 32% reported destruction of crops and livestock. Significant proportions of the affected individuals also had to relocate temporarily (45%) or suffered major disruption in routine activities such as attending work or school (Table 9). The impacts of these flood episodes reflect high levels of sensitivity.

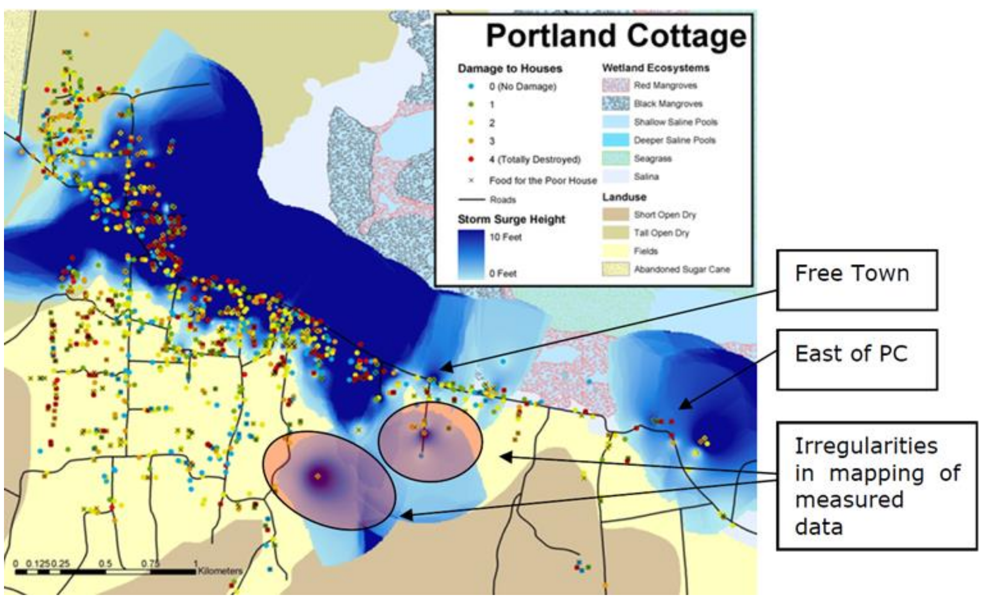


Figure 38: Post Ivan damage assessments for Portland Cottage superimposed on a height differentiated storm surge model.

Table 9: Nature of flood impacts represented as a percentage of households reporting flood experience

Impacts of flooding	n	% of households that experienced impact
Children could not attend school	35	50.7
Could not attend work	38	55.1
Injury to yourself/family members	9	13.0
Destroyed/damaged livelihood equipment (e.g. boats)	31	44.9
Destroyed/damaged crops and livestock	22	31.9
Had to relocate permanently	4	5.8
Had to relocate temporarily	31	44.9
Other	6	8.7

Adaptive Capacity

Other dimensions of vulnerability include the socioeconomic attributes which potentially moderate the severity of impacts from coastal hazards. Many vulnerability studies assert that greater adaptive capacity is associated with factors such as higher levels of education and employment, income and the strength of networks of support in the community. In this regard, Portland Cottage could be considered as having relatively low levels of educational attainment with only 4.8% of the individuals residing in the households surveyed attaining tertiary level education – a proportion that falls far below national level estimates of 8.4% (World Bank 2010). Adaptive capacity is also conditioned by the high unemployment rate (33.7%) which significantly exceeds the national average (14%) (PIOJ 2014).

Reported income levels, for the month prior to the survey, were generally low as mean income approximated JM$31,917 (s.d.= 61845.39, n=126) and median income was JM$18,000. Given the high standard deviation, which reflects significant variability in the data, the median potentially captures estimated earnings more accurately than the mean. Approximately 33% stated that they were able to save from last month's income and 12% indicated that they had outstanding loans. The fact that several of the respondents had relatively favourable debt profiles but unfavourable savings profiles indicates the existence of a potentially compromised adaptive capacity. Additionally, only 2% stated that they had insurance which protected them from flood damage. However, it appears that remittances potentially play a significant role in offsetting adverse economic circumstances. Approximately 45% of households reported that they received remittances during the previous month. This reflects the potential for adaptive capacity to be enhanced through external networks in the form of external networks of family and friends.

Adaptive capacity may also be examined relative to the mitigative and recovery measures deployed by households in the community. These measures potentially indicate their ability to navigate the effects of a similar hazard. The majority of respondents (60.4%) stated that they did not engage in any mitigation measures which could potentially offset the effects flooding (Figure 39).

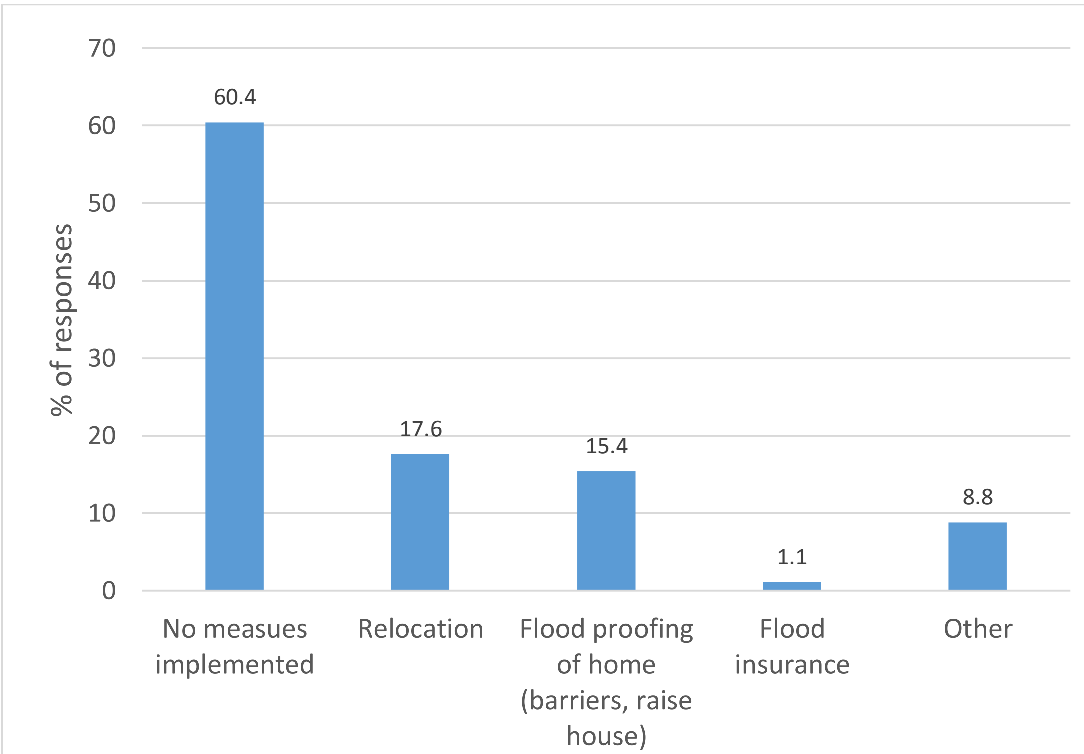


Figure 39: Measures implemented to reduce impact of future flood events

Ecosystem Services Provisions

Ecosystem services were examined both in terms of livelihood and the value of mangroves to the community**.** Only 37 (35.6%) of the sample were fishermen. However, 24 responded to whether fishing is carried out in the mangrove. Of that amount, 13 (54.2%) stated that they fish in the mangrove mainly for home use and to a lesser extent commercial purpose. This speaks to the importance of mangroves to the livelihoods of these fishermen particularly since this area is protected and it is illegal to fish. Majority of these fishers utilize the areas for fishing 1 to 3 times per week. Among the fishes caught in the mangroves, for domestic consumption or sale, are Grunt, Parrot, Sprat, Jack, Snapper and Doctor Fish. Snapper, Grunt and Parrot fish are primarily consumed in these communities and amounted to 27.7%, 32.7% and 23.8% of respondents respectively.

Fishes are sold only in the community. Income on a weekly basis according to information sourced from 11 respondents – they informed that the income from the sale of fish ranged from J$3000 to J$40000 with an average income of J$12090.90.

However, most respondents (62.5%) reported a decrease in income in the last 5 years, while 18.8% said they have seen an increase. Volume of fish has also decreased according to 81.3% respondents.

Apart from fish, it was reported that oysters, shells and more importantly fish bait and crabs were also extracted. However, majority (91.5%) of the respondents stated that they did not earn any other income or livelihood from the mangrove. Only six respondents reported that the mangrove forest was used for other livelihoods such as fishing equipment and tours. Still this number is too insignificant to draw any conclusions or to highlight other factors such as income generated from the mangrove and whether this income has seen any changes – either an increase or a decrease in the last 5 years. Such data can be, in the future, best acquired through interviews or focus groups targeting specific groups such as fishers.

In Portland Cottage, respondents recognized several services as being of high importance (see Figure 40). Among the services that was recognized by 50% or more of the respondents said that mangrove functioned as a fish habitat, a source of medicine, shoreline protection services, a support for near or off shore fishing and a wild life habitat. S=Some of these functions, particularly fish habitat and shoreline protection services, may be of direct importance to the community giving the importance of fishing as a livelihood and the impact of flooding on the community over the years. Other benefits are indirect or potential benefits.

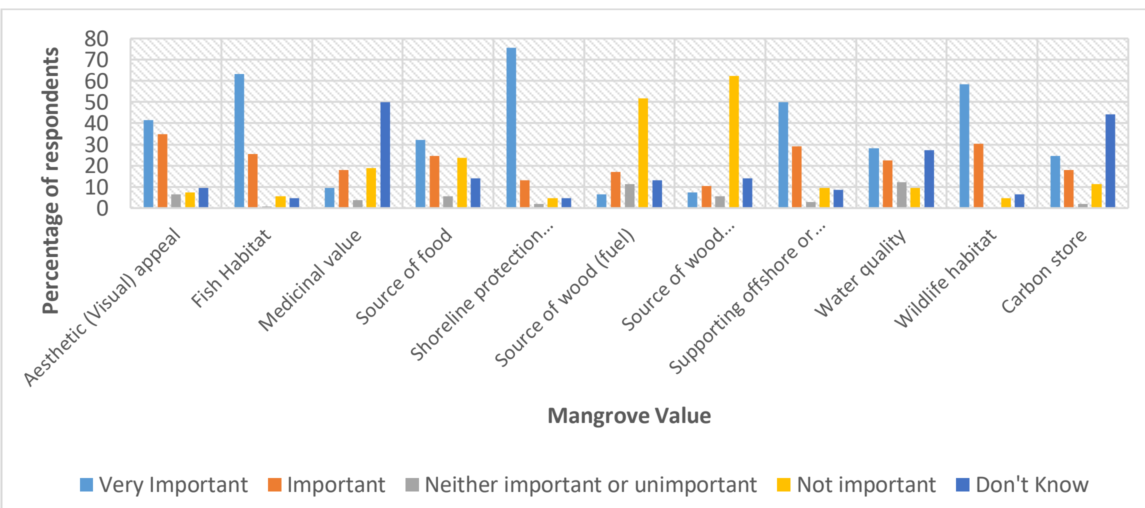


Figure 40: The Value of Mangrove to Community Members of Portland Cottage.

Issues Affecting Mangrove Services

Most respondents in Portland Cottage recognized an increase in mangrove forest (Figure 41). There was a statistically significant relationship (p-value 0.002[2]) in looking at changes observed in the mangrove forest in the last 10 years by gender. Majority of both males (51.9%) and females (41.5%) stated there was an increased in the forest, but there was a noticeable greater percentage of males (28.8% compared to 17% females) who stated there was a decrease and only females (24.5%) who stated they did not know if there were any change. This result might reflect greater involvement of men in activities relating to mangrove degradation such as clearing forest to build homes as women are, at times, consumed with domestic activities.

The increase in the mangroves was attributed mainly to restoration activities. Several respondents used keywords such as planting/replanting, reforestation and restoration as the reasons behind this increase. This suggests that the mangrove replanting activity which took place in Portland Cottage under Component 2 of the Climate Change Adaptation and Disaster Risk Reduction Project (CCADRRP) was successful. The project aimed to assist with climate change adaptation in Jamaica and contribute to sustainable development by increasing the resilience of vulnerable areas such as Portland Cottage and reduce their risks to natural hazards (JIS, 2013). Other respondents noted that persons have stopped cutting down the trees and that the occurrence of less hurricanes have caused the seeds to settle and grow.

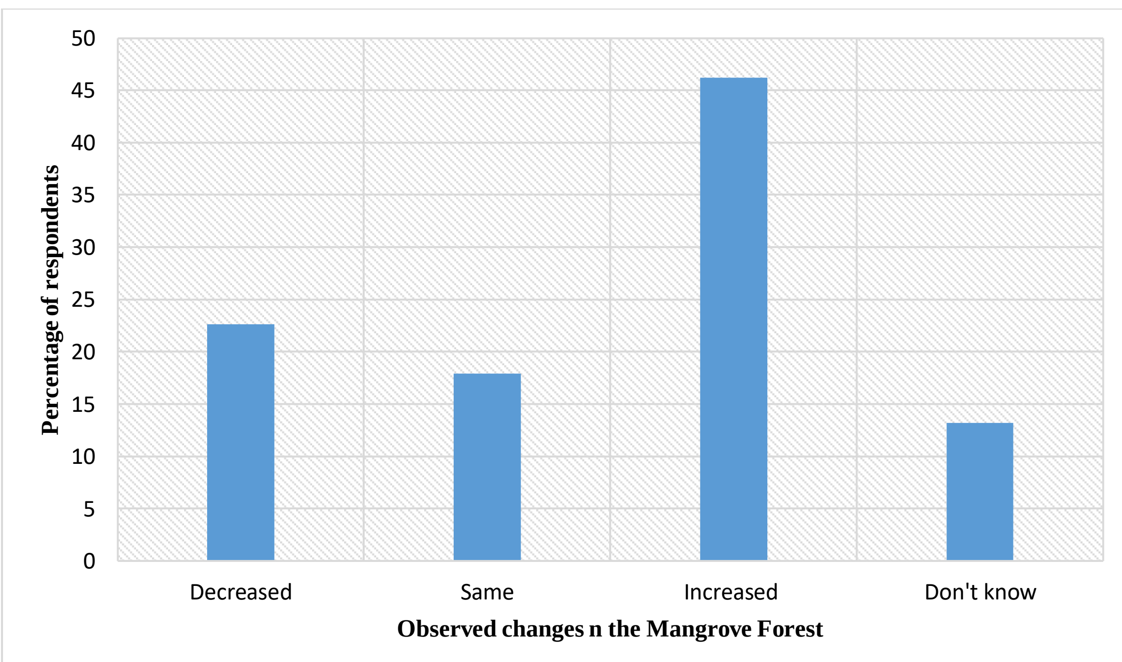


Figure 41: Perceived changes in mangrove forest in Portland for the last 10 years (2008-2018).

[2] Significance is established ar p value less than or equal to 0.05

On the contrary, several respondents noted a decreased in the mangrove forest which they believed has been caused by pollution, overfishing and drought. Only 19 (17.9%) of the respondents attributed to the decrease in the mangrove cover to illegal activities which included illegal fishing and illegal logging noted by 10 and 9 of the respondents respectively and to a lesser extent sewage waste, garbage/ solid waste, and illegal fishing ponds. However, none of respondents identified mangrove being removed for housing. Majority of respondents (50%) claimed that illegal logging does not take place in the mangrove forest, while 42.9% and 22.9% respectively claimed that illegal clearing or cutting of the forest does not take place in the forest or is not having any impact. In terms of illegal fishing, 40% stated it does not take place, while 28.6% believe it does take place but is not having any impact on the forest.

Only 19% of respondents believed that illegal fishing is having any significant impact, which could be linked to their knowledge of the area as a protected system. Households with fishermen identified several areas that they were prohibited from fishing which included mangrove areas in the community, fish nurseries near the harbour, reefs and area referred to as Rocky Point.

Mangrove Management and Restorative Efforts

A noteworthy percentage of respondents (35.8%) said that they are aware of restoration activities for the mangrove forest in Portland. Still, majority (64.1%) said they are unaware of these activities.

This not only questions whether the community was informed, but also how effective were the methodologies of engaging it. In order to ensure restoration activities are effective and maintained, community involvement need to be a critical part of the process.

The results further supported the noteworthy percentages of respondents who could not respond to how well the mangrove were managed (don’t know response) or those who believe that they were not managed (Figure 42). Nevertheless over 40% of the respondents described the management as adequate or excellent. There is however room for improvement in management as indicated by 20.8% of the respondents

Figure 42: Perception on how well mangrove forest is managed in Portland Cottage.

Most respondents (50.9%) reported that the government is responsible for the management of the mangrove within the community. However, the community also plays an important role as 21.7% of the respondents said. Other less groups mentioned by the respondents were private organisations (4.7%) and non-government organisations (NGO) (6.6%). However, only the Caribbean Coastal Area Management Foundation (CCAM) and schools assisting in replanting were named with some respondents stating that they did know the names of the other organisations that were involved.

Opportunities for Private Public Partnership

There is opportunity for involving the community in mangrove restoration as majority of the respondents (71.7%) stated that they are willing to be a part of the process. Only a small percentage (18.9%) stated that they did not want to be involved and 9.4% who were uncertain, but this could possibly change if they are engaged and educated on the importance of mangrove restoration.

The results also show a statistically significant relationship between willingness to be involved in mangrove restoration and gender with a p-value of 0.013 with a slightly higher percentage of females (73.6% compared to 72.2% males) willing to get involved and a greater majority of males (26.9% compared to 11.3% females) showing no interest. However, only 6.7% of respondents were currently involved in restoration activities and majority (93.3%) said they were not involved with no statistically significant relationship according to gender. This is interesting as it brings to the fore questions on how mangrove forest is currently managed and to what extent is the community educated and engaged in restoration efforts, particularly since some of the issues related to damage/destruction of the mangrove forest is caused by the community

Ecological

Mangrove Biometrics

Mangrove species composition and relative abundance (for diversity)

The Portland Cottage, Portland Bight study location was covered by an almost homogenous, dense stand of *Rhizophora mangle (*red mangrove) trees with infrequent occurrences of *Avicennia germinans* (black) and *Laguncularia racemosa* (white) trees. Mean diversity for Site 1 was 0.46 while Site 2 had a diversity of 0.02. Again, as indicated by Hogarth (2015), low diversity is expected within mangrove ecosystems and would be lowest in relatively monospecific stands. There were 194 red, 100 black and 5 white mangrove trees in Site 1 while Site 2 had 310 red and 4 black trees.

Overall tree density varied between both sites (Figure 43) with Site 1 showing 0.38 m-^{2} for red mangroves, 0.20 m-^{2} for black and 0.01 m-^{2} for white mangroves. Site 2 had 0.62 m-^{2} red and 0.01 m-^{2} black mangroves. These tree densities are lower than those obtained by Chin (2014) within the Port Royal mangroves. Generally red mangroves were also found to have greater densities when compared to the other species (Pellegrini et al. 2009).

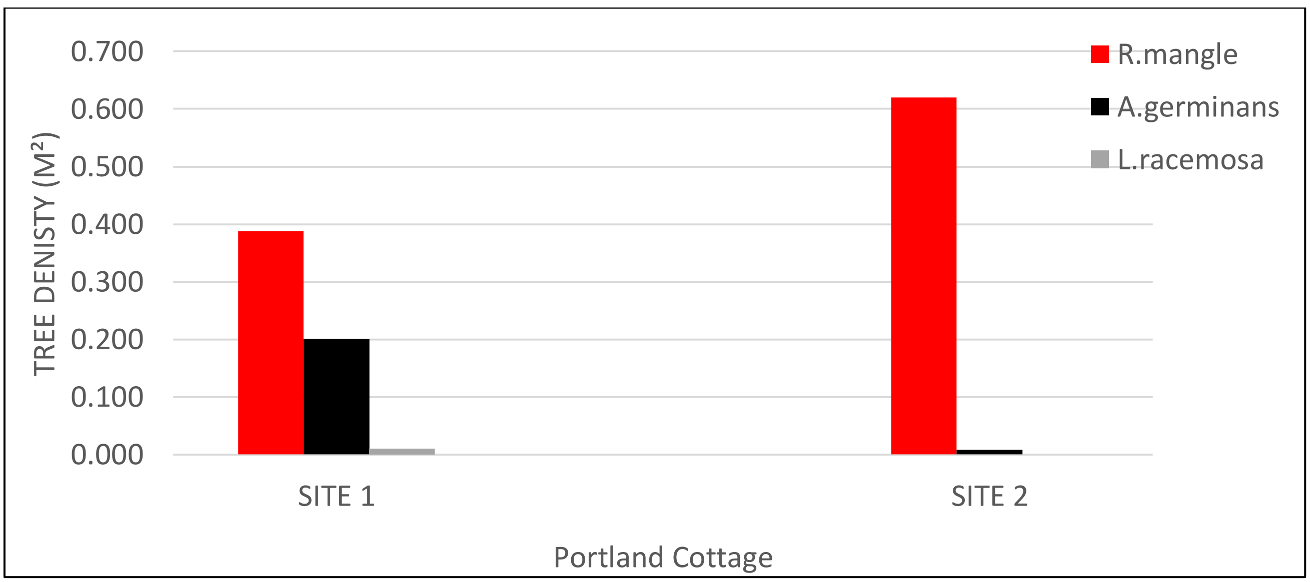


Figure 43: Overall tree density at both sites in Portland Cottage.

Mangrove Trunk Diameter

Diameter at Breast height (DBH) values ranged between 3 and 118 mm at this location. At site 1, DBH values ranged from 5 to 118 mm (mean 28.3 ± 1.54 SE) for *Rhizophora mangle,* 3 to 90 mm (mean 30.9 ± 1.60 SE) for *Avicennia germinans* and 19-25 mm (mean 21.6 ± 1.10 SE) for *Laguncularia racemosa*. Site 2's DBH ranged between 5 mm and77 mm (mean 30.7 ± 1.28 SE) for *Rhizophora mangle* and8 to 40 mm (mean 20.5 ± 6.95 SE) for *Avicennia germinans*.

Mean DBH generally decreased towards the landward end of the transect (Figure 44) for all species except *Laguncularia* which remained constant between 10 and 30m distance along the transect. DBH was expected to increase from the seaward edge of the forest to the landward edge as trees to the landward edge represent those that colonised the area first and so are usually the older trees. As the forest area extends seaward, the newer colonisers are expected to be on the edge near the sea. However, such comparisons are only valid if the landward and seaward trees belong to the same species (McDonald-Senior 2000). Similar diameter ranges and pattern of change were recorded by Rankine (2014) as well as Chin (2014) for all species of mangroves along the sea to land gradient. The absence of pattern shown for the white mangrove in the present study could be because the transect did not penetrate as far enough inland.

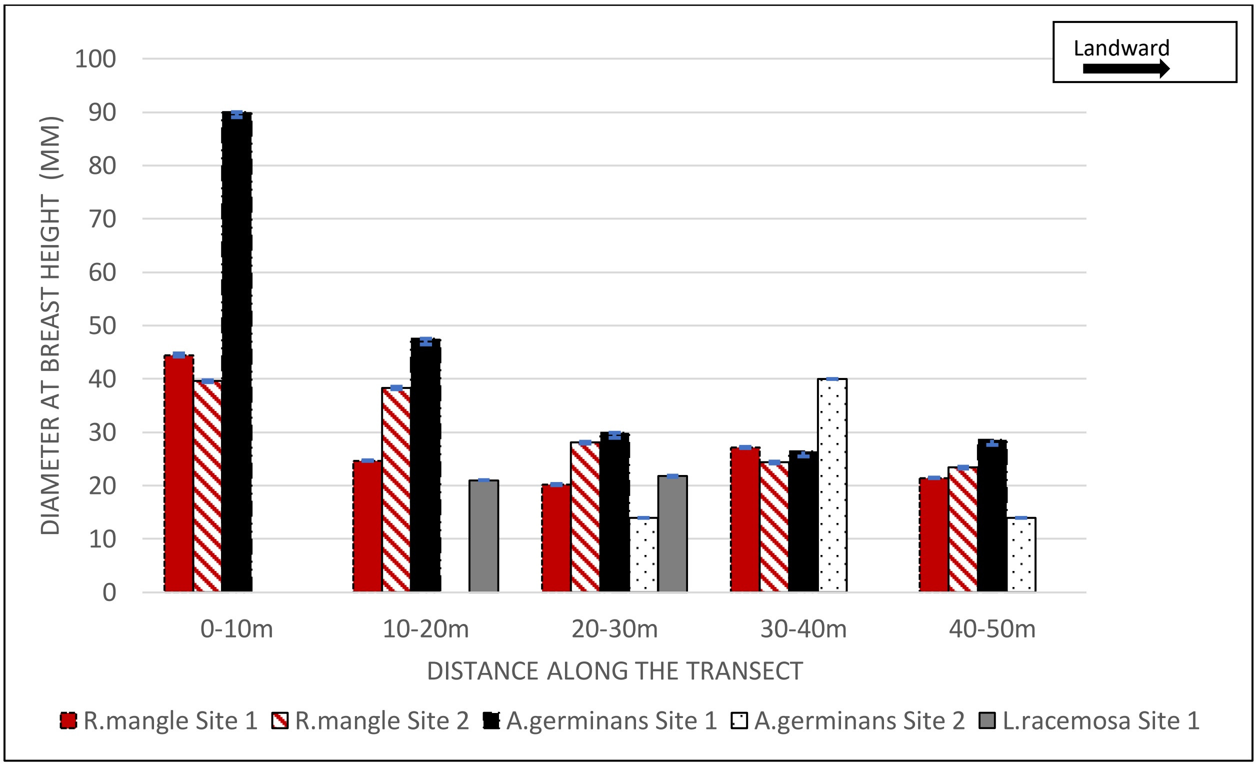


Figure 44: Mean Diameter at Breast Height (with SE) along the transects at Site 1 and 2.

Mangrove Height and Canopy Width

Tree heights within Site 1 (Figure 45) ranged from 1.7 m to 6.7 m (mean 3.7 ± 0.11) for *Rhizophora mangle,* 1.7-7 m (mean 3.6 ± 0.12 SE) for *Avicennia germinans* and 2.8 m to 4.3 m (mean 3.5 ± 0.32 SE) for *Laguncularia racemosa* (Annex 2). Site 2 tree heights (Figure 45) ranged from 1.4 to 6.2 m (mean 3.9 ± 0.09 SE) for *Rhizophora mangle,* 1.3-4 m (mean 3.1 ± 0.56 SE) for *Avicennia germinans*.

The height of mangrove vegetation typically decreases with distance from the water's edge along low energy coastlines but increases with distance along high energy coastlines (Lugo 1989; Feller1995; McDonald-Senior 2000, McDonald et al., 2003).

Mean height showed a general decline towards land (Figure 46). The pattern and range of tree heights are similar to forests studies along the North coast of Jamaica (Chin, 2014) mangrove forests in Errol Flynn Marina, Seville and Falmouth showing an overall similar decline in tree height towards the land. These forest areas had similar physiography (degree of shelter and salinity influences) to Portland cottage but were more exposed.

When compared to previous studies done on the south coast of Jamaica in the Port Royal mangroves by McDonald –Senior in 2000, mean height ranged between 2 m -7 m and by Chin in 2014, mean height was 4.5 m, the mangroves at this location in Portland Cottage were comparable to those studies.

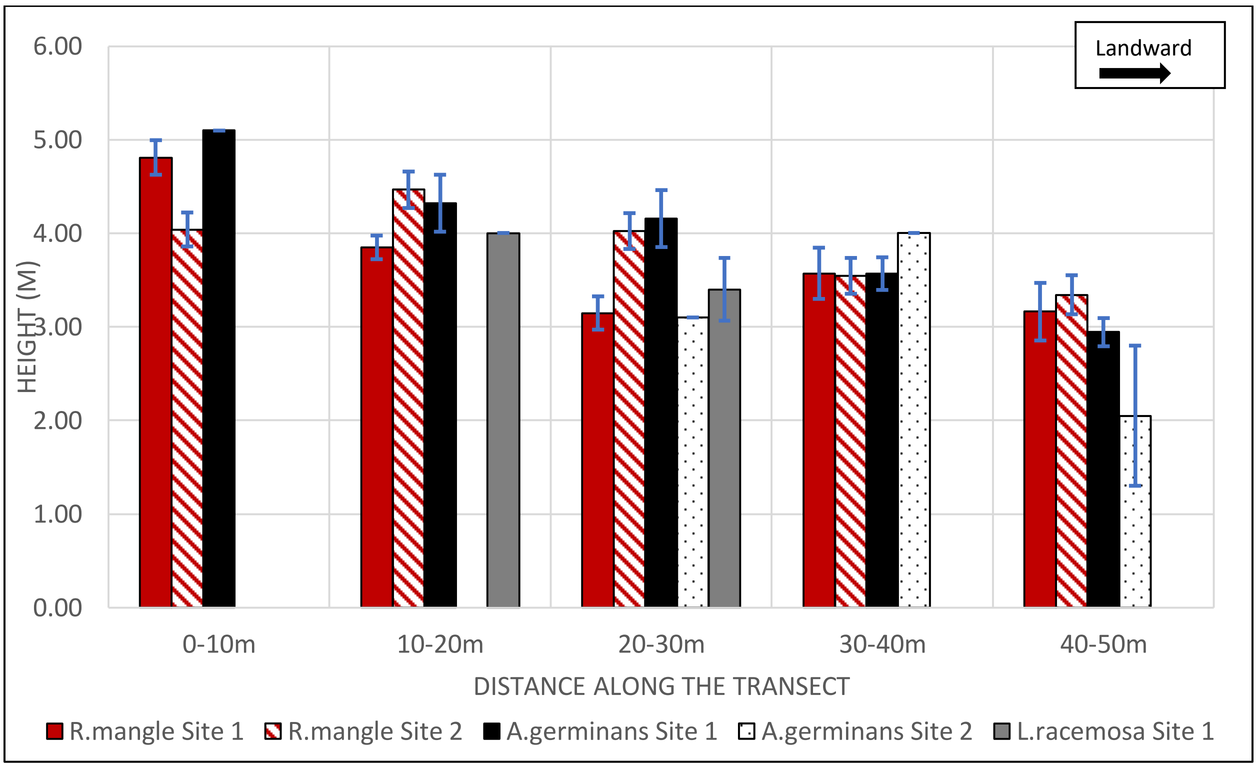


Figure 45: Mean Height (with SE) along the transects at Site 1 and 2.

Canopy width values ranged between 0.1 m to6 m (mean 0.9 ± 0.09 SE) for *R.* mangle, 0.1 m to 4.3 m (mean 0.9 ± 0.08 SE) for *A.* germinans and 0.4 m to 1 m (mean 30.6 ± 0.12 SE) for *L. racemosa* at Site 1. Site 2 had values ranging from 0.2 m to 5 m (mean 1.4 ± 0.10 SE) for *R. mangle* and 0.3 m to 4 m (mean 1.3 ± 0.91 SE) for *A. germinans*. All species canopy width values at both sites decreased landward towards the end of transect, with the exception of *A. germinans* which showed a tremendous increase at 30-40 m before declining at 40 – 50 m.

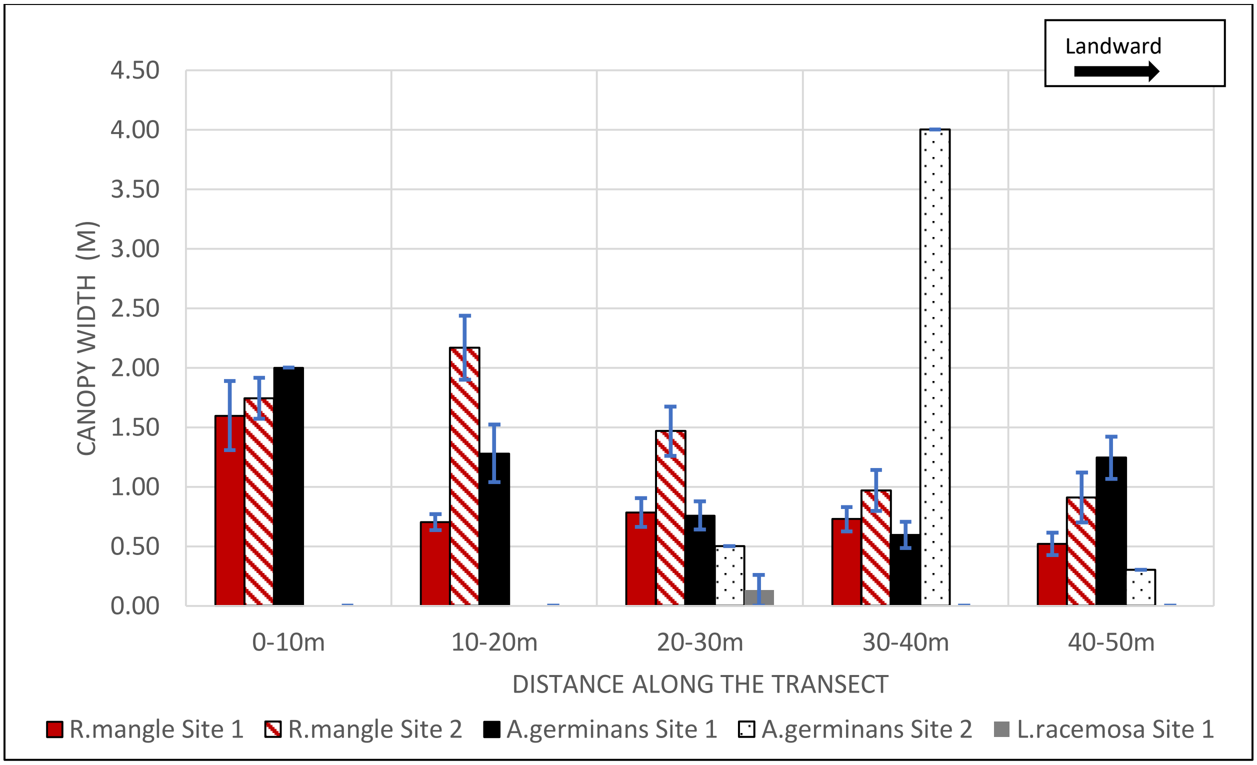


Figure 46: Mean Canopy width (with SE) along the transects at Site 1 and 2, Portland Cottage.

Prop root/aerial root network

Low prop root density category values decline along the transect from 36 roots m^{-2} at the start of the transect to 2 roots m^{-2} at the end of the transect. Medium prop root density category values increased from 68 roots m^{-2} between 0 and 10 m to 78 roots m^{-2}. It then decreased between 20 and 50 m towards the end of the transect (Figure 47).

High prop root density category values ranged from 79 roots m^{-2}between 0-10 m and 84 roots m^{-2} between 20 and 30 m. Representation of the high prop root density category was absent between 10 and 20; 30 and 40 and 40 and 50 m. These prop root densities were expected to decrease with increasing distance from the water's edge towards land as red mangroves typically achieve optimal growth near the water's edge (Figure 47).

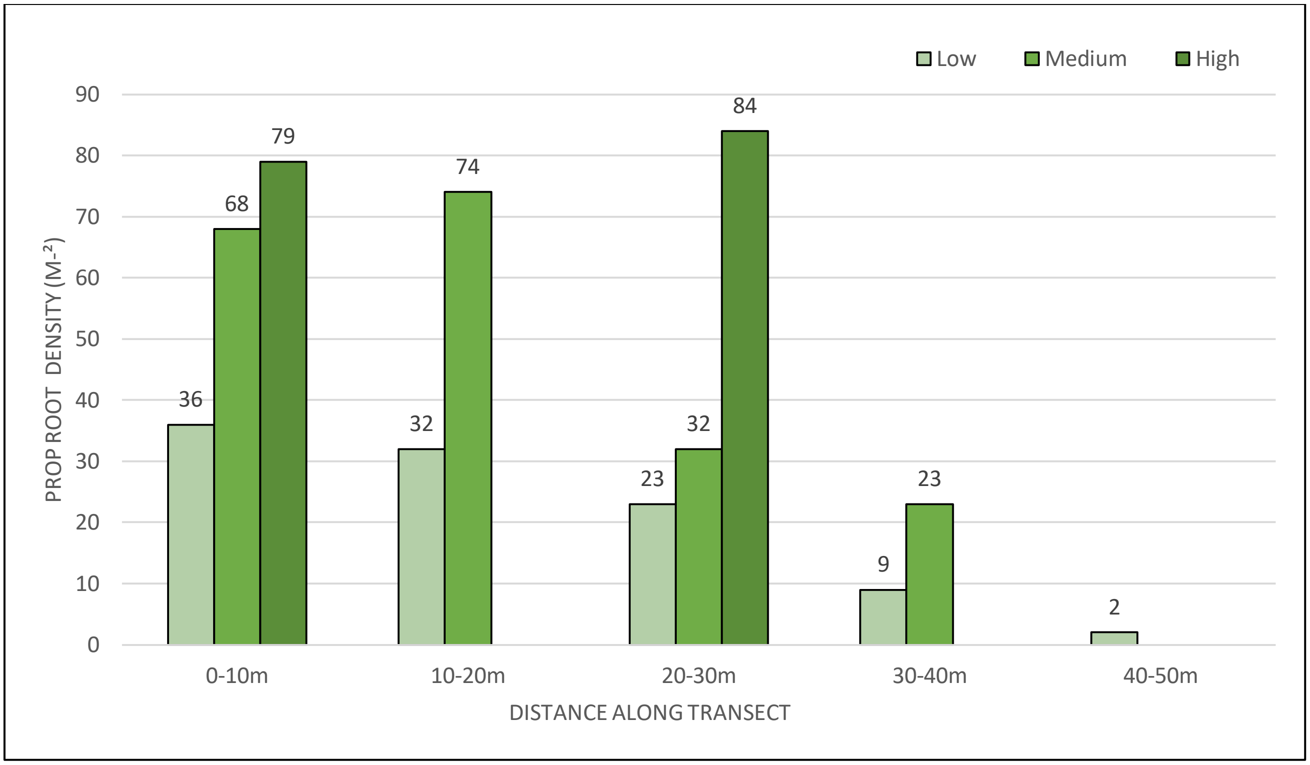


Figure 47: Prop root densities representing low, medium and high root densities along the transect at Site 1-Portland Cottage.

Pneumatophores were absent at the start of the transect (between 0 and 10 m). For all three categories, pneumatophore density drastically increased between 10 and 20 m and 40 and 50 m along the transect. Low pneumatophore density values ranged between 6 pneumatophores m^{-2} to 123 pneumatophores m^{-2}. Medium pneumatophores density values ranged between 66 pneumatophores m^{-2} to 480 pneumatophores m^{-2}. Within the high pneumatophore density category, values ranged between 370 (at 10-20m) and 656 pneumatophores m^2 (at 40-50m) (Figure 48).

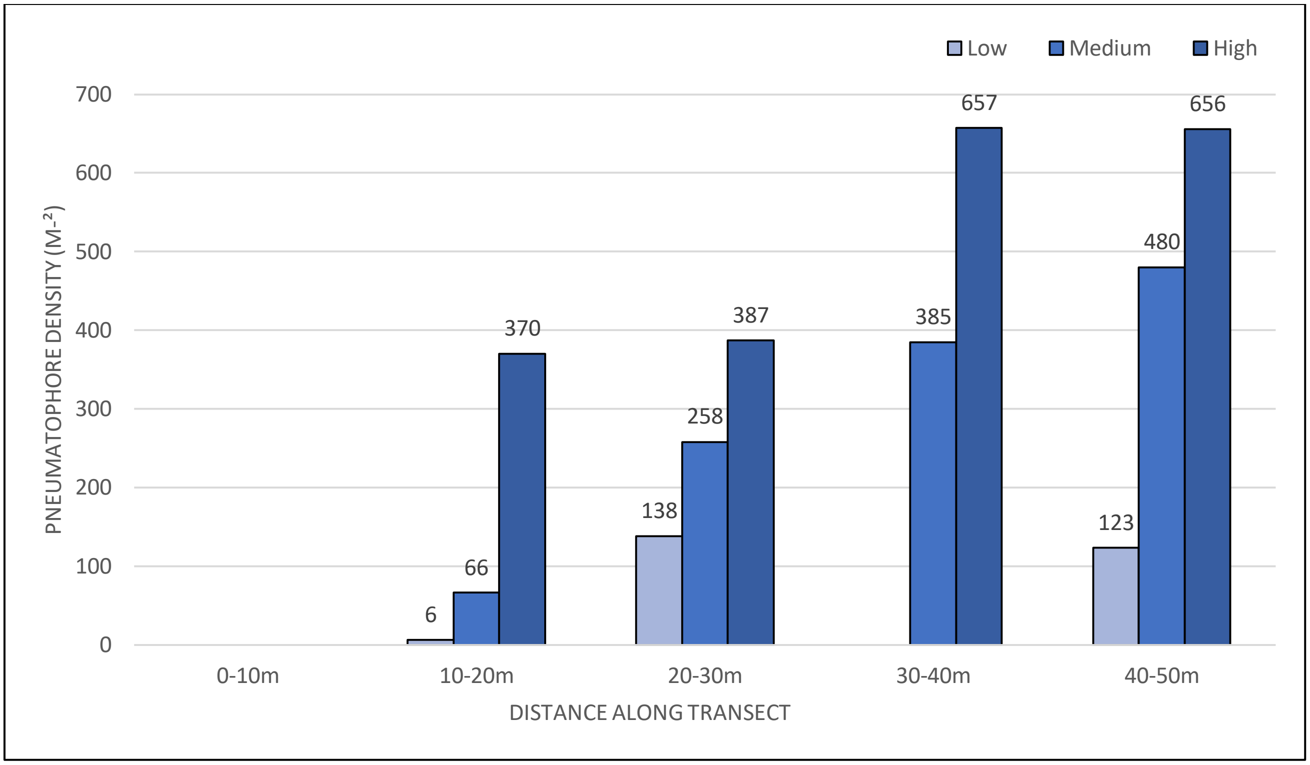


Figure 48: Pneumatophore densities representing low, medium and high root densities along the transect at Site 1-Portland Cottage.

For the low prop root density category, values decreased from 28 prop roots m^{-2} at 0-10 m to 10 prop roots m^{-2} at 20-30 m, then increased to 20 prop roots m^2 at 30-40 m. There were no representations for the low-density prop root category at the 30-40 m distance. Medium density category values increased from 41 prop roots m^{-2} at 0-10 m to 43 at 10-20 m. Figure 49 shows the prop root densities along transect 2 at Portland Cottage.

The value recorded for the medium density category at the end of the transect (40-50 m) was 23 prop roots m^{-2}. High density prop root category values also increased between 0-10 m from 52 prop roots m^{-2} to 80 prop roots (10-20 m). The values then decreased from 69 prop roots m^{-2} (20-30 m) to 50 prop roots m^{-2} (30-40 m) and increased at the end of the transect (40-50 m) to 62 prop roots m^{-2}.

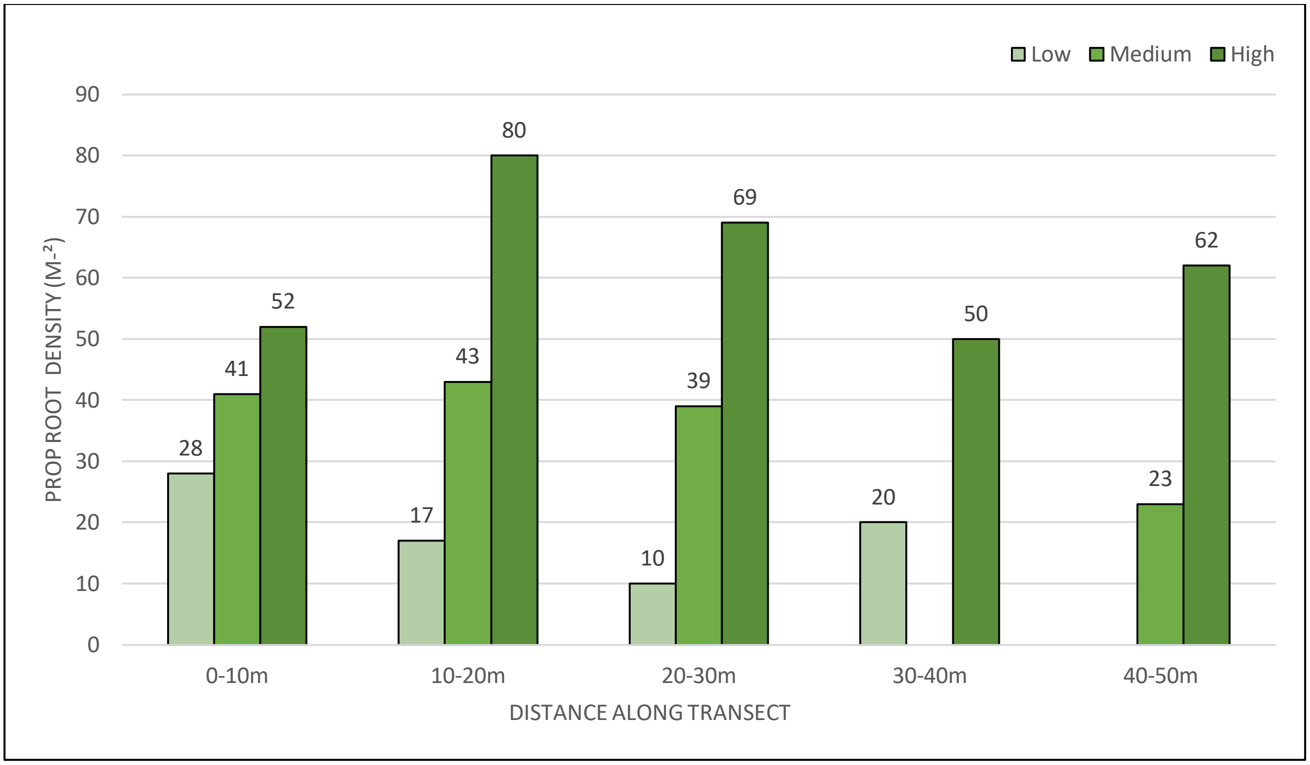


Figure 49: Prop root densities representing low, medium and high root densities along the transect at Site 2-Portland Cottage.

Pneumatophores were only present between 30 and 50 m. For the low pneumatophore density category, values decreased from 23 pneumatophore m^{-2} to 16 pneumatophore m^{-2}. There was an increase in both the medium and high-density categories between 30-50 m, with medium density category increasing from 58 pneumatophore m^{-2} to 142 pneumatophore m^{-2} and in the high-density category from 117 pneumatophore m^{-2} to 168 pneumatophore m^{-2} (Figure 50).

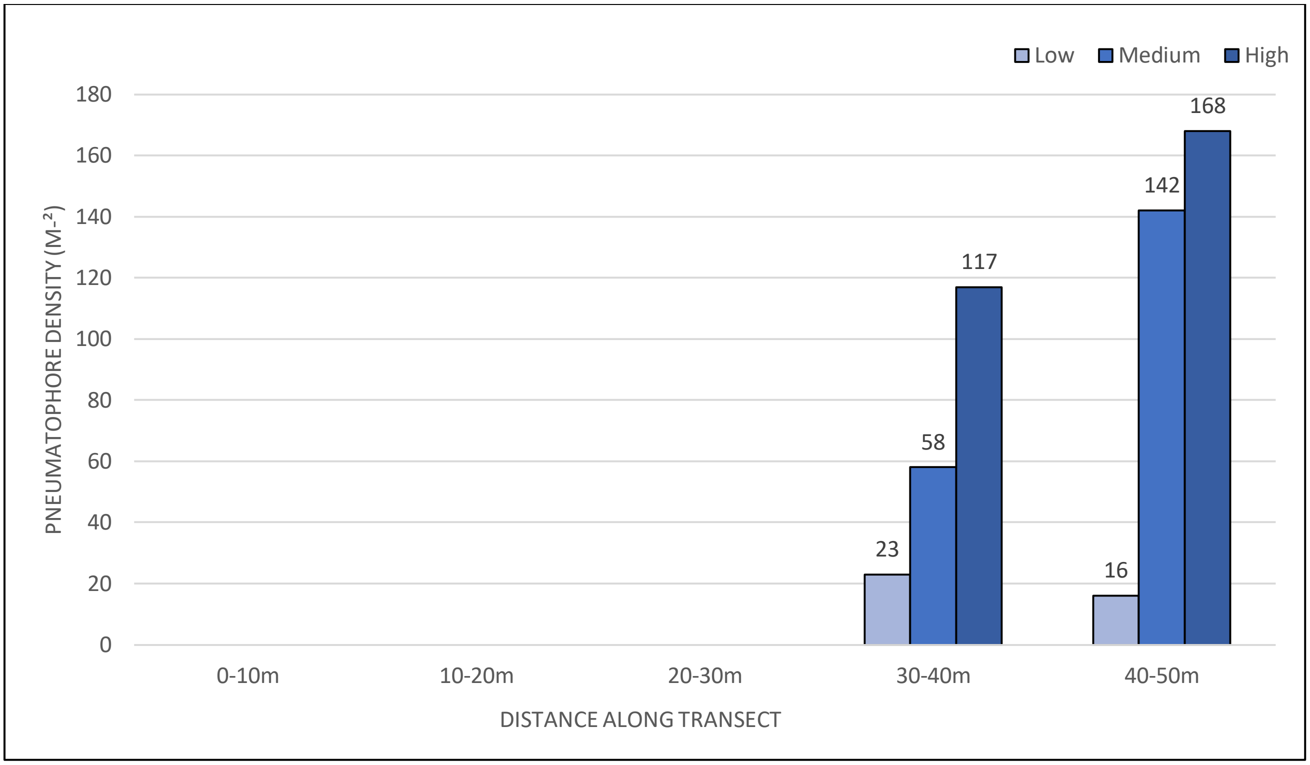


Figure 50: Pneumatophore densities representing low, medium and high root densities along the transect at Site 2- Portland Cottage.

Based on Pellegrini et al. (2009) structural categories, the Portland Cottage area is a forest with low structural development- DBH between 1.6 and 3.1 cm, and mean height of the most developed trees between 2.4 and 4.7 m.

Ecosystem Services

The provisioning ecosystem service of mangroves whereby they create nursery habitat for fish which was explored through presence of fish larvae, did not yield positive results for this area. Only 1 fin-fish family (Gerreidae) was identified in the Portland Cottage larval assessment. Gerreidae also known as mojarra include silver jenny. This species is a common prey/ bait fish used throughout the Caribbean and is not considered of high commercial value. Furthermore, while site 1 had fish larvae from one species, assessment of the other site yielded only large amounts of crustacean (crab) larvae in the trap.

Physical

Elevation and Topography

Elevation along the transect at Site 1, Portland Cottage (Figure 51), is variable ranging from 0.15 m below MSL to 0.03 m above MSL. Site 1 is dominated on the seaward end by *R. mangle*, but also has abundant *A. germinans* (with pneumatophores) presumably with geomorphology being a controlling factor in mangrove distribution. The significant drop in elevation at Site 1 landward corresponds to an area that is devoid of mangrove trees and suggests loss in elevation as a result of peat collapse contributing to shallow subsidence.

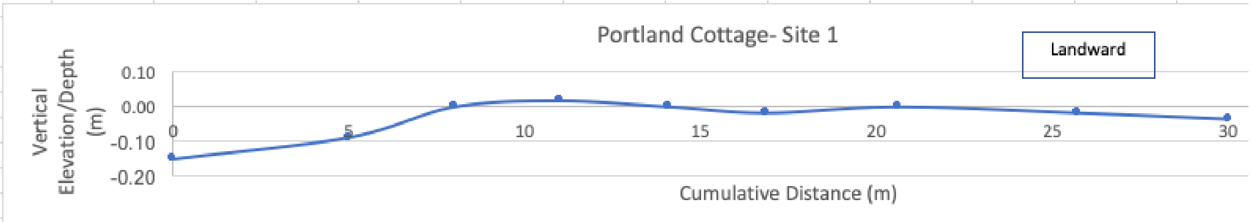


Figure 51: Moderate slope variability along the transect (Site 1, Portland Cottage), 0.00 represents mean sea-level (MSL).

At Site 2, the transect ranged from 0.30 m below MSL to 0.06 m above MSL. Site 2 is dominated by *R. mangle*. Unlike the transect at Site 1, there is no undulating profile but a gentle rise and a gentle lowering off towards the landward extent of the transect. Towards the interior there is another collapse in elevation giving rise to a basinal feature (end of transect and landward) which is inundated with water and devoid of vegetation (Figure 52).

These basinal features landward of both sites and without vegetation suggest some sort of ponding especial taken in context with the spatio-temporal studies shown later. The peat collapse may be as a result of stressors to the ecosystem and the death of trees facilitating a domino effect as explained in Cahoon et al. (2003) for sites at Honduras.

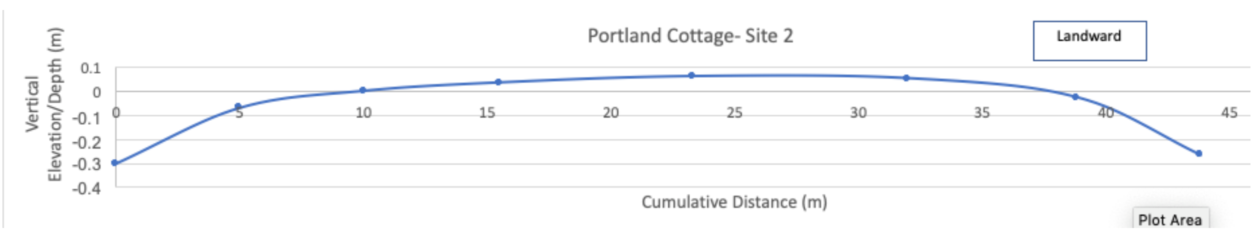


Figure 52: Moderately flat terrain within the extent of the transect (Site 2, Portland Cottage), zero represents MSL.

Sediment & Litter Retention and Accretion

Accretion was negative at Site 1 in Portland Cottage evidenced by the absence of the horizon markers were eroded, there was no leaf litter because there were no trees at the site of the RSET and in the vicinity of the horizon markers. Site 2 had mean accretion of 0.9 mm m^{-1}, and mean leaf litter was 3.5 g over a 4-month period. The variation of leaf litter from sites 1 and 2 is as a result of the geomorphology and the vegetation status.

Sediment supply is significantly higher at this location than all other sites and is likely coming in from redistribution of eroded sediments and possibly from the redistribution of overbank deposits of the Rio Minho river system which drains hinterlands to the north (unlike Montego

Rivers (Bogue Lagoon) and Martha Brae (Salt Marsh), this river brings abundant siliciclastic sediments from the Central Inlier, and occasionally floods.

Elevation Change

The RSET benchmark penetrated a depth of 2.44 m at Site 1 elevation change ranged from -1.58 mm m^{-1} to 0.96 mm m^{-1} with a mean of -1.03 ± 0.68 mm m^{-1}at Portland Cottage. At Site 2 the length of the benchmark was 3.64 m and positive elevation change was depicted, ranging from -0.27 to 2.96 mm m^{-1} with a mean of 1.1 ± 0.78 mm m^{-1}. Unlike Site 1 there was accretion at Site 2, based on the study period of 4 months; the positive elevation could be attributed to root mass increase and/or in combination with the hydro-period of the tide increasing the elevation from pore-water pressure and the sedimentation. Due to the positive elevation change here at Site 2, shallow subsidence is playing a less significant role than at Site 1. As Cahoon et al. (2003) explained, fluctuation in elevation occurs while accretion continued to increase linearly with time as a result of change in pore water and shallow subsurface processes. Based on the state of Site 1 compared to Site 2, the interpreter believes the localised increased subsidence and erosion could be in relation to peat collapse and absence of mangrove trees rather than other transient features of the system.

Horizontal Variation (progradation/retreat) of Mangrove Coastline

The section of Portland Cottage studied is bordered by rural residential accommodation largely for fisher folk and minor road networks. Land use north of the bay transitioned to less commercial agriculture and is now abandoned or shrub land. The length of the coastline with long-term accretion is smaller (3.8 km) than the length of the coastal area with long-term erosion (8.2 km). The area of lateral accretion seaward (green areas at the north west and south west fringes - Figure 53) is 19.2 ha at a rate of 3.4 km^2 yr^{-1}, in addition, a smaller area of 8.2 ha landward (Site 2) that was unvegetated in 1961 is now vegetated in 2017. The area eroded is 55 hectares of the seaward section and eroded if constant at a rate of 9.8 km^2 yr^{-1}, furthermore, another 84 hectares of mangrove forest has been lost between 1961 and 2017 landward of the seaward edges of the mangroves at the Portland Cottage locality (Figure 53).

On the 1961 aerial photograph, areas to the northwest of the study area was prime farm land. Today it is deforested in some sections whereas other areas appear as abandoned shrubland (Annex 9, Figure 53).

The significant decline and dieback landward of Mangroves at and around Portland Cottage has been an ongoing trend probably spanning either 5 decades or at least in the last decade. Sippo et al. (2018) explained that this can be an ongoing long-term process rather than immediate death. This may be linked to natural events such as hurricanes Ivan (2004) and Sandy (2013) that affected this area. Field reconnaissance identified dead trees at Mitchell Town to the north east of the study area. The transportation of bauxite and alumina may play a role, or the kind of fishing and transportation activities that occur in the bay area, but it is impossible to determine the cause of the significant dieback. However, if the denudated areas continue to expand, and subsequently become, and remain, flooded as the peat stocks below them decay and collapse, then overtime the existing seaward fringes will become isolated. These mangrove forest at Portland Cottage are therefore offering reduced ecosystem services. Site 1 is most threatened, but Site 2 is also vulnerable and likely to become isolated from behind. Therefore, continued monitoring is recommended.

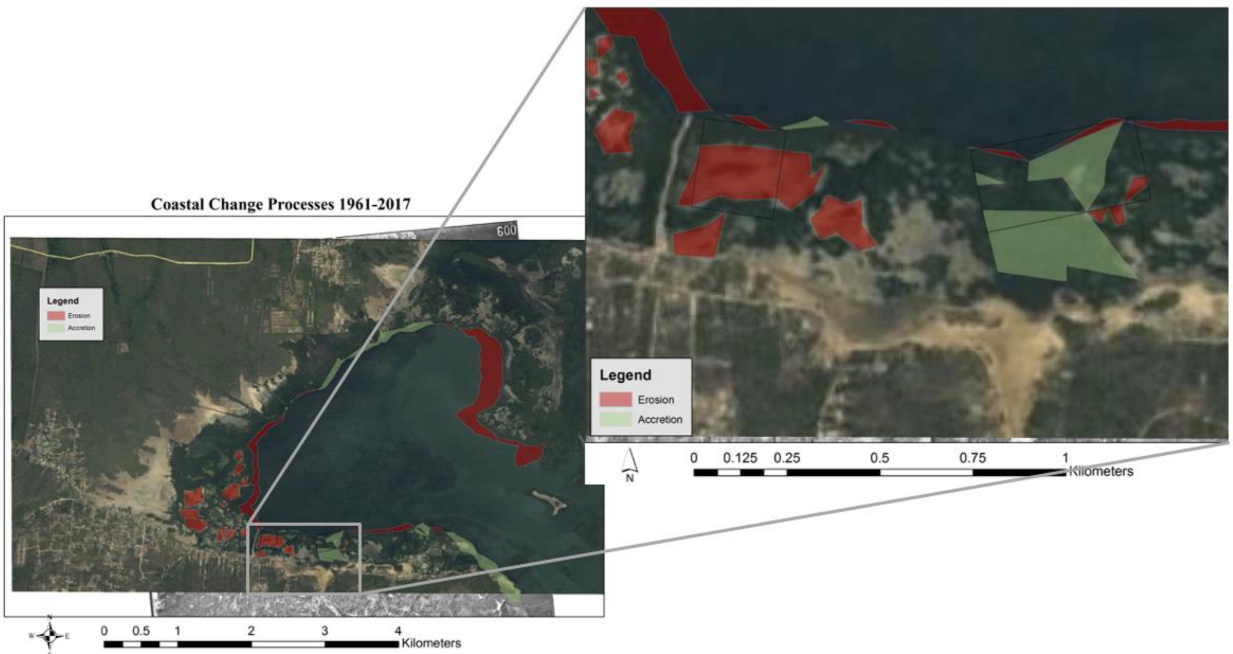


Figure 53: Spatiotemporal lateral erosion or accretion on the coastline, where mangrove trees occupation migrates seaward or retreat landward. Within the strands are also evidence of reduced mangrove coverage (west of and within Site 1), identified as eroded and accretion or increased mangrove coverage identified as lateral and vertical accretion.

Bathymetry

The bathymetry at both sites at Portland Cottage (Figure 54) was very similar. Site 1 had shallow depths water ranging in depth from 0.9 to 1.4 m; Site 2 had water depth.

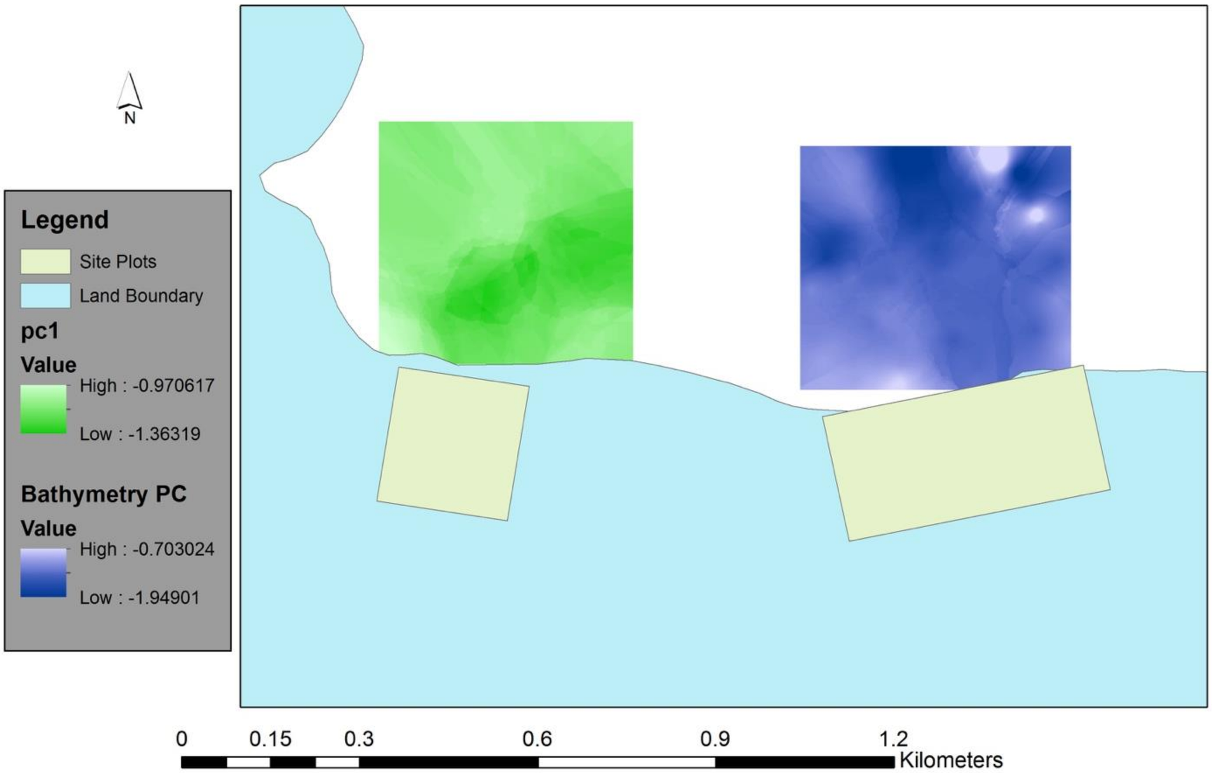


Figure 54: Bathymetry at Sites 1 (west) and 2(east) of Portland Cottage, created by Taneisha Edwards,2019.

Wind and Wave Parameters & Attenuation

At Portland Cottage, on the days of the field study, the wind along a transect landward reduced landward from 5.7 ms^{-1} (seaward) to 2.4 ms^{-1} and was reduced by a significantly higher percentage within the mangrove forest (68%) than outside (13%) at Site 1 (Figure 55). Similarly at Site 2 wind was attenuated by the mangrove canopy from mean highest wind speed of 5.9 to 2.5 ms^{-1}, a 58% reduction of wind speed within the mangrove forest compared to a 11 % reduction outside of the mangrove forest (Figure 55). Wave energy attenuation by reduction in wave height of 2 % outside of the mangrove forest with a rate of 0.001 per m while within the mangrove forest that reduction was more than double at 58% and a rate of reduction of 0.008 per m (Figure 55). Wave readings by pressure sensors were only presented from Site 2 at Portland Cottage. Wind speed is reduced outside of the mangrove because of surface friction expected to be at a lower rate than beyond the mangrove canopy landward. Wave energy reductions outside the mangrove are driven by the morphodynamics influence of the site.

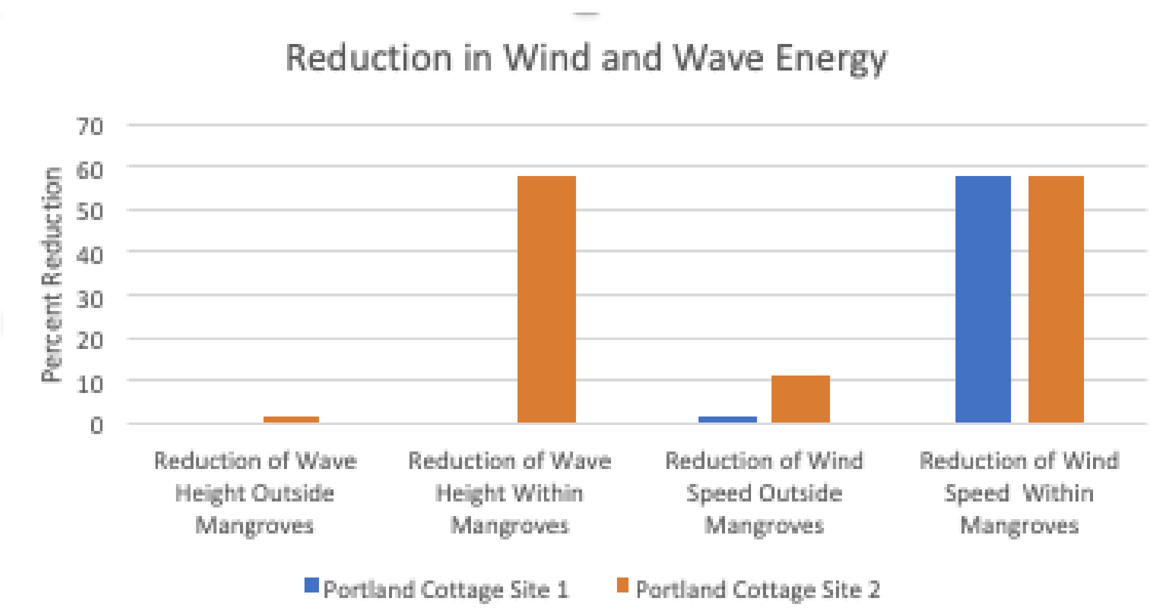


Figure 55: Percentage reduction in wind and wave energies outside and within the mangrove at Portland Cottage. Due to technical difficulties complete wave data were not captured for Site 1 and therefore not presented.

Substrate Constituents and Properties

For Site 1 percentage weight of plant/animal (washable & digestible component) ranged from 71 to 85% (n=5) with a mean of 79% and standard deviation of 6%. For Site 2, the percentage weight of the plant component ranged from 72 to 95 % (n=5) with a mean of 90 % and a standard deviation of 10 % (Figure 56)

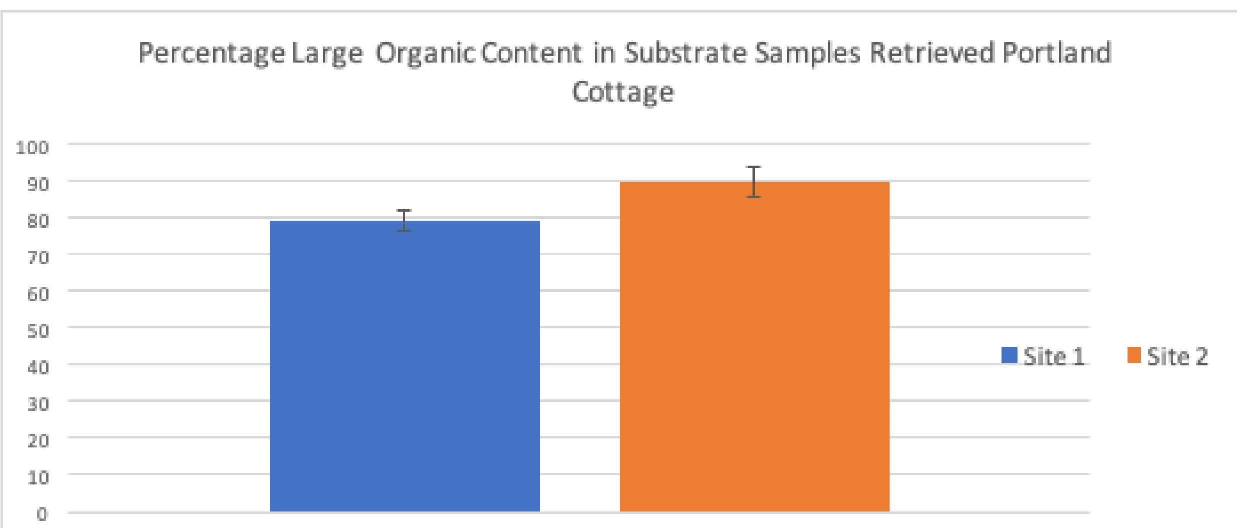


Figure 56: Mean plant percentage removed by handwashing together with percentage loss from hydrogen peroxide digestion of organic matter for each studied at Portland Cottage. The error bars represent standard errors of the mean (SEM) and are 3 and 9 percent respectively for Sites 1 and 2.

The remaining sediment after organic content removal plots as silty clay by percentage weight at the Portland Cottage study sites in areas where samples were collected (Figure 57).

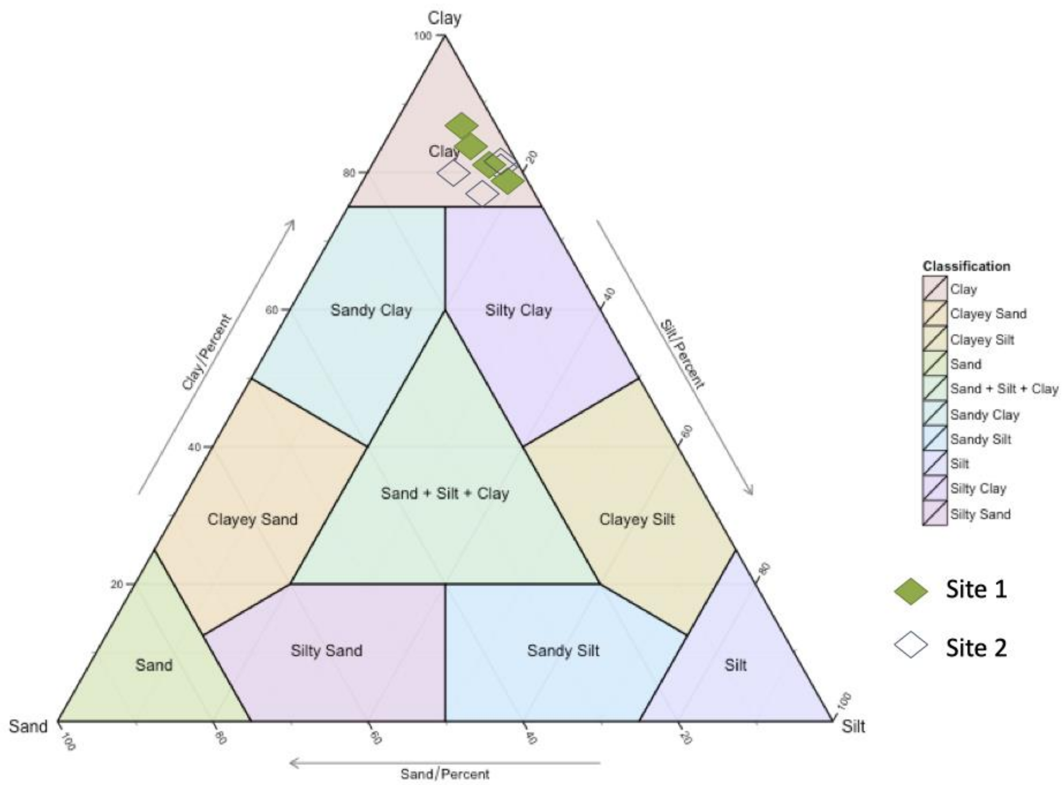


Figure 57: Ternary diagram showing textural characteristics of clay for the remaining soil fraction at Portland Cottage normalised after the removal of larger than sand sized particles and vegetation (after Shephard, 1954).

Because there was no carbonate sandy component in the samples, no identification of skeletal or non-skeletal grains was possible. Furthermore, mangal molluscs and other grazing organisms that could contribute to the substrate upon death that are expected within the system were not seen.

This lack of skeletal grains within the system shows that carbonate reef and sea-grass beds and associated sediment production may be low in this region or has not being distributed by currents to either of the study sites. Furthermore, acidic conditions in the substrate could cause carbonate grains to dissolve and this could be another reason for the absence of carbonate allochems. Because allochems are absent, this warrants further study as this could also be related to the state of these mangal systems.

Soil Quality

Ecosystem Carbon Biogeochemistry

The soils from Portland Cottage sites exhibited less SOM variability (are comparable to other sites) with values ranging from 24.80% to 41.86% (median 38.50% and mean 36.75%) for Site 1 and 30.95% to 44.14% (median 32.05% and mean 36.35%) for Site 2 (Annex 4). The SOC content of Portland Cottage Site 1 varied from 14.39% to 24.28% (median 22.33% and Mean 21.32%), with near identical values for Portland Cottage Site 2 (Annex 5).

Table 10 provides a summary illustration the relative concentrations of selected elements from Portland Cottage. Cd, Co, Cr, Fe, K and Zn are relatively similar for both sites. Whereas Br and As are lower for Site 1, while Sr is higher for Site 1 than Site 2. Similar to Bogue Lagoon, Br and Na abundances fall outside of the global mean.

Table 10: Concentrations of major and trace elements analysed in mangrove surface soils (0–30 cm) from the Portland Cottage locality.

Sites		[As] (mg Kg^{-1})	[Br] (mg Kg^{-1})	[Cd] (mg Kg^{-1})	[Co] (mg Kg^{-1})	[Cr] (mg Kg^{-1})	[Fe] (%)	[K] (%)	[Na] (%)	[Sr] (mg Kg^{-1})	[Zn] (mg Kg^{-1})
Site 1	Min	3.1	323.1	8.6	4.9	19.9	1.4	1.0	4.1	162.2	35.7
	Max	18.7	761.9	21.7	10.5	27.2	2.3	1.2	5.6	232.3	49.5
	Median	7.3	553.3	16.2	6.2	22.4	1.7	1.1	4.5	179.9	42.9
	Mean	8.7	533.9	15.2	6.8	23.2	1.8	1.1	4.8	187.4	42.4
Site 2	Min	6.5	482.8	8.2	5.6	23.8	1.6	1.1	5.0	82.6	33.6
	Max	17.5	641.5	24.5	7.2	34.1	2.2	1.4	7.7	169.1	52.0
	Median	10.0	544.4	14.5	6.1	30.5	2.2	1.3	5.7	132.1	48.6
	Mean	11.7	550.8	15.7	6.3	29.8	2.1	1.2	6.2	129.8	46.4

*10,000 mg Kg^{-1} = 1%.

Soils from the Portland Cottage locality are predominantly acidic (site 1, pH 5.6 to pH 7.2; site 2, pH 6.2 to pH 6.9), with median values of pH 6.4 (Annex 7)

Water quality

The mean surface water temperature of Portland Cottage Site 1 is roughly 33°C, while Site 2 averages 29°C (Table 11); these are marginally higher than those for Bogue Lagoon. Similarly, the salinities (mean = 40 g Kg^{-1}) and conductivity (mean = 72 MS cm^{-1}: Site 1; 72 MS cm^{-1}: Site 2) are also higher than those reported for Bogue Lagoon. These results would suggest that enrichment by evaporation is like to be an important control on salinity. Salinity is an important water quality variable as it influences plant community and primary productivity. The concentration of TDS is also lower than the minimum value (500 mg L^{-1}) for brackish waters. The average DO concentrations generally fall below the threshold concentration (5 mg L^{-1}). These values may be explained by the presence of oxygen depleting source(s) (possibly of an organic nature) at these sites. The mean pH of Site 1 is moderately basic (pH 9.01), whereas Site 2 is weakly acidic (pH 6.83), which may be due in part to contributions from organic species, high concentration of CO_2 dissolution in water, or weakly buffered soils. The acidic pH is similar to most local mineral soils.

The mean concentrations of Na (0.76%: Site 1; 0.82%: Site 2) and K (417 mg L^{-1}: Site 1; 413 mg L^{-1}: Site 2) are similar to Bogue Lagoon (Table 12). There is also very little difference between the concentrations of Ca (500 Mg L^{-1}: Site 1; 587 mg L^{-1}: Site 2) and Mg (0.12%: Site 1; 0.1%: Site 2) between the sites (Table 11). The Ca/Mg ratio is 0.41 for Site 1 and 0.59 for Site 2, implying that there is limited lithological control on water chemistry at these sites. The soils from Portland Cottage are predominantly acidic (Site 1, pH 5.6 to pH 7.2; Site 2, pH 6.2 to pH 6.9), with median values of pH 6.4.

Table 11: Water quality parameters determined in situ at Portland Cottage.

Site		Temperature (°C)	Conductivity (MS cm^{-1})	Total Dissolved Solids (mg L^{-1})	Salinity (g Kg^{-1})	Dissolved Organics (mg L^{-1})	pH
Site 1	Min	29.77	71.03	39.74	40.73	1.59	8.01
	Max	35.12	73.09	43.37	45.21	7.75	10.22
	Median	33.52	72.79	39.81	40.78	2.80	8.56
	Mean	33.22	72.29	40.66	41.85	4.44	9.01
Site 2	Min	27.29	55.93	34.25	34.63	0.07	5.00
	Max	30.70	65.98	39.62	40.87	5.78	8.29
	Median	29.05	63.56	38.33	39.30	2.21	6.92
	Mean	28.92	62.69	37.91	38.83	2.59	6.83

Table 12: Elemental concentrations of mangrove water samples at Portland Cottage.

Site		**[Ca] (mg/kg)**	**[K] (mg/kg)**	**[Mg] (mg/kg)**	**[Na] (mg/kg)**
Site 1	Min	273.2	236.5	744.7	5012.6
	Max	659.2	536.9	1570.8	9258.4
	Median	465.8	427.8	1338.1	8679.6
	Mean	500.2	417.7	1219.8	7644.3
Site 2	Min	415.9	358.0	762.9	6194.3
	Max	997.6	457.4	1630.1	10005.5
	Median	526.2	414.3	914.5	8353.3
	Mean	587.6	412.9	1005.0	8225.8

Soil Atmospheric Carbon Flux, Soil Carbon Stocks and Above Ground Carbon Stocks

Soil carbon flux

Soil CO_2 flux varied spatially and is clearly illustrated in Annex 7. Portland Cottage Site 1 shows median flux of 1.02 $\mu molm^{-2}s^{-1}$ and a mean value of 2.22 $\mu molm^{-2}s^{-1}$, while the Portland Cottage Site 2 exhibits a median value of 0.50 $\mu molm^{-2}s^{-1}$ and a mean of 0.55 $\mu molm^{-2}s^{-1}$. The median and mean flux rates are comparable with values of approximately 2 $\mu molm^{-2}s^{-1}$ and 3 $\mu molm^{-2}s^{-1}$ respectively. Table 13 shows the estimated carbon loss through CO_2 emissions from these sites.

Portland Cottage 1 and 2 yielded soil carbon stock estimates of approximately 179 Mg C ha^{-1} and 177 Mg C ha^{-1}, respectively (Table 13). Overall, the carbon stock estimates mirrored the mean SOM and SOC values. The SOM, SOC and therefore the carbon stock estimates are a function of the difference between inputs into, and losses from the system.

Table 13: Soil organic carbon stocks in mangrove ecosystems.

Site	[a]Mg C ha^{-1}	[b]Mg C ha^{-1}
Portland Cottage 1	179.09	1023.12
Portland Cottage 2	177.01	1011.98

[a] Stock estimates (Mg C ha^{-1}) determined using the mean bulk density value of regional mangrove soils (Adame et al., 2013).

[b] Stock estimates (Mg C ha^{-1}) determined using bulk density value from a pedotransfer function (e.g. Grigal et al., 1989).

Carbon losses for mangrove soils at Portland Cottage is shown Table 14.

Table 14: Carbon losses from mangrove soils through respiration.

Site	$MgCO_2$-C $ha^{-1}y^{-1}$ (Mean)	$MgCO_2$-C $ha^{-1}y^{-1}$ (Median)
Portland Cottage 1	8.40	3.86
Portland Cottage 2	2.08	1.89

Above ground biomass for Portland Cottage is reported at an estimated 13.45 Mg per hectare for Site 1 and 11.38 Mg per hectare for Site 2. Below ground biomass was also lowest in this area as 2.69 Mg per hectare for Site 1 and 2.28 Mg per hectare for Site 2 (Table 15).

Table 15: Aboveground biomass, belowground biomass and total C stocks in mangrove vegetation (Mg ha-1) Portland Cottage.

Site	Biomass (Mg ha^{-1})		C (Mg ha^{-1})
	Aboveground	Belowground	
Portland Cottage 1	13.45	2.69	7.59 (1.79)
Portland Cottage 2	11.38	2.28	6.42 (1.51)

*Data are mean (standard error) *Five plots (10m x 10m each) were sampled for each site.

Flooding

The risk of flooding here is related to merged buffers of 250 and 500 m based on historical reported floods (red triangles) and reports of experienced floods (green triangles) in relation to the projected 1 m, 5 m and 10 m coastal inundation events. Figure 58 shows that the experienced flood (triangles) and the buffers extend beyond the inundation water level predictions and into the communities. This highlights the vulnerability of the communities at Portland Cottage and highlights the important ecosystem services that could be provided by healthy mangal systems. Additionally, the patterns of inundation predictions suggest that communities to the north of the sites will be cut off from communities to the south during a 5 and 10 m coastal inundation event, most likely a storm surge. Moreover, the surge susceptibility polygon and the number of coastal flood experienced highlights the risk in the area of lower income communities and the importance of maintaining and increasing the protective services offered by the mangroves as a proactive method to prevent increased risk from wide scale collapse of the mangal systems. Any collapse of mangrove ecosystem at Portland cottage may push a call for relocation of the population and loss of livelihood which could have large economic costs.

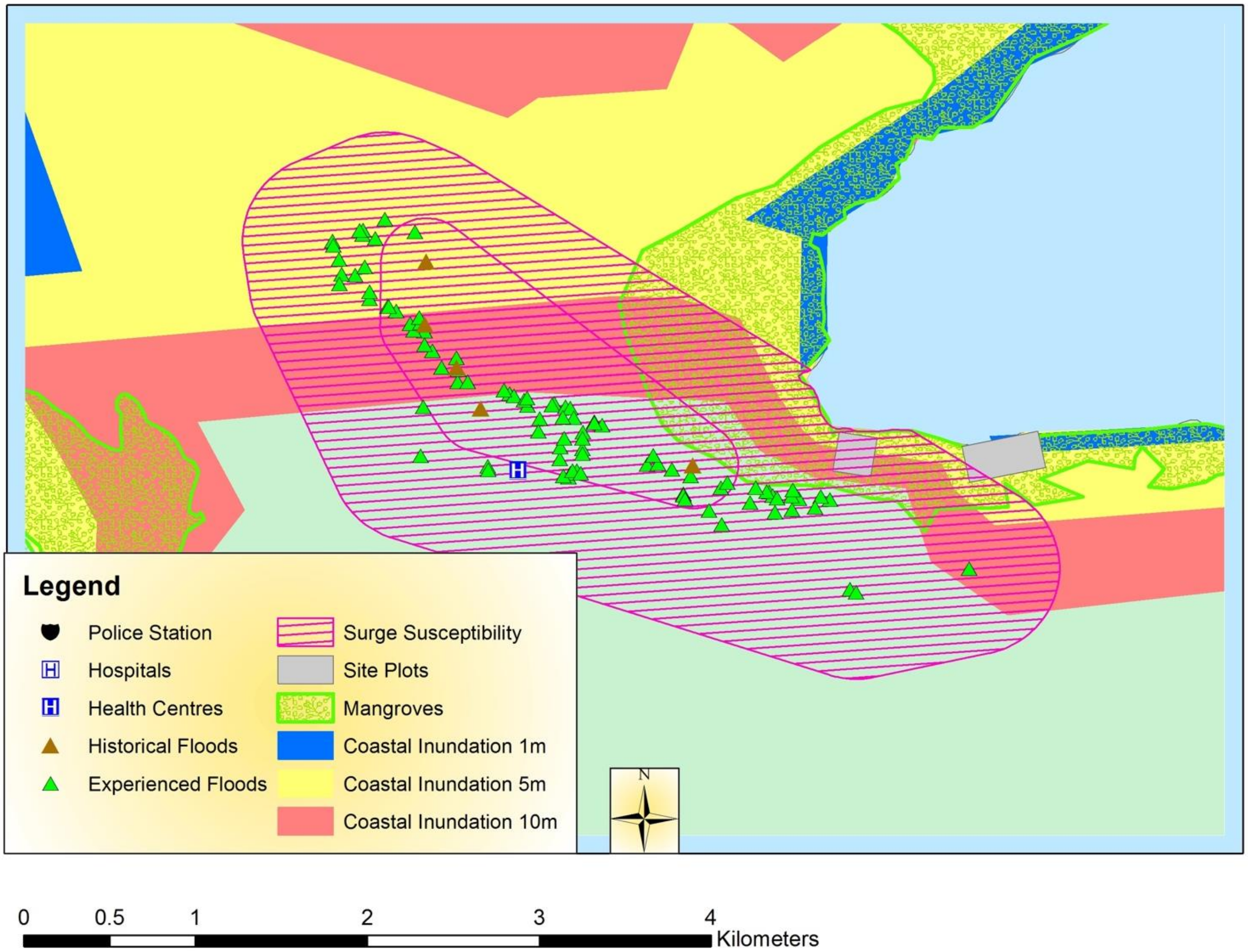


Figure 58: Hazard map for a section of Portland Cottage, historical floods data from WRA, and experienced floods (this study) and surge susceptibility.

Salt Marsh

Socio-Economic

Socio-Economic Context

The Salt Marsh community is located along the island's northern coastline and is characterized by lower levels of social and economic blight than Portland Cottage. Only 21% of household heads are unemployed while 19% have no formal education (SDC 2019). Field data was collected from a sample of 85 respondents within the community. Although this data was not specific to household heads, majority of respondents (48.2%) have Secondary School education and only 7.1% have University level education. About 24.7% have less than secondary education. There was no statistically significant difference between gender and education level.

Primary data further revealed that the main household income is through self-employment (44.7%) followed by employment in the private sector (41%). Although remittance as a source of income for 4.7% households, it is possibly an important additional source of income for 28.2% of households who reported that they received remittances in the last 6 months[3]. For the 78 respondents who responded to whether the households were able to save from their last income, the results show majority (51.3%) of households said yes. Still, a large percentage (48.7%) were unable to do so which could be a result of the disparity between income and expenses.

Most of the homes (81%) are owned, according to the respondents. However, in terms of land tenure, 51.8% owned the land, while a notable percentage (25.9%) were squatters. This is in keeping with secondary data which shows that most households, though a much lower percentage (67%) owned the buildings in which they lived and a large percentage (42%) owned the land suggesting that there might be squatters (SDC, 2019).

Majority of the houses of the sample population (72%) are constructed from concrete and blocks. This is in keeping with the secondary data which reported eighty percent (80%) of the homes are constructed from concrete and blocks (SDC 2019).

Additionally, most households had access to electricity. There are high percentage of households who have access to piped water and only 7% of the homes use pit latrines (SDC 2019), which also supports the primary data collected which revealed that 78.8% have water piped into their dwelling and only 9.4% used pit latrines.

Vulnerability to Coastal Flooding

Exposure

Like Portland Cottage and Bogue, the low-lying coastal topography positions the community of Salt Marsh as highly exposed to the effects of coastal inundation from storm surges and other environmental changes which may occur from the impacts of hydrometeorological hazards. While several tropical storms and hurricanes have affected the island and, by extension, the Salt Marsh community, the history of devastation appears to be less severe in Salt Marsh when compared to Portland Cottage. Nevertheless, exposure to these events places the population and infrastructure at risk. The community boundaries encompass both high and low elevation dwellings and several of the structures are located along the coastline. Like the other two locations, sections of the Salt Marsh mangrove community have been cleared for construction of homes and other infrastructure and this may result greater levels of hazard exposure. Figure 59 illustrates the exposure of the households surveyed to the type of coastal inundation which may occur during a storm surge. The figure indicates obvious differences in the location of these

[3] Data was collected in May 2018

dwellings relative to the mangroves community. While some are possibly sheltered by extensive mangrove forest, other dwellings are much more exposed. Such patterns may indicate important micro-scale variations that may have implications for overall levels of vulnerability.

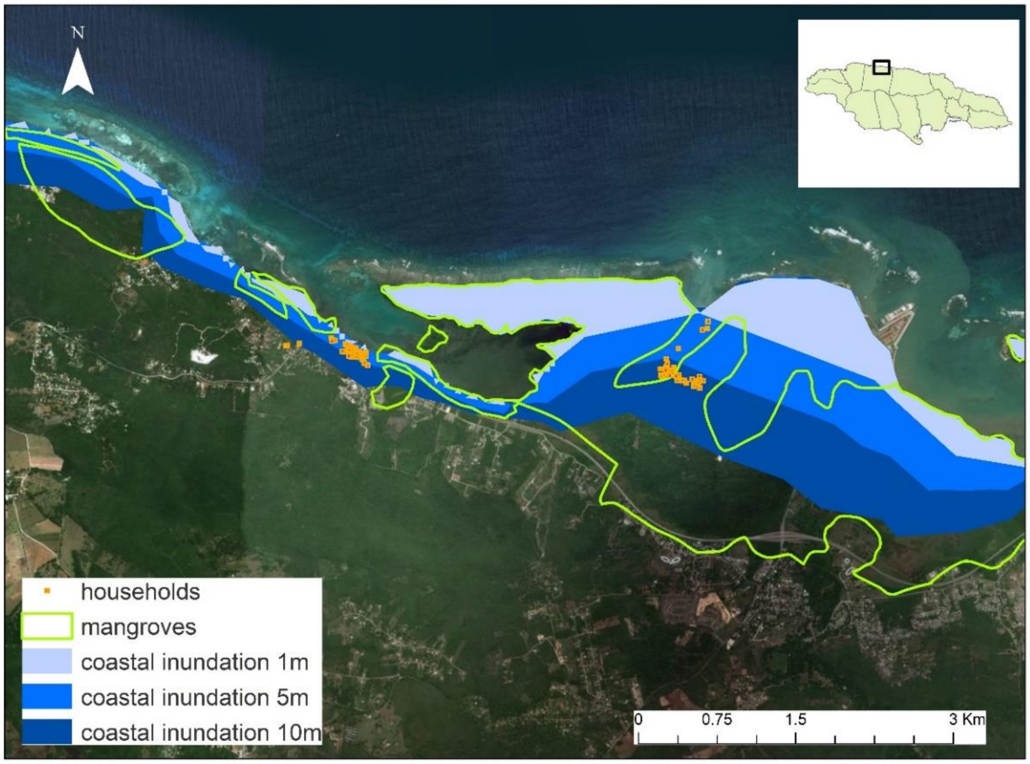


Figure 59: Map showing the exposure of the households surveyed to the type of coastal inundation which may occur during a storm surge.

Sensitivity

Given the spatial variations in the location of dwellings, it can be assumed that differential exposure may potentially influence levels of sensitivity. In addition to data derived from inundation models, the experience of flooding in the community was directly assessed through resident's historical accounts. Approximately 34% of respondents reported an experience with flooding while living in the community. Of this proportion, the most commonly cited impacts involved the disruption of routine activities such as work (50.0%) or school attendance (44.8%) (Table 16). Destruction of equipment, crops or livestock was far less commonly cited when compared to Portland Cottage, the other primarily residential site. Permanent or temporary relocation was also not a common experience among residents at this site.

Table 16: Nature of flood impacts represented as a percentage of the households that reported experiences with flooding in the community.

Impacts of flooding	n	% of households that experienced impact
Children could not attend school	8	44.4
Could not attend work	9	50.0
Injury to yourself/family members	1	5.6
Destroyed/damaged livelihood equipment (e.g. boats)	1	5.6
Destroyed/damaged crops and livestock	1	5.6
Had to relocate permanently	1	5.6
Had to relocate temporarily	8	44.4
Other	5	27.8

Adaptive Capacity

While having higher levels of educational attainment than Portland Cottage, the Salt Marsh community could still be considered as having relatively low levels of educational attainment. Approximately 9% of the individuals residing in the households surveyed attained tertiary level education – a proportion that closely approximates national levels of 8.4% (World Bank 2010). Unemployment rates approximated 16 % and may also be considered to align closely with national estimates.

Reported income levels, for the month prior to the survey, were generally low as mean income approximated JM$29,603 (s.d.= 48170.64, n=122) and median income was JM$16,150. Given the high standard deviation, which reflects significant variability in the data, the median potentially captures estimated earnings more accurately than the mean. Approximately 47% stated that they were able to save from last month's income and 12% indicated that they had outstanding loans. The fact that several of the respondents had relatively favourable debt profiles but unfavourable savings profiles indicates the existence of a potentially compromised adaptive capacity. About 28% of households reported that they received remittances during the previous month, and this may potentially serve to enhance their adaptive capacity. Adaptive capacity was however constrained by the fact that none of the sampled households has insurance which protected them from flooding. Additionally, a significant majority of households (80.0%) stated that no measures were taken to mitigate against future effects of flooding (Figure 60).

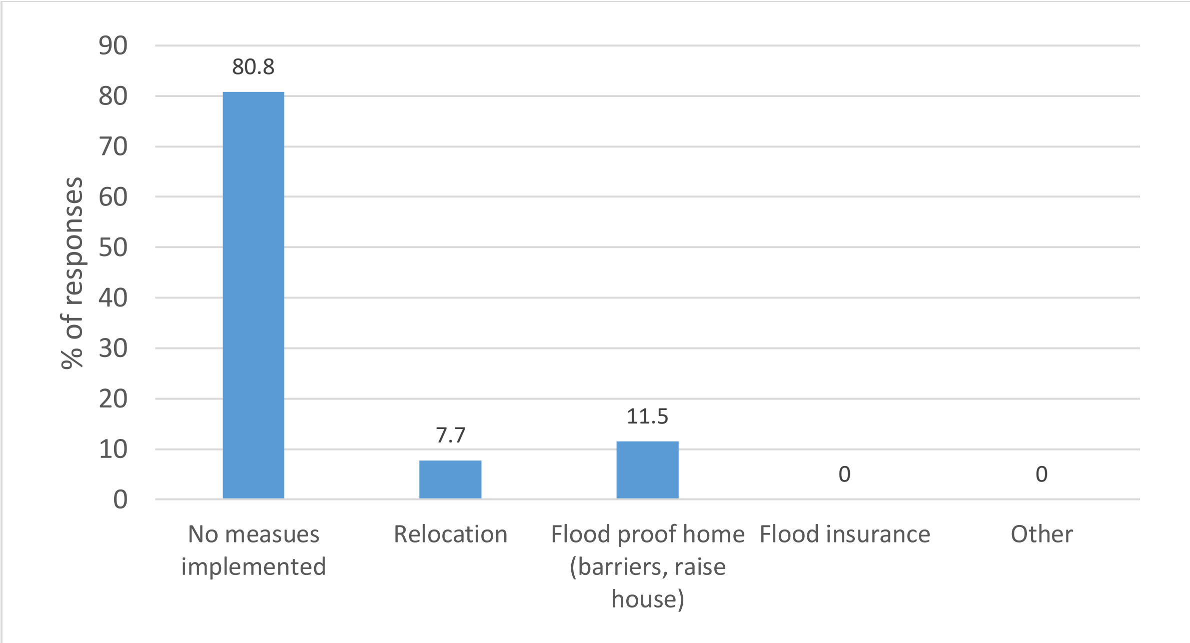


Figure 60: Measures implemented to reduce impact of future flood events.

Ecosystem Services Provisions

The survey did not reveal many fisher folks. Only 14 (16.7%) of the respondents said that there were fishermen and only 6 of these respondents reported that fishing was done in the mangrove, mainly for domestic use and to a lesser extent commercial sale.

These numbers are too small to draw any real conclusion and as such it is recommended that interviews or focus groups may be conducted to target specific groups such as fishermen. Still, oysters, shell, shrimps and crabs are some of the other catch extracted from the mangrove. It is therefore not surprising that majority (95.3%) of the respondents stated that do not earn any other income or livelihood from the mangrove.

While it was illustrated that the community recognised several benefits of mangroves, the most important as reported by 50% or more respondents said that mangroves provided shoreline protection and wildlife habitat (Figure 60). These benefits might be particularly important to community members who have been affected by coastal flooding or have interest in ecotourism.

It is also possible that these benefits may be of more indirectly valuable to community members. Still, it shows that community members are aware of the importance of mangroves to the ecosystem.

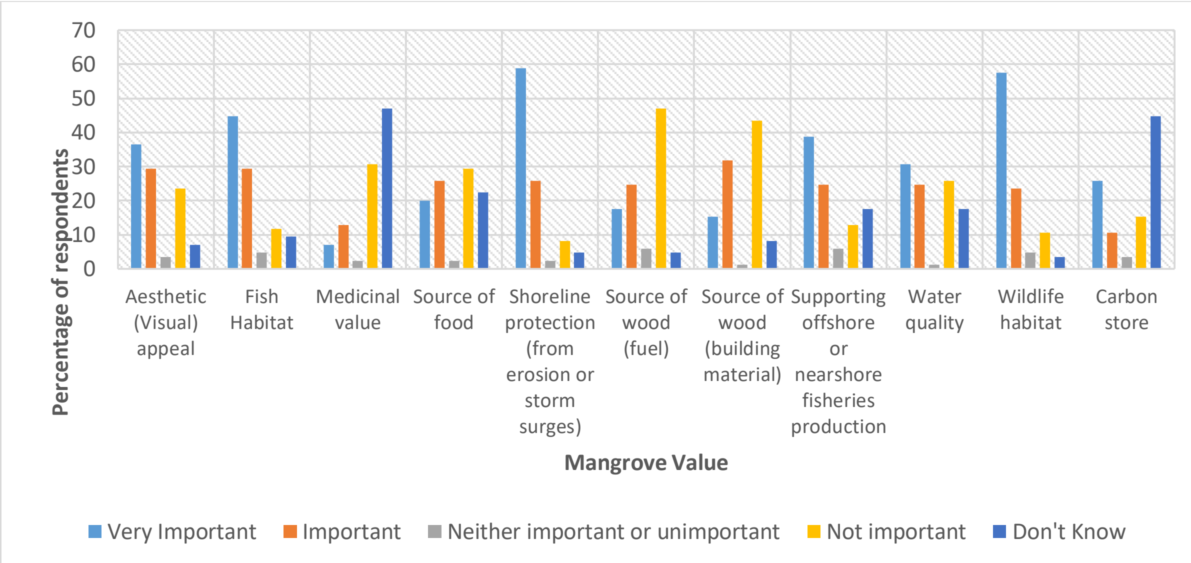


Figure 61: The Value of Mangrove to Community Members of Salt Marsh.

Issues Affecting Mangrove Services

In Salt Marsh, 46% of the respondents reported a decrease in the mangrove forest (Figure 62). There was no statistically significant relationship between gender and changes observed in the mangrove in the last 10 years.

A qualitative look at the reasons for these changes revealed that majority of the respondents (24 respondents) attributed it to the cutting down of trees particularly for housing development.

Illegal logging and clearing of the forest might be linked to housing development as 29 (34.5%) respondents reported that mangrove was removed for the construction of homes. Further, 31.8% of respondents said that illegal cutting/clearing and illegal logging (20% of respondents) had a big impact on the mangrove forest in the community. Still, a noteworthy percentage of respondents (38.8%) believe that illegal logging does not take place in the mangrove forest which may be linked to a decrease in these activities over the years or possible lack of knowledge and awareness. A few of the respondents cited pollution as a cause of this decrease.

Only 18 (21.2%) of the respondents said they were aware of illegal activities in the mangrove with most (11 and 10 respectively) stating that illegal logging and garbage/solid waste disposal was being carried out. Other activities reported were, illegal fishing and sewage waste. Waste disposal was reported as having a big impact on the mangrove forest by 31.8% of the respondents.

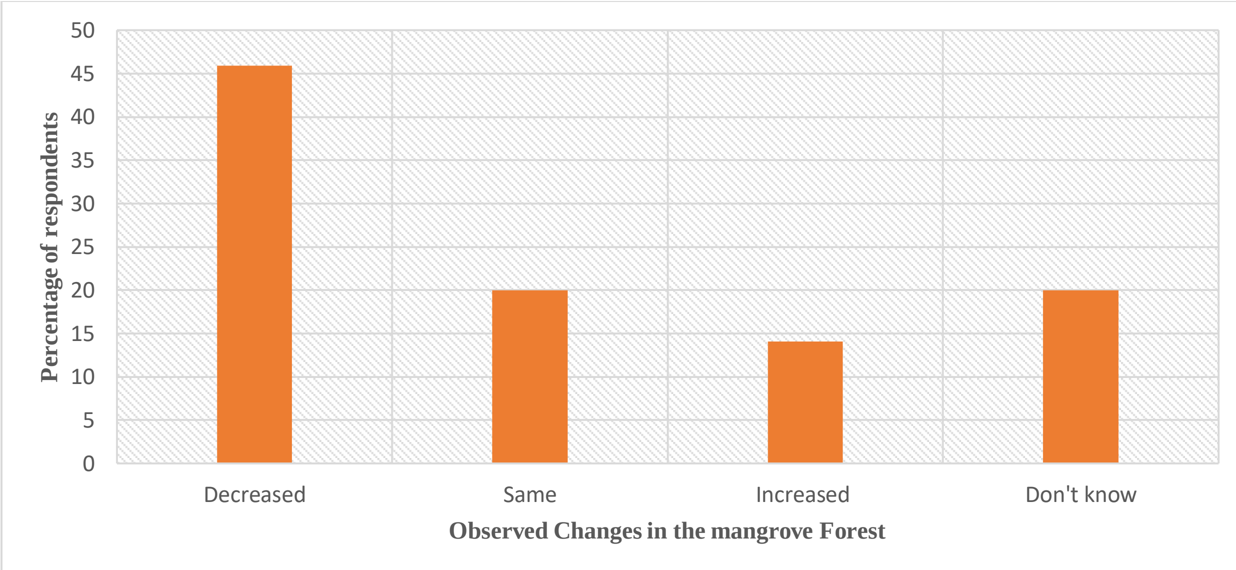


Figure 62: Perceived changes in mangrove forest in Salt Marsh for the last 10 years (2008-2018).

Mangrove Management and Restorative Efforts

Majority (93%) of the respondents were unaware of mangrove restoration activities within Salt Marsh, which may explain the general lack of knowledge and awareness about mangrove management in the area as shown in Figure 63. Most respondents believe that there is no management, while others stated they don't know or that it is not managed well (Figure 63). Respondents who believed that the mangrove is managed, they stated the government (18.8%), the community (9.4%) and private organisations (2.4%) are involved in the management.

Figure 63: Perception on how well mangrove forest is managed in Salt Marsh.

Opportunities for Private Public Partnership

Respondents in Salt Marsh show a strong willingness to become involved in mangrove restoration activities with majority (67.1%) expressing that interest and only 24.7% and 8.2% saying no or don't know respectively. There was no statistically significant relationship in looking at the data by gender.

However, like Portland Cottage majority of the residents (94.1%) are not currently involved in mangrove restoration activities with any statistically significant difference between males and females, which again highlights the lack of information disseminated to the community members as it relates to the importance of this ecosystem and its restoration. There is therefore an opportunity and a need to involve the community into such activities that may not only minimize the current negative impacts on mangrove forest, but also promote its growth and restoration.

Ecological

Mangrove Biometrics

Mangrove species composition and relative abundance (for diversity)

Rhizophora mangle (red mangrove) was the dominant species found within the Salt Marsh study location. This was also the dominant species found previously in this area by McDonald-Senior (2000) as well as Chin (2014). *Avicennia germinans* (black mangrove) as well as *Laguncularia racemosa* (white mangrove) were also identified within the study location with *L. racemosa* only being present at Site 2. The coastal associate species, *Thespesia populnea* (seaside mahoe) was observed at both sites. Mean diversity excluding, the non-mangrove species for Site 1 was 0.47 while Site 2 had a diversity of 0.27. Again, this low diversity is expected as mangroves tend to grow in relative monospecific stands within a forest preventing succession and species accumulation.

Tree density varied between both sites with Site 1 having 0.11 m^{-2} red mangroves and 0.07 m^{-2} black. Site 2 had 0.12 m^{-2} red, 0.02 m^{-2} black and 0.008 white mangroves (Figure 64). Red mangroves as expected had higher densities compared to the other species. The tree densities for red mangroves fall within the range of those recorded by Chin (2014) for her Falmouth location. She recorded 0.12 m^{-2} red. Black and white densities for the current study were lower than those recorded by Chin (2014), 0.36 m^{-2} black and 0.15 white mangroves. This difference may be due to the difference in the transect length where Chin sampled 195 m versus 50 m used in this study as well as the difference in the orientation of transects between both sites.

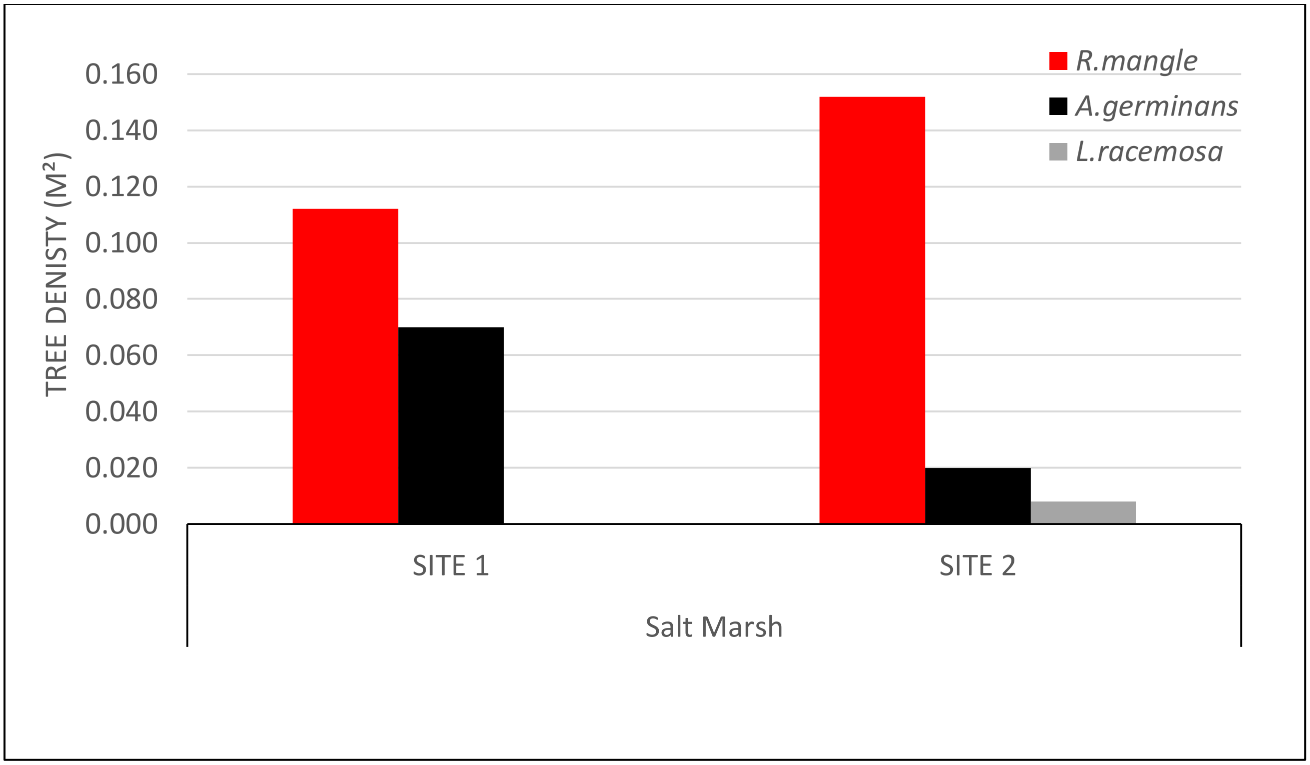


Figure 64: Overall tree density at both sites in Salt Marsh.

Mangrove Trunk Diameter

DBH values at Site 1 ranged from a low of 21 mm to a high of 133 mm (mean 62.59 ± 3.35 SE for *R. mangle* and 15 mm to 164 mm (mean 80.84 ± 6.11 SE) for *A. germinans*. Similar mean diameter value (67.45 mm) were recorded by Chin (2014) in her study of the Falmouth mangroves.

Mean DBH values fluctuated along the transect (Figure 65). *R. mangle* and *A. germinans* DBH values decreased towards the landward end of the transect while *L. racemosa* only present between 20 and 40 m, began to increase towards the end (from 50 mm to 94 mm). As indicated before DBH generally increased towards land as the trees landward colonised first. The trend seen by *L. racemosa* was therefore expected.

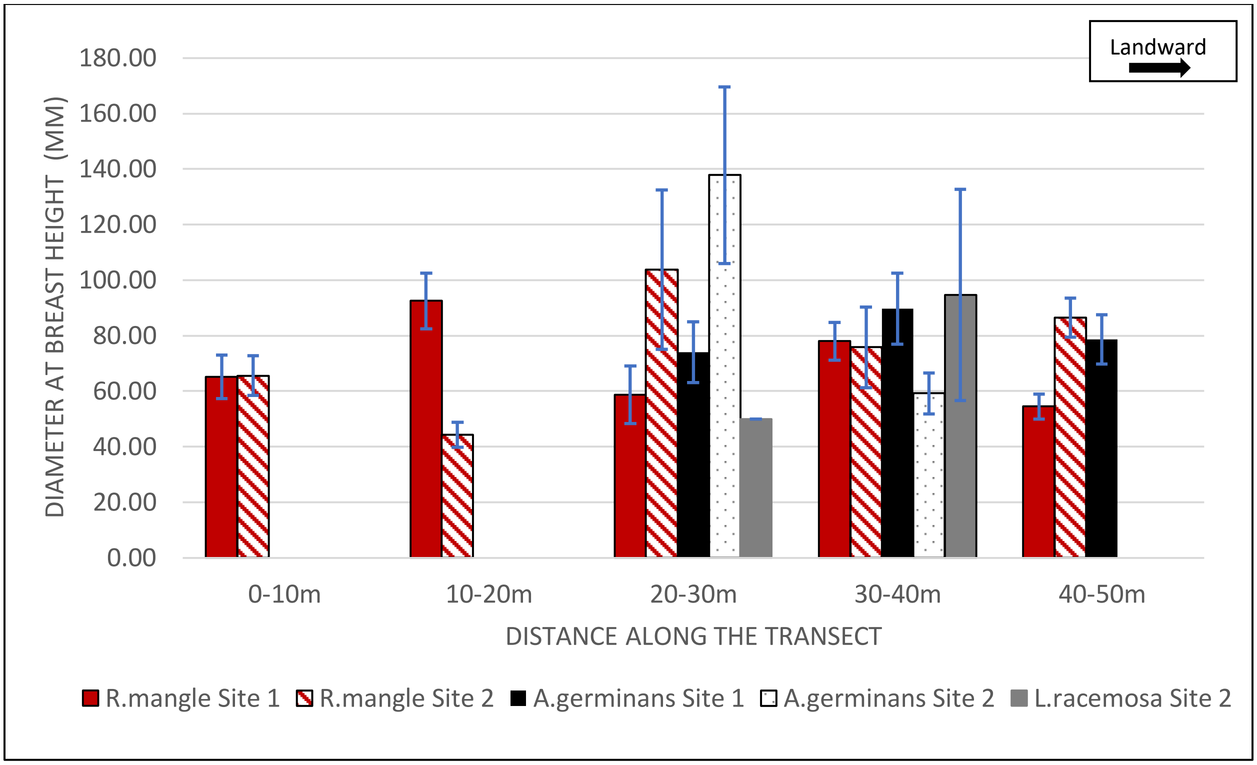


Figure 65: Mean Diameter at Breast Height (with SE) along the transects at Site 1 and 2, Salt Marsh.

Mangrove Height and canopy width

The heights of the trees recorded along the transect at Site 1 ranged from 2.0 m to 12.0 m (mean 6.48 ± 0.25 SE) for *R. mangle* and 2.8 m to 13.5 m (mean 7.24 ± 0.40 SE) for *A. germinans*. While at Site 2, heights of individual trees ranged from 2.0 m to 12. 2 m (mean 7.48 ± 0.25 SE) for *R. mangle,* 2.8 m to 13.5 m (8.0 ± 0.42 SE) for *A. germinans* and 8.5 m to 10.8 m (mean 10.20 ± 0.57) for *L. racemosa.*

Mean tree height (Figure 66) fluctuated along the transect towards land. At site 1, red height increased from 5.6 m between 0-10 m distance along the transect to 7.10 m between 10-20 m distance then declined to 5.1 between 20-30 after which it increased to 7.4 m between 30-40 m and finally declined to 6.83 m between 40-50 m.

A. germinans when identified along the transect had heights increasing from 6.0 m between 20-30 m to 7.8 m between 40-50 m. Black mangrove height is expected to decline after 40-50 m since soil salinity is expected to increase and begin to cause stunting as the plants use the energy for growth to maintain salt concentrations. Trees were overall taller at Site 2 than Site 1. Average *R. mangle* decreased from 8.9 m between 0-10 m distance along the transect to 7.71 m between 10-20 m. It then increased to 9.48 m, decline to 8.1 and then increased to 8.8 m.

The pattern of tree height decreasing with distance is similar to those patterns recorded by Chin (2014) in the Falmouth forests, which showed an overall decline in tree height towards the land.

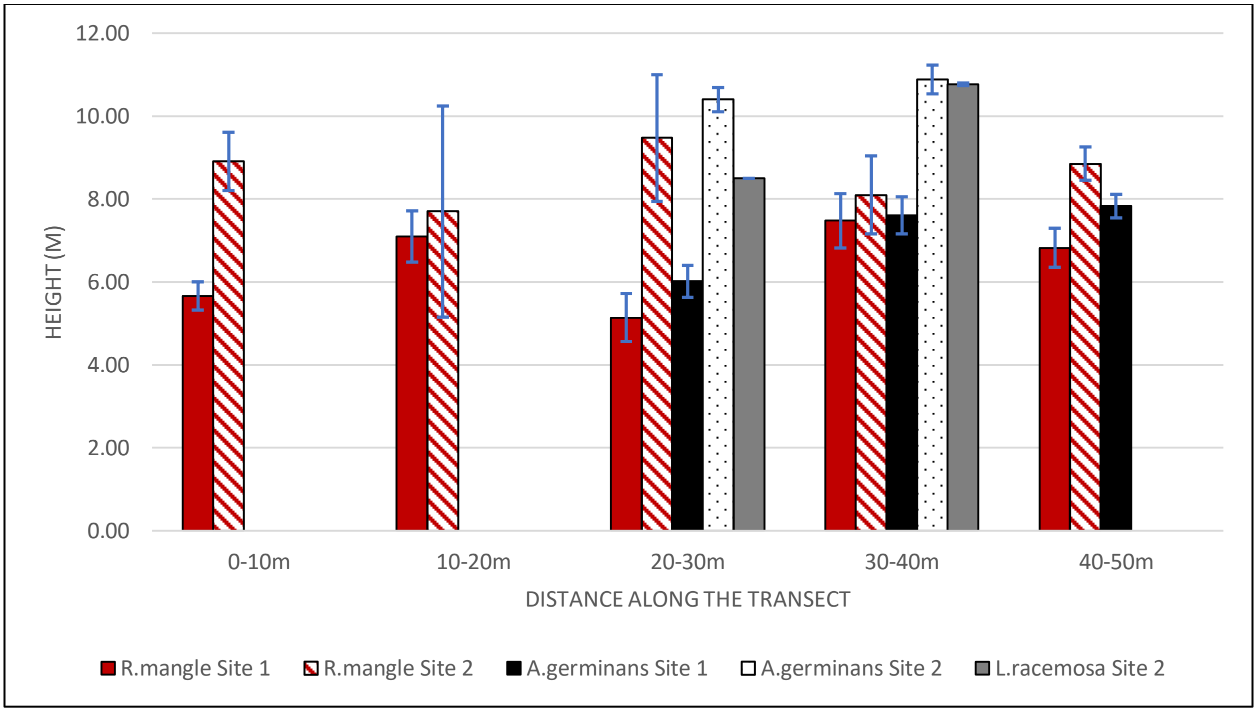


Figure 66: Mean Height (with SE) along the transects at Site 1 and 2, Salt Marsh.

Canopy width values ranged between 0.3 m - 5 m (mean 2.25 ± 0.16 SE) for *R*. mangle and 0.1 m – 4 m (mean 1.69 ± 0.22 SE) for *A*. germinans at Site 1. Site 2 had values ranging between 0.1 m -7.3 m (mean 2.27 ± 0.16 SE) for *R. mangle* and 0.1- 4.2 m (mean 1.60 ± 0.18 SE) for *A. germinans* and 0.5-5 m for *L. racemose* (Figure 67).

Mean canopy width values fluctuated along the transect. At site 1, the mean R. mangle canopy width increased from 2.2- 2.78 m, then decreased to 1.95 between 20-30 m. It then increased to 2.5 m between 40-50 m. The smallest (0.5 m) and largest (5.6 m) mean canopy width was recorded at Site 2 between 20-30 m for *L. racemosa* and *R. mangle* respectively.

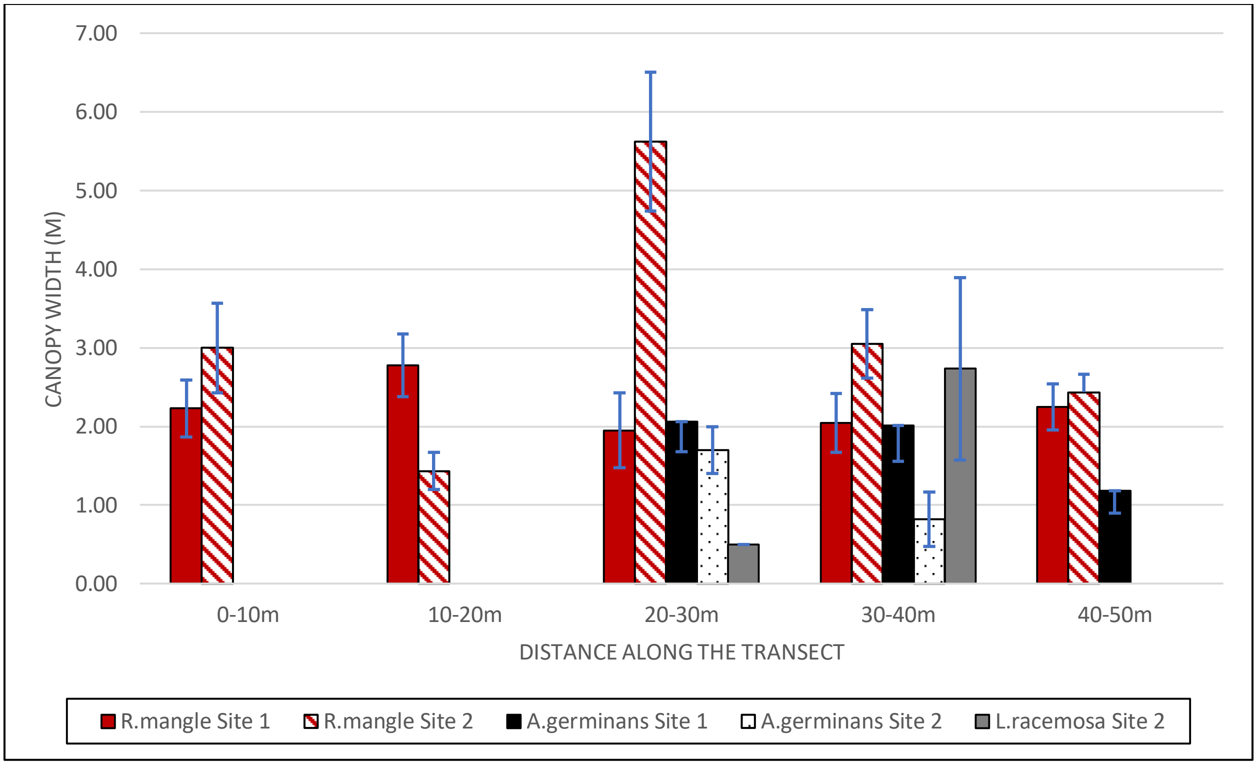


Figure 67: Mean Canopy width (with SE) along the transects at Site 1 and 2, Salt Marsh.

Prop root/aerial root network

Prop root densities fluctuated along the transect but with a generally decreasing trend. Low prop root density category values decline along the transect from 19 roots m^{-2} at the start of the transect to 8 roots m^{-2} at the end of the transect. Smallest low prop root density (7 roots m^{-2}) was located at 20-30 m.

Medium prop root density category values decreased from 32 roots m^{-2} between 0-10 m to 16 roots m^{-2} between 20-30 m. It then decreased between 30-50 m towards the end of the transect to 23 roots m^{-2}.

High prop root density category values ranged from 67 roots m^{-2} between 0-10 m and 49 roots m^{-2} between 10-20 m. Representation of the high prop root density category was absent between 20-30m. The high prop root density reappeared at 30-40 m with 36 roots m^{-2} but ended with 34 roots m^{-2} between 40-50 m (Figure 68). Prop root densities were expected to decrease with increasing distance from the water's edge towards land.

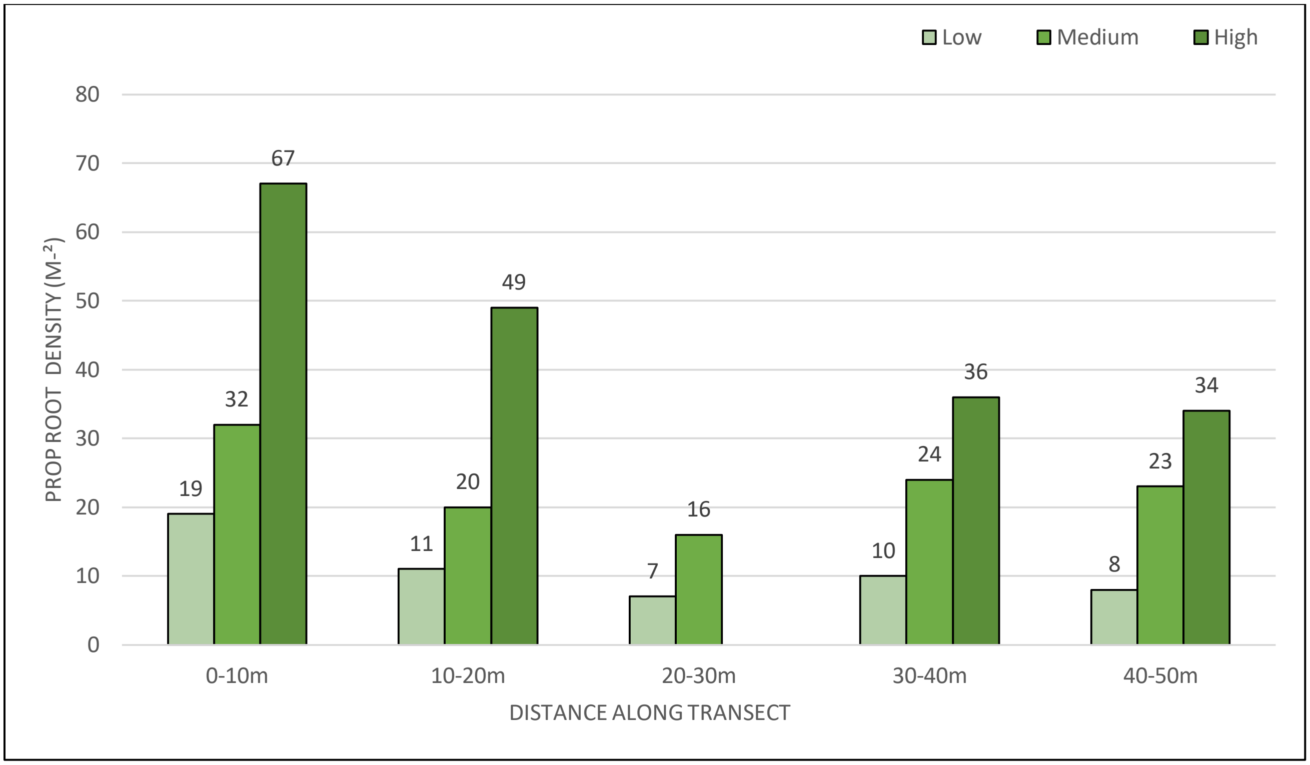


Figure 68: Prop root densities representing low, medium and high root densities along the transect at Site 1-Salt Marsh.

Pneumatophores were absent at the start of the transect (between 0-10 m). Low pneumatophore density category was the only category present between 10- 20 m with 26 pneumatophores m^{-2}. Low pneumatophore density values decreased to 8 pneumatophores m^{-2} between 20-30 m then drastically increased to 80 pneumatophores m^{-2} before decreasing to 74 pneumatophores m^{-2} at the end of transect.

Medium and High pneumatophores density categories started between 20-30 m with medium density values of 36 pneumatophores m^{-2} to 224 pneumatophores m^{-2} then 165 pneumatophores m^{-2} at the end of the transect. Within the high pneumatophore density category, values ranged from 287 pneumatophores m^{-2} (at 20-30 m) and 379 pneumatophores m^{2} (at 40-50 m). The greatest high density (586 pneumatophores m^{-2}) was recorded at 30-40 m (Figure 69).

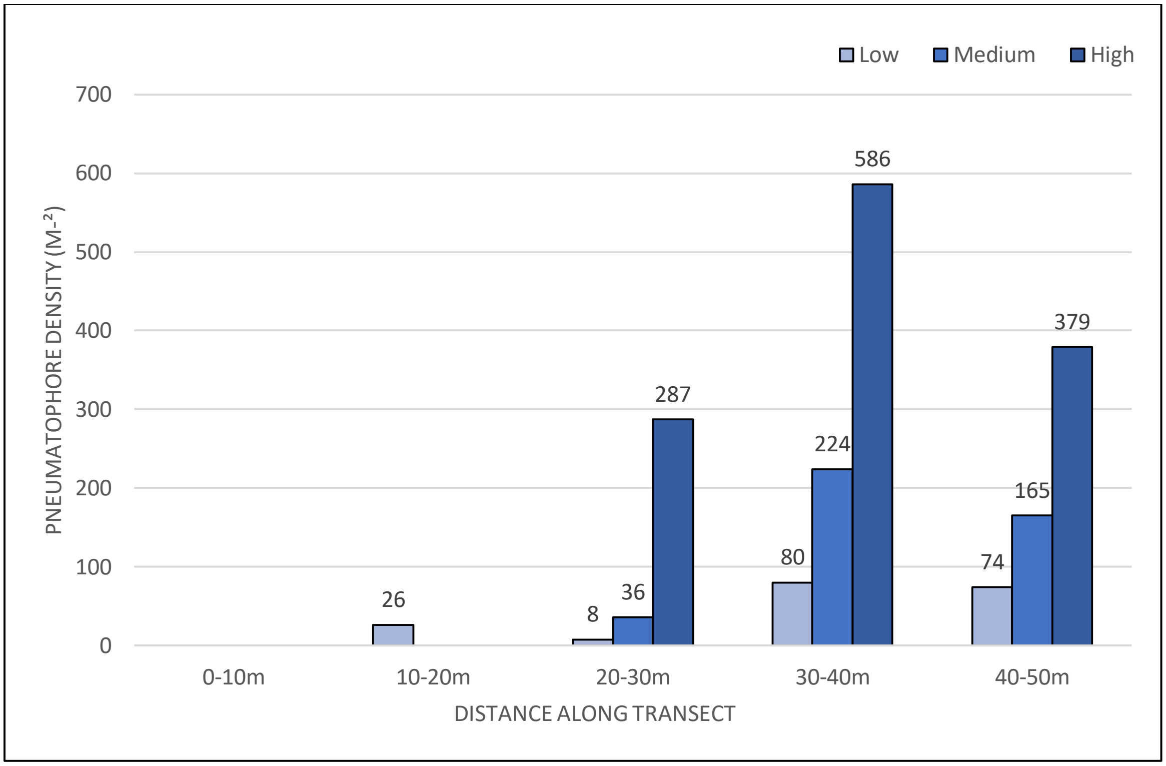


Figure 69: Pneumatophore density representing low, medium and high root densities along the transect at Site 1, Salt Marsh.

Low prop root density category values decline along the transect from 30 roots m^{-2} at the start of the transect to 2 roots m^{-2} between 30-40 m and then increased to 19 roots m^{-2} at the end of the transect (Figure 70). Medium prop root density category values decreased from 42 roots m^{-2} between 0-10 m to 8 roots m^{-2} between 30-40 m. It then increased to 33 roots m^{-2} at the end of the transect (40-50 m).

High prop root density category values increased from 79 roots m^{-2} between 0-10 m to 182 roots m^{-2} between 10-20 m, then drastically decreased to 25 roots m^{-2} between 20-30 m. Density values then increased to 53 roots m^{-2} between 30-40 m before decreasing to 51 roots m^{-2} at the end of the transect.

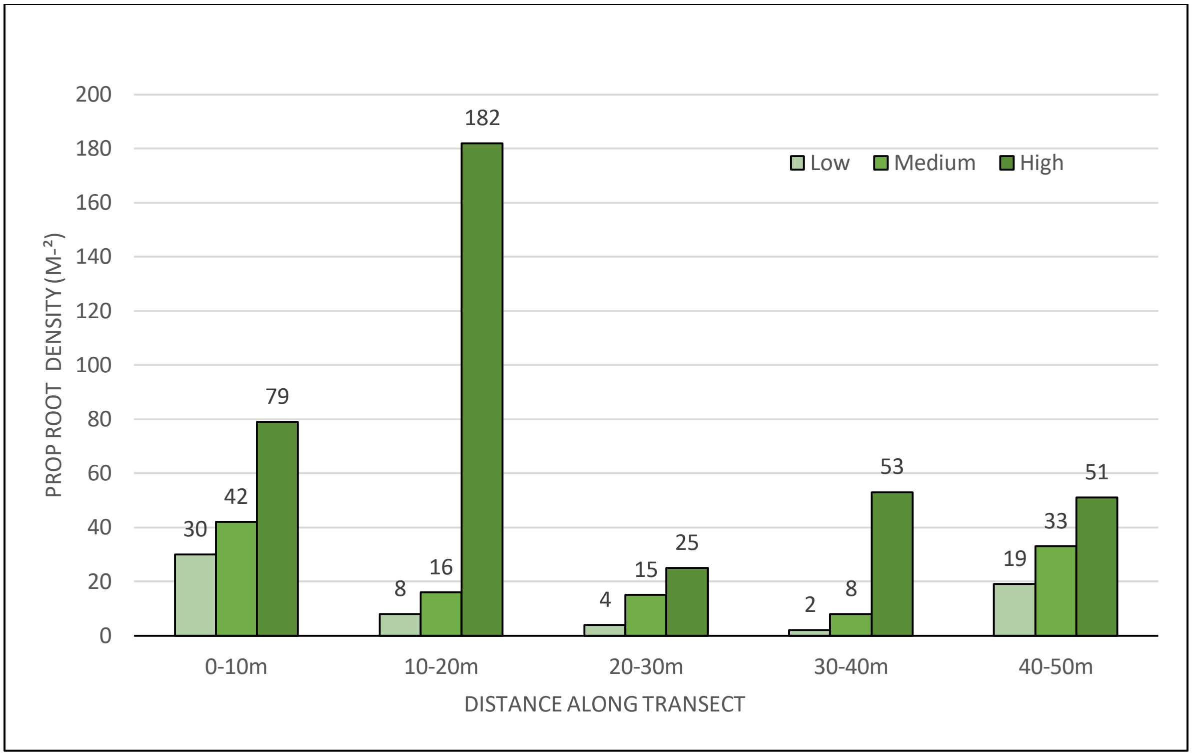


Figure 70: Prop root density representing low, medium and high root densities along the transect at Site 2, Salt Marsh.

Pneumatophores were only present between 30-40 m along the transect. Densities ranged from a low of 88 pneumatophores m^{-2} to 176 pneumatophores m^{-2} then finally to 294 pneumatophores m^{-2}. Pneumatophore present at 30-40 m along the transect corresponds to the presence of the white trees between 20-40 m (Figure 71).

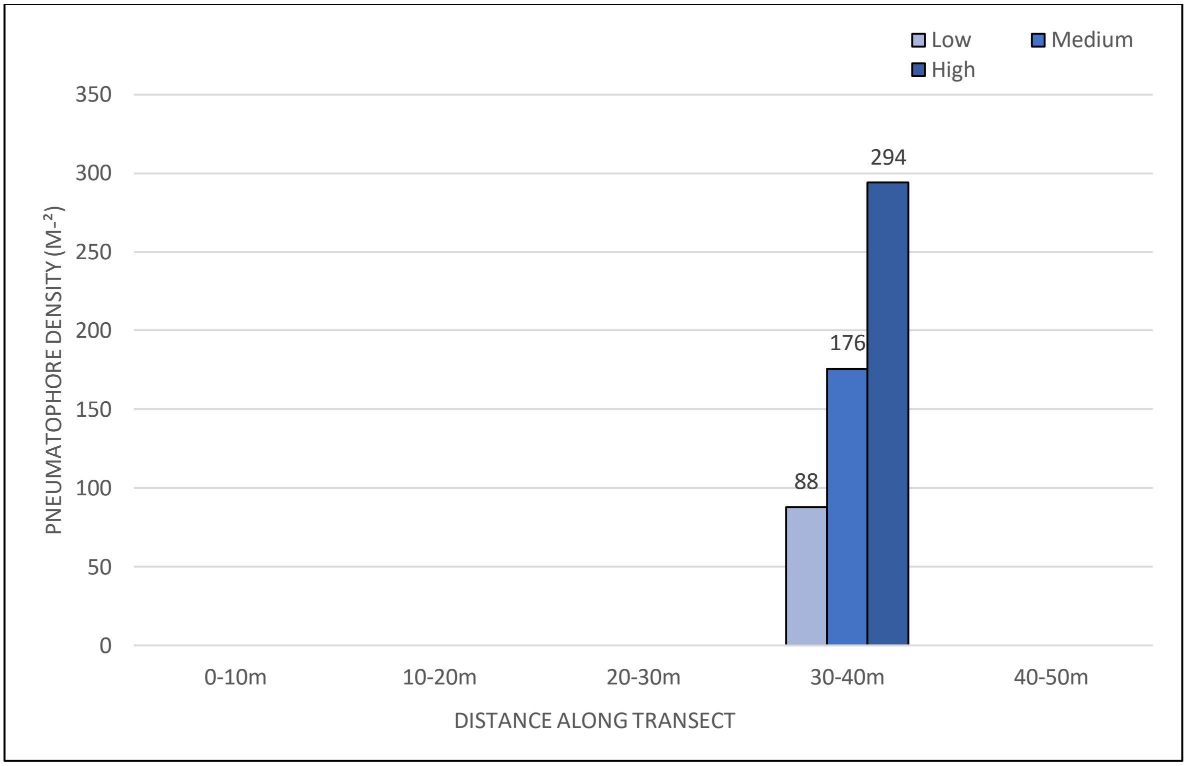


Figure 71: Pneumatophore density representing low, medium and high root densities along the transect at Site 2, Salt Marsh.

Based on Pellegrini et al. (2009) structural categories, the Salt Marsh area is a forest with intermediate structural development- DBH between 4.5 and 14.8 cm and mean height of the most developed trees between 5.7 and 13.7 m.

Ecosystem Services

The provisioning ecosystem service of mangroves whereby they create nursery habitat for fish which was explored through presence of fish larvae, yielded good results for this area. Eleven fish families were identified within the Salt Marsh study location. Site 1 (Figure 72) had 2 families, Atherinidae (5%) and Clupeidae (95%). *Jenkinsia lamprotaenia* was identified as a species belonging to the Clupeidae family. This family includes sardine, sprat, and small herring/ green fry. This is a minor commercial fish harvested for use as bait (Munroe & Priede, 2010).

Site 2 (Figure 72) had a larger number of families (11). 58 % of the species found, belonged to the Labridae family, which includes the Dwarf wrasse (*Doratonotus megalepsis*), 7% belonged to the Blennidae family which includes species such as *Hypleurochilus multifiliis* (Featherduster blenny), and 1% belonged to the Eleotridae family which includes *Erotelis smaragdus*(Emerald sleeper). These species are not considered of high commercial value.

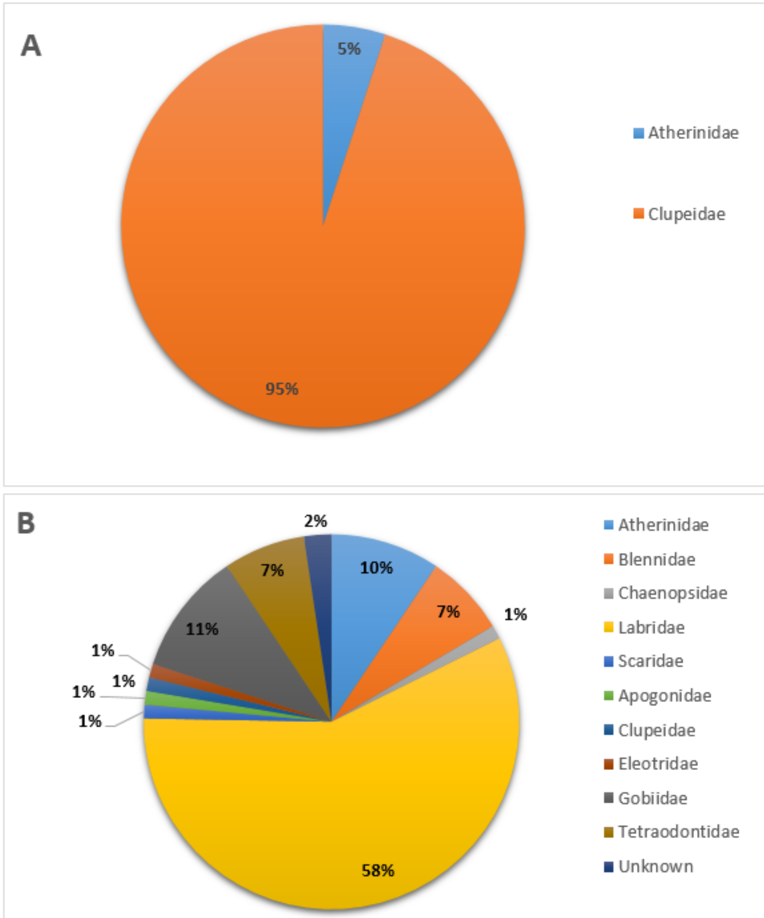


Figure 72: Percentage contribution of each family at Site 1 (A) and Site 2 (B), Salt Marsh.

Physical

Elevation and Topography

Elevation determined by trigonometry is presented for the two transects studied at Salt Marsh. Salt Marsh has a higher elevation seaward due to the geomorphology.

The elevation along the transect for Site 1 (Figure 73) ranged from 0.03 m below MSL in a depressed basin landward (to the right) to 0.07 m above MSL. The slope is very gentle seaward. This elevation is attributed to abundant sediment being provided by the reef and sea grass beds at this locality, in conjunction with previous storm events that have transported sediments inland. Furthermore, sediments are also transported by longshore drift in some sections adjacent to Site 1, and the peninsula is also fault controlled. This transect was depicted by a pure sandy (carbonate) section seaward of the transect and less carbonate sand and mud stained sediments landward. The terrain at Site 1 causes a break in the coverage of *R. mangle* at the highest elevation between 23 and 28 m.

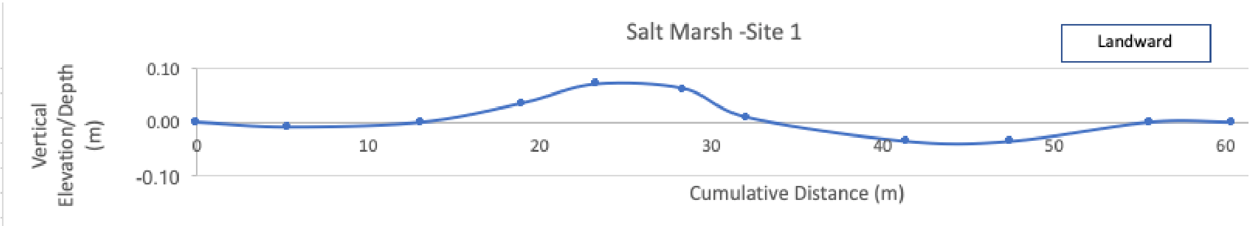


Figure 73: Terrain elevation variability along the transect (Site 1, Salt Marsh), zero represents MSL.

The terrain at Site 2 (Figure 74) has less undulating variability seaward, but the transition from sandy shoreline to peat and darker soil toward the interior is also shown here. The elevation along the transect ranged from 0.07 m below MSL to 0.07 m above MSL, but with more changes in the elevation and the trees that occupy the landscape. *R. mangle* occupies the seaward extent and the areas with the lowest elevation between 30 and 50 m along the transect.

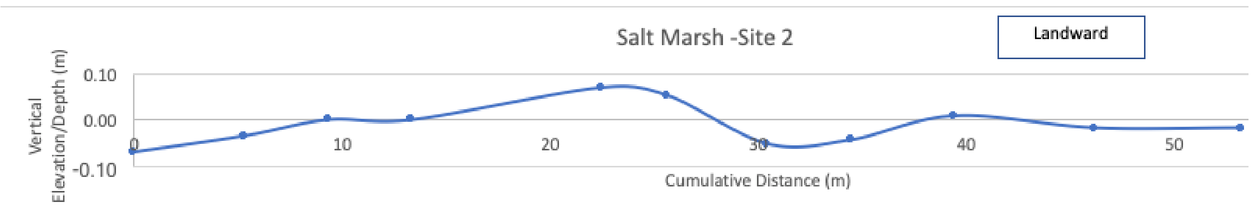


Figure 74: Terrain elevation variability along the transect (Site 2, Salt Marsh), zero represents MSL.

Elevation Change

The benchmark penetrated the substrate to depths of 3.4 m and 2.7 m for Sites 1 and 2, respectively. Elevation change ranged from -0.09 to 1.25 mm m^{-1}, with a mean of 0.50 mm m^{-1} ± 0.28 mm m^{-1} for Site 1, while ranging from -1.62 to -0.92 mm m^{-1} with a mean of-1.40 mm m^{-1} ± 0.18 mm m^{-1} for Site 2. This variability between Sites 1 and 2 are unclear but may be related to variability between the hydroperiod between the time of the capture of data.

Sediment and Litter Retention and Accretion

(Despite having the influence of the Martha Brae, there was no measurable vertical accretion at Site 1 (n=4) or Site 2 (n=4) over 3-month and 2-month periods, respectively. The horizon markers were still present during each visit which demonstrates that sediment supply was low at Salt Marsh during the period of study and erosion was not a factor. In the absence of vertical accretion, leaf litter was observed above the horizon markers and is expected to contribute to substrate vertical accretion under anoxic conditions. Leaf litter for Site 1 was higher ranging from 0.58 to 1.59 g than for Site 2 which ranged from 0.38 to 0.9 g. The variation from sites 1 and 2 is as a result of the variations with tree density and types. The areas of these plots had horizon markers that were partially wet and others that were on higher coarser-grained sand and lighter soil.

Horizontal Variation (progradation/retreat) of Mangrove Coastline

Small-scale urban sprawl along the road networks is seen extending from Falmouth (not shown on the map, but to the east of the sites). However, in one section (Figure 71) mangroves have been replaced by informal and formal residential settings and road networks. Along the peninsula where Site 1 is located, minor erosion is taking place following from the erosion of the sandy bay to the west and is likely driven by long-shore drift which is a factor in the formation of the peninsula. Further west along the peninsula (to the west of Site 1), long-term lateral accretion is observed (Figure 71). Both lateral erosion and accretion are seen at Site 2. The total length of accreted coastline is more (4.7 km) than the total length of eroded coastline (2.5 km). The total area accreted is 12 hectares at a rate of 2.1 km^2 yr^{-1}; whereas, the total area eroded is 8.7 hectares, at a rate of 1.6 km^2 yr^{-1}. Generally, in many sections there is an alternating pattern of erosion and accretion which may be explained by the behaviour of the currents as similar patterns are often seen on sandy coastlines (Edwards, 2018).

The long stretch (1 km) of erosion in the vicinity of the junction of Rodney Street and the North Coast Main Road network may be attributed to dumping with marl (saw the evidence in the field) of the land that was reclaimed. Additionally, across the bay on the landward side of the peninsula, a similar long stretch of erosion (0.8 km) may be linked to this reclamation activity, due to circulation of material (sediment) used in the reclamation across the bay.

Site 2 has more accretion and minor erosion occurring. This is very concerning as this area is the most sheltered and would not be expected to experience that kind of erosion as it is not affected by direct ocean currents.

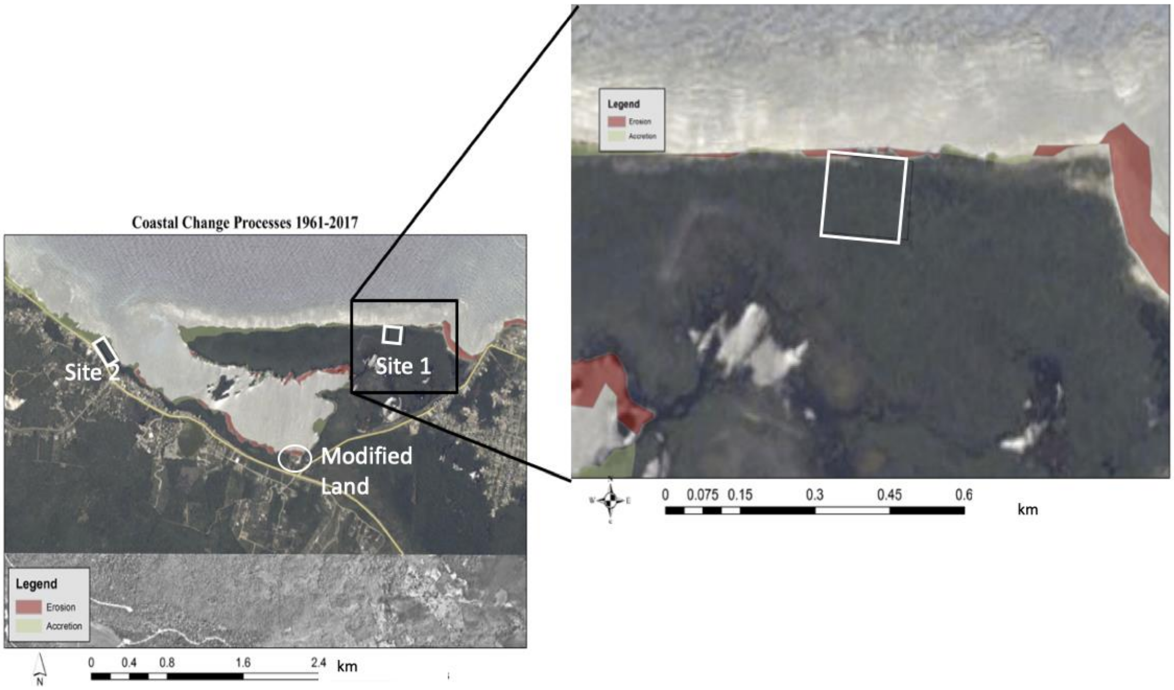


Figure 75: Spatiotemporal lateral erosion (red) or accretion (green) on the coastline, where mangrove trees occupation increases or decreases the lateral space it occupies. Longshore drift a coastal sedimentation process is a factor in the accretion of the peninsula.

Bathymetry

Salt Marsh Site 2 is having greater water depths (ranging from 0.4 to 3.8 m) than Site 1 (with water depths of 0.03 to 1 m), although some sections were not exactly accessible by boat because of the reef. Beyond the reef, water depths increased significantly (Figure 76).

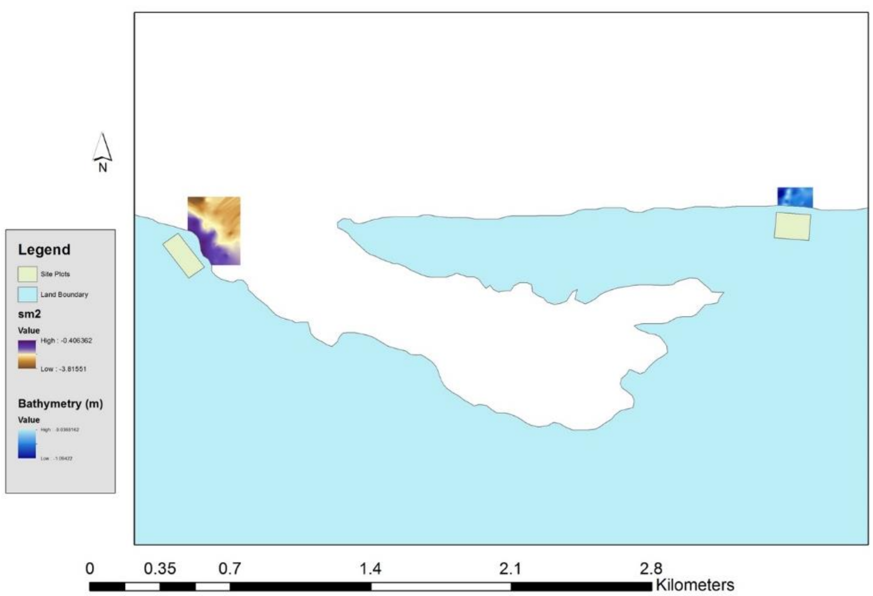


Figure 76: Bathymetry at Sites 1 (east) and 2 (west) at Salt Marsh, created by T. Edwards, 2019 using ArcGIS.

Wind, Wave Parameters & Attenuation

At Salt Marsh Site 1, wind velocities were reduced from 7.5 ms^{-1} to 3.4 ms^{-1} within the mangrove canopy, the reduction almost doubled within the mangroves (66%) compared to the reduction in wind speed outside the canopy (34%) (Figure 77). At Site 2 the wind speed varied from 6.9 ms^{-1} (seaward) to 4.1 ms^{-1} (landward) with a similar higher reduction within the canopy than outside (41 vs 12% respectively, Figure 77) albeit as a smaller rate. This lower rate may be as a result of a more sheltered setting at Site 2 and lower wind speeds to begin.

At Site 2 wave height mean reduction (80%) were higher than at Site 1 (66%) and maybe related to higher wave energies and depth at Site 2. Wave heights were reduced by less (34% and 29%) outside of the mangrove for Sites 1 & Sites 2 respectively (Figure 77). The rate of wave height reduction was considerably higher within the mangroves than outside at 0.003 m^{-1} and 0.008 m^{-1} for Sites 1 and 2. The values are lower per m at 0.002 and 0.001 for Sites 1 and 2 of Salt Marsh. This means that the larger the forest width the more attenuation of normal and storm waves will be possible as waves transition landward. Site 2 will therefore be able to attenuate bigger waves faster than site 1. Reduction of wind speed and wave energies outside of the mangroves are as a result of frictional forces determined by the physiography, morphodynamics of the sites and the fair-weather conditions experienced on the days of sampling.

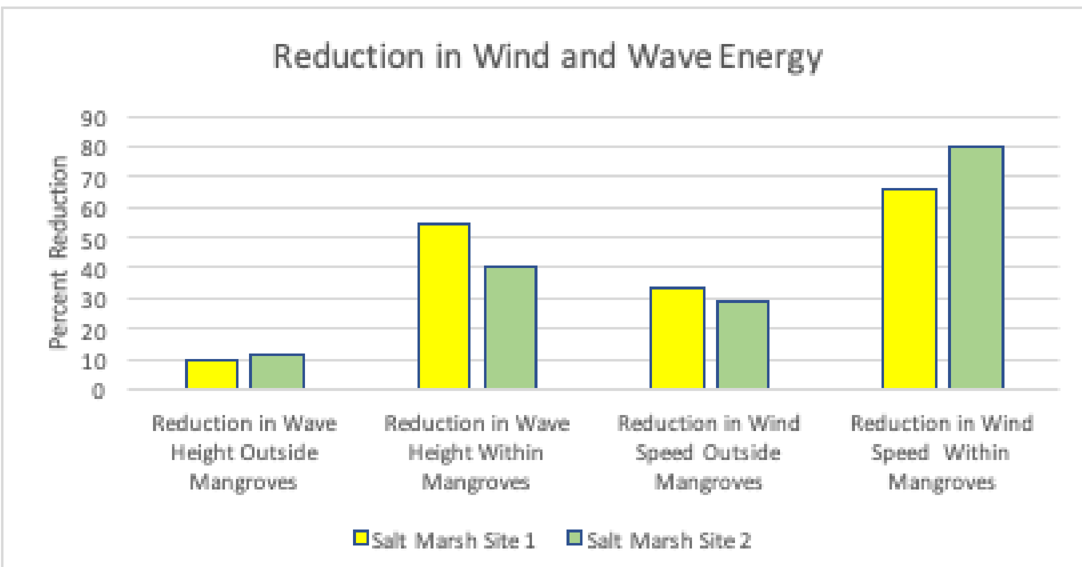


Figure 77: Percentage reduction in wind and wave energies outside and within the mangrove at Salt Marsh at fair-weather conditions, reductions are an artefact of restive forces by the physiography of the terrain with more retardation within the forest than outside. (Source: T. Edwards)

Substrate Constituents and Properties

Soil Organic content in the form of visible vegetation removed by % weight and vegetation digested by hydrogen peroxide % weight together is presented Figure 78. For Site 1 (n=5), the percentage weight of plant/animal (washable & digestible component) ranged from 1 to 88 %

with a mean of 20% and a standard deviation of 38 %. For Site 2, the percentage ranged from 20 to 83% (n=5) with a mean of 35% and a standard deviation of 27%. The percentages were much lower at this site than compared with other sites because of the composition of the substrate, which was very sandy with an abundance of skeletal and non-skeletal carbonate grains.

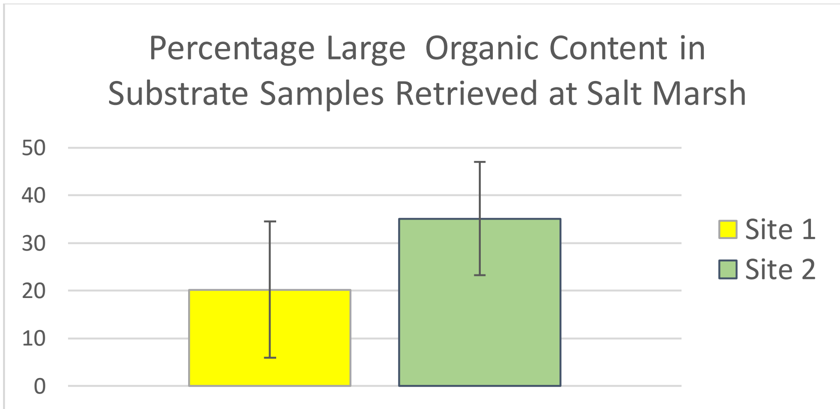


Figure 78: Mean plant percentage removed by handwashing together with percentage loss from hydrogen peroxide digestion of organic matter for each studied at Salt Marsh. The error bars represent standard errors of the mean (SEM) and are 14 and 12 percent respectively for Sites 1 and 2.

The remaining sediment after organic content removal plots as sand for both sites 1 and 2, except for one sample plotting landward as sand-silt-clay of Site 1 (Figure 79). The texture and composition at this site are evidence of a very productive coral reef and sea-grass system. The abundant carbonate sediment reduced the proportion of roots and vegetation matter within the substrate. It is however, unclear of the immediate and long-term effects of these coarse-grained carbonate sediments within this system at Salt Marsh as there is a threshold where sedimentation can pose a threat to mangrove sustainability. In some situations too much sedimentation can be deleterious to mangrove ecosystems (Woodroffe, 1992) while in other instances it can help against a fast pace of rising see level (by trapping more than 80% of incoming fine-grained sediment (Furukawa et al., 1997) and contribute to sedimentation rates of the order of 1–8 mm m^{-1}, generally higher than local rates of mean sea-level rise (Horstman et al., 2014) and thereby provide extensive ecosystem services in the face of expected sea-level rise and climate variability including increased storminess and erosion events. It is not typical for mangroves to thrive in sandy shorelines so long-term monitoring and protected status should be considered for this locality in a bid to reduce the potential pressures and monitor the effects of the abundant sedimentation

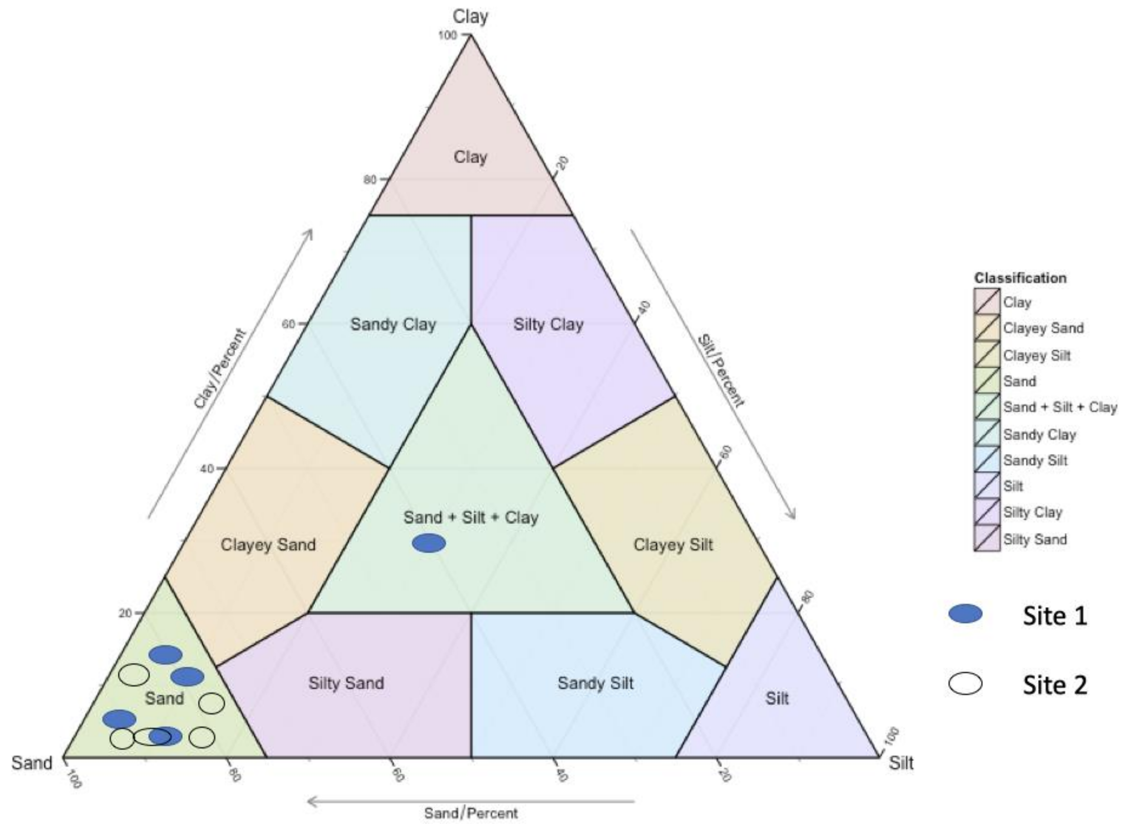


Figure 79: Ternary diagram showing textural characteristics of sand and sand silt clay for the remaining soil fraction at Portland Cottage normalised after the removal of larger than sand sized particles and vegetation (after Shephard, 1954).

Of the coarse fraction of the sandy component of the sediment of Salt Marsh, there was variability in the sediments between Site 1 and Site 2. The skeletal grains identified are a variety of benthic foraminifers, echinoid spines, molluscs and *Halimeda* plates. More *Halimeda* plates and molluscs were found at Site 2 than at Site 1, whereas Site 1 had more foraminifers and molluscs. Some of the molluscs are taken to be being autochthonous (derived from within the mangrove ecosystem) especially because of their pristine preservation. Other components of the sediment (e.g., the foraminiferans *Homotrema rubra*, *Amphistegina* and *Archaias*) are thought to be allochthonous, being brought into the mangal environment by currents during storm events. *H. rubra* is an encrusting foraminiferan normally living on the underside of corals, and when found in the shore environment suggest recent transport from the coral reef by storm activity as the red/pink specimen normally bleaches to white with extended exposure on the shore. *Amphistegina* and *Archaias* are typical of sandy lagoon deposits with sea grass beds, and again indicate transportation when found in mangrove sediments. Equally, the green alga *Halimeda* is a characteristic component of both sea grass beds and reef environments and demonstrates transportation. This demonstrates that the high carbonate sand content in the mangrove sediments indicates significant landward transport of sediment.

Soil Quality

The SOM content of the Salt Marsh sites varied widely, with values ranging from 4.27% to 68.9% (median 9.65% and mean 31.57%) for Site 1 and <1% to 34.76% (median 6.34% and mean 10.53%) for Site 2. The SOC content of the Salt Marsh Sites is characterized by values ranging from 2.48% to 39.96% (median 5.60% and mean 18.31) for Site 1 and <1% to 20.16% (median 3.68 and mean 6.11%) for Site 2.

Table 17 provides a summary illustration the relative concentrations of selected elements from Salt Marsh, such that As, Co, Fe and K have similar mean amounts for Sites 1 and 2, wheareas Br, Cd and Na have smaller mean amounts in site 2 than Site 1. Furthermore, Sr, Zn and Cr has larger mean amounts at Site 2 than at Site 1. The three localities clearly show a high degree of spatial variability. The geochemical variability observed within and among localities may be due in part to a range of local soil forming conditions. The elemental profile of the samples (regardless of origin) is consistently dominated by Na, K, Fe, Sr, and Br. In all cases, the mean concentration of Br is higher than that reported for world soils and may be due in part to a strong marine influence on these coastal soils. Similarly, the mean concentration of Na in the soils is greater than the global mean, but within range of the national average of unpolluted soils. On the other hand, the mean concentrations observed for Cd, Co, Cr, Fe, Sr and Zn are within range of national and global averages for unpolluted soils (Lalor 1995).

Table 17: Concentrations of major and trace elements analysed in mangrove surface soils (0–30 cm) from the Salt Marsh locality.

Sites		[As] (mg Kg^{-1})	[Br] (mg Kg^{-1})	[Cd] (mg Kg^{-1})	[Co] (mg Kg^{-1})	[Cr] (mg Kg^{-1})	[Fe] (%)	[K] (%)	[Na] (%)	[Sr] (mg Kg^{-1})	[Zn] (mg Kg^{-1})
Salt Marsh Site 1	Min	2.1	39.2	3.6	0.6	6.7	0.1	0.1	0.4	162.6	4.5
	Max	5.0	1360.4	17.9	1.1	16.2	0.2	0.7	8.8	3732.5	12.5
	Median	3.7	1149.2	10.7	1.0	15.5	0.1	0.4	6.3	174.7	11.5
	Mean	3.6	849.6	10.7	0.9	12.8	0.1	0.4	5.2	1356.6	9.5
Salt Marsh Site 2	Min	1.9	104.5	5.3	0.7	7.4	0.0	0.1	0.8	1981.0	5.9
	Max	4.0	468.0	9.2	1.6	30.8	0.3	0.4	4.6	3773.7	30.8
	Median	3.0	286.2	7.3	1.2	19.1	0.2	0.3	2.7	2877.4	18.3
	Mean	3.0	286.2	7.3	1.2	19.1	0.2	0.3	2.7	2877.4	18.3

*10,000 mg Kg^{-1} = 1%.

The pH values of the Salt Marsh soils are moderately basic with median values of pH 8.7 and pH 8.5 for sites 1 and 2, respectively (Annex 6).

A comparison of the concentration profiles of elements between the Portland Cottage and Salt Marsh localities reveal near identical patterns (Table 18). Similarly, there is little to separate between the Ca/Mg ratios of site in both localities. The Ca/Mg ratios for Salt March 1 and 2 are 0.40 and 0.42, respectively. Critically, a number of trace elements (Al, Cd, Cu, Fe, Pb, Zn) of particular geochemical significance were generally below the instrument level of detection for all samples analysed. This would suggest that there is no clear lithological control or anthropogenic influence on their spatial distribution in these ecosystems. These results agree well with the elemental profile of local waters and would suggest that the systems are generally in relatively good health.

Table 18: Elemental concentrations of mangrove water samples at Salt Marsh.

Site		[Ca] (mg/kg)	[K] (mg/kg)	[Mg] (mg/kg)	[Na] (mg/kg)
Site 1	Min	412.0	348.6	985.4	5394.8
	Max	462.9	396.7	1213.5	7425.6
	Median	422.4	362.1	1054.7	6053.8
	Mean	427.4	365.3	1069.4	6302.0
Site 2	Min	440.3	370.1	1155.6	5816.6
	Max	634.7	424.3	1304.6	7951.1
	Median	444.4	373.7	1174.0	5851.8
	Mean	506.5	389.3	1211.4	6539.8

Water Quality

The mean temperatures of the Salt Marsh sites are similar to those for the Portland Cottage sites (Table 19). While the mean salinities for both sites are indistinguishable (~35 g Kg^{-1}). Conductivity values are also comparable (mean = 59 MS cm^{-1}: Site 1; 56 MS cm^{-1}: Site 2). The concentrations of TDS are also lower than the minimum value (500 mg L^{-1}) for brackish waters (Table 20). The median DO concentrations are relatively higher that the threshold concentration (5 mg L^{-1}). The median values are considered here because they represent a better spread of the current data set. The mean pH values for both sites are strongly alkaline and are considered elevated and could have potentially adverse impacts on a number of vital biotic and abiotic processes not adaptable to these conditions. The mean, median, minimum and maximum concentration of the major elements in the water samples are also shown in Table 19.

Table 19: Water quality parameters determined in situ at Salt Marsh.

Site		Temperature (°C)	Conductivity (MS cm^{-1})	Total Dissolved Solids (mg L^{-1})	Salinity (g Kg^{-1})	Dissolved Organics (mg L^{-1})	pH
Site 1	Min	27.44	51.70	32.11	32.24	0.44	11.2
	Max	34.29	63.84	385.25	36.53	7.59	12.6
	Median	31.79	61.05	35.13	35.51	7.01	11.9
	Mean	31.32	59.45	104.44	34.94	4.58	11.8
Site 2	Min	28.66	55.50	33.48	33.72	1.42	12.13
	Max	29.32	56.86	34.54	34.96	5.49	14.00
	Median	28.96	55.75	33.54	33.80	5.35	14.00
	Mean	28.98	56.04	33.85	34.16	4.09	14.00

Soil Atmospheric Carbon Flux, Soil Carbon Stocks and Above Ground Carbon Stocks

Soil carbon flux

Soil CO_2 flux The Salt Marsh sites demonstrate the largest spatial variability. The median and mean carbon loss (expressed as Mg CO_2-C ha^{-1} y^{-1}) are summarized in Table 20. These variations may be due in part to the transitions between well aerated sandy soils (of varying OC content) to organic-rich soils inundated by tidal waters. Additionally, variation in soil temperature at the local sites, differences in the quantity and quality DOC, and losses of mangroves due to natural and anthropogenic forcing may play crucial roles. Generally, low soil flux rates would suggest that there is little or no SOM/SOC, or soil microbial activity. However, this may also signify that soil conditions (temperature, aeration, moisture) are constraining biological activity. Note also, that respiration from roots and soil fauna (autotrophic respiration) may contribute to these values.

Table 20: Carbon losses from mangrove soils through respiration.

Site	$MgCO_2$-C $ha^{-1}y^{-1}$ (Mean)	$MgCO_2$-C $ha^{-1}y^{-1}$ (Median)
Salt Marsh 1	11.54	8.63
Salt Marsh 2	13.70	7.34

Table 21 illustrates the aboveground and belowground carbon stocks for the Salt Marsh mangrove forest and clearly shows that that Site 2 has a higher live tree carbon stock than Site 1. These differences may be due in part to species richness.

Table 21: Aboveground and belowground carbon stock estimates.

Site	Biomass (Mg ha^{-1})		C (Mg ha $^{-1}$)
	Aboveground	Belowground	
Salt Marsh 1	45.46	9.09	25.64 (6.04)
Salt Marsh 2	63.81	12.76	35.99 (8.48)

*Data are mean (standard error). *Five plots (10 m x 10 m each) were sampled for each site.

The carbon stock estimates for the Salt Marsh sites are slightly more variable that the other locations, with Site 1 accounting for roughly 134 Mg C ha^{-1} and Site 2 averaging 51 Mg C ha^{-1}. Overall, the carbon stock estimates mirrored the mean SOM and SOC values. Stock estimates derived from the use a pedotransfer function are included in Table 22 for ease of comparison. The SOM, SOC and therefore the carbon stock estimates are a function of the difference between inputs into, and losses from the system.

Table 22: Soil organic carbon stocks in mangrove ecosystems.

Site	[a]Mg C ha^{-1}	[b]Mg C ha^{-1}
Salt Marsh 1	153.80	878.91
Salt Marsh 2	51.34	293.16

[a] Stock estimates (Mg C ha^{-1}) determined using the mean bulk density value of regional mangrove soils (Adame et al. 2013).

[b] Stock estimates (Mg C ha^{-1}) determined using bulk density value from a pedotransfer function (e.g. Grigal et al. 1989).

Flooding

Flood extent is presented as the area of risk (inundations in this study from storm surge) and we can see that reported, and experienced flooding occupies a wider area than the maximum projections of inundation for the area demarcated for Salt Marsh. The surge susceptibility polygon represents the likely area to be at risk from projections of conservative buffers of 250 and 500 m for storm surge impact if the area would be in the impact zone of a hurricane (Figure 80). This means that flooding can be a significant problem for this area based on the terrain and in the face of climate change this will continue to be a problem. Intact and healthy mangrove forest will therefore be able and will continue to provide some protection against flood severity by the reduction of the impact in the event of storm surges, which are the most likely immediate risks.

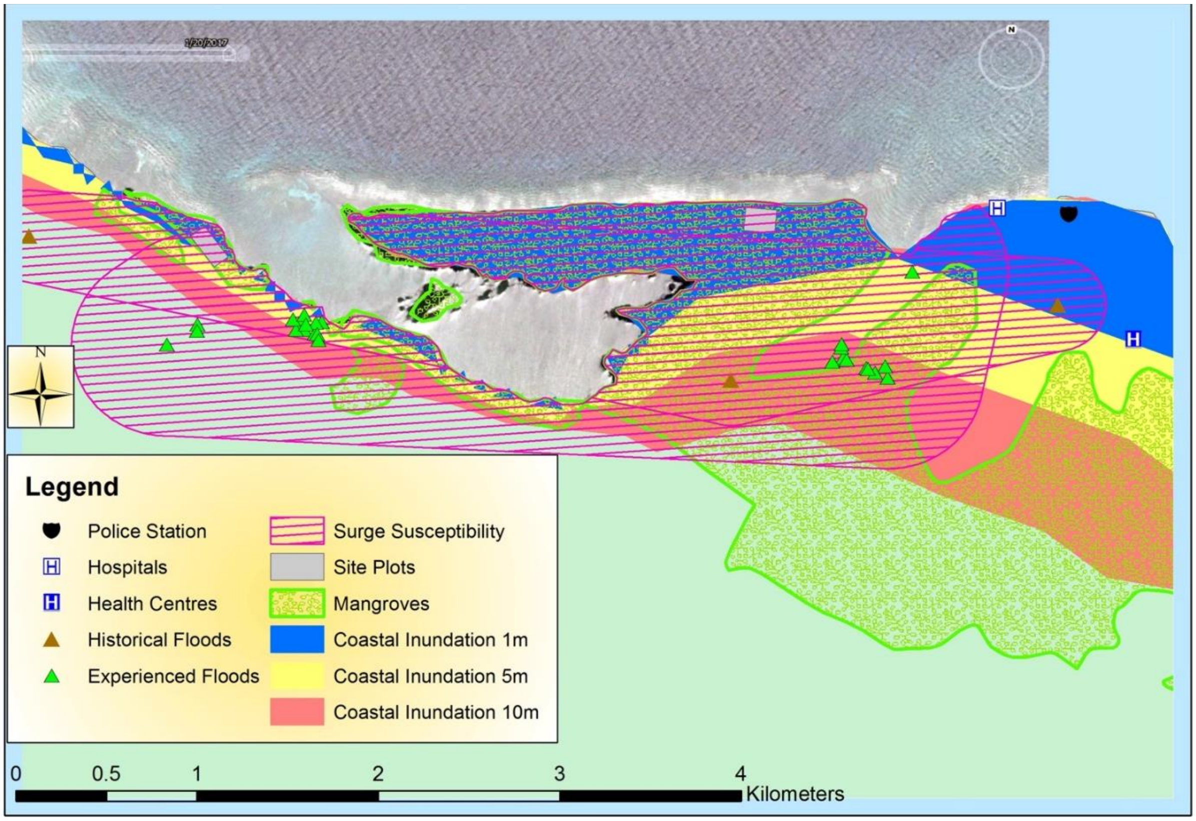


Figure 80: Hazard map for a section of Trelawny, shows flood experiences and susceptibility of coastal inundation risk (surge susceptibility) occupying a larger extent than projected areas likely to be affected by 1 m, 5 m and 10 m water level coastal inundation.

There is considerable overlap of the location of floods experienced (triangles on the map) and the various inundation water level projections. However, the surge susceptibility which is based off actual experience and on the premise that if a coordinate location experiences flooding, and the topography is moderately uniform then adjacent areas are likely to experience similar flood risk and impacts. Furthermore, if a landward area experiences flooding then areas seaward of that must has also experienced the same flood impact. The surge susceptible polygon is covering a larger landward extent than the inundation projections, this implies that more land is at risk for impact and the mangroves left intact will protect even more land and occupations of landward at Salt Marsh from the heightened impacts of coastal inundations in the event of a storm surge or other coastal flooding event.

Broad comparisons/Associations between assessments

Ecological comparisons of overall forest areas.

The mangrove communities' ecological features and associated services can be compared across the three areas using spatially significant parameters. Only Red mangrove parameters (tree numbers, tree height, trunk width (DBH), canopy width and medium prop root density) as well as ichthyoplankton were found to vary significantly between the three forests. Please see box-plots in Annex 15). The indications are that while having the largest number of trees and prop root density (for medium plots), the red trees were shortest at Portland Cottage with the smallest canopy and tree width. This agrees with the previous indication that the Portland Cottage forest is affected by disturbance (storms and or human activity) and so the forest would be in a state of regeneration. Comparisons between the three forests indicate that Bogue, while having the lowest red tree density is the healthiest forest since the red trees had the greatest DBH, canopy width and tree height. These parameters indicate a mature forest with little or no disturbance. Salt marsh ranked second with respect to DBH, canopy width and tree height. Nevertheless, only Salt Marsh had all three mangrove species represented; which could also be an artefact of the length of the transect used. The ichthyoplankton data further supports the indication of disturbance at the Portland Cottage mangrove with Bogue again having the greatest mean/median and lowest fluctuation around the mean. The latter infers stability. However, it is important to note that the brief sampling period is inadequate for definite conclusions to be drawn for water quality and ichthyoplankton parameters. E.g. The absence of ichthyoplankton at Portland Cottage, site 2 is most likely due to the one-off sampling.

The physical properties of the mangroves can be quite unique for each study area, for example the textural composition of the substrate after the removal of all organic components was different for each site. Geological study of the study areas imply tectonically driven subsidence has occurred recently or is still occurring. Elevations on five of these transects showed the transects ranging between just below to just above MSL, which means that the forests are keeping pace with the subsidence and rise in sea level that is occurring as a result of climate change. Generally, Portland Cottage was identified as the mangrove area, providing the lowest ecosystem service despite recording the highest accretion (at one site), while the other site was experiencing erosion. The studies determined that subsidence seems to be playing an important role within the study sites and coupled with sea-level rise will increase the vulnerability of communities and infrastructure associated with these systems if proper management and protection is not enforced. Bogue Lagoon was identified as the most stable and resilient forest system. Due to the sedimentation patterns at Salt Marsh this forest fringe is considered suspect to increased risk from over sedimentation however, it is not as degraded as the south coast site. Bogue is offering the most ecosystem service in protection of the coastline as it protects critical road infrastructure with linkages within the Parish of St. James (the most populated and urban of the three study areas) and to neighbouring Parishes Trelawny and Hanover and contributes to the viability of mainstream and alternative tourism industries. Salt Marsh would be second protecting infrastructure and livelihood for the adjacent and dependent communities including the important town of Falmouth and road networks. The Portland Cottage has the least critical infrastructure and connection to mainstream tourism, but the population here are most at risk and vulnerable so it could be argued that the greatest protection to life and livelihood is offered at Portland Cottage and cost to the government in the event of serious disasters. Geographical spatial and temporal studies show that all sites experience lengths of coastline undergoing both lateral erosion and accretion. Lateral (horizontal) accretion was greater at Bogue and Salt Marsh, but lateral erosion was more predominant at Portland Cottage, possibly as a result of recent hurricanes.

Physical, Ecological and Socio associations

Mangrove species composition and carbon

In order to better understand the interlinkages between the ecological and physical aspects of the forests, we applied Spearman analysis to discern the significant relationships (positive and negative) between mangrove species and carbon stocks. Annex 11-14 illustrate the correlation coefficients (r_s) and *p* values between the species and vegetation (aboveground and belowground) carbon. Results indicate moderate correlation between red and white mangroves, white mangroves and total vegetative carbon, and a strong positive correlation between red mangroves and total vegetative carbon for Bogue Lagoon. All values were significant ($p<0.05$). It is also apparent that there is a significant positive correlation between red mangroves and total vegetative carbon, compared with a small to moderate (positive) correlation between white mangroves and total carbon and black mangroves and total carbon, respectively for the Portland Cottage forest. The relationship between black and white mangrove carbon stocks was small. Similar relationships are observed for the Salt Marsh forest.

Mangrove canopy/tree density and wind

Because the wind measurements were taken just within the mangroves from the seaward edge at breast height the best information to look at would be the DBH and the *R. mangle* density within the first 0-10 m. The relationship is such that more wind was attenuated for largest DBH in red mangroves and most density of trees. At Portland Cottage *R. mangle* DBH is 40 and 45 mm respectively for Sites 1 and 2 and *R. mangle is* denser at Site 2 than Site 1 and as such saw moderate reduction in wind speed within the edge of the forest seaward. At Bogue there is a considerable larger mean DBH (140 mm) at Site 2 than Site 1 (80 mm), furthermore, Site 2 had more red mangrove trees and saw more wind reduction than Site 1. Together Sites 1 and 2 of Bogue saw more wind speed reduction within the edges of the mangrove than Portland because of the larger DBH. At Salt Marsh DBH was similar for Sites 1 and 2 but the density was higher at Site 2 and as a result Site 2 saw more reduction in wind speed. Although DBH of R. mangle trees within 0-10 m of the transect was smaller at Salt Marsh than Bogue the densities were similar and the % wind reduction also appear to be similar, therefore tree density is considered most important.

Prop root density and wave attenuation

The prop root density charts at Bogue and Salt Marsh Sites 2 shows higher densities within the first 10 m landward from the water's edge than Sites 1 and Sites 2 saw greater wave energy attenuation. The reverse is seen at Portland Cottage where prop root densities appear higher at Site 1 than Site 2, however, wave attenuation was only collected from Site 1 and was highest among the three study areas because the prop root density at the edge of that forest was slightly higher than all the others.

Recommendations

The socio-economic component can be improved by greater access to data that can provide asset value. If possible, such data can be obtained from real estate companies since households or business might either be unaware or unwilling to provide an estimated value on their businesses.

Greater reconnaissance work in the beginning involving field mapping will help in understanding population within the demarcated area which can allow for probability sampling techniques. During this period, surveys should be piloted. This is especially important when technologies such as the ODK is used.

It is also possible that 2 days might not be enough for training which includes not only understanding the survey questions but using the technology, so it is recommended that training be extended to 3 to 4 days. If the budget allows, training should also include more than the targeted number of persons who will be administering the survey so that there are back up field workers should there be any drop outs.

It would have been valuable to obtain information from fisherfolks within the various communities to allow for greater understanding of fish data and value. A household survey geared towards household heads or a respondent who can provide information on the household can still result in gaps where that respondent is unable to provide valuable and necessary information as it relates to fish livelihoods. Further, interviews and focus groups may support household surveys especially in understanding other socioeconomic benefits provided by mangrove forest such as ecotours.

It would have also been useful to include an examination of the historical land changes which would have been useful in corroborating several findings of the socioeconomic and ecological survey such as observed changes in mangrove forest by residents in the different communities.

Based on the results, there are several recommendations that can be made to policy makers. There is a need greater local involvement in mangrove research, restoration and management. Communities' knowledge and awareness of the mangrove changes and the reasons behind these can be used to support the changes identified through the ecological data collection.

It is recommended that policy makers capitalize on the opportunities for private/public partnerships in restorative efforts. The community including fishermen should be central to decision making concerning assignment of protected areas and the monitoring and management of these. This may reduce some of the illegal activities that occur in the mangrove forest and result in greater buy in and support from community members in restoration initiatives.

Businesses within the community should also be central to this process as they may can learn about the importance of mangrove and integrate such knowledge in their business development plans and may also be able to fill resource gaps in restoration and management efforts.

Encourage businesses to conserve and restore mangroves as part of the natural coastal infrastructure that may reduce their vulnerability to coastal flooding and increase resilience to climate change impacts.

Both community members and businesses show great interest in being a part of restoration initiatives. Hence, it is recommended that such initiatives do not only include schools and NGOs, but community members who are willing to be a part of the process.

Finally, it is recommended that ecotours be encouraged and supported in mangrove forest which may result in greater awareness and a concerted effort for preservation of the forest with some economic benefits (income and employment) for local communities. This will also improve knowledge on the social and economic importance of mangrove forest and allow for greater outreach.

The physical component of this multidisciplinary project is complimentary to the ecological and socio-economic evaluations and has provided a baseline of local data not previously in existence. These data will allow scientists to continue to monitor and evaluate these important ecosystems in order to facilitate sustainable management of resilient coastlines island wide. This is especially critical for small island developing states of the Caribbean where most of our infrastructure, road networks and economic activities are located near the coastline. Since mangrove forest zones may vary in width (as well as the total width of the forest), the length of each transect laid along the sea to land continuum should be allowed to vary according to the forest, with representativeness used as a guide. The transect should therefore match the width of different zones or the absolute width of the forest to represent all mangrove tree types along the forest continuum. Keeping forest transects constant across areas may result in bands (zones) being omitted and so the transect should be continued until terrestrial vegetation is encountered or there is evidence of mono-specific mangrove trees. If plot areas are known, numbers per unit area can be computed for comparison between areas.

Since it is shown that elevation change can vary in mangrove soils as a result of pore-water fluctuations, long-term observation is recommended for all the RSET plots to capture long-term trends in accretion, slower accretion rates, and to compensate and nullify uncertainties of the data and elevation change as transient occurrences such as storms, which can have significant effects, did not occur during the collection of the data. Deeper cores (1 m or more if possible) should be considered to understand the palaeo-sedimentology and drivers of sedimentation and any fluctuations within these systems in order to understand how these mangrove stands have been maintained now that bulk current analysis has been done on surface substrate. Layered analysis of cores at the cm level in conjunction with carbon dating can be carried out to identify variability over time and its influences on the systems. Furthermore, root growth rates and contribution to substrate was not quantified and should be examined to further quantify shallow subsurface activities and health of mangrove systems.

Elevation studies need to be executed especially at Portland cottage by trained surveyors relative to mean sea level, National Land Agency benchmarks and fixed GPS installation for satellite altimetry for long-term assessment of deep subsidence rates as a result of tectonic activity in the region to understand the role and rate of deep tectonic subsidence at all sites.

The wave attenuation was determined for normal weather conditions, and within several hours of a day, it would therefore be useful to get readings in high swell waves or stormy conditions when the opportunities present themselves (although remote monitoring is suggested for safety reasons).

Since the production and release of particulate and DOC represent a primary loss pathway, it would be useful to investigate the hydrological controls on POC and DOC (total OC = DOC + POC) production and release in order to provide better estimates of the blue carbon and mitigation potentials of these systems.

Further work should also aim to quantify methane (CH_4) emissions from local mangrove forest since (a) these anaerobic (oxygen deprived) systems are likely to produce high concentrations of the gas, and (b) CH_4 has a global warming potential (GWP) 28 times more powerful than CO_2 albeit a short-lived GHG (12.5 years).

Additionally, in order to provide better estimates of whole-ecosystem carbon stocks, it may be necessary to consider the contribution from downed wood (wood debris) in local mangrove ecosystems.

Biological oxygen demand (BOD) and chemical oxygen demand (COD) analyses of water samples should be done to complement DO measurements. Overall more biological parameters are recommended for use in assessment of water quality between areas.

The combined effort was an ambitious project and can be scaled up to include other critical sites that may also be endangered such as Mangroves forests in Portmore, and Hellshire, St. Catherine, as well as localities in St. Thomas and Negril. This will enable the government and policy makers to be more pro-active rather than reactive and to entertain a variety of ecosystem-based management and defence (green defence) ideas or hybrid defence systems which include some ecosystem and some hard engineering combined for a more natural effect, rather than hard structural engineering defences when ecosystem collapse.

Recommendations for Policy Makers

Based on the hazards experienced at Portland Cottage, policy makers should consider planned retreat as an option or redesigning of houses to place them on stilts and rigorous rehabilitation programs for the mangroves areas that are being lost to allow regeneration where possible and landward migration of mangroves and prevent coastal squeeze. The fisher folk livelihood could be maintained by the maintenance of access and temporary housing for their equipment, but permanent residences would benefit from reduced food risk by being relocated to higher ground or redesigned for withstanding inundation. Planned relocation is an option that many at risk coastal communities are looking at globally. For the Bogue Lagoon and Salt Marsh communities, the fringe mangrove forests should be maintained as they are currently protecting the critical north coast transportation networks which pass behind them and the communities along these networks. Reclamation of wetland for developments should be prohibited to prevent the domino effects of die back in adjacent mangrove from anthropogenic sedimentation and where mangrove property is not owned by the government of Jamaica, they should be acquired to safeguard mangal coastlines. Salt Marsh is the only site studied that does not have protected status and should be protected before it reaches a state of degradation which is very possible as some sections seemed to be privately owned and in the time of the study was being cleared for development. The recommendation is that the if it is possible the planned constructions on the peninsula section (near Site 1) must be stopped or at the very least, critical measures should be put in place to reduce disturbances and safeguard the ecosystem whilst construction is occurring in order to try to prevent deleterious effects, which may have long term impacts.

Conclusions

Mangrove forests are very important ecosystems. They provide several direct and indirect socio-economic, ecological and physical benefits to local communities. These benefits were examined in three local communities: Portland Cottage, Salt March and Bogue Lagoon. All three communities show some differences in terms of their socio-economic context.

While Portland Cottage and Salt Marsh are both residential communities, there were differences in terms of level of poverty within these communities. Portland Cottage, for example, showed higher levels of poverty as exhibited by greater levels of illiteracy, low levels of education, limited access to piped water and electricity by a larger number of households and a larger percentage of households that use pit latrines. The main source of household income was also self-employment.

Salt Marsh however showed lower levels of poverty relating to these variables. Bogue, on the other hand, can be described as highly dense urban area characterized by a mixture of commercial, industrial and residential land use. Majority of the businesses were sole proprietorship. However, significant amounts were corporations and to a lesser extent the business were partnership enterprises.

Businesses show differences in terms of length of establishment with an average of 12.36 years reflecting some well-established businesses. Most recent sales turnover was on average US$2.889 million.

A major ecosystem service that is supported by mangrove community particularly in the area of Portland is fishing. However, this was less important in Salt Marsh and was not captured in Bogue. Nevertheless, several services were shown to be very important to the communities. Among them are a fish habitat, shoreline protection services, a support for near or off shore fishing and a wild life habitat and medicinal value. These provide both direct and indirect benefits to the community whether, for example, through fish consumption or fish sales.

Mangrove forest is affected by several issues many of which are common among the three communities. These include pollution, overfishing or illegal fishing and illegal logging or clearing of forest for residential or commercial use. These were responsible for the decrease in mangrove forests as observed in Salt Marsh and Bogue Lagoon. A notable difference for the decrease in forest in Bogue Lagoon was shoreline development and shoreline erosion. Portland Cottage however showed a greater increase in the forest which was attributed mainly to restoration activities.

Data also shows that there was limited involvement of locals in all three communities in restoration activities with no statistically significant differences by gender. However, there are opportunities for private/public partnership as reflected by the greater percentage of respondents including businesses are willing to be involved in these activities. In Portland Cottage, there was a statistically significant relation by gender.

Ecologically, *Rhizophora mangle* was the dominant species at sites per location with infrequent occurrences of *Avicenna germinans* and *Laguncularia racemosa*. Generally, mangroves have low diversities as mangroves tend to grow in relative monospecific stands within a forest which prevents succession and species accumulation.

Based on Pellegrini et al. (2009) suggested categories of mangrove forest structural development, the mangrove forest on the north coast at Bogue Lagoon and Salt Marsh are forests with intermediate structural development while the forest on the south coast is a low structural development forest. This low structure may be due to damage caused by frequent hurricanes.

Overall prop root densities decreased with increasing distance towards land while pneumatophore densities generally increased toward the end of the transect.

Of the three study areas Portland Cottage seemed to be the most at-risk mangrove area and providing the lowest ecosystem service despite recording the most accretion at one site, the other site was experiencing erosion. Subsidence seems to be playing an important role within the study sites and coupled with sea-level rise will increase the vulnerability of these systems if proper management and protection is not enforced. Bogue Lagoon seems to be the most stable and resilient forest system and because of the sedimentation patterns at Salt Marsh this forest fringe is considered suspect to increased risk from over sedimentation and any attempt to change the land use for traditional tourism or economic activities which would include more traffic than currently experienced should be prevented.

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Annex 1: Survey instrument

QUESTIONNAIRE

Name of Community: _______________

Questionnaire ID

1. Residential
2. Commercial **if commercial skip to Section C**

SECTION A- DEMOGRAPHICS

1. Gender
    1. Male
    2. Female
2. Please state age ________________
3. Highest level of educational attainment:
    1. No schooling
    2. Primary/preparatory
    3. All age/Elementary
    4. Junior Secondary
    5. New Secondary
    6. Secondary High
    7. Vocational High
    8. University
    9. Community College
    10. Other tertiary
    11. Other, please state _________________
4. Relationship status:
    1. Single
    2. Common law union
    3. Married
    4. Divorce
    5. Widow
    6. Other ___________________
5. How many persons live in the household? __________
6. How long have you resided in the area? ___________

7. What is the main income source for the household?
    1. Paid government employee
    2. Paid private employee
    3. Unpaid employee in agriculture or any other business
    4. Self-employed with paid employees
    5. Self-employed without paid employees
    6. Remittances
    7. Other, please state
8. Have you receive any remittances in the last 6 months?
    1. Yes
    2. No
9. If yes, from where did you receive it?
    1. Abroad, please state where _____
    2. Same community
    3. Outside of your community, please state where _______________
    4. Please fill out Table on each person living in the household
10. Do you or anyone in the household currently receive any Social Welfare benefits or pension?
    1. Yes
    2. No
11. If yes, what benefits or pensions? Tick all that apply.
    1. Employment related pension
    2. National Insurance
    3. PATH Program
    4. Other Public Assistance/Poor
    5. Other (Specify)___________
    6. Not State

12. Please fill out the necessary information for all members of your household

Household size	Gender of member	Age of member	Highest level of education	Main Employment status (full time, part time, self-employed)	Main Occupation	Source of income other than occupational earnings	Total Income past month per member
1(respondent)							
2							
3							
4							
5							

13. Was the household able to save from their last month's income?
    1. Yes
    2. No

14. Do you have any form of savings in the bank, credit union or any other financial institution? Please tick all that apply
    1. Banks
    2. Credit Union
    3. Partner
    4. other financial institutions, please state ___________
15. Do you participate in partner?
    1. Yes

2. No

16. Do you have access to subsidies from the government?
    1. Yes
    2. No
17. Do you have any outstanding loans?
    1. Yes
    2. No
18. If yes, where did you obtain this loans? Tick all that apply
    1. Friends
    2. Relatives
    3. Banks
    4. Credit unions
    5. Other, please state _______________
19. What is the purpose of the loan? Tick all that apply
    1. Mortgage
    2. Borrowed to purchase food
    3. Borrowed to pay rent
    4. Borrowed to send children to school
    5. Other, please state ______________

SECTION B HOUSING CHARACTERISTICS

20. Does any member of your household own, rent or lease this dwelling?
    1. Owned
    2. Rented
    3. Leased
    4. Squatted
    5. Rent-free
    6. Other, please state _____________

21. What about the land- is it owned, leased etc. by any member of the household?
    1. Owned
    2. Rented
    3. Leased
    4. Squatted
    5. Rent-free

6. Other, please state _______________

22. How many rooms does the household occupy?
23. How many rooms are used for mainly sleeping?
24. What does the household used most for lighting?
    1. Kerosene
    2. Shared electricity
    3. Owned electricity
    4. Candle
    5. Other, please state __________

25. How does this household obtain water for domestic purposes? Tick all that apply
    1. Public piped into dwelling
    2. Public piped into yard
    3. Private piped into dwelling
    4. Private catchment, not piped
    5. Public standpipe
    6. Public catchment
    7. Spring or river
    8. Trucked water/water truck
    9. Other, please state __________________

26. Which kind of fuel does this household use most for cooking?
    1. Wood
    2. LPG
    3. Charcoal
    4. Kerosene
    5. Biogas
    6. Solar energy
    7. Electric
    8. Other, please state __________________

27. Please fill in the following Table to describe your home and assets. Tick where appropriate.

OUTER MATERIALS	✓	**ROOF MATERIALS**	✓	**OTHER PARTS OF THE HOME**	✓
Concrete and blocks		Metal sheeting		Landline	
Stone and brick		Shingle (Fiber glass)		Mobile/Cell phone	
Concrete and wood		Tile (clay)		Radio	
Wood and brick		Tile (other)		Television	
wood		Concrete		Personal computer/laptop	
Other, please state		Other material (specify:_________			
OTHER PARTS OF THE HOME	✓	**OTHER PARTS OF THE HOME**	✓	Notes:	
Kitchen attached to the house		Inside toilet			
Kitchen unattached from the house		Outside toilet/latrine			
Bathroom attached to the house					
Bathroom unattached from the house					

28. Please tick where appropriate if you have the following household assets

Non-financial Assets **beds** **Fridge** **Stove** **Chair set** **Dining Table set** **Computer or laptop** **Motor vehicle** **Other**	

Section C- Commercial Demographics

29. Gender
    1. Male
    2. Female
30. Please state age ________________
31. Highest level of educational attainment:
    1. No schooling
    2. Primary
    3. Secondary
    4. Tertiary
    5. Other, please state _________________
32. How would you describe your role or function in the business?
    1. Owner
    2. Manager
    3. Other, please state ____________
33. How many employees work in the establishment? __________
34. How long has the business been in operation within the community? ___________
35. What type of business form do you have?
    1. Sole proprietorship
    2. Partnership
    3. Corporation
36. Which of the options below best describes the industry or activities in which your business operates?
    1. Wholesale
    2. Craft
    3. Hotels/guest house
    4. Restaurants
    5. Industrial sales and equipment
    6. Call Center
    7. Other, please state _____________________

37. What would be the value of your business if sold today? $______________
38. How did you arrive at this value?
    1. Formal Appraisal

2. Estimate by Owner
3. Other, please state ____

39. What is your business's most recent annual sales turnover?
    1. Less than or equal to US$100 000
    2. US$100 000 - 600 000
    3. US$600 001 - 1 000 000
    4. US$1 000 001 - 1 400 000
    5. US$1 400 001 - 1 800 000
    6. US$1 800 001 - 2 200 000
    7. US$2 200 001 - 2 600 000
    8. US$2 600 001 - 3 000 000
    9. Greater than US$3 000 000

Section D - Fishing and other livelihoods

40. Do you or any member of your household consume fish as a protein source?
    1. Yes
    2. No
41. If yes, where do you purchase fish? Tick all that apply
    1. In the town
    2. At the jetty as soon as the fishers come in
    3. At the supermarket
    4. I receive from family and friends at no charge
    5. I catch my own fish
42. What type of fish do you buy for consumption?
    1. Snapper
    2. Parrot
    3. Grunt
    4. Other, please state

43. Do you or anyone in your household fish within the community? **If no, skip to Section E**
    1. Yes
    2. No
44. If yes, where exactly is your main fishing spot/area?
45. How long have you been fishing in this area?

46. What types of fish do you catch there?
47. Do you fish within the mangrove area?
    1. Yes
    2. No
48. How often do you fish there?
    1. Daily
    2. 2X per week
    3. 3X per week
    4. More than 3X per week

49. What types of fish do you catch in those areas? ________________
50. Besides fish, do you extract any other product from the sea within these mangrove areas?
    1. Oysters
    2. Shells
    3. Shrimps
    4. Fish bait
    5. Crabs
    6. Other, please state ____________

51. What is the purpose of the fish catch? Tick all that apply
    1. Home used
    2. Commercial use
52. If for commercial use, which fish do you sell commercially? __________________
53. Where/ to whom do you sell your fish? Tick all that apply
    1. Supermarkets
    2. Hotels/resorts
    3. Restaurants
    4. Shops
    5. Community members
    6. Other, please state ___________
54. What is your estimated income from these fish on a weekly basis? _______________
55. How has your income from fishery changed over the past 5 years?
    1. Decreased
    2. Same

3. Increased
4. Don't know

56. How has the number of your fish catch changed over the past 5 years?
    1. Decreased
    2. Same
    3. Increased
    4. Don't know
57. Are there any areas that you are prohibited from fishing?
    1. Yes
    2. No
58. If yes, please state where ______________________________

SECTION E- MANGROVE KNOWLEDGE, USES AND IMPORTANCE

59. Please rate which mangrove ecosystem services are directly important to you? Tick where applies.

	Very Important	important	Neither important	Not important	N/A

			or unimportant		
Aesthetic (Visual) appeal					
Fish Habitat					
Medicinal value					
Source of food					
Shoreline protection (from erosion or storm surges)					
Source of wood (fuel)					
Source of wood (building material)					
Supporting offshore or nearshore fisheries production					
Water quality					
Wildlife habitat					
Carbon store					
Cultural value					

Other, Please state ____

60. Do you earn any other income/ livelihood from services provided by mangroves in your community? **If no, skip to Question 69.**
    1. No
    2. Yes

61. In what other ways (apart from fishing), do you earn an income/livelihood from mangrove? Tick all that apply

1. Fuel wood
2. Tours through mangrove forest
3. Boat building
4. Making fences
5. Fishing equipment
6. Other, please state ____

62. How many years have you been earning an income from mangrove?
63. How has your income from mangrove forest changed over the past 5 years?
    1. Decreased
    2. Same
    3. Increased
    4. Don't know
64. How do you think your income from mangrove forest will change in the next 5 years?
    1. Decreased
    2. Same
    3. Increased
    4. Don't know
65. Which species of mangrove is/are widely used by you for income generating activities? Tick all that apply.
    1. White
    2. Red
    3. Black
    4. Button
66. How many times have you cut down/ gather these mangroves for use in the past month?
    1. None
    2. 1 to 5X
    3. 6 to 10X
    4. 11 to 15X
    5. Greater than 15X
67. Was mangrove removed for the establishment of your home/ business?
    1. Yes
    2. No

3. Don't know

68. Rate the extent to which the following issues are having an impact on mangroves in your community? Tick in the appropriate spaces

	This is having a big impact	This is having an impact, but not big	Not causing any damage	Not present in this area
Deforestation				
Overfishing				
Illegal fishing				
Illegal logging				
Waste disposal (garbage, sewage)				
Illegal fishpond operation				
Shoreline erosion				
Illegal cutting/clearing				
Shoreline development (reclamation)				
Sea level rise				
Climate change (more severe drought, storms, floods)				

SECTION F- FLOOD RISK AND COPING CAPACITY

69. Have you experienced any coastal flooding in the community?
    1. Yes

2. No

70. If yes, how many times in the past year, have the community flooded?
    1. Once a year
    2. Two times per year
    3. Three times per year
    4. Four times per year
    5. Five times per year
    6. Greater than 5 times per year
71. When was the last time you were affected in anyway by a flood? ___________

72. Did this flooding affect your property? If no, skip to question 70
    1. Yes
    2. No
73. Did the water enter your house?
    1. Water did not enter house
    2. Water was under the floor boards
    3. Water was above floor boards
    4. Water was above skirting boards
74. In what other ways, did the last flood affect you? Tick all that apply
    1. Could not attend work
    2. Children could not attend school
    3. Injury to yourself/family members
    4. Destroy livelihood equipment (e.g. boats)
    5. Destroy crops and livestock
    6. Had to relocate permanently
    7. Had to relocate temporarily
    8. Other, please state _______________
75. Was your house insured against flood damage?
    1. Yes
    2. No
    3. Unsure
76. Do you have any flood defenses in place at your property? Tick all that apply
    1. Sandbags
    2. Non-return valves
    3. Placed home on concrete blocks/stilts

4. Disconnected drainage
5. Floor / door modification
6. Bolted down manholes
7. Other..
8. None

77. Did these help to prevent water entering your house?
    1. Yes
    2. No
    3. Unsure
78. What were the main factors that helped you to recover from the flood? Tick all that apply
    1. Savings
    2. Remittances
    3. Borrowing money from friends and/or relatives
    4. Crediting goods from shops or supermarkets
    5. Government assistance
    6. Sold assets
    7. Move to safer place
    8. Other, please state ______________________
79. How long did it take you to recover from the impact of the last flood?
    1. Less than 1 month
    2. 1 to 4 months
    3. 5 to 8 months
    4. 9 months to 1 year
    5. Over 1 year
    6. I have not recovered.
80. Apart from the last date you experience flood, were there other dates on which you have suffered flooding? Please list
81. What actions have you taken to minimize the impact of future flood events on your household? Tick all that apply
    1. I have not done anything
    2. Relocated
    3. Flood proof home (barriers, raise house)
    4. Took out Flood insurance
    5. Other, please state ______________

SECTION G- MANGROVE MANAGEMENT AND RESTORATIVE EFFORTS

82. How healthy are the mangroves in your area?
    1. Very healthy
    2. Healthy
    3. Average
    4. Unhealthy
    5. Very unhealthy
    6. Don't know
83. Based on your experience, what changes, if any, have you observed in the extent of the mangrove forest over the last 30 years?
    1. Decline
    2. Increase
    3. No change
    4. Don't know
84. If you believe that some change has occurred, what do you think is responsible for the observed change identified above? ________________________________
85. Are you aware of any illegal or destructive activities in the mangrove forest of your community?
    1. Yes
    2. No
    3. Don't know
86. If yes, what activities are these? Tick all that apply
    1. Illegal fishing
    2. Illegal logging
    3. Garbage/solid waste dumping
    4. Sewage waste
    5. Theft
    6. Illegal fishpond operation
    7. Other, please state ______________
87. How well are mangroves managed in your area?
    1. Excellently
    2. Adequately
    3. Could be better

4. Not very well managed
5. No management

88. Who are currently responsible for the management of mangroves in your area?
    1. Government
    2. Community members
    3. Private organisation, Please state which __________
    4. Non-governmental organisation, please state which ______
    5. Other, please state ____________
    6. No one
    7. Don't know
89. How can we ensure mangroves are better protected and maintained in your community? Tick all that apply
    1. Engaging community members
    2. Fines or penalties for damaging mangroves
    3. Community education
    4. On gound works (fencing, groynes)
    5. Planting/Replanting mangroves
    6. Long-term monitoring programs
    7. Restoration and rehabilitation programs
    8. Policies for mangrove protection
    9. Enact laws for mangrove protection
    10. More research on local mangroves
    11. Educating local government
    12. Other, please state________________________________
90. Are you aware of any initiatives designed to improve the condition of/restore mangroves in your area?
    1. Yes
    2. No
91. Are you currently involved in mangrove restorative activities?
    1. Yes
    2. No
92. If yes, what some of these activities you participated in? Tick all that apply
    1. Planting/Replanting mangroves
    2. Community education
    3. Research

4. Other, please state ______________________________________

93. Are you willing to be a part of mangrove restoration efforts?

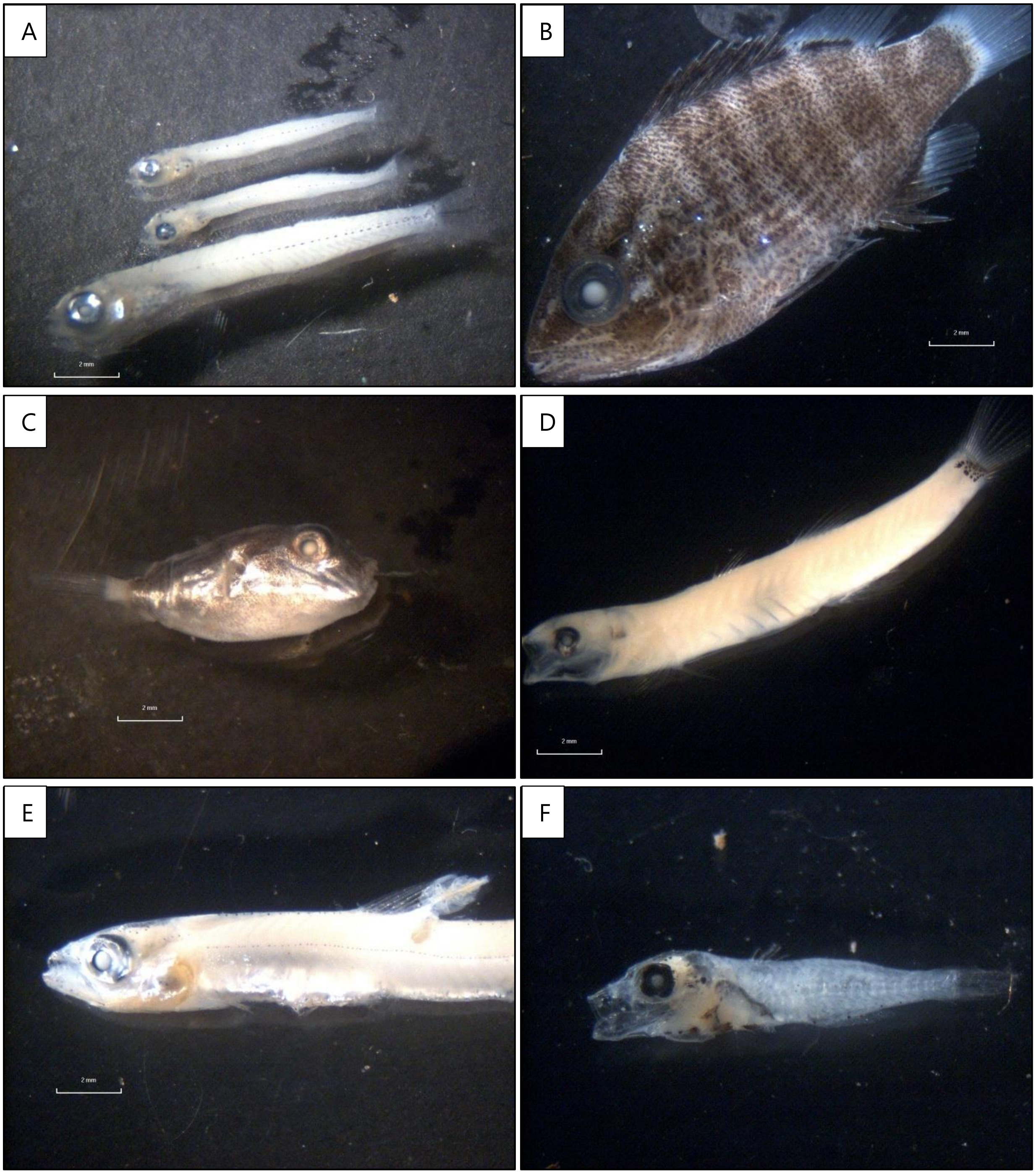
1. Yes
2. No

Annex 2: Summary of means and ranges of values of mangrove structural attributes at each site

Species	**Mean DBH (mm)** ±SE	**Min-Max DBH (mm)**	**Mean height (m)** ±SE	**Min-Max height (m)**	**Mean Canopy width (m)** ±SE	**Min-Max Canopy width (m)**
Bogue Lagoon Site 1						
Rhizophora mangle	133.35 ±10.97	36 - 332	10.03 ± 0.43	6 -16	4.93 ±0.52	0.1 - 13.0
Bogue Lagoon Site 2						
Rhizophora mangle	68.94 ±6.39	7 -221	7.38 ±0.38	2.5 - 13. 2	2.33 ±0.24	0.1 - 9.0
Laguncularia racemosa	147.90 ±24.97	58 - 297	10.03 ±0.87	6.8 -15	2.55 ±0.71	0.5 -8.0
Salt Marsh Site 1						
Rhizophora mangle	62.59 ±3.35	21-133	6.48 ±0.25	2.0 -12.0	2.25 ±0.16	0.3 -5.0
Avicennia germinans	80.84 ±6.11	15-164	7.24 ±0.40	2.8 - 13.5	1.69 ±0.22	0.1 - 4.0
Salt Marsh Site 2						
Rhizophora mangle	64.44 ±3.67	4 - 193	7.49 ±0.25	2.0 - 12.2	2.27 ±0.16	0.1 - 7.3
Avicennia germinans	84.77 ±6.49	15 - 218	8.00 ±0.42	2.8 - 13.5	1.60 ±0.18	0.1 - 4.2
Laguncularia racemosa	83.50 ±29.06	49 -170	10.20 ±0.57	8.5 - 10.8	2.18 ±0.99	0.5 - 5.0
Portland Cottage Site 1						

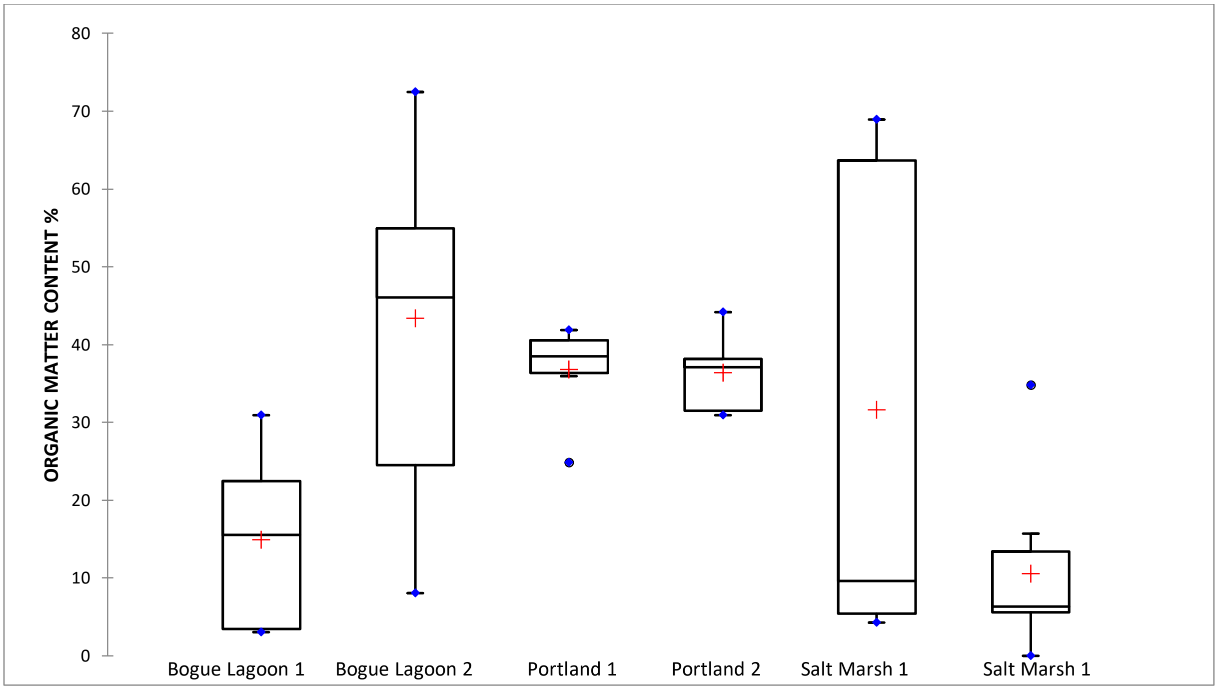
Rhizophora mangle	28.3 ± 1.54	5 - 118	3.7 ±0.11	1.7- 6.7	0.9 ± 0.09	0.1 - 6.0
Avicennia germinans	30.9 ± 1.60	3 - 90	3.6 ± 0.12	1.7 - 7.0	0.9 ± 0.08	0.1 - 4.3
Laguncularia racemosa	21.6 ± 1.10	19 - 25	3.5 ± 0.32	2.8 - 4.3	0.6 ± 0.12	0.4 - 1
Portland Cottage Site 2						
Rhizophora mangle	30.7 ±1.28	5 - 77	3.9 ±0.09	1.4 - 6.2	1.4± 0.10	0.2 - 5.0
Avicennia germinans	20.5 ±6.95	8 - 40	2.8 ±0.56	1.3 - 4.0	1.3 ±0.91	0.3 - 4.0

Annex 3: Photographs of selected fish larvae found within Jamaican mangroves

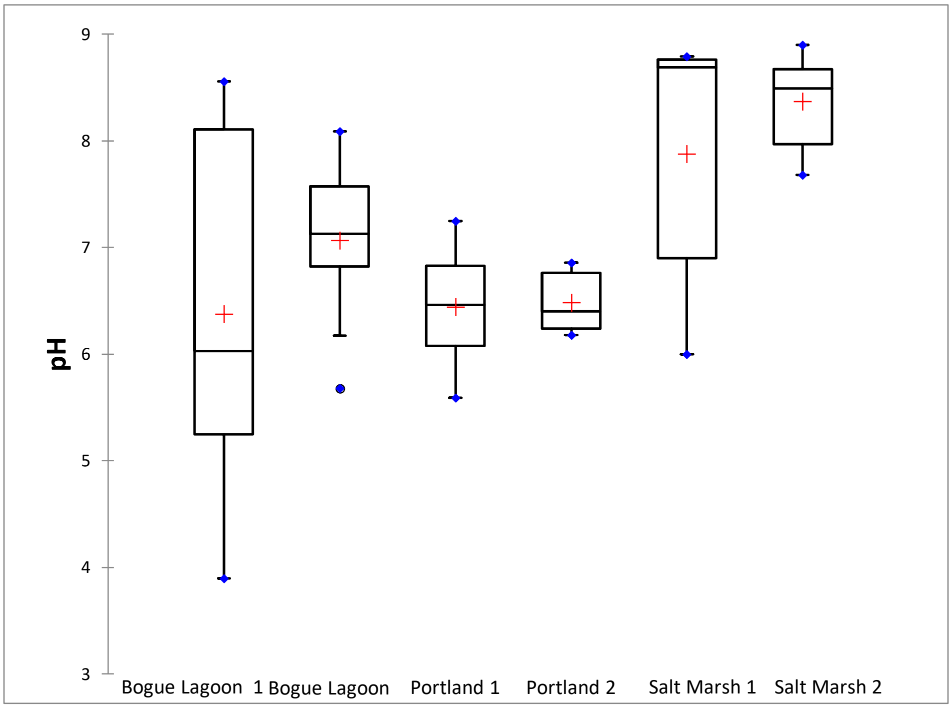


A- Atherinidae family, B- Lutjanidae family: School master snapper, C- Tetraodontidae: Pufferfish, D-Eleotridae family: *Erotelis smaragdus*, E-Clupeidae family and F-Gerreidae family. Photo credit: Nasheika Guyah, 2018

Annex 4: Soil organic matter content of mangrove surface soils (0-30 cm)

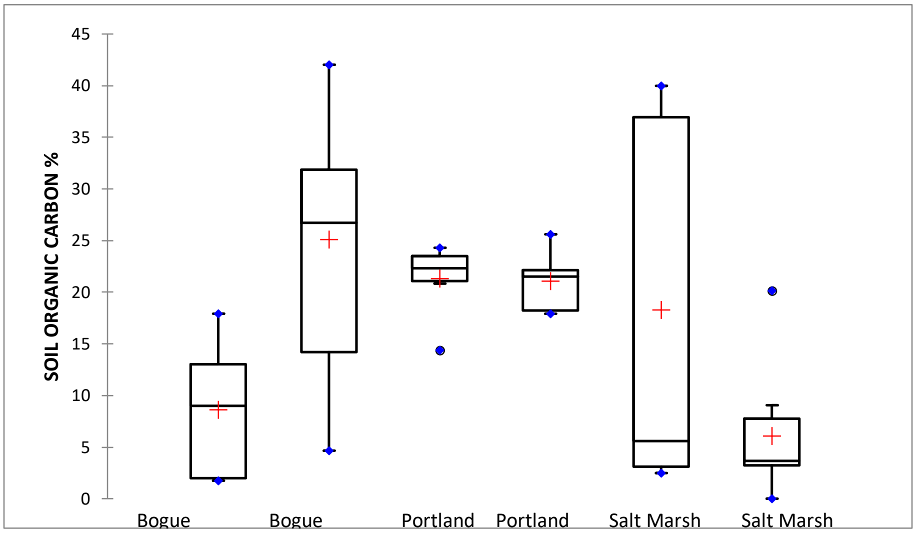


Annex 5: Soil organic carbon content of mangrove surface soils (0-30 cm), (Source: Adrian Spence 2019)



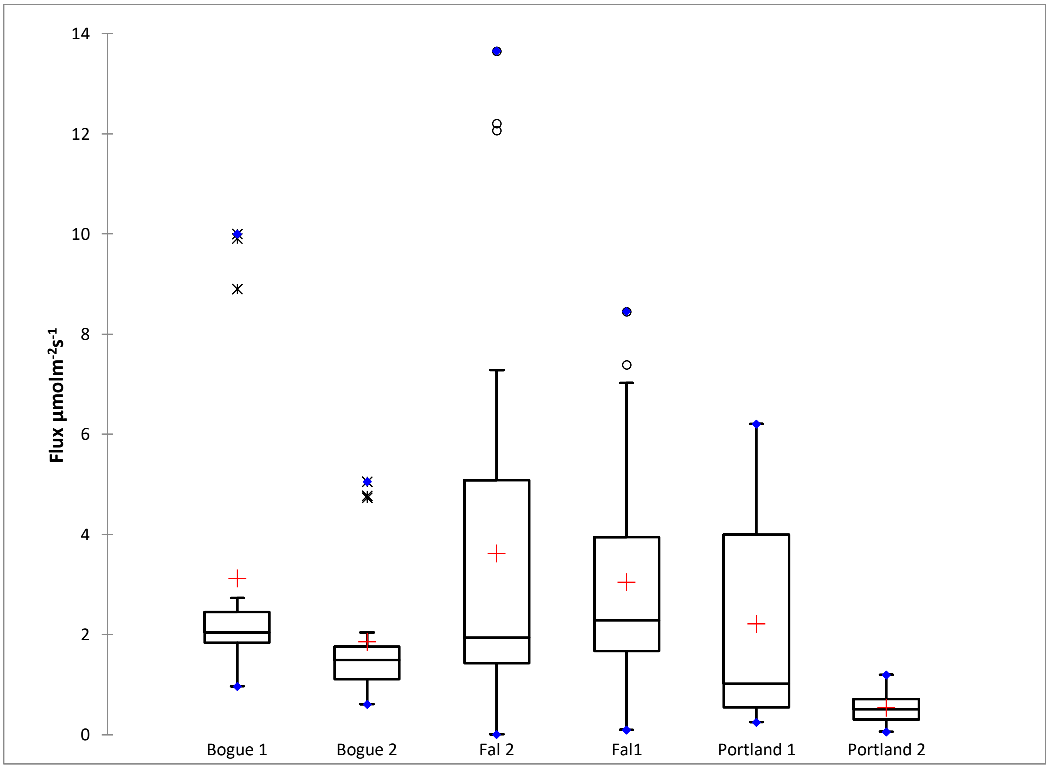
Annex 6: Soil organic carbon data distribution Box and whisker plot

Box and whisker plot summarizing data distribution include the quartiles (boxes); median (horizontal line); mean (red cross); maximum and minimum values (solid circle); and the whiskers show the range of values that fall within the inner fences, (Source: Adrian Spence 2019).

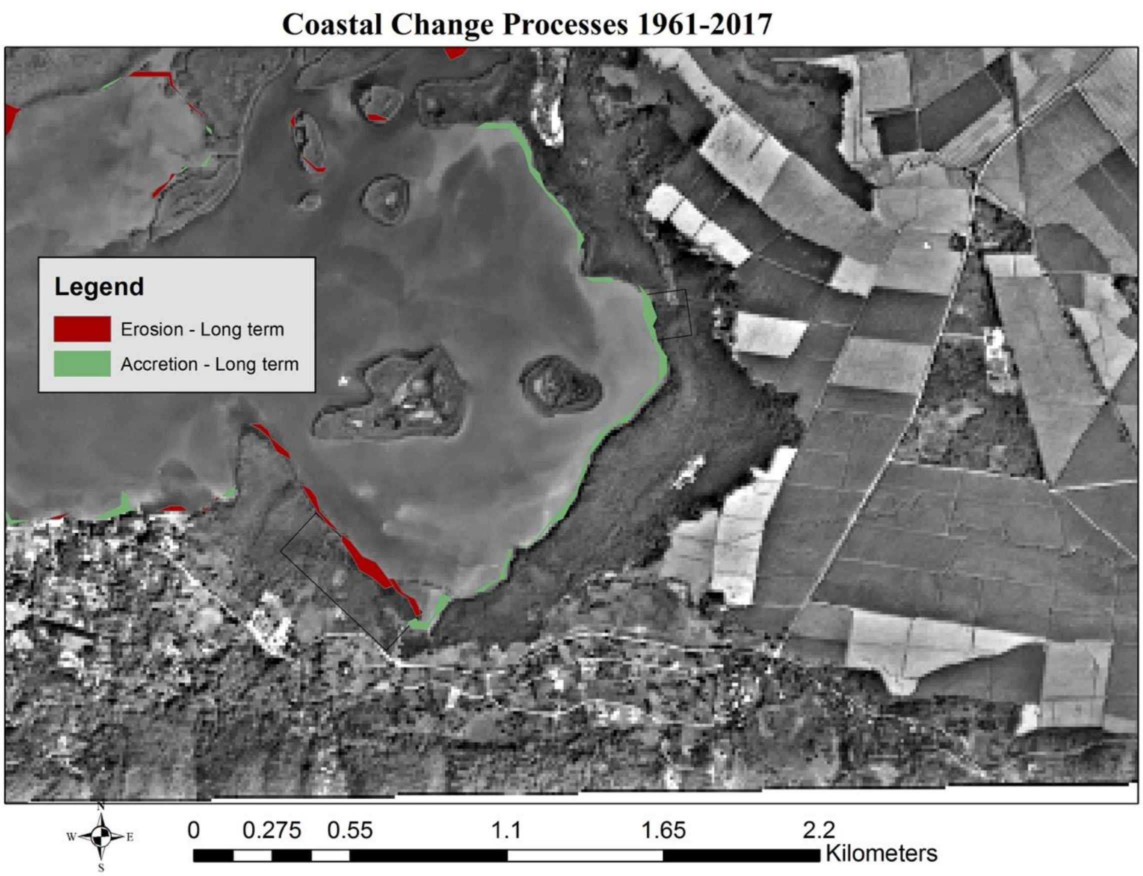

SOIL ORGANIC CARBON %
45
40
35
30
25
20
15
10
5
0
Bogue
Bogue
Portland
Portland
Salt Marsh
Salt Marsh

Annex 7: CO_2 Flux data distribution Box and whisker plot

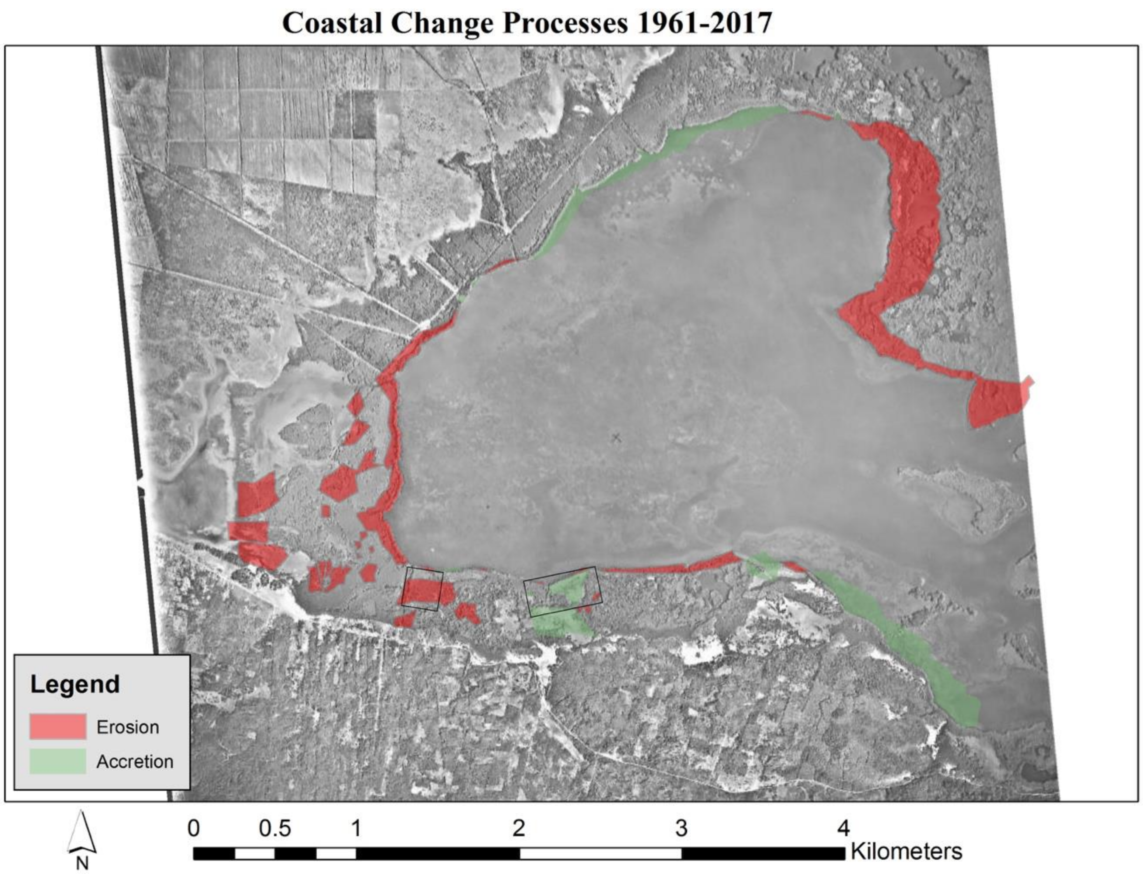
CO2 Flux Box and whisker plot summarizing data distribution include the quartiles (boxes); median (horizontal line); mean (red cross); maximum and minimum values (solid circle); and outliers (open circle = mild outliers, asterisk = extreme outliers). The whiskers show the range of values that fall within the inner fences. (Source: Adrian Spence 2019)



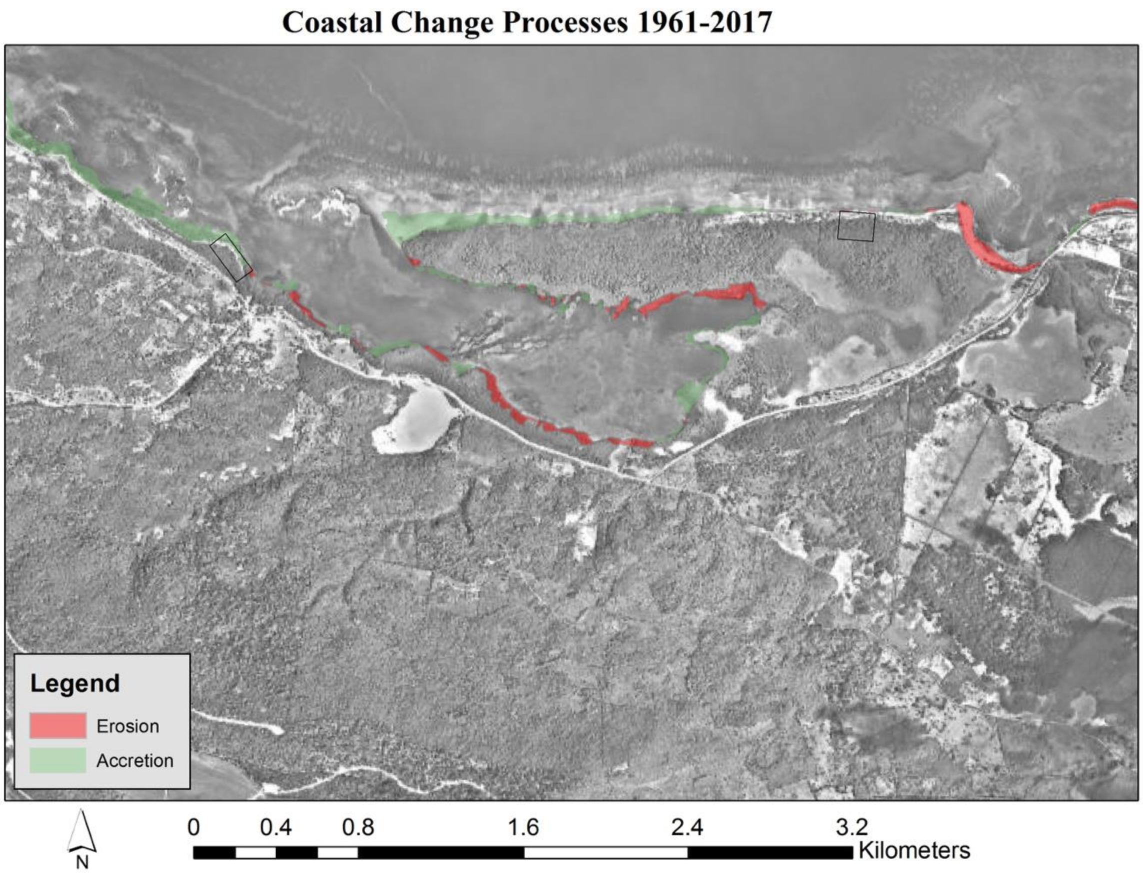
Annex 8: Spatio-temporal gain/ loss in mangrove occupation at Bogue, shapefiles overlain on 1961 aerial photo (created using Arc-GIS by Taneisha Edwards, 2019)



Annex 9: Spatio-temporal gain/ loss in mangrove occupation at Portland Cottage, shapefiles overlain on 1961 aerial photo (created using Arc-GIS by Taneisha Edwards, 2019)



Annex 10: Spatio-temporal gain/ loss in mangrove occupation at Salt Marsh, shapefiles overlain on 1961 aerial photo (created using Arc-GIS by Taneisha Edwards, 2019)



Sites	SOC stock (Mg C ha^{-1})	[a]Vegetation Carbon (Mg ha $^{-1}$)	Whole Ecosystem Carbon (Mg C ha -1)
Bogue Lagoon 1	72.66	51.67	124.33
Bogue Lagoon 2	211.01	41.69	252.70
Portland Cottage 1	179.09	7.59	186.68
Portland Cottage2	177.01	6.42	183.43
Salt Marsh 1	153.80	25.64	179.44
Salt Marsh 2	51.34	35.99	87.33

Annex 11: Whole ecosystem carbon stocks

[a]Vegetation carbon is the sum of aboveground and belowground carbon.

	Carbon in Vegetation (Mg C ha^{-1})		
	Red Mangrove	White Mangrove	Total Biomass Carbon
Red Mangrove	**1.000 (0.000)**	**0.319 (0.001)**	**0.981 (< 0.0001)**
White Mangrove	**0.319 (0.001)**	**1.000 (0.000)**	**0.446 (< 0.0001)**
Total Biomass Carbon	**0.981 (< 0.0001)**	**0.446 (< 0.0001)**	**1.000 (0.000)**

Annex 12: Spearman correlation matrix for the relationship between mangrove species and vegetative carbon for Bogue Lagoon.

***p* values are in parenthesis.**

Bold entries in tables represent statistically significant values at the 95% confidence level.

Annex 13: Spearman correlation matrix for the relationship between mangrove species and vegetative carbon for Portland Cottage.

Annex 14: Spearman correlation matrix for the relationship between mangrove species and vegetative carbon for Salt Marsh

Annex 15: Graphical comparison of mangrove structural attributes

The appended graphs facilitate comparison of mangrove parameters across the three forests sampled.

	Carbon in Vegetation (Mg C ha^{-1})			
	Red Mangrove	Black Mangrove	White Mangrove	Total Biomass Carbon
Red Mangrove	**1.000 (0.000)**	0.043 (0.478	0.099 (0.104	**0.933 (< 0.0001)**
Black Mangrove	0.043 (0.478)	**1.000 (0.000)**	**0.271 (< 0.0001**	**0.305 (< 0.0001)**
White Mangrove	0.099 (0.104)	**0.271 (< 0.0001)**	**1.000) (0.000)**	**0.215 (0.000)**
Total Biomass Carbon	**0.933 (< 0.0001)**	**0.305 (< 0.0001)**	**0.215 (0.000)**	**1.000 (0.000)**

Comparison of study locations using tree abundance:

Abundance of adult trees was one such parameter that occurred at all locations and while

	Carbon in Vegetation (Mg C ha^{-1})			
	Red Mangrove	Black Mangrove	White Mangrove	Total Biomass Carbon
Red Mangrove	**1.000 (0. 000)**	-0.085 (0.331)	0.108 (0.216)	**0.735(< 0.0001)**
Black Mangrove	-0.085 (0.331)	**1.000 (0.000)**	**0.236 (0.006)**	**0.492 (< 0.0001)**
White Mangrove	0.108 (0.216)	**0.236 (0.006)**	**1.000 (0.000)**	**0.217 (0.012)**
Total Biomass Carbon	**0.735 (< 0.0001)**	**0.492 (< 0.0001)**	**0.217 (0.012)**	**1.000 (0.000)**

red mangroves were found at all forest areas (Figure 1a), black and white mangroves were not seen within the sampling areas at Bogue and Portland cottage respectively (Figure 1 a, b, c).

Portland cottage had the greatest abundance of red trees (over 50/transect) while Salt marsh and Bogue were similar with ~10 per transect.

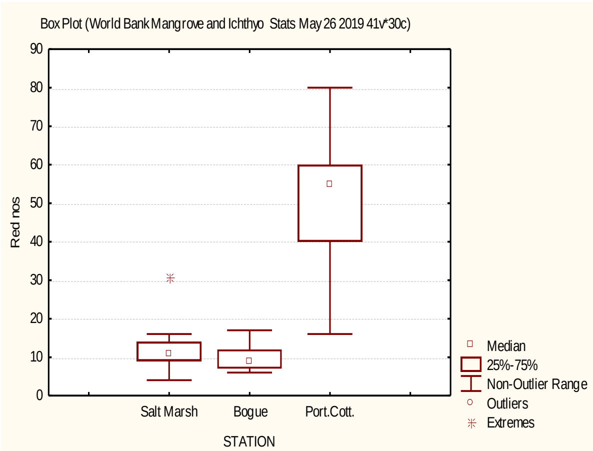


Figure 1a. Median Red mangrove tree abundances between locations, with variability, outliers and extremes.

Abundance of black trees fluctuated widely between the two sites sampled at Portland cottage (ranged from 0 – 30 trees), while at Bogue the fluctuation was between 5 and 15 trees (median of 10).

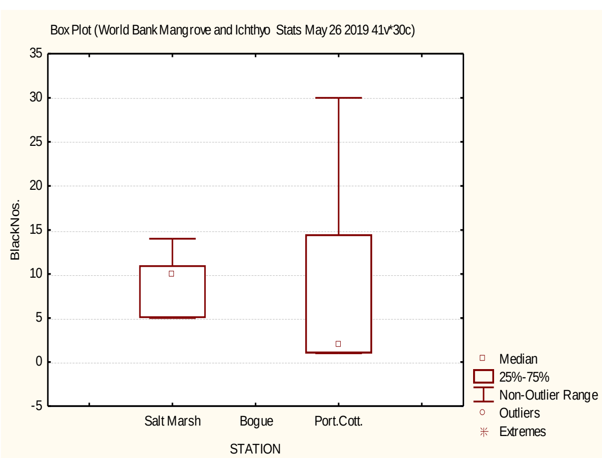


Figure 1b. Median Black mangrove tree abundances between locations, with variability and outliers.

Abundance of white trees were similar at Salt marsh and Bogue (2 and 2.5, respectively)- Figure 1c.

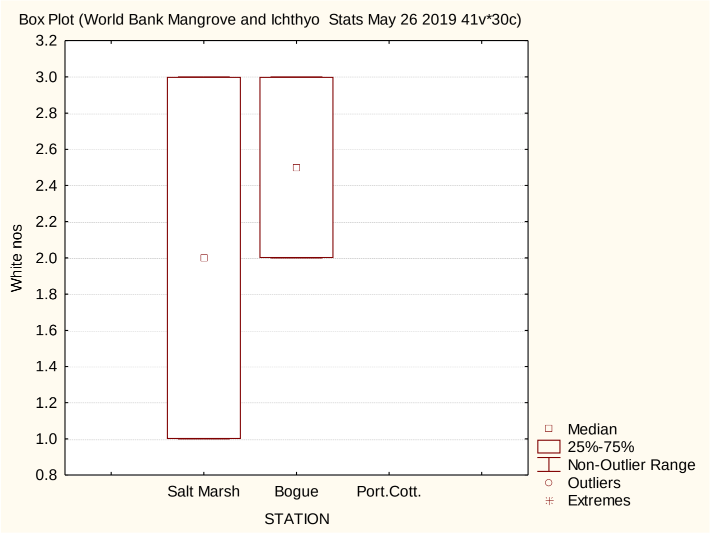


Figure 1c. Median white mangrove tree abundances between locations, with variability and outliers.

Comparison of study locations using rooting systems:

Only red mangrove prop roots (medium density) occurred with sufficient spread to allow for between forest comparisons. Medium density red prop roots (as expected) followed a similar pattern to abundance of red trees, with greatest densities at Portland cottage (Figure 2). Pneumatophores could not be compared between the forests based on low occurrences within the transects.

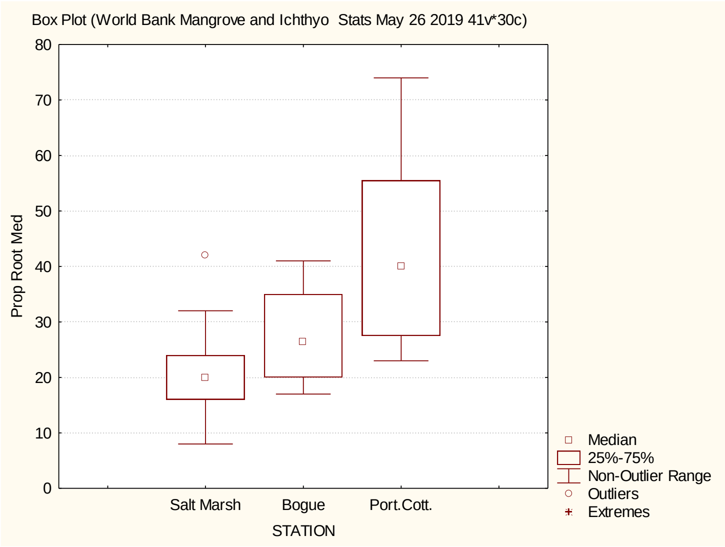


Figure 2. Median Red mangrove prop roots (medium density) between locations, with variability and outliers.

Comparison of sites using tree features (height, DBH and canopy width):

Only Red mangrove trees occurred with sufficient spread between forests to have their tree features (height, DBH and canopy width) compared (Figures 3a, b, c).

Height of red trees (Figure 3a) was greatest at Bogue and lowest at Portland cottage. Bogue also had greatest DBH and canopy width (Figures 3b,c). Thus. Although having the lowest abundance of red mangrove trees (cf. figure 1 above), the protective services of the Bogue stand would be expected to be great and that forest was clearly the most mature/undisturbed of the three. By contrast, Portland cottage which had the greatest abundance of red mangrove trees, had trees with lowest height and DBH. This supports the previous indication in the body of the report that Portland cottage was highly disturbed by storms and so the trees were recovering. The Portland cottage stand would not be expected to offer high protection. Only prop root abundance at Portland could indicate possible value for protecting land and infrastructure from wave action and it would have been useful to have measured the height/width of the prop roots to see if they would likely be effective.

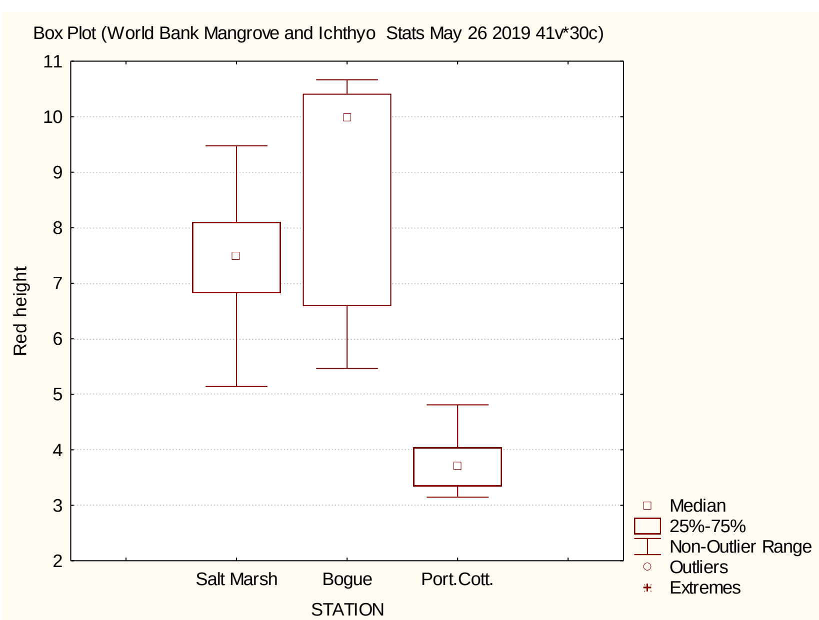


Figure 3a. Median Red mangroge height between locations, with variability and outliers.

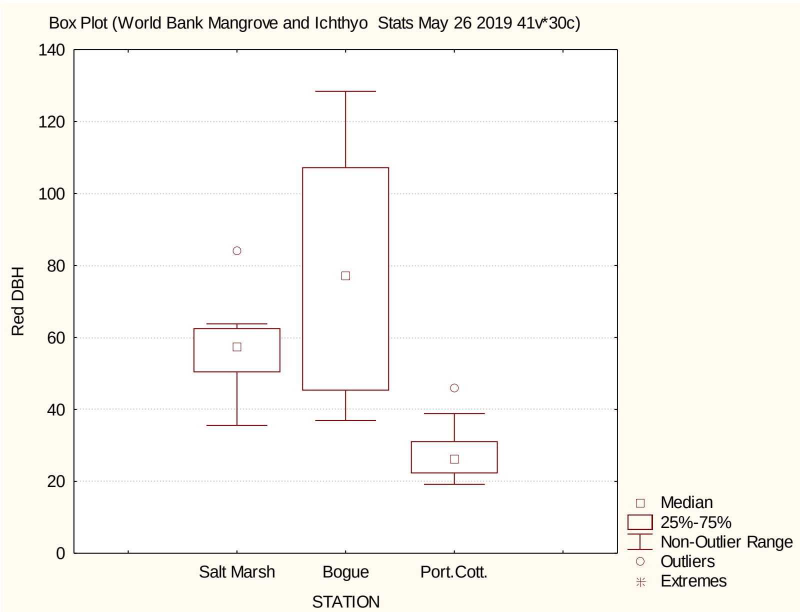


Figure 3b. Median Red mangroge DBH between locations, with variability and outliers.

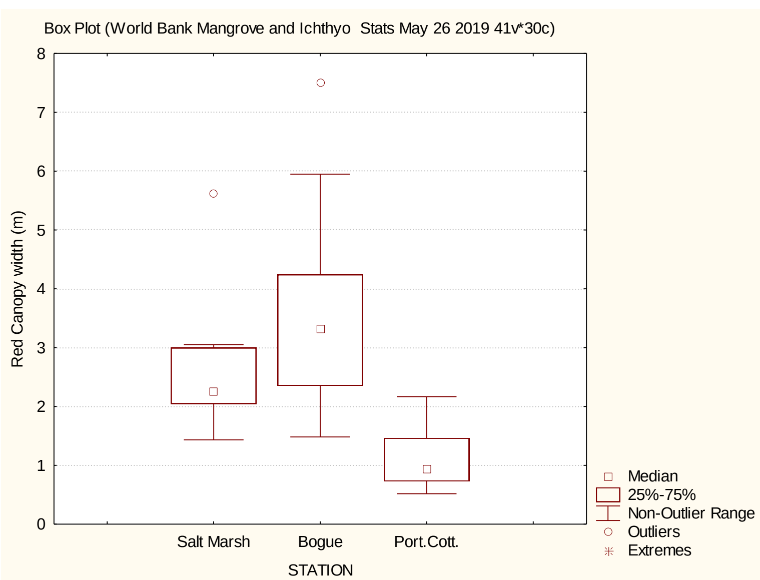


Figure 3c. Median Red mangroge canopy width between locations, with variability and outliers.

Overall comparison between forests using forest/tree parameters (where possible) indicates that Bogue swamp should offer the greatest protective services followed by Salt Marsh, with Portland cottage mangroves being least able to protect land and associated infrastructure.